Tips and Tricks in Plastic Surgery

Seth R. Thaller
Zubin J. Panthaki
Editors

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This book is dedicated to all the teachers who have enhanced my training so I could provide excellent care to my patients, and to the residents and fellows who have allowed me the opportunity to participate in their education. Hopefully, this has led to a successful and enjoyable career in plastic surgery. And to my many friends and professional colleagues in our specialty who have enlightened me to a wide array of topics. Lastly, to my family, who have been the backbone of my existence: my wife for more than 30 years, Pat, and my two children, Steven Cody and Alexandra Lee.

To all, my everlasting gratitude and wishing you a future that has been as fulfilling as mine has been.

Seth R. Thaller, MD, DMD, FACS.
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This book is dedicated to my parents, Jal and Nergish Panthaki, for encouraging me to study medicine and supporting me every step of the way. To my wife, Dimple, for being a wonderful wife and a loving mother. To my children Karl, Kayaan, and Kaizad, and our dog Carol. Without family, none of this is possible, nor is it meaningful. Also, in loving memory, my father-in-law Satish and our dogs Emily and Christmas.

This book is a compendium of the knowledge of many authors and represents their best practices and advice for the next generation. I am indebted to all of them for their generous efforts.

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Foreword

Have you ever tried a recipe given to you by a friend or relative, and it just did not taste the same as when they made the same dish? Something was missing, a nuance, a small detail that would have made all the difference. You may ask what do recipes have to do with plastic surgery. We read books and papers, and study technical descriptions of operations, and yet there are issues, something is missing.

In this book, *Tricks and Tips in Plastic Surgery,* Drs. Thaller and Panthaki, both accomplished surgeons and educators, have invited other surgical experts and teachers from academia and private practice to reveal the secrets of their "recipes," or tips and tricks to enhance results, reduce morbidity, and ensure patient satisfaction. The book is in five parts, starting with Aesthetic Surgery in Part 1 and ending with Hand Surgery in Part 5. In between are reconstructive procedures, craniofacial pediatrics, and adjunctive procedures. All of our vast specialty of plastic surgery is covered. All chapter authors are recognized as capable surgeons, leaders, and contributors in their fields who generously share their secrets.

Each chapter clearly describes the authors' tricks and tips through clear technical details, medical illustrations, and, in some chapters, a detailed video. Nothing is held back, no "secret ingredient" or special maneuvers are missing. Be it a surgical step that enhances the result, prevents a problem, or adds to patient safety, it's all here.

This book has tips for all of us whether, like me, we have been in practice for decades, or are in mid-career, just starting, or in training.

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Foreword

The authors, Dr. Seth R. Thaller and Dr. Zubin J. Panthaki from the University Miami Miller School of Medicine, have put together this very informative and novel plastic surgery book. They have gathered well-respected surgeons to share their helpful hints that facilitate and enhance their results. The most common operations are covered over the 45 chapters.

Every surgeon has their own bag of tricks to produce excellent results. The sharing of their secrets will only augment the readers' armamentarium. Therefore, this unique book will enhance their results and practice.

Although I personally do not know Dr. Panthaki, since early in my career I drifted away from hand surgery, Seth R. Thaller did his craniofacial fellowship with me at UCLA. Seth was a bundle of energy going in all very productive academic and clinical directions. At one point I liken his activity to Brownian movement. His parents once visited him at his apartment in Venice Beach. As they stepped over drunks and addicts in the streets, his father, who was a dentist at NYU School of Dentistry, offered to provide additional funds that would allow him to move to safer surroundings. Seth declined and continued his very prolific output in his Bohemian surrounding. After the fellowship, Seth joined the plastic surgery faculty at the University of Davis.

I enjoyed pursuing through this book and am sure that others would also do so. There are gems that all can immediately enjoy and apply to enhance their practice.

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Preface

Many become interested in plastic surgery because it centers on problem solving, unlike many other specialties, which frequently follow a cookbook of recipes. To solve a clinical challenge or successfully accomplish a surgical procedure, the plastic surgeon must often dig deep into a bag of "tricks." These are developed over a period of time and with extensive experience. The goal of this book is to have experts in the field—who have established solid clinical and technical skills through their extensive and lengthy knowledge in the arena—share those learned tips and tricks with our readers. Our expectation is that this will result in improved patient results and, ultimately, satisfaction, without the surgeon having to painstakingly work through a multitude of challenges.

We would like to thank each of our contributors for allowing us the opportunity to share the skills that they have established through years of trials and tribulations.

Miami, FL, USA

Seth R. Thaller
Zubin J. Panthaki

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Abbreviations

ACTH	adrenocorticotropic hormone
ADM	abductor digiti minimi
ADM	acellular dermal matrices/matrix
ALCL	anaplastic large cell lymphoma
ALT	anterolateral thigh
AMT	antero-medial thigh (flap)
ANS	anterior nasal spine
AP	action potentials
APB	abductor pollicis brevis
ASAPS	American Society for Aesthetic Plastic Surgery
ASPS	American Society of Plastic Surgeons
AT	auriculotemporal
ATLS	advanced trauma life support
AV	arteriovenous
AVM(s)	arteriovenous malformation(s)
BBL	Brazilian butt lift
BCC	basal cell carcinoma
BIA-ALCL	breast implant associated-anaplastic large cell lymphoma
BIS	bioimpedance spectroscopy
BLT	benzocaine, lidocaine, tetracaine
BMI	body mass index
BP	brachial plexus
BPOPs	bizarre periosteal osteochondromatous proliferations
BT-A	botulinum toxin, type A
CABG	coronary artery bypass graft
CAD/CAM	computer-aided design/computer-aided manufacturing
CaHA	calcium hydroxylapatite
CBT	cognitive behavioral therapy
CCH	collagenase clostridium histolyticum
CCS	clear cell carcinoma
CDC	Centers for Disease Control and Prevention
CDT	complex decongestive therapy
CM(s)	capillary malformation(s)
CMAP(s)	compound muscle action potential(s)
CMC	carpometacarpal
CMN	congenital melanocytic nevus
CNS	central nervous system

CO2	carbon dioxide
CRH	corticotropin-releasing hormone
CRP	C-reactive protein
CRPP	closed reduction percutaneous pinning
CSF	cerebrospinal fluid
CSHT	cross-sex hormone therapy
CT	computed tomography
CTS	carpal tunnel syndrome
CuTS	cubital tunnel syndrome
DAO	depressor anguli oris
DDAVP	desmopressin
DFSP	dermatofibrosarcoma protuberans
DIC	disseminated intravascular coagulation
DIEP	deep inferior epigastric perforator
DIP	distal interphalangeal
DTI	direct to implant
DTPI	deep-tissue pressure injury
DVT	deep vein thromboembolism (thrombosis)
ECM	extracellular matrix
ECRB	extensor carpi radialis brevis
ECRL	extensor carpi radialis longus
ECU	extensor carpi ulnaris
ED	extrinsic distraction
EDS	electrodiagnostic studies
EFT	emotional freedom technique
EGF	epidermal growth factor
EIP	extensor indicis proprius
EMG	electromyography
Er: YAG	erbium-doped yttrium aluminum garnet (laser)
FAS	fetal alcohol syndrome
FCU	flexor carpi ulnaris
FDA	Food and Drug Administration
FDMA	First dorsal metacarpal/ metatarsal artery
FDP	flexor digitorum profundus
FDPs	fibrin degradation products
FDS	flexor digitorum sublimis/superficialis
FGM	female genital mutilation
FPL	flexor pollicis longus
FPMA	first plantar metatarsal artery
FTSG(s)	full-thickness skin graft(s)
FTV	follow the vein
GABA	gamma-aminobutyric acid
GON	greater occipital nerve
GSW	gunshot wound
HA	hydraulic acid
HDPE	high-density porous polyethylene
HIFEM	high-intensity focused electromagnetic field
HIFU	high-intensity focused ultrasound

HPA	hypothalamic-pituitary-adrenal
HSV	herpes simplex virus
ICG	indocyanine green lymphography
ICNs	intercostal nerves
IH	infantile hemangiomas
IM	internal mammary
IMA	internal mammary artery
IMBT	integrative mind–body training
IMF	inframammary fold
IMF	intermaxillary fixation
IPL	intense pulsed light
IRF6	interferon regulatory factor 6
IS	intrinsic support
ISSVA	International Society for Study of Vascular Anomalies
ITR^2	injectable tissue replacement and regeneration
IV	intravenous
IVVP	intra-velar veloplasty
LABC	lateral antebrachial cutaneous
LBL	lower body lift
LEAP	Lower Extremity Assessment Project
LFH	lower facial height
LIC	localized intravascular coagulation
LLLT	low-level laser therapy
LM(s)	lymphatic malformation(s)
LON	lesser occipital
LVA	lymphaticovenular anastomosis
LVB	lympho-venous bypass
MABC	medial antebrachial cutaneous
MBSR	mindfulness-based stress reduction
MBT(s)	mind–body therapy (ies)
MCP	metacarpal phalangeal
MCT	medial canthal tendon
MFC	medial femoral condyle
MICS	minimally invasive component separation
MP	metacarpophalangeal
MPNST	malignant peripheral nerve sheath tumor
MRA	magnetic resonance angiogram
MRC	Medical Research Council
MRI	magnetic resonance imaging
MRSA	methicillin-resistant Stapholococcus aureus
MSAP	medial sural artery perforator
MSFTRAM	muscle-sparing free transverse rectus abdominis myocutaneous
mTOR	mammalian target of rapamycin
MUPs	motor unit potentials
MWL	massive weight loss
NAC	nipple-areola complex
NCS	nerve conduction studies

NFOT	nasofrontal outflow tract
NGF	nerve growth factor
NICH	non-involuting congenital hemangioma
NOE	nasoorbitoethmoid
NP	nascent potentials
NPUAP	National Pressure Ulcer Advisory Panel
NPWT	negative-pressure wound therapy
OFLA	oblique flankplasty with lipoabdominoplasty
ORIF	open reduction internal fixation
PACU	postoperative anesthesia care unit
PAL	power-assisted liposuction
PAP	profunda artery perforator
PAX7	paired box protein 7
PCS	posterior component separation
PDL	pulsed-dye laser
PE	pulmonary emboli
PEEP	positive end expiratory pressure
PI(s)	pressure injury (ies)
PICH	partially involuting congenital hemangioma
PIN	posterior interosseous nerve
PIP	proximal interphalangeal
PLLA	poly-L-lactic acid
PMT	posteromedial thigh (flap)
PNAM	pre-surgical nasoalveolar molding
PNF	percutaneous needle fasciotomy
PPFI	porous polyethylene facial implants
PRP	platelet-rich plasma
PRS	Pierre-Robin sequence
PSIO	pre-surgical infant orthopedics
PSWs	positive sharp waves
PTAP	posterior tibial artery perforator flap
QS	quality-switched (lasers)
RFF	radial forearm flap
RICH	rapidly involuting congenital hemangioma
ROOF	retro-orbicularis oculi fat
RRPP	radical resection with perforator preservation
RSTLs	relaxed skin tension lines
RT	radiation therapy
SAL	suction-assisted lipectomy
SAM	sympathetic adrenal medullary
SCC	squamous cell carcinoma
SCIP	superficial circumflex artery perforator (flap)
SIEA	superficial inferior epigastric artery
SMAS	superficial musculoaponeurotic system
SMCP	submucous cleft palate
SNAP(s)	sensory nerve action potential(s)
SNIF	sharp-needle intradermal fat
SOC	standards of care

SON	supraorbital nerve
SOOF	suborbicularis oculi fat
SRT	stress relaxation time
SSI	surgical site infection
SSRO	sagittal split ramus osteotomy
STN	supratrochlear nerve
STPF	superficial temporoparietal fascia
STS	sodium tetradecyl sulfate
STSG	split-thickness skin graft
SWM	Semmes-Weinstein monofilament
TAR	thrombocytopenia-absent radius [syndrome]
TAR	transversus abdominis release
TBSA	total body surface area
TCL	transverse carpal ligament
TCM	traditional Chinese medicine
TD	thorocodorsal
TDAP	thoracodorsal artery perforator (flap)
TE	tissue expander
TFL	tensor fascia lata (flap)
TGD	transgender and gender diverse
Th	T helper
TLA	tumescent local anesthesia
TP	transition point
TRT	thermal relaxation time
TUG	transverse upper gracilis
TZ	transition zone
UAL	ultrasound-assisted liposuction
UCL	ulnar collateral ligament
UFH	upper facial height
US	ultrasound
UTS	ulnar tunnel syndrome
VAC(s)	vacuum-assisted closure(s)
VAL	VASER-assisted liposuction
VAX1	ventral anterior homeobox 1
VHWG	Ventral Hernia Working Group
VLNT	vascularized lymph node transfer
VLVT	vascularized lymph vessel transfer
VM(s)	venous malformation(s)
VPI	velopharyngeal insufficiency
WALANT	wide-awake local anesthesia no tourniquet
WPATH	World Professional Association for Transgender Health
XI	spinal accessory nerve
ZT	zygomaticotemporal

Part I

Aesthetic Surgery

Breast Reduction

1

Natalia B. Vidal-Laureano, Ethan Lee Plotsker, Zubin J. Panthaki, and Seth R. Thaller

Introduction

Breast reductions are one of the most common surgical procedures performed by plastic surgeons. According to the American Society of Plastic Surgeons, breast reduction surgeries increased by 11% in 2017. It was the seventh most common reconstructive procedure performed in the United States in 2017 [1]. It is also associated with some of the highest patient-reported levels of satisfaction [2–5]. This is related to the complex burden of pain, discomfort, and emotional distress these patients undergo [6]. Common indications for surgery include shoulder, neck, or back pain; intertrigus rash; shoulder bra strap grooving; postural problems; difficulty performing exercise; and poorly fitting clothes [7, 8].

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_1) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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There are different skin resection patterns and pedicle techniques described in the literature. The skin pattern resection technique chosen should depend on the amount of ptosis and skin laxity the patient has, spanning from periareolar, vertical, or wise pattern, among others, in an attempt to sculpt the ptotic, heavy breast into the patient's aesthetic and functional ideal [9]. In our practice, we frequently perform a wise-pattern skin resection, as this allows for more tissue resection, improvement of ptosis, and better nipple position. Regarding the pedicle type, we prefer to use the inferior dermal pedicle. The inferior pedicle is the most commonly used pedicle type due to its reliability, reproducibility, and easy-to-teach markings that yield consistent results [9]. These characteristics have made the wise pattern-inferior pedicle our preferred method for breast reductions.

Common complications include wound dehiscence, seroma, hematoma, pseudoptosis, areola malposition, hypertrophic scarring, and poor long-term projection. Increased complication rates have been described in patients with obesity, as well as in smokers. Technical modifications may aid in the decrease of some of these commonly encountered sequela, thereby improving results and patient satisfaction.

This chapter will discuss several techniques performed in our practice that have facilitated the perioperative management of these patients. In our hands, it has helped decrease common

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complications of this procedure. It is our goal to optimize patient safety and operative efficiency and improve aesthetic outcomes in breast reduction.

Inferior Pedicle

The most commonly employed dermal pedicle design remains the inferior pedicle [9]. It was first described by Robbins, Ribeiro, Courtiss and Goldwyn in 1975–1977 [10–12]. It was soon found to be a very reliable pedicle, with a rate of 20–27% minor complications and 3–5% major complications [13–16]. These include delayed wound healing, hematoma, spitting sutures, nipple necrosis, hypertrophic scars, fat necrosis, seroma, and infection [17]. Another common complaint is the formation of pseudoptosis or "bottoming-out" with time and higher risk of developing hypertrophic scars [18]. Nevertheless, several studies report high patient satisfaction rate with this technique [13, 19–21].

We design our pedicle with a 10 cm base, centered in breast meridian. By doing so, we create a symmetric and reliable vascular supply to our pedicle and help centralize the breast tissue. We then design a seagull shape in the middle at the inframammary line, which will be explained in detail later in this chapter. Then, using a 42 mm "cookie cutter," we mark our new nipple-areola complex (NAC), and lines are drawn from the NAC borders inferiorly to the edges of the pedicle base. We start by deepithelializing our pedicle. During pedicle dissection, we avoid undermining and we keep the medial pole of the breast attached to the pedicle. This medial pole tissue is kept to enhance medial pole fullness and accentuate cleavage. We have found, as is described in the literature, that the inferior dermal pedicle is very reliable, reproducible, and easy to teach. The markings can be reproduced with different breast types and shapes, giving consistent results with high patient satisfaction.

Markings (Fig. 1.1)

As with most of the plastic surgery procedures, the preoperative markings are one of the most important steps in the surgery. It is important to place the patient in standing position and mention any torso anomalies or asymmetries preoperatively, as these asymmetries will become more noticeable to the patient after reduction mammoplasty is performed. Also, at this time, it is important to inspect the breasts and the chest; verify skin laxity, degree of ptosis, signs of dermal fragility (such as striae and intertrigo), presence of nipple anomalies (like inverted nipple); and confirm nipple-areolar complex measurements to

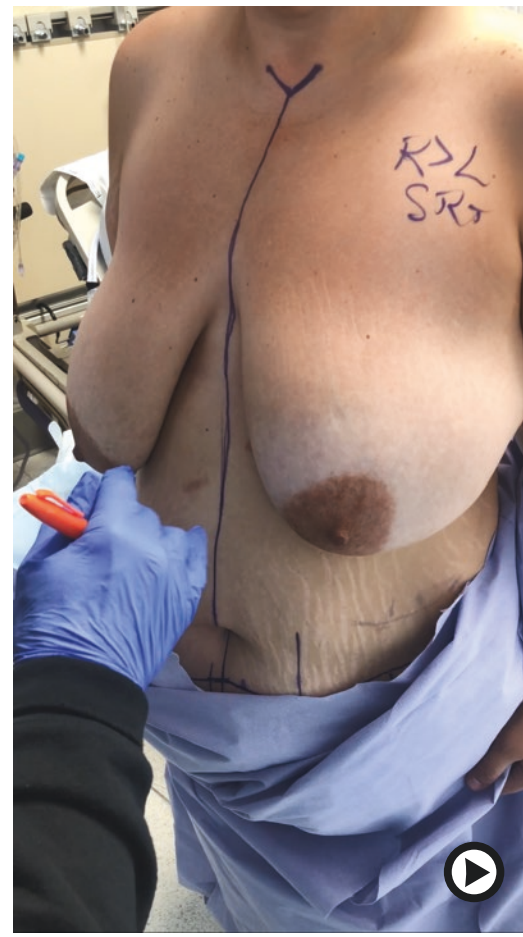

Fig. 1.1 Preoperative markings (▶ https://doi.org/10.1007/000-3tf)

sternal notch and to inframammary fold (IMF). It is also important to document breast asymmetry.

We first start by marking the sternal notch and the midline. Then, we mark the new nipple position by transposing the IMF to the anterior breast (Pitanguy's point). We measure 1.5 cm superior to this point. This would be the top of our new NAC position. To measure breast meridian, we measure 7.5 cm from sternal notch bilaterally, and using a measuring tape, a line is drawn inferiorly in the midpoint of breast volume. This may correspond to NAC position, but it does not necessarily need to. We then mark the IMF and use a dry gauze to be placed in IMF, when the patient's breast is placed down, to avoid markings disruption with sheering of skin and perspiration. At this time, we use our premade stencil. This will give a final nipple-areolar complex diameter of 14 cm and vertical limb length of 5 cm. We then connect medially and laterally the lower marks of the vertical limb to the IMF line. Laterally you may extend incision posterolaterally to resect excess lateral chest tissue as needed (Fig. 1.2).

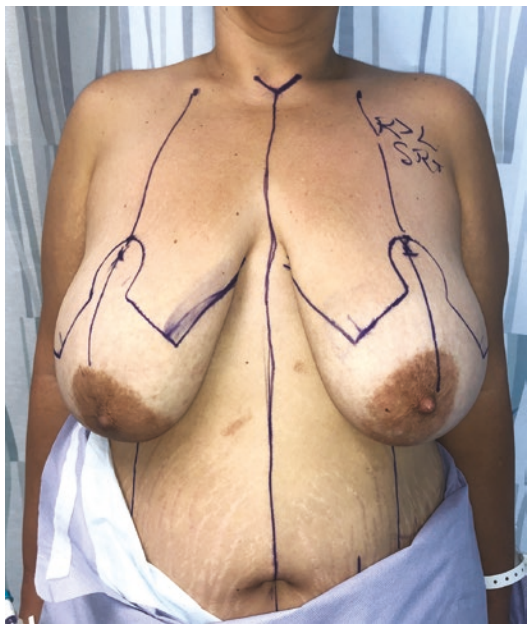

Fig. 1.2 Wise-pattern markings using premade stencil on a patient with grade 2 ptosis

Tattooing the Markings

It is common in our practice to have problems with our markings after cleaning and prepping the patient in a sterile field. Most of our prep products are alcohol based. Even though we try to be gentle, we may encounter problems with erasing some of the markings. Combination of loss of preop marking with the patients' usual extensive degree of ptosis may interfere with all landmarks. All the anatomical markings, including IMF, NAC position, and even midline, may change when the patient is in supine position. Placing the patient in a sitting position on the operative table would not resolve all these problems, as the abdominal fold and arm positions are suboptimal. These issues may compromise the whole surgical plan and could alter the results, giving NAC positions that are inadequate, incomplete resection with poor ptosis repair, or incorrect IMF positions, among other things.

Therefore, to correct for the aforementioned issues, we tattoo our corners with methylene blue before prepping the surgical field. We use a 1 cc syringe with a 25- to 29-gauge needle and inject in each corner a small amount, approximately 0.1 ml, of methylene blue. It is important that the tattooing be made outside of the skin resection area; therefore, the markings are preserved until the end of the resection and will be useful in the closing, when approximating the corners. This has been found to be helpful with erasing the markings not only during the prepping of the surgical field but also intraoperatively when blood or dissecting fatty tissue may erase the markings. It is not time-consuming and prevents you from performing a blind resection. The use of this technique in reduction mammaplasty was derived from its role in cleft lip repair at our institution (Fig. 1.3).

Tumescence

Among the different techniques used for breast reduction is the use of preoperative infiltration of tumescent solution. G. Bretteville-Jensen first

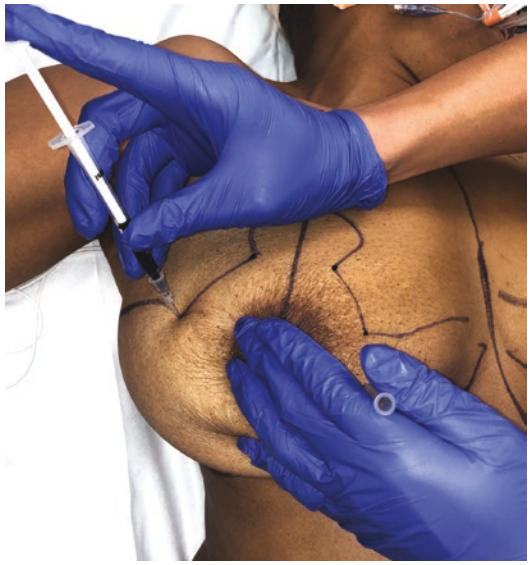

Fig. 1.3 Tattooing of preoperative markings using methylene blue before prepping the surgical field

described this technique in 1974, when he found that patients have decreased blood loss, by half, during mammaplasty after infiltrating breast tissue and incision lines with norepinephrine solution [22]. Advantages other than blood loss control include reduced postoperative pain when the solution is combined with local anesthesia [23, 24]. Also, some studies have documented the plausibility of performing this procedure on an outpatient basis under local anesthesia [25]. Complications associated with this technique may include lidocaine toxicity or allergic reaction. Others have documented concerns of skin flap necrosis, rebound bleeding, and postoperative hematoma using this technique. There are some studies that report potential increase in hematoma complications by describing a rebound effect after vasoconstrictive effect of epinephrine subsides. But others have found no difference in hematoma rate with the tumescent technique [26].

Before we start the procedure, we routinely inject tumescence solution along our resection lines. We use a solution with 30 ml of Lidocaine 1% with 1:100,000 epinephrine in 1 L of normal saline solution. We use 18-gauge spinal needles with 60 ml syringes for infiltration. After induction of anesthesia, we infiltrate 120 ml of tumescent solution into each breast along our incisions lines into the skin and subcutaneous tissue. Careful infiltration is performed to avoid inadvertent injury to lung and causing a pneumothorax.

We have found that infiltrating along our resection lines, before prepping the patient, helps with hemostasis and ease of dissection. Macromastia patients with dense breast tissue may have large subcutaneous and intraparenchymal vessels, making hemostasis challenging. By causing bleeding at the beginning of the dissection, the dissection plane may get distorted, causing inadvertent undermining or underresection. It is important that during the infiltration, the inferior dermal pedicle is avoided (Figs. 1.4 and 1.5).

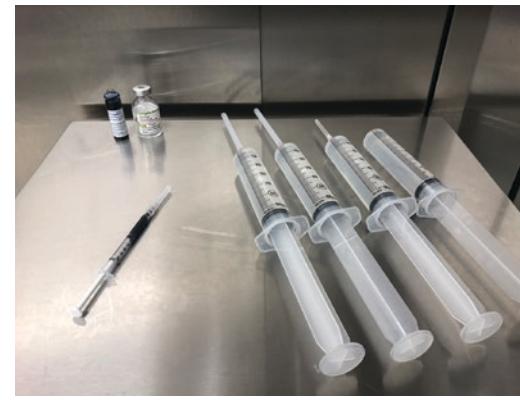

Fig. 1.4 We use a-1 ml syringe with a 30-gauge needle for infiltrating methylene blue at the corners of the markings. For infiltrating the tumescence solution, we use 60 ml syringes with 18-gauge spinal needles

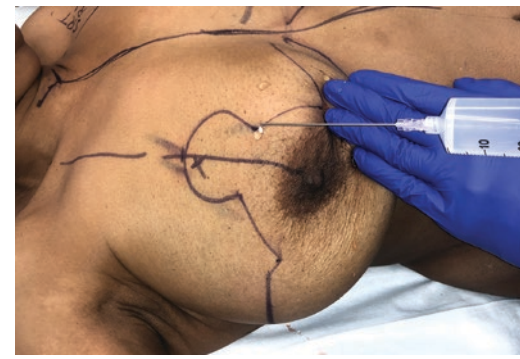

Fig. 1.5 Angle and direction used for infiltration of tumescence solution using an 18-gauge spinal needle

Seagull the Lower Part

One of the most common complications of this surgery is wound dehiscence at the inverted-T point in the wise-pattern resection. This point is a poorly vascularized area, receiving two corners in an area of tension. Most of these complications resolve with local care and without the need for further surgical interventions, but they impose a longer recovery for the patients. Complication rates of this sort have been documented as ranging from 7% to 51% [27].

We create a seagull pattern at the IMF line in the middle of the inferior dermal pedicle to help reduce the tension at this point and decrease the rate of wound complications. After prepping and draping our patient, we use a 42 mm cookie cutter to mark our new NAC. In the IMF, to create our inferior pedicle, we use our breast meridian as center of the pedicle and design a 10-cm-wide pedicle base. We then create a seagull shape in the middle of our pedicle (5 cm mark), or a triangle. We design it at least 0.5–1 cm tall, with a 120° angle at the apex. Each limb is at least 1–2 cm in length, and the base of the triangle is at the IMF. It is important to protect this area during deepithelialization of pedicle to avoid removing it. This provides additional, well-vascularized, tissue from IMF, to decrease tension and improve healing. The scar hides well at the IMF and it does not affect the final aesthetic result of the breast (Fig. 1.6).

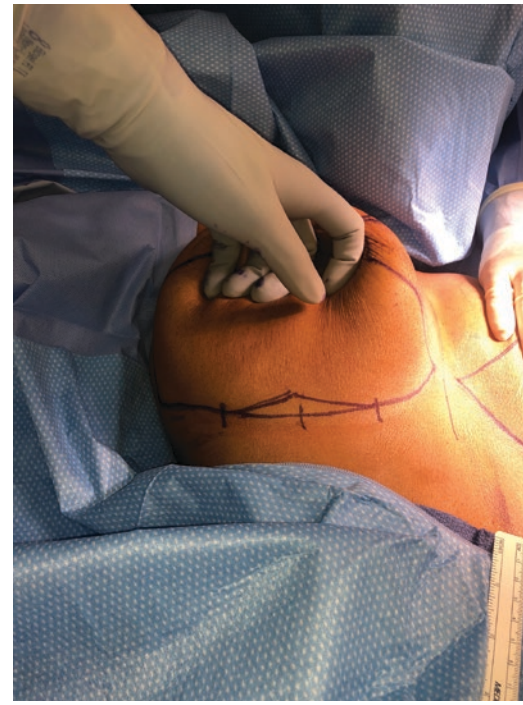

Fig. 1.6 Seagull pattern at the IMF line in the center of the inferior dermal pedicle

Dermatome Blade Resection

Patients with macromastia frequently have very dense breast tissue, especially young females, making the breasts heavy and more symptomatic, even not at very large volumes. With this breast type, it is common to encounter difficulties with the resection part. Electrocautery is hard to maneuver in dense tissue and using a regular blade could cause inadvertent undermining of the pedicle.

By using a dermatome blade, angled perpendicular to the chest wall, you can ensure no undermining occurs. Long blade makes a one cut easier, saving time, and decreasing the risk of creating false planes of resection. For the undermining of the upper flaps, we place three or four penetrating clamps in the dermis edge and retract the superior breast tissue upward. Then, we perform the resection with the dermatome blade, parallel to the skin to avoid thinning and skin flap necrosis. This method allows for faster resection and avoids risk for pedicle compromise.

DeFazio et al. [28] reported that this technique was found to decrease operative time almost by half when compared to electrocautery dissection: 203 minutes average without the dermatome blade and 131 minutes average with the use of the dermatome blade. This same study did not report an increase in hematoma, seroma, or postoperative bleeding in the patients who underwent resection using this technique. In our practice we have found, that after irrigating the surgical field with warm saline, and obtaining meticulous hemostasis with electrocautery, using the dermatome blade for resection is a safe practice without increased risk for bleeding complications (Fig. 1.7).

Fig. 1.7 Dermatome blade used for en bloc resection of breast tissue

Preserving Medial Breast Tissue

A common complaint after inferior pedicle breast reductions is the lack of medial pole fullness. Pseudoptosis or "bottoming out" deformity after inferior pedicle, wise-pattern reduction, is associated with poor aesthetic results. By resecting most of the medial and lateral aspect of the breast tissue and preserving the middle and inferior tissue, final breast shape may lack medial projection and cleavage. There is a strong correlation between patient satisfaction and breast volume as well as contour; therefore, attempting to optimize final contour by preserving superomedial breast tissue will improve patient satisfaction.

We prefer to remove more tissue laterally and superiorly, and preserve the medial breast tissue. When performing our resection, we keep the medial breast tissue by resecting from approximately 5 cm cephalad from IMF and medial mark. We preserve this tissue attached to the inferior pedicle and deskin this portion that would be covered by the superior skin flaps when approximating the wise pattern. This not only provides more volume in the cleavage area but it also preserves the second intercostal space perforator from the internal mammary artery providing better perfusion to our pedicle and decreasing the rate for fat necrosis. Patients are happier with the extra medial fullness and more defined cleavage. We have not had any complaints about breasts being too large or heavy by preserving this part.

Permanent Suture in Inverted-T Point

As we discussed previously, the most common wound dehiscence site is the inverted-T point when closing the wise-pattern resection. Increased tension and poor vascularity of superior flap corners meeting in the IMF cause an increased risk for breakdown. Adequate mobilization of superior flaps and performing an adequate resection will aid in decreasing tension at this point. Also, adding some technical modifications helps to lower the tension and improves wound healing.

We have found that by leaving the seagull pattern in the IMF incision, it decreases tension in this area and recruits more vascularized tissue to aid in wound healing. We have also included in this area the placement of a three-point permanent suture. We use an inverted u-stitch starting in the IMF, followed by each of the superior flap corners of the three-point closure, and finalizing in the IMF. We keep the knot outside and remove the stitch in the 2-week follow-up appointment. This provides extra support in the area of tension while the most critical period of wound healing occurs. The suture is hidden in the IMF; therefore, scar formation is minimal, while providing extra support during the most important time of the wound-healing process.

Conclusion

Macromastia has become a more prevalent condition with the increase in obesity. Debilitating symptoms such as neck, shoulder, and back pain make surgical treatment an important option. High patient satisfaction rates only confirm the physical and psychological burden of breast hypertrophy. Patient selection should be an

important component in the process of evaluating these patients for surgery, modifying high-risk factors such as obesity and smoking, which have been found to increase complication rates. We have found that by incorporating these steps into our practice, we can obtain reliable results, decreased complication rates, and improved efficiency in the perioperative period. We recognize that avoiding all complications is impossible, and a continuous review of individual practices is paramount for improving patient outcomes and satisfaction rates.

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2 Augmentation Mammoplasty and Mastopexy

M. Bradley Calobrace and Chet Mays

Introduction

Achieving a successful outcome in aesthetic breast surgery requires an assessment of the patient's desired look in conjunction with the anatomic characteristics of the breast. Whereas many patients have simply underdeveloped breasts or congenitally mal-shaped breasts, other patients seek correction for undesirable changes that have occurred. The shape and size of the breasts may experience significant deleterious effects over time secondary to pregnancy, weight fluctuations, and aging. Breast augmentation can provide improvement in shape, size, and symmetry, and improved body proportion in patients with micromastia. Patients with more significant changes resulting in breast ptosis may require only a breast augmentation when it is mild, but will often need a mastopexy when more significant ptosis exists. In patients with more significant ptosis and volume loss, a successful breast procedure may include not only adding much needed volume and shape stability that is offered with a breast implant but also tightening of the ptotic skin envelope and repositioning of the low nipple-areolar complex through a mastopexy, either simultaneously or in a staged fashion. Fat grafting can also be utilized with or without the use of an implant to improve upper pole fullness and cleavage. Thoughtful consideration of the patient's desired aesthetic result in conjunction with the anatomic characteristics of her breast and chest wall provide insight into the optimal surgical approach to achieve a successful outcome.

Preoperative Planning

One of the most critical steps in achieving excellence in aesthetic breast surgery is the preoperative evaluation. The preoperative evaluation through a thorough assessment should identify not only the appropriate implant to achieve optimal results but also the location of the incision; the implant pocket; asymmetries of the breast, chest wall, and/or nipple-areolar complex; and the potential need to lower the inframammary fold. The preoperative markings create a road map for the planned procedure. This includes marking the inframammary fold, midline, and meridian of the breast. The base diameter,

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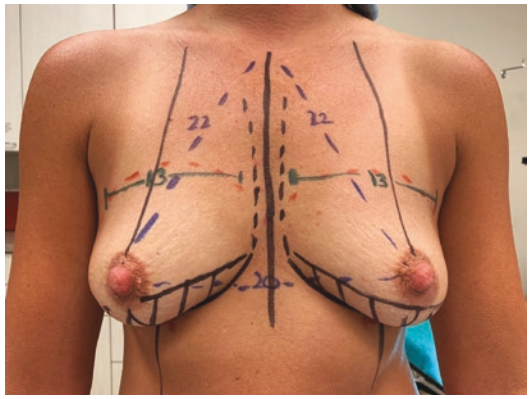


Fig. 2.1 Preoperative markings: inframammary fold, midline, and meridian of the breast. The breast width shown as 13 cm. The sternal notch-to-nipple distance shown as 22 cm. The vertical lines along the base of the breast represent the planned dual-plane level

intermammary line, and dual-plane planning can be also helpful in strategizing the surgical plan (Fig. 2.1).

Critical to success is determining the appropriate approach—breast augmentation, mastopexy, augmentation mastopexy, and/or fat grafting. Evaluation of the soft tissue coverage, including quality of skin and breast tissue, amount of breast parenchyma, the footprint of the breast, and the level of ptosis, is essential to determining the optimal approach:

Breast Assessment of the Soft Tissue
- Quality of the skin and breast tissue
- Amount of breast parenchyma
- Footprint of the breast
- Level of breast ptosis

When using an implant, precise pocket creation and appropriate implant choice are the best safeguards against postoperative implant malposition issues. Likewise, the most common reason for revisional surgery after a breast surgery with implants is capsular contracture [1, 2]. There is strong evidence that biofilm development from bacterial contamination is a significant causative component in the development of capsular contracture [3–6], Part of the operative planning, therefore, should include efforts to minimize this risk when possible. The list below summarizes some of the implant and surgical technique options that have been associated with lower capsular contractures [7–23].

Options Associated with Reduced Capsular Contracture Incidence
- No-touch technique [7–9]
- Nipple shields [8]
- Pocket irrigation with triple antibiotics [10]
- Insertion sleeve [9]
- Submuscular implant pocket [11–13]
- Textured implants [11, 13–18]
- Inframammary incision [13–19]
- Cohesive-shaped implants [20–23]

Breast Augmentation

Achieving a successful outcome in breast augmentation requires excellent preoperative and intraoperative decision-making and expert surgical execution. Thoughtful consideration of the patient's desired aesthetic result in conjunction with the anatomic characteristics of her breast and chest wall provides insight into the optimal surgical approach to achieve a successful outcome. There are many incisional approaches to breast augmentation, including inframammary, periareolar, transaxillary, and transumbilical. The inframammary approach has increasingly become the preferred incisional approach, and is the most commonly performed today.

Implant Selection

The selection of the appropriate implant is determined not only by the objective findings during the examination but also by the patient's expectations and desired final outcome. Today's implants can be saline or silicone, textured or smooth, and come in a variety of projections. The base diameter of the chest is considered one of the most important determinants in sizing of the implant. Classically, the final base diameter of the breast will be the diameter of the implant plus the width increase provided by the soft tissue contributions.

Thus, the final desired breast width minus the soft tissue contributions should provide guidance to the implant base diameter. (Implant Base Diameter = Desired breast width − (½ Medial pinch + ½ Lateral pinch.)

Patient Positioning

Patients are placed on the operating room table in the supine position. The arms are secured to the arm board with soft gauze wraps at 45 degrees to stabilize the patient in the upright position (Fig. 2.2). This relaxes the pectoralis muscle, providing a more accurate assessment of the implant position and the redraping of the overlying breast tissue. Alternatively, some surgeons prefer placing the arms alongside the patient on the operative table, but an arm board at 90 degrees should be avoided, as it does not allow accurate assessment of the breast when the patient is placed in the upright position.

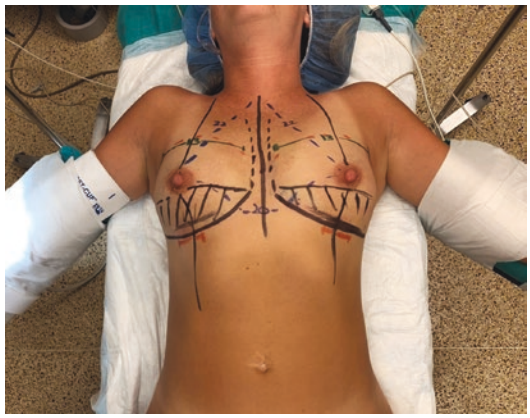


Fig. 2.2 Patient positioning on the operating room table

Infiltration of Local

Prior to surgical preparation, 50 ml of a local field block is injected of 1/4% lidocaine, 1/8% bupivicaine, and 1:400,000 epinephrine (Table 2.1). The injection is placed in the dermis along the planned incision line, and as a field block with injections along the inframammary fold, the medial pectoral border, the anterior axillary line, and finally, deep to the breast parenchyma in a fanning fashion throughout the area of planned pocket creation (Fig. 2.3).

These injections provide assistance not only in operative hemostasis but also in the management of postoperative pain.

Table 2.1 Breast local anesthetic formula

1/2% Lidocaine plain	25 ml
1/2% Lidocaine/1:200,000 epinephrine	25 ml
1/2% Bupivacaine/1:200,000 epinephrine	25 ml
Injectable saline	25 ml
1/4% Lidocaine, 1/8% bupivacaine, and 1:400,000 epinephrine	100 ml

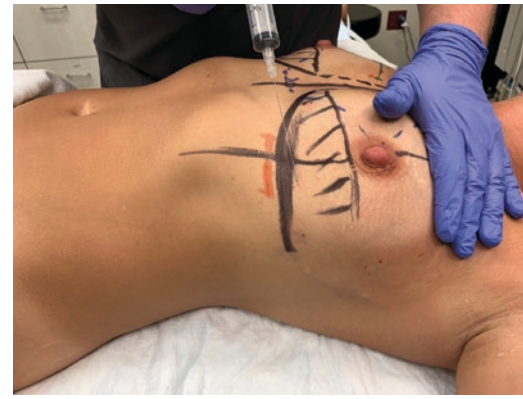


Fig. 2.3 Breast local infiltration preoperatively prior to surgical prep

Surgical Preparation and Sterile Draping

After local infiltration, nipple shields (created by placing a small piece of Tegaderm over each nipple-areolar complex) provide a barrier against potential bacterial contamination [8] (Fig. 2.4). The patient is prepped with chlorhexidine and draped to provide a sterile field, with the entire chest and bilateral breasts visible for assessment during the procedure. The sterile dressings must be secured to prevent disruption in the sterile field while placing the patient in the upright position.

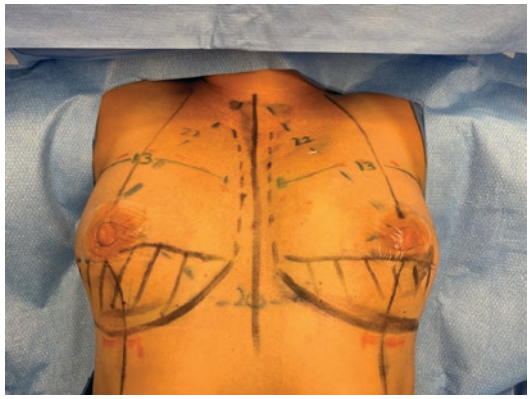


Fig. 2.4 Tegaderm nipple shields

Inframammary Incision

The inframammary fold has become the preferred incision location for most surgeons today. There are many advantages, and some disadvantages, which must be considered to ensure the appropriateness of the IMF approach:

Advantages

- Well-hidden scar in the fold of the breast.
- Incisional length is unlimited and thus can accommodate any and all implant choices.
- Excellent visualization for dissection of the implant pocket.
- The ability to control the IMF position during incision closure.
- Can be used for any complication revision.
- Lower capsular contracture rates.
- Minimal issue of a scar contracture creating deformity.
- Potentially less nipple-sensation changes.

Disadvantages

- The scar is located on the breast.
- Scar may be more visible if breast fold is absent or if the scar becomes pigmented.
- Must determine final IMF position preaugmentation and place scar precisely in planned new fold.
- Scar position is more vulnerable to irritation from the bra.

The size of the incision depends on the location but, in general, should be as small as possible and yet large enough to safely dissect the pocket and place the implant without distortion or injury to the device. In general, the incision length increases with increases in implant size, gel cohesiveness, optimal fills, and texturization of the implant. Additionally, the quality of the scar is often better if a slightly larger scar is utilized, reducing the stretch and retraction injury placed on the scar. Incision length ranges include: 3–4.5 cm for saline implants, 4–6 cm for silicone round implants, and 4.5–7 cm for shaped cohesive silicone implants.

Inframammary Fold Positioning

Predicting the final position of the inframammary fold is critical to determining the placement of all breast incisions, but especially the inframammary incision. This can be a challenging task, as so many variables contribute to the final position of the fold. The inframammary fold is formed by the fusion of the anterior and posterior leaves of the superficial fascia, which is intimately associated with the dermis at the lowest aspect of the inferior pole of the breast [24]. During preoperative markings, the native inframammary fold is identified and marked in the sitting position. The true IMF position is determined by performing an IMF expansion test. The breast is grasped and autorotated inferiorly to identify the inferior extent of the attachments of the inframammary fold (Fig. 2.5). This is the best predictor of where the fold will naturally sit after breast augmentation. The amount of lower pole skin required and the ultimate position of the fold is a function of many factors, including the type of implant (saline vs. silicone and round vs. shaped), size of implant, pocket location, and the strength and stability of the soft tissue of the lower pole. The distance measured from the nipple to true fold under maximal stretch assesses the amount of lower pole skin available to accommodate the selected implant. An acceptable standard that has been used is an

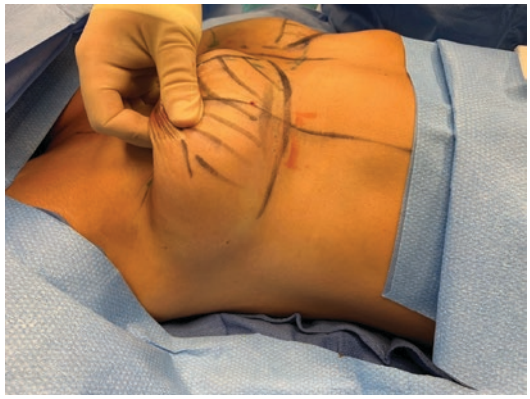


Fig. 2.5 Determining the true IMF position by autorotating the breast

Table 2.2 Techniques for determining lower pole skin requirements nipple to inframammory fold

Optimal N-IMF distance on maximal stretch = ½ implant projection + ½ implant height *Optimal N-IMF distance on maximal stretch* =		
N-IMF distance	*Base diameter*	*Fill volume*
7 cm	11 cm	200 cc
8 cm	12 cm	300 cc
9 cm	13 cm	400 cc

implant with a base diameter of 11 cm requiring 7 cm, a base diameter of 12 cm requiring 8 cm, and a base diameter of 13 cm requiring a 9 cm nipple to fold distance [25]. A more comprehensive evaluation has been described using tissue-based planning principles [26]. In the High Five System analysis, variables are analyzed including implant volume, patient's base width, implant base width, anterior pulled skin stretch, and nipple-to-fold distance under maximal stretch. Based on the selected implant, a reference chart provides the desired nipple-to-fold distance on maximal stretch, which if longer than the measured distance, will require IMF lowering.

In determining fold position, our team has found three alternative methods extremely useful by using the implant dimensions and fill volume (Table 2.2).

If the desired N-IMF distance is equal or less than the measured N-IMF distance, then the fold does not require lowering. The distance can be adjusted based upon expectation for lower pole stretch postoperatively. It is important to recognize that inframammary fold lowering is less often required when placing a larger smooth saline or silicone implant, especially if higher profile, secondary to lower pole stretch over time [27, 28]. However, when implant choice or soft tissue characteristics predict less lower pole stretching, inframammary fold lowering may be required [13, 29]. Likewise, shaped implants are not only textured but also have a greater volume of a more cohesive gel present in the lower pole of the implant, thus requiring more lower pole skin to accommodate the implant [20–23, 30, 31]. The list below identifies some implant and soft tissue characteristics that may be associated with a greater need to lower the inframammary fold due to less postoperative stretching of the lower pole [13, 20–23, 26–31, 39].

Characteristics Associated with Less Stretching of the Lower Pole

- Textured implants
- Cohesive implants
- Shaped implants
- Silicone compared to saline implants
- Lower profile implants
- Smaller implants
- Tight, firm breast skin

Incision

The inframammary incision provides direct access and visualization of the pocket with the least injury to surrounding structures. After determining the inframammary fold position (either the native true fold position or the planned lowered position), a paramedian line is drawn through the center of the breast and bisects the newly drawn inframammary fold. The incision's medial extent begins 1 cm medial to the paramedian line and extends laterally for the appropriate distance as previously described (Fig. 2.6). The initial incision is made with a 15-blade and dis-

section is then carried out with electrocautery through the skin and subcutaneous tissue, beveling upward while rotating the breast off of the chest wall. The dissection proceeds subcutaneous for approximately 1 cm and then deep through the superficial fascia and toward the lateral pectoral border deep on the chest wall. This technique preserves a small cuff of superficial fascia at the incision, which helps to protect the IMF and will prove useful during closure (Fig. 2.7).

Implant Pocket

There continues to be divergent thought with regard to the optimal pocket for breast implants.

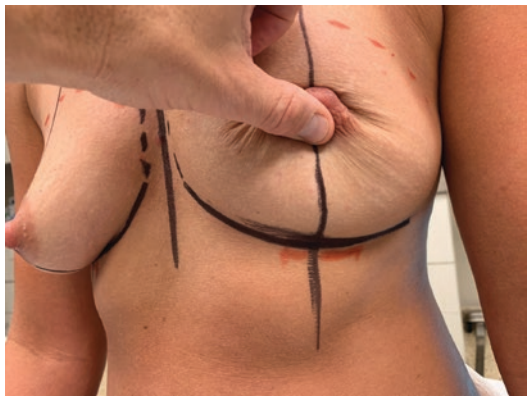


Fig. 2.6 IMF incision extending 1 cm medial to paramedian line and laterally. The length of incision is based on the implant choice

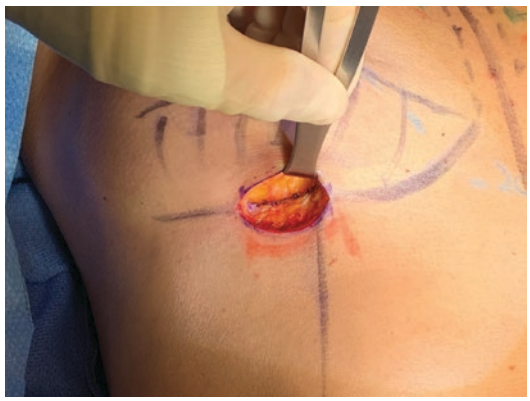


Fig. 2.7 IMF incision preserving a small cuff of the superficial (or Scarpa's) fascia

The subglandular/subfascial pocket is the most natural for the implant, with avoidance of animation deformities seen with submuscular implants, enhanced correction of constricted breast or ptotic breasts, ease of dissection, and less postoperative discomfort for the patient [32–35]. The submuscular pocket advantages have included lower capsular contracture rates, enhanced coverage of the implant to minimize issues of wrinkling, provides a more natural upper pole, and provides enhanced support for the breast implant [11–13, 32–34, 36]. Undoubtedly, the issues of wrinkling and need for enhanced coverage with saline implants provided the impetus for submuscular pockets becoming the preferred pocket by US surgeons [29, 37, 38]. It has been widely accepted that an upper pole pinch test of 2 cm is required to place an implant in the subglandular/subfascial pocket to reduce the risk of upper pole implant visibility or wrinkling. With the availability of silicone implants, both round and shaped, optimally filled with increased cohesiveness and simultaneous fat grafting, optimal pocket choice may be even more elusive.

No matter which pocket is selected, it is helpful during the marking process to identify as accurately as possible the pocket size necessary to accommodate the selected implant. This will provide a pocket that maintains the implant in a control position and minimizes the risk of postoperative implant malposition. In breast augmentation with round implants, the accurate placement of the inframammary fold and control of the medial and lateral extent of the pockets provide ideal implant positioning to achieve the desired cleavage and minimize lateral migration of the implant [29]. When using a shaped implant, a controlled pocket including the superior extent is even more essential to minimize the risk of implant rotation postoperatively [23, 30, 31].

Dual-Plane Submuscular Pocket

The importance of optimizing soft tissue coverage in breast augmentation cannot be overstated. Inadequate coverage, often combined with oversized implants, can lead to parenchymal atrophy

and skin stretching, resulting in wrinkling and palpability of the implants and other associated breast deformities [27, 28]. The dual plane, initially described by Tebbetts, maximizes coverage and support of the breast implant while minimizing the disadvantages of submuscular placement, including animation deformities and pseudoptosis of the breast tissue overlying the submuscular implant (i.e., waterfall deformity) [36].

When performing a dual-plane pocket, the lateral pectoral border is identified, and fascia incised to expose the underlying muscle. Upward retraction of the breast tissue will usually elevate the lateral border, allowing further dissection and placement of the retractor beneath the overlying pectoralis muscle (Fig. 2.8). A very helpful "rule" is to never cut through the muscle that cannot be elevated. The inability to tent the muscle up off the chest wall may indicate that the muscle fascia is extremely adherent, but more likely that the identified muscle is actually not the pectoralis, but rather the serratus, rectus, or an intercostal muscle. Continuing the dissection through an intercostal could inadvertently penetrate the pleural space, resulting in a pneumothorax. Once the edge of the pectoralis is safely elevated and the subpectoral space is identified, dissection is carried upward centrally to the superior extent of the pocket. Dissection is then carried laterally to identify the pectoralis minor, and then carried directly over the fascia until the lateral border of the pocket is reached. Dissection is then continued along the lateral border of the pocket, identifying and staying superficial to the serratus muscle until the inferior extent of the pocket at the inframammary fold is reached. The muscle is then released along the planned inframammary fold, staying 1 cm superior to the fold to account for postoperative caudal muscle descent (Fig. 2.9). Dissection directly at the fold will often lead to a fold that is lower than planned as the muscle retracts inferiorly. As you carry your dissection medially along the IMF, it is critically important to stop the dissection at the most medial extent along the sternum. Preservation of the most caudal attachment of the pectoralis muscle at the transition point (TP) along the sternum is critical to minimize the chance of window shading of the pectoralis with subsequent medial implant exposure and animation deformities. A transition zone (TZ) of tapered muscle release connects the transition point to the main body of medial pectoral muscle along the sternum (Fig. 2.10).

The extent of the pocket is completed by defining the medial pectoral border by dividing the accessory slips of pectoralis muscle that insert along the ribs, preserving the main body of the muscle as it inserts along the sternum. Dividing these muscles with electrocautery rather than blunt dissection improves postoperative cleavage and maintains prospective hemostasis.

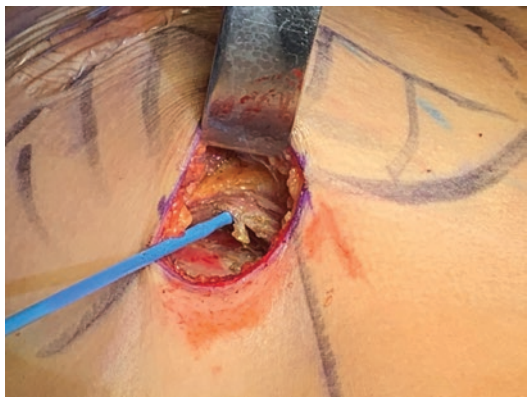


Fig. 2.8 Upward retraction of the breast tissue allows exposure of the lateral border of the pectoralis major muscle

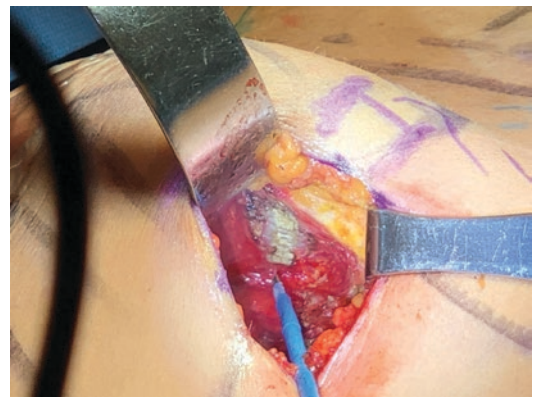


Fig. 2.9 Release of the pectoralis major muscle along the IMF, being careful to stay 1 cm superior to the inframammary fold

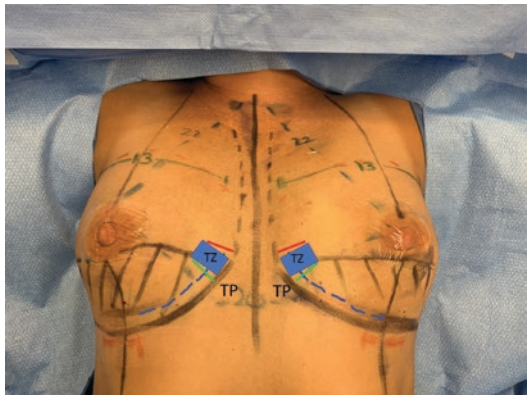


Fig. 2.10 Transition Zone (TZ) and Transition Point (TP). Dashed line (blue) reveals the location of the pectoralis muscle release 1 cm superior to the IMF (dark solid line), medially up to the TP (vertical green line). The TZ (blue shaded region) is a tapering of pectoralis, major up to the sternal attachment (red vertical line)

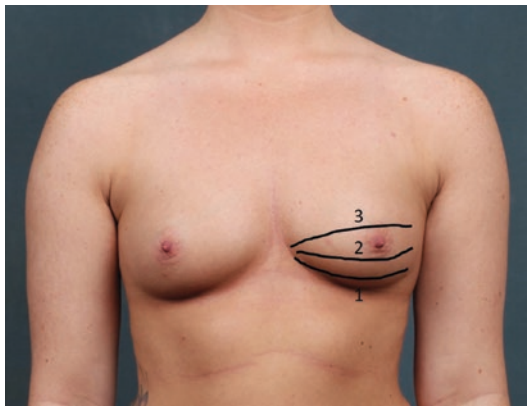


Fig. 2.11 Dual-plane levels. Dual plane 1 is a complete division of the pectoralis major muscle (PMM) along the IMF. Dual-plane 2 is release of the breast tissue off the PMM up to the lower areola. Dual plane 3 is release of the breast tissue off the PMM up to the upper border of the areola

The dual-plane approach ultimately creates a subglandular pocket in the inferior breast pocket. The levels of dual plane represent the amount of muscle released from the inferior breast tissue and resultant inferior subglandular pocket (Fig. 2.11). Division of the inferior pectoralis muscle just above the inframammary fold during initial pocket dissection created a dual-plane level 1. The level of dual plane required varies, and each surgery can be tailored to provide the optimal level based on soft tissue requirements and implant selection. In general, creating a subglandular pocket inferiorly is required to either redrape the skin and breast tissue more accurately over the implant, or for expansion and exposure of the lower pole, such as in a tuberous or constricted breast. The release of the caudal edge of the muscle is performed incrementally, creating the least amount of release that will adequately address the lower pole (Fig. 2.12). Placement of a retractor into the breast pocket and elevating superiorly while rocking the breast tissue over the retractor will assist in assessing the effects of the implant on the overlying skin and breast tissue once placed in the pocket. When a dual plane is created for expansion and exposure in a tight envelope, the level will depend on the need to access the parenchyma for scoring and expansion. This usually requires at least a level 2 and often a level 3 to expose the retroareolar tissue.

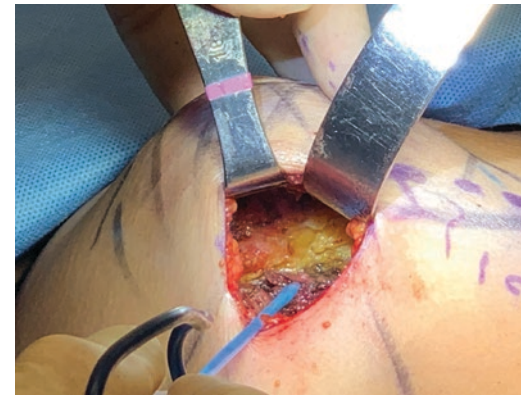


Fig. 2.12 Release of the pectoralis major muscle caudal edge off of the overlying breast tissue

Subglandular/Subfascial Pocket

The subglandular or subfascial pocket can be easily developed through the inframammary incision, and this dissection is performed without the need for muscle division or dual-plane creation. Once the incision is made and the lateral pectoral border has been identified, the dissection is carried out either above (subglandular) or deep to (subfascial) the pectoralis fascia. This is important, as inadvertent

overdissection can lead to implant medialization, visibility, and potentially symmastia. The subfascial plane can be a more challenging dissection as there is no natural plane present for this dissection. The subfascial pocket is often preferred over a subglandular pocket when shaped implants are used, as it potentially provides a more precise and stable pocket in the upper pole to avoid implant rotation.

Implant Placement

Once the pocket has been created, it is irrigated with triple antibiotic betadine solution (50 ml of povidone-iodine, 1 g of cefazolin sodium, and 80 mg of gentamycin mixed in 500 ml of normal saline) or 50% povidine-iodine saline solution and hemostasis is assessed [10]. It is the goal during the operation to achieve prospective hemostasis with minimal blood staining; however, a final assessment is mandatory prior to implant placement. The implants are soaked in the irrigation solution prior to insertion. Gloves are changed and rinsed with the irrigation solution to remove any lint or powder.

The implant is then placed either manually or with the assistance of an insertion sleeve such as the Keller funnel [9] (Fig. 2.13). The funnel provides a *minimal* to "no touch" technique, which has been associated with lower capsular contracture rates [7]. The funnel allows for easier implant placement with potentially smaller incision requirements, compared to manual placement. Repeated removal and insertions of the implant should be avoided to minimize implant or incision damage, potential contamination, and pocket overdissection.

Closure

Prior to incision closure, the patient should be placed in the upright position to assess implant position, fold position, symmetry, and the adequacy of the dual plane (Fig. 2.14). Any additional adjustments of the dual plane can be accomplished after the patient is placed back in the recumbent position by simply retracting the breast tissue superiorly off the implant, identifying the caudal edge of the muscle, and releasing it incrementally off the overlying breast tissue to the desired level.

A significant advantage of the inframammary approach is the ability to accurately and effectively control the fold position during closure of the incision. The cuff of superficial fascia that was preserved during the initial incision is utilized to secure the fold during closure. Although in our practice all inframammary folds are "locked-down" during incisional closure, it could be argued that a well-developed stable IMF that has not been violated or lowered during the procedure is potentially stable, and may only require a more superficial closure. However,

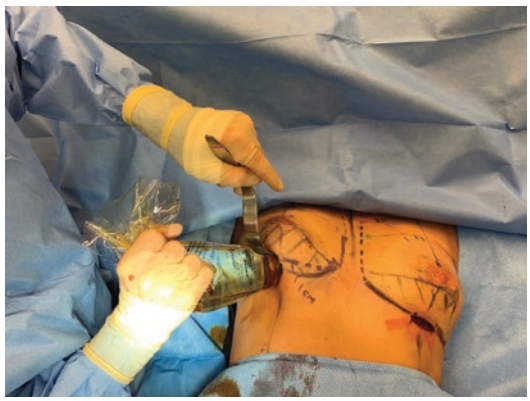


Fig. 2.13 "No touch" technique with Keller funnel insertion

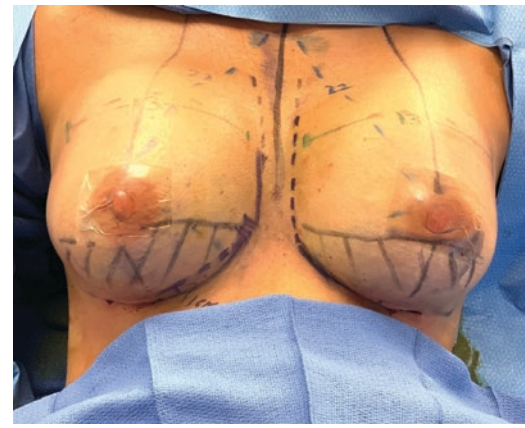


Fig. 2.14 Patient sitting upright on operating room table to confirm final result

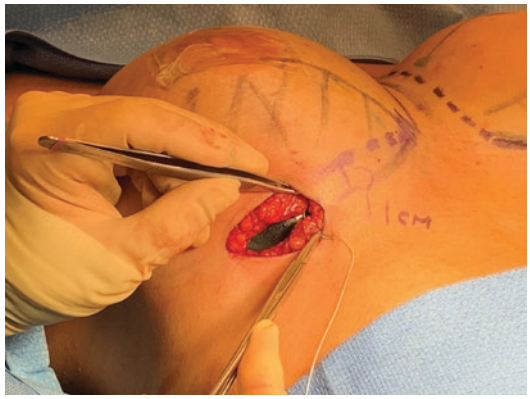


Fig. 2.15 Closure of breast pocket and locking the IMF. Running 2-0 Vicryl securing superficial fascia to the deep fascia

when the fold is unstable due to either inherent weakness in the fold structure or from disrupting it with fold lowering, closure should include stabilization of the fold structure. This is accomplished by securing caudal edge of the scarpa's fascia present on the lower incisional edge to the underlying deep fascial structures with an absorbable suture such as 2-0 vicryl (Fig. 2.15). This is usually done by simply incorporating the superficial and deep fascia together during a running closure. It may also be performed by first placing three to four interrupted sutures on the lower flap, securing scarpa's fascia to the underlying deep fascia, followed by closure of the incision. The incision is closed in three layers: scarpa's fascia superiorly to scarpa's fascia, and deep fascia inferiorly, deep dermis, and subcuticular.

Case Examples (Figs. 2.16 and 2.17)

Management of Breast Ptosis

Introduction

Breast ptosis is one of the most common issues seen for evaluation in a plastic surgeon's office. It can be developmental or more commonly acquired, secondary to weight loss, hormonal changes, pregnancy, and aging. Mild breast ptosis can often be corrected with a breast augmentation, but when more significant ptosis is present, a breast augmentation will not provide the correction of ptosis present and a mastopexy is required, with or without an implant. When evaluating the ptotic breast, the volume status of the breasts should be a part of the initial assessment, as this will determine whether a mastopexy is adequate and whether augmentation with an implant or fat is indicated.

Mastopexy

A mastopexy alone is reserved for a patient in whom the major concern is breast ptosis and not an issue of breast volume or upper pole fullness, as the procedure repositions the breast with only limited removal or transposition of breast tissue. There are many types of mastopexy techniques described to address the ptotic breast. The techniques are often described in reference to the final scar placement, such as the circumareolar technique [40], circumvertical technique [41, 42], and inverted-T scar technique [43, 44]. However, there is much more variation in the techniques, including the vascular pedicle orientation, management of the parenchyma, and additional ancillary procedures, to enhance the results. Long-term success of any mastopexy procedure is partially influenced not only by the scar technique but also, and maybe more importantly, by the pedicle selection and management of the parenchyma [42]. Thus, in general, the mastopexy can be performed with an inferior/central pedicle technique or a superior or superomedial technique, which describes the pedicle blood supply and the surgical approach. Secondarily, the skin excision pattern is determined and variable based on the surgeon's preference with excising excess skin along the inframammary fold, or maintaining a purely vertical approach and limiting the scar to only a periareolar vertical, with the excess skin reestablished on the abdominal skin below the fold if indicated.

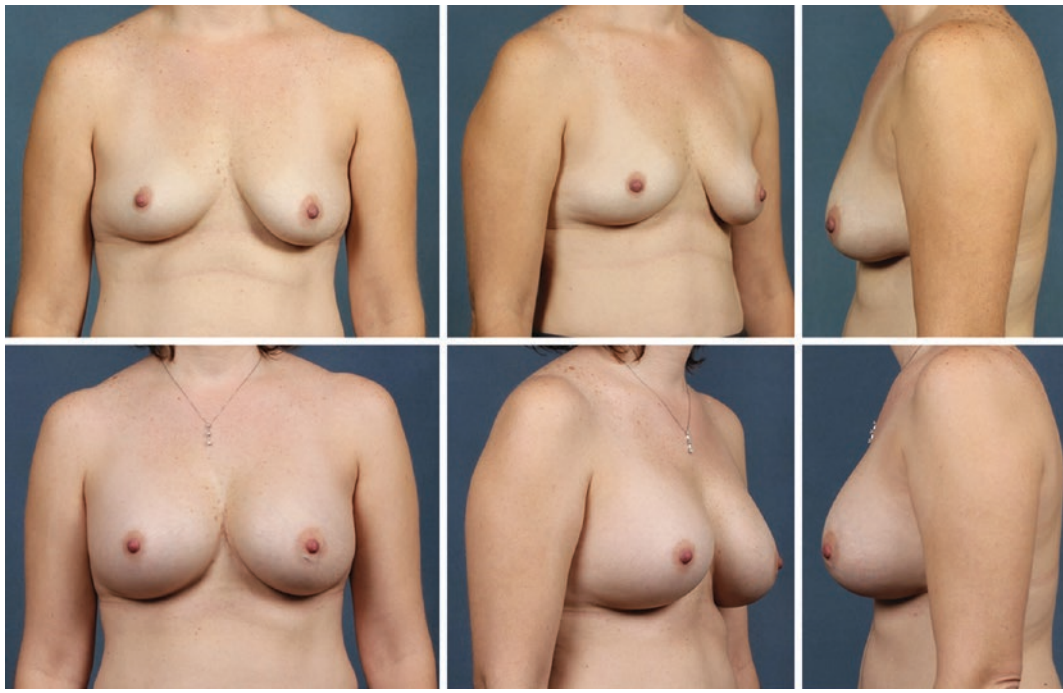


Fig. 2.16 Thirty-five-year-old female with grade I ptosis on the right and grade II ptosis on the left underwent bilateral submuscular augmentation mammoplasty with a dual plane 3 on the left using a 375cc moderate plus smooth round silicone implant. On the right she underwent a dual plane 2 with a 425cc high profile smooth round silicone implant

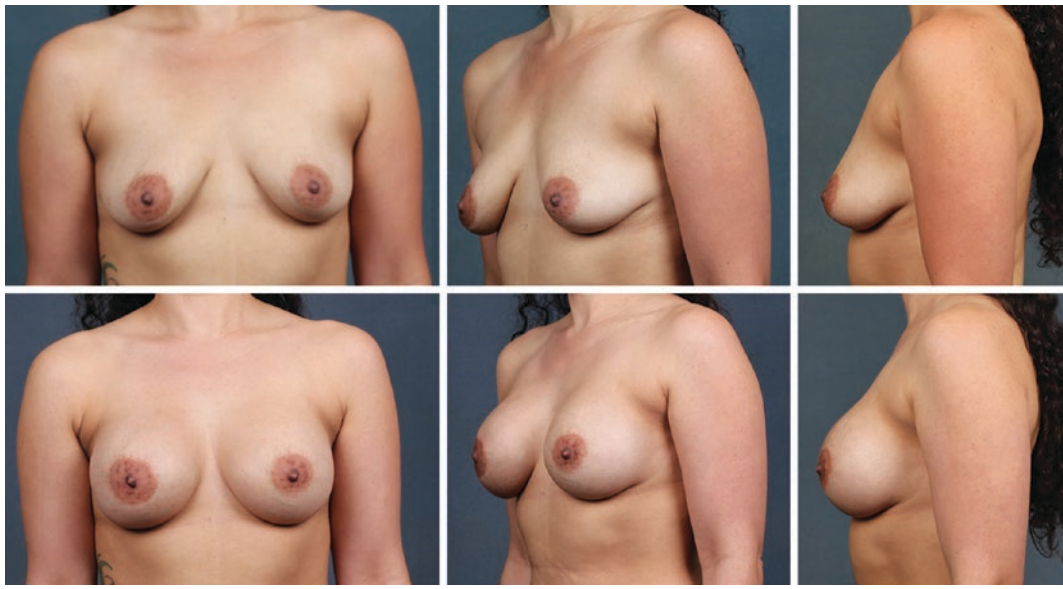


Fig. 2.17 Thirty-one-year-old female with grade II ptosis on the right and grade I ptosis on the left underwent bilateral subglandular augmentation mammoplasty with 355cc moderate plus textured round silicone implants

Preoperative Evaluation

The amount of ptosis present should also be assessed. Ptosis has classically been described, as per Regnault, based on the relationship of the NAC with the inframammary fold, but this falls short of adequately identifying and characterizing the breast ptosis [45]. A more complete assessment of ptosis is summarized in Table 2.3.

Patients with different grades of ptosis may have completely different breast compositions, including the quality of breast tissue and skin, the quantity of breast tissue present, and the vertical excess present. Assessment should also include evaluation of the skin thickness and elasticity, the quantity and distribution of subcutaneous fat, the composition and firmness of the breast parenchyma, the integrity of the Cooper's ligaments, the nature and position of the underlying musculature, and the shape and slope of the underlying chest wall. All these aspects of the breast composition influence the shape of the breast and, ultimately, the outcome after the augmentation mastopexy.

The preoperative evaluation is used to determine the mastopexy technique that will achieve an optimal outcome that meets the patient's desired results. For patients with less ptosis and minimal vertical excess, a circumareolar or circumvertical mastopexy can be performed without the need for skin removal along the fold. In our experience, if the distance from the new nipple position to the fold is less than 10–12 cm, most likely only a vertical or a vertical with small horizontal wedge or j-extension will be adequate for correction, usually employing a superior pedicle. To avoid the inframammary scar with a circumvertical mastopexy, the tissue at the base of the breast is resected internally, causing elevation of the fold with the excess vertical length tucked under the new breast fold, eliminating the need for the horizontal scar. However, we often choose to remove excess skin along the fold if necessary, no matter whether the flap is inferiorly or superiorly based. Not removing the skin at the fold increases the risk of fold malposition, scar irregularities or dog ears, or elongation of the lower pole with bottoming out over time.

The decision on whether to utilize a superior pedicle or inferior pedicle must be determined. That decision is based mostly on the amount of ptosis, the quality of the breast tissue, and the position of the nipple-areolar complex. For patients with good-quality breast tissue and the amount of nipple-areolar complex (NAC) elevation is less than 5–6 cm, a superior pedicle is utilized and a circumvertical mastopexy with inverted-T scar (Fig. 2.18). The superior pedicle also allows for the use of the lower pole tissue for autoaugmentation. The NAC can be elevated to a greater extent through the use of a superomedial or medial pedicle as well, and this is based on the surgeon's preferred approach and the likelihood of success with

Table 2.3 Assessment of breast ptosis

Relationship of the NAC to the IMF (Regnault's degree of ptosis) (*a*) *Grade 1*: Nipple at the level of the inframammary fold above the lower contour of the gland (*b*) *Grade 2:* Nipple below the level of the inframammary fold above the lower contour of the gland (*c*) *Grade 3:* Nipple below the level of the inframammary fold at the lower contour of the gland
Amount of breast tissue overhanging the fold
Location of the NAC on the breast mound
Amount of vertical excess and horizontal excess
Footprint of the breast on the chest wall —low, medium, and high
Quality and quantity of breast parenchyma and skin

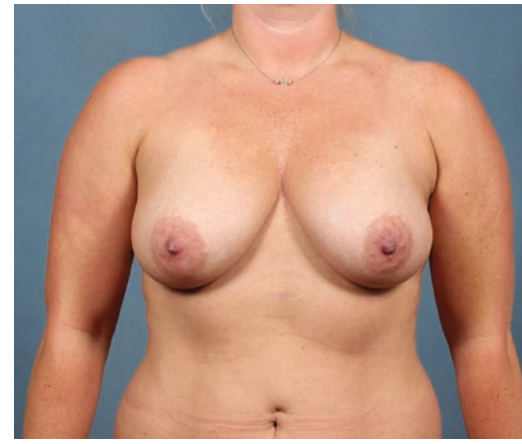


Fig. 2.18 Example of a good candidate for a circumvertical mastopexy

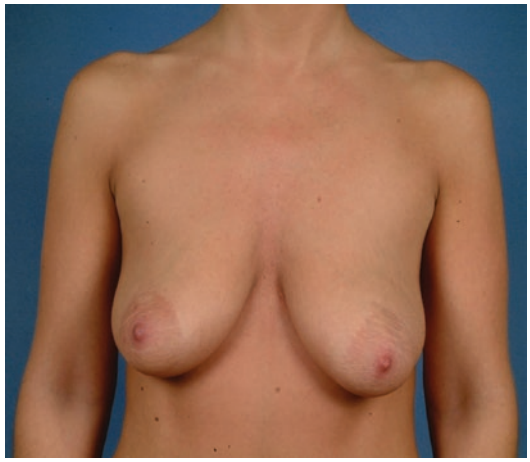


Fig. 2.19 Example of a good candidate for an inverted-T mastopexy or full wise mastopexy based on the amount of breast ptosis

the approach. In breasts with poor-quality tissue with associated laxity, and breasts requiring significant volume reductions and ptosis where NAC elevation is greater than 6 cm, an inferior pedicle inverted-T mastopexy is our preferred technique (Fig. 2.19). Often, a mesh reinforcement is secured across the inferior pedicle to limit the lower pole stretch due to the extra volume of the pedicle being retained in the lower pole.

Relevant Surgical Anatomy

When performing a mastopexy, an understanding and assessment of the vascular anatomy is critical to performing the procedure safely. The breast has a rich blood supply from multiple sources, including the internal mammary artery perforators, the lateral thoracic arteries, the thoracoacromial, and the anterolateral and anteromedial intercostal perforators. The superior pedicle is supplied by the second branch of the internal mammary artery (IMA) that emerges deep from the second interspace and courses superficial across the medial upper breast to enter the NAC slightly medial to the midline and approximately 1 cm deep. The medial pedicle is supplied by the third branch of the IMA that emerges from the third interspace and similarly courses superficially across the breast parenchyma to the medial aspect of the NAC. The inferior pedicle and central pedicle are supplied by the fourth branch of the IMA that courses deeply across the medial breast to enter through Wuringer's septum approximately 1–2 cm above the IMF and just medial to the breast paramedian line. The inferior pedicle also has additional blood supply through contribution from intercostal perforators along the IMF [46] (Fig. 2.20).

Preoperative Markings

Appropriate preoperative markings provide a road map and are essential to planning and performing mastopexy surgery. The markings guide the surgeon in providing symmetrical NAC placement and mastopexy design. The patient is sitting upright during the markings. A line is initially drawn along the midline of the breasts and bilaterally down the meridians. The meridian lines bisect the breast equally and may not intersect through the nipple if there is NAC malposition. The inframammary folds are then drawn, noting any asymmetries to be addressed at surgery. The position of the IMF is

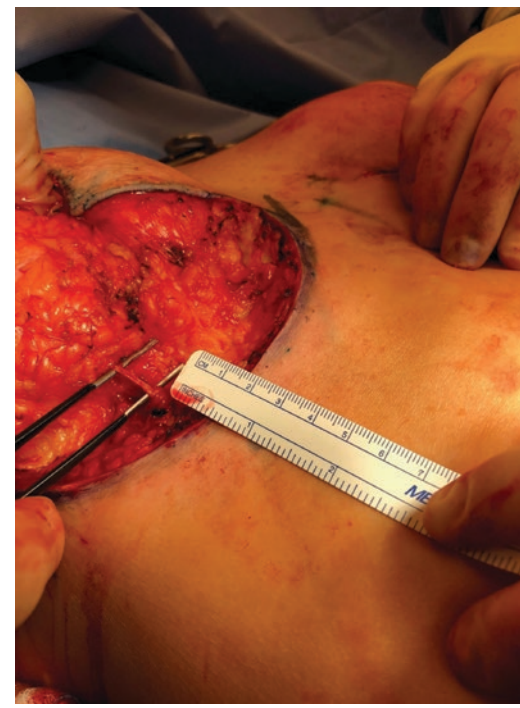


Fig. 2.20 The fourth branch of the internal mammary artery coursing through Wuringer's septum (1–2 cm above the IMF)

then drawn on the anterior breast through the meridian incision. The breasts are then rotated medially and laterally to mark the location of the vertical incisions. Placement of the areola is then marked, starting approximately 2 cm above the nipple position and extending the curved drawing down to meet the medial and lateral vertical markings. This areolar opening marking should produce an areolar opening of approximately 42 mm. Approximately 7 cm below the bottom of the keyhole opening, a line is drawn marking the inferior extent of the vertical incision. Curved transverse lines are then drawn from these medial and lateral points extending down to the IMF. When performing a superior pedicle, approximately 2–3 cm above the fold a U-shaped line connects the medial and lateral vertical markings to define the extent of skin resection (Fig. 2.21). With inferior pedicles, the entire lower segment between the two medial and lateral vertical lines is deepithelialized, making this line unnecessary (Fig. 2.22).

Intraoperative Markings

Once the patient is under anesthesia and has been prepped for the operative procedure, all markings are confirmed and retraced as necessary. The symmetry of the drawings is also confirmed. If any questions exist as to the accuracy of the markings, tailor tacking can be performed in many cases to reconfirm the markings. Tailor tacking is performed with a stapler and the patient is placed in an upright position to confirm design, symmetry, and NAC positioning. In the supine position, the staples are removed, and the selected pedicle is designed and then marked out. For the superior pedicle, the pedicle is positioned in the superior keyhole from the 8 o'clock to 4 o'clock position. If utilizing an inferior pedicle, the markings include at least a 1-cm cuff around the areola, and is designed between the vertical and lateral pillars extending down to the IMF. The pedicle is designed with a width of approximately 6–8 cm based on the length of the pedicle, ensuring that the length-to-width ratio does not exceed 3:1.

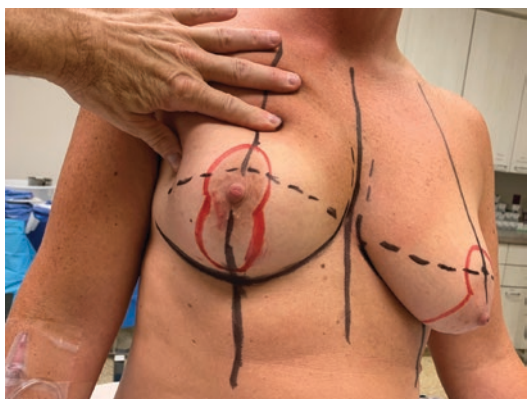


Fig. 2.21 Preoperative markings. The black dotted line represents the transposed IMF. The red vertical markings represent the circumvertical markings of the NAC and medial and lateral planned skin resections

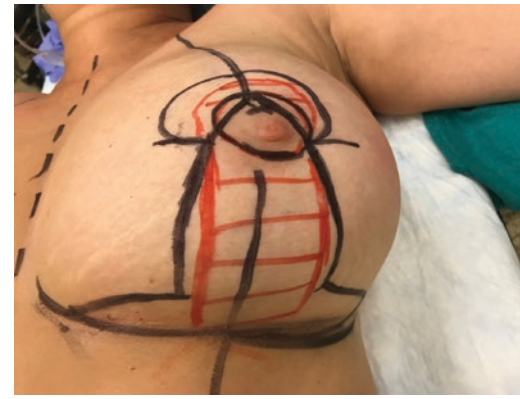


Fig. 2.22 Preoperative markings of an inverted-T mastopexy with vertical and horizontal resection markings. The red markings represent the anticipated inferior pedicle for deepithelialization

Inferior Pedicle Inverted-T Mastopexy with or Without Mesh Reinforcement

The patient is positioned as has been described and preinjected. Each breast is placed under maximal stretch, and the areolas are marked with a 42-mm cookie cutter (range 38–45 mm depending on desired aesthetics) and superficially incised with a 15-blade scalpel (Fig. 2.23). Incisions are then made along the planned skin resection for the inverted-T mastopexy. The inferior pedicle is then deepithelialized from the inframammary fold up to the NAC, ensuring to include at least a 1-cm cuff of dermis around the NAC (Fig. 2.24). Care is taken to preserve the subdermal plexus during the

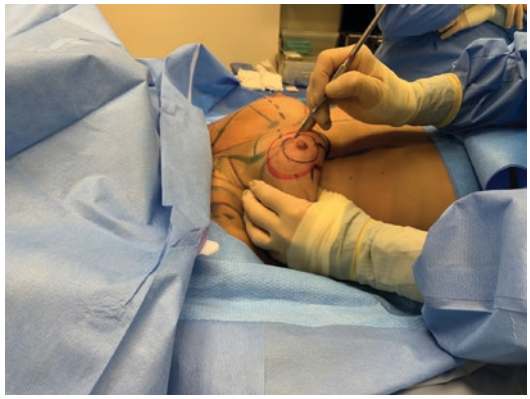


Fig. 2.23 NAC incision made of the NAC with a 15-blade scalpel

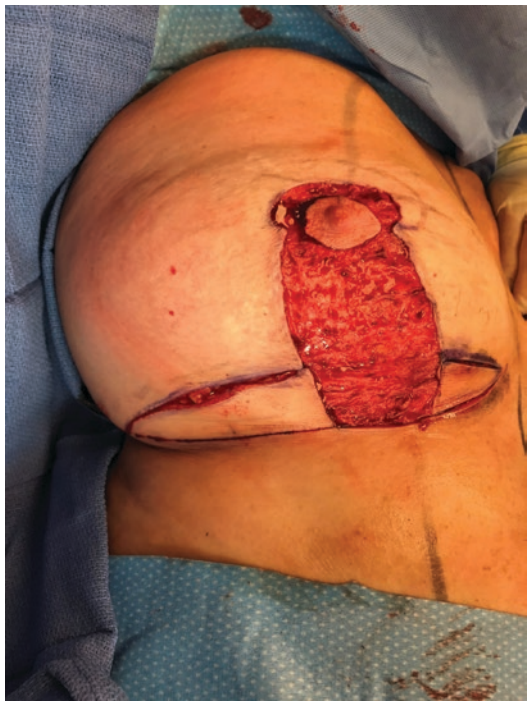


Fig. 2.24 Deepithelialized inferior pedicle

deepithelialization. Dissection is then carried out around the entire deepithelized inferior pedicle, ensuring not to narrow the base of the pedicle at its attachments to the chest wall perforators by beveling outward to maintain its integrity and bulk (Fig. 2.25). The medial and lateral dermoglandular segments are then resected. The upper breast skin flaps are then undermined to the pectoral fascia, excising fat and glandular tissue as necessary for shaping. In an inverted-T inferior pedicle mastopexy, volume reduction is not generally the goal, so the amount of tissue resected is limited to the skin resection and additional breast tissue and fat, as required, to create the desired size and contour of the final breasts.

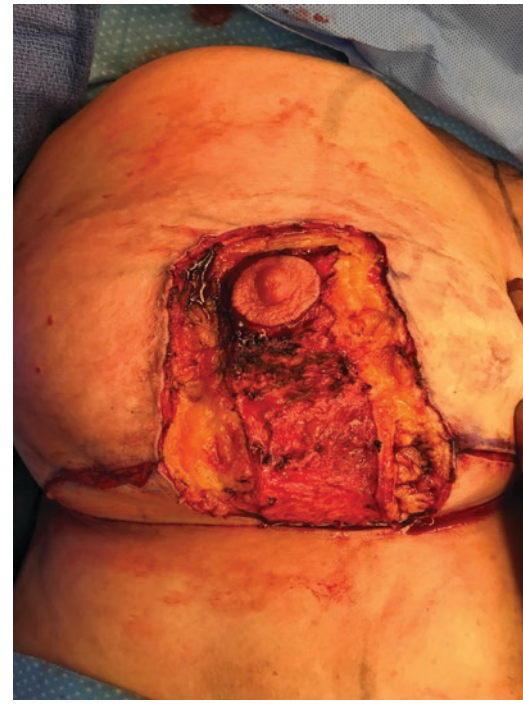


Fig. 2.25 Dissection of the inferior pedicle. Be sure to keep a wide base to maintain integrity of the blood supply

In our experience, success in any mastopexy or reduction procedure is more likely long term if the new breast shape is created by parenchymal resection and shaping, as opposed to skin envelope reduction. Additionally, reduction in long-term bottoming out or pseudoptosis postoperatively is best assured through unloading the lower pole of the breast, usually accomplished with tissue resection or rearrangement as with a superior pedicle technique.

With the inferior pedicle technique, the pedicle is located in the lower pole, and thus, resection or tissue rearrangement is not possible. To help address this, we have found stabilizing the inferior pedicle can be valuable in planning final shape and potentially reducing the lower pole stretch postoperatively. The inferior pedicle is rather unstable after resection of surrounding tis-

sue and will generally fall laterally into the dissected space. The inferior pedicle is positioned centrally in the pocket and 2-0 vicryl sutures are placed from the pedicle to pectoralis fascia to stabilize its position (Fig. 2.26). It is helpful, if possible, to secure the pedicle from the dermis to the fascia for the best suture purchase, but this is not always feasible. The inferior pedicle has to be stabilized in a position that allows the NAC to be brought through the keyhole once the position of the NAC is confirmed and the opening created. Although these pectoralis-to-pedicle sutures can be used to provide some stabilization, long-term stability is not always reliable.

To ensure stability, we now placed a piece of poly-4-hyroxybutyrate mesh (GalaFLEX; Galatea Corp., Lexington, Mass.) reinforcement across the inferior pedicle, stabilized with 2-0 vicryl sutures on the medial and lateral pectoralis fascia [47] (Fig. 2.27). The size of the mesh is variable but, in general, a piece 5 × 15 cm per side has been adequate to create stability of the pedicle. This mesh resorbs in 12–18 months, but with retention of wound strength often four to five times the strength of the native tissue. The mesh should be placed snug enough to stabilize the pedicle, but without compressing or compromising the circulation through the inferior pedicle.

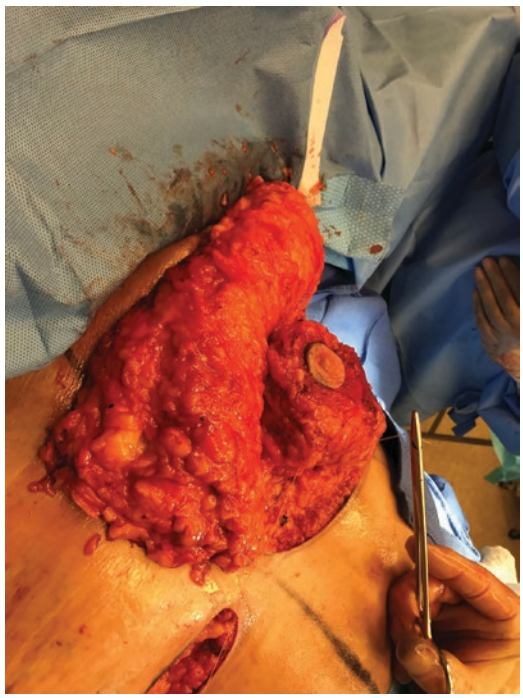


Fig. 2.26 2-0 Vicryl suture used to suture the pedicle to the underlying fascia for position stabilization

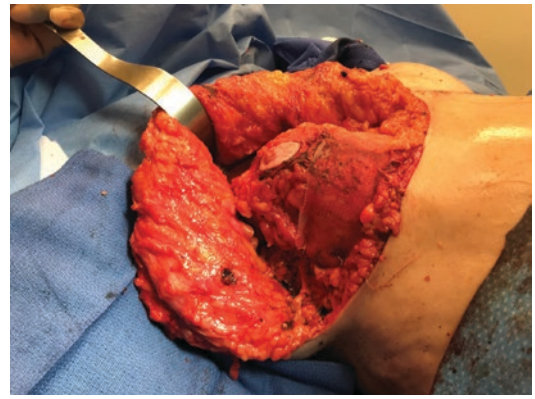


Fig. 2.27 The use of poly-4-hyroxybutyrate mesh across the inferior pedicle for soft tissue support. The mesh is sutured medially and laterally to the pectoralis fascia

The wounds are irrigated, and hemostasis is established with electrocautery. The nipple-areolar complex circulation is assessed for arterial and venous bleeding from the cut edges. The skin is then temporarily brought together with staples to confirm the final shape. The patient is then placed in the upright position to assess the volume, contour, and symmetry of the breast (Fig. 2.28). Tailor tacking to make some final adjustments in the shape of the breast is almost always performed to create the optimal postoperative outcome.

In contrast to the a superior pedicle technique described in the following section, one of the advantages in the inferior pedicle technique is that the keyhole is planned but not excised until nearly the end of the procedure to allow for adjustments in the NAC position during final tailor tacking. Therefore, while the patient is upright, the position of the nipple-areolar complex can be selected. A cookie cutter is placed at the apex of the vertical incision and positioned in an aesthetically pleasing location. The inferior areola to inframammary fold position is generally 5–7 cm based on the final breast size. Symmetry is confirmed by measuring the distance from the midline to medial areola, and by placing a suture at the sternal notch and checking that equal distance is achieved to the top of each areola (see Fig. 2.49 in the "Augmentation Mastopexy" section). With the patient supine, the

staples are removed, and the keyhole and any additional tissue marked during tailor tacking are excised. The pockets are irrigated with bacitracin saline solution and hemostasis is ensured. Deep parenchymal sutures of 2-0 vicryl are then placed along the vertical incision, bringing the medial and lateral pillars together at the midline. The incisions are then closed with interrupted 3-0 PDS dermal sutures. The vertical and horizontal scars are closed with a 4-0 monocryl running subcuticular suture. The areolas are then closed with a simple running 5-0 nylon suture. Steri-strips are placed over the incision. Contour tape is then placed along the lateral breast border and inframammary fold. The breasts are wrapped with a kerlix and ace wrap to provide gentle compression and support (Fig. 2.29).

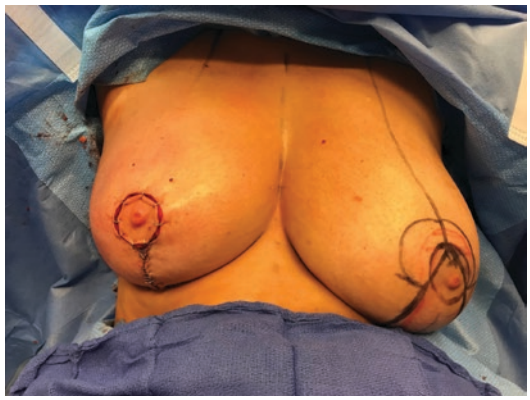


Fig. 2.28 Tailor tacking of the breast to assess for shape and contour

Superior Pedicle Circumvertical Mastopexy with Inverted-T Scar

Each breast is placed under maximal stretch, and the areolas are marked with a 42-mm cookie cutter (range 38–45 mm depending on desired aesthetics) and incised with a 15-blade scalpel. Utilizing a 10-blade, the entire area within the marks is then deepithelized and cauterized for hemostasis (Fig. 2.30).

The lateral and medial flaps are dissected straight down toward the chest wall. The lateral and medial pillars are then developed, keeping them at least 2 cm thick (Fig. 2.31). If there is additional breast tissue deep to the developed pillars, this is either resected if it is not needed, or mobilized from lateral to medial and sutured to the main pedicle with 2-0 vicryl suture to maintain volume.

Option 1—Standard Approach

This central main pedicle located in the lower pole is then dissected off the pectoralis fascia, starting inferiorly and progressing superiorly under the central pedicle to the upper portion of the breast. This allows the entire breast to be effectively mobilized superiorly. With retractors under the breast, approximately four 2-0 vicryl Marchac sutures are placed between the deep breast parenchyma and the pectoralis fascia [44]. This central pedicle in the lower pole is then sutured in an ele-

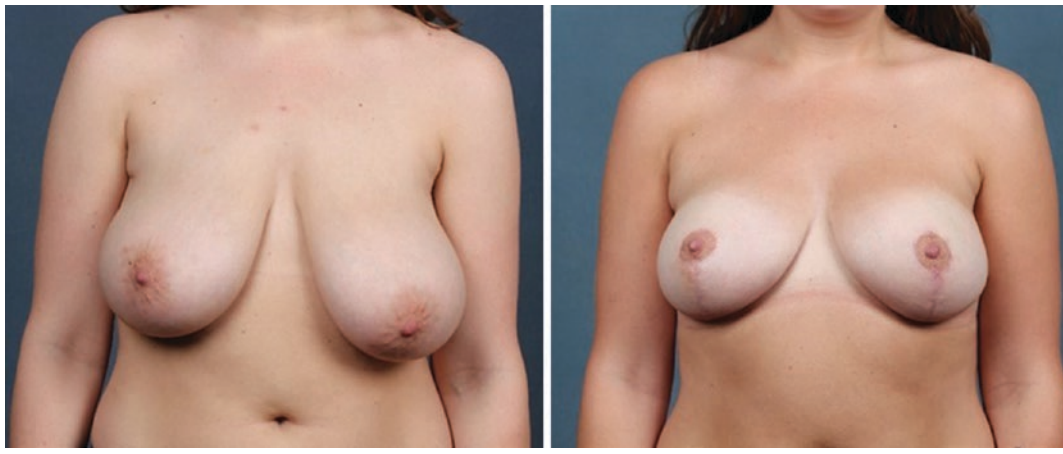


Fig. 2.29 Twenty-eight-year-old female before and after bilateral mastopexy reduction with an inverted-T mastopexy/reduction with an inferior pedicle using Galaflex soft tissue support

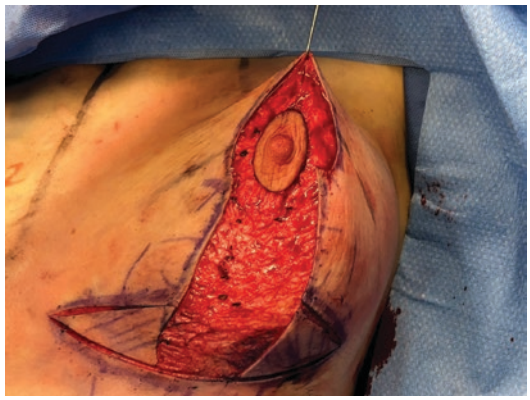


Fig. 2.30 Area of deepithelialization for the superior pedicle circumvertical mastopexy with a short horizontal incision

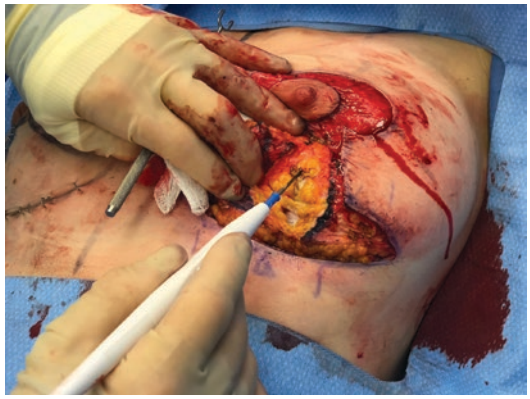


Fig. 2.31 Dissection of the medial and lateral breast pillars

vated position approximately 1–2 cm above the IMF. This stabilizes the tissue in a higher position during the healing process and elevates the inframammary fold. Care must be taken not to elevate too much or aggressively evacuate the lower pole, as this can lead to a flattening in the lower pole or retraction of the IMF, superiorly creating a contour defect along the fold (Fig. 2.32).

Option 2—Lower Island Flap Autoaugmentation

An alternative to the above-described approach is to use the central pedicle in the lower pole as a flap to transposition into the upper pole, as originally described by Ribiero and more recently by Hammond [48, 49]. Instead of elevating this central lower island flap off of the fascia, a flap is created that is based off the central pedicle just above the IMF (Fig. 2.33). This flap is dissected circumferentially, and then incrementally dissected to free its attachment to create a mobile flap still attached to the deep fourth branch of the IMA that courses through Wuringer's septum. Once the flap has been dissected and released for mobilization, the remainder of the breast above the flap is elevated off of the pectoralis fascia (Fig. 2.34). The

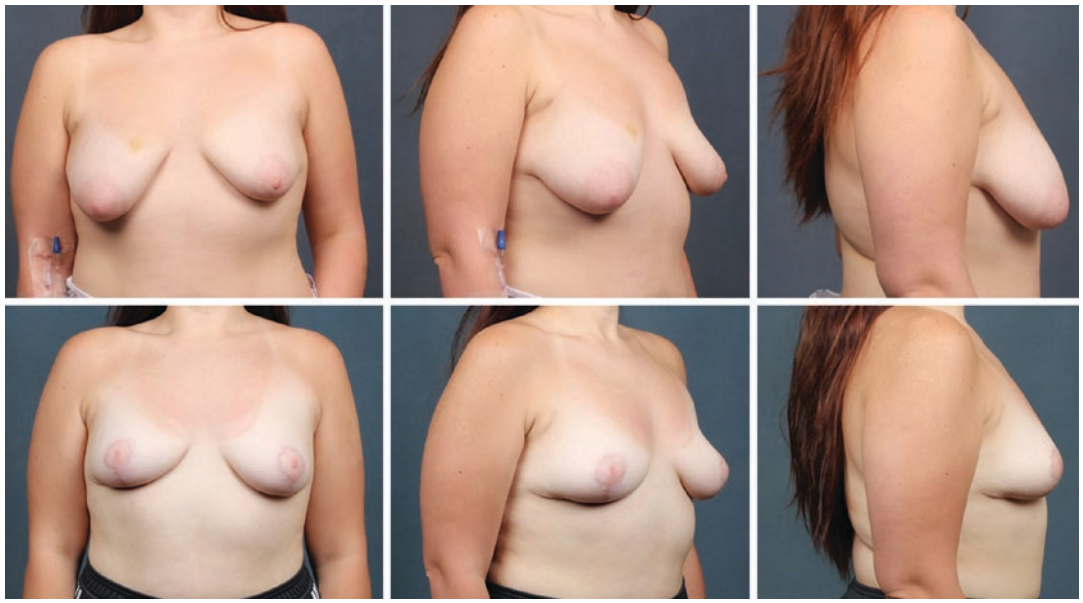


Fig. 2.32 Case example of patient who underwent mastopexy with a superomedial pedicle circumvertical (periareolar vertical) with a short horizontal on the right and a circumvertical mastopexy on the left

lower island flap is then transposed into the upper pole and sutured into place with approximately four 2-0 vicryl sutures (Fig. 2.35).

Once the parenchyma is positioned and stabilized, tailor tacking is performed to confirm the shape of the breast. Tailor tacking begins at the inferior areola (6 o'clock position) and proceeds inferiorly toward the IMF. The ideal inferior areola-to-fold distance varies based on the size of the breast, but is usually 6–7 cm. Adjustments are made with the tailor tacking to create the desired breast shape. Markings for the horizontal wedge excisions are then extended medially and laterally to create the inverted-T scar (Fig. 2.36). Once confirmed, all staples are removed, and the horizontal wedge is excised. The pockets are irrigated with bacitracin saline solution and hemostasis is ensured. Deep parenchymal sutures of 2-0 vicryl are then placed along the vertical incision, bringing the medial and lateral pillars together at the midline (Fig. 2.37). The incisions are then closed with interrupted 3-0 PDS dermal sutures. The vertical and horizontal scar are closed with a 4-0

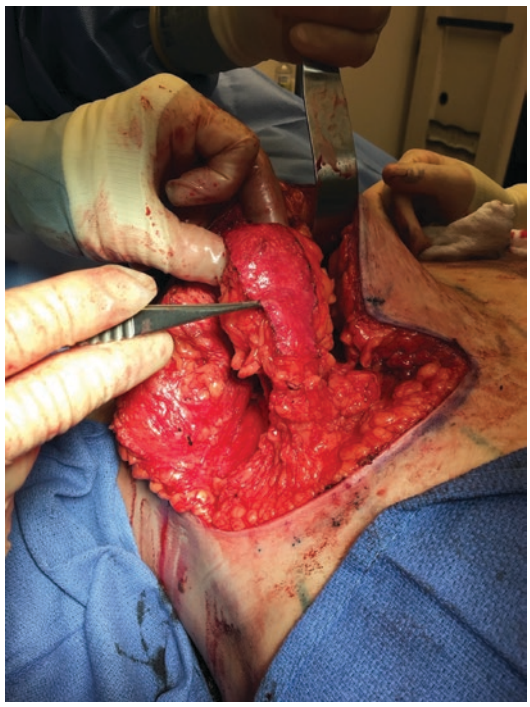


Fig. 2.33 Ribiero flap designed off of the central pedicle just above the IMF

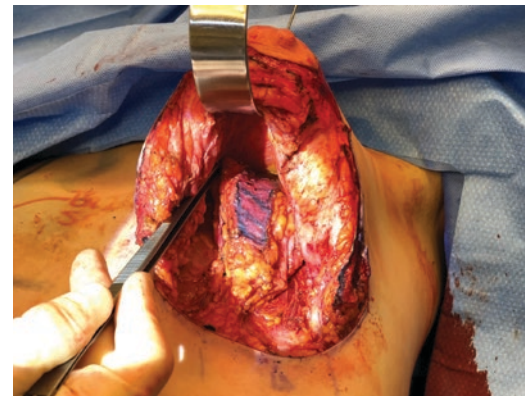


Fig. 2.34 Elevation of the breast tissue off of the pectoralis fascia to allow for flap transposition

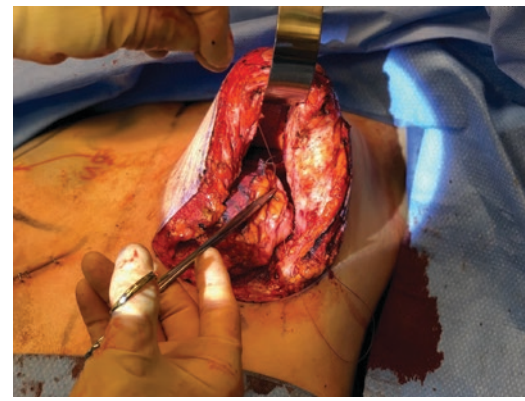


Fig. 2.35 Flap elevation superiorly then sutured to the fascia with 2-0 Vicryl sutures for stability

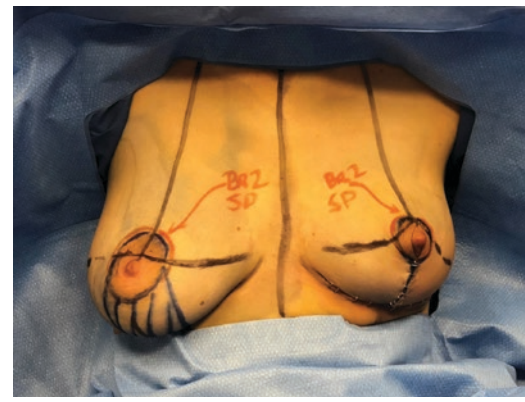


Fig. 2.36 Tailor tacking of the breast to confirm breast shape and size

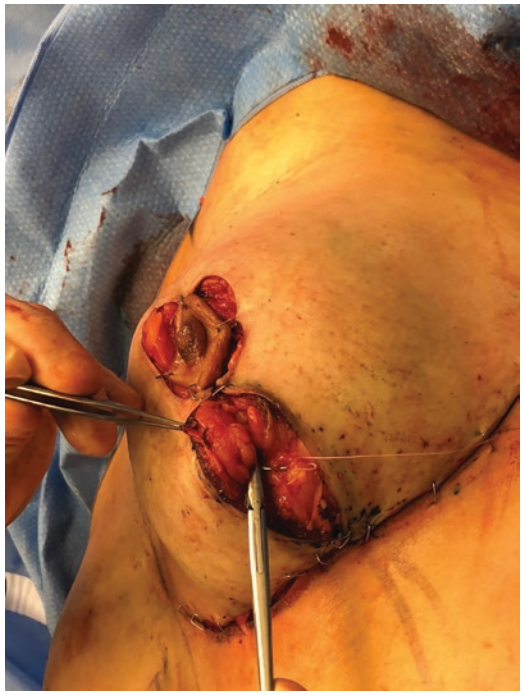


Fig. 2.37 Medial and Lateral vertical breast pillars sutured with interrupted 2-0 Vicryl

monocryl running subcuticular suture. The areolas are then closed with a simple running 5-0 nylon suture. Steri-strips are placed over the incision. Contour tape is then placed along the lateral breast border and inframammary fold. If a drain is used, a biopatch is placed at the base of the drain as it exits the skin, and the drain is secured with a 2-0 nylon. The breasts are wrapped with a Kerlix and ace wrap.

Postoperative Care and Expected Outcomes

The patients are instructed to leave all dressings on for 24 hours. The wraps are then removed, and a sports bra is worn for the following 4 weeks. Dressing changes with antibiotic ointment and gauze are used over incisions for 1 week. Patients can shower after 48 hours. The contour tape is removed at day 4 through 7. Nylons around the areolas are removed 6–8 days postoperatively. The subcuticular monocryls are clipped on the ends as they exit the skin at 2 weeks. Scar management with silicone gel or silicone sheeting is initiated on all patients at 2 weeks. Patients are allowed to resume activities of daily living almost immediately. Exercise is usually allowed at 4 weeks, with heavy lifting at 6 weeks.

Patients are counseled that they can expect swelling and firmness to develop as their breasts heal. The breasts will continue to soften over time, and the breast will relax over the first few months. The results are stable after 6 months, but scars can continue to improve over the first year, and some additional relaxation of the breast with loss of upper pole volume can continue for even longer. Whereas inferior pedicle shape looks relatively normal shortly after the procedure, superior pedicle technique may take longer to obtain its natural shape.

Case Examples

Case 1 Sixty-four-year-old female with asymmetric grade 3 ptosis with a SN-N distance of 34 cm on the right and 32 cm on the left (Fig. 2.38). Due to the amount of ptosis requiring significant NAC elevation of greater than 6 cm, an inferior pedicle inverted-T mastopexy reduction was performed. The inferior pedicle was supported with a soft tissue scaffolding (Galaflex). She has uplifted, stable, symmetric breasts with no bottoming out as demonstrated in her 4-month postoperative results.

Case 2 Twenty-nine-year-old female with 34 DD cup breasts desiring a smaller, more uplifted appearance (Fig. 2.39). Her SN-N distance was 26 cm with grade 2 ptosis; thus, only requiring a few cm of NAC elevation. A superior pedicle inverted-T mastopexy was performed with a lower island flap autoaugmentation. Her postoperative photographs at 2 months demonstrate an uplifted C cup with good upper pole volume thus far.

Case 3 Thirty-five-year-old wearing a 32 DD cup complained of saggy, heavy breasts (Fig. 2.40). She presented with grade 3 ptosis on the right and grade 2 ptosis on the left. She desired an uplifted, full C cup appearance. She underwent a superior pedicle inverted-T mastopexy with removal of 152 g from the right and 86 g from the left breast. Her 3-month results reveal good uplifted volume with improved symmetry.

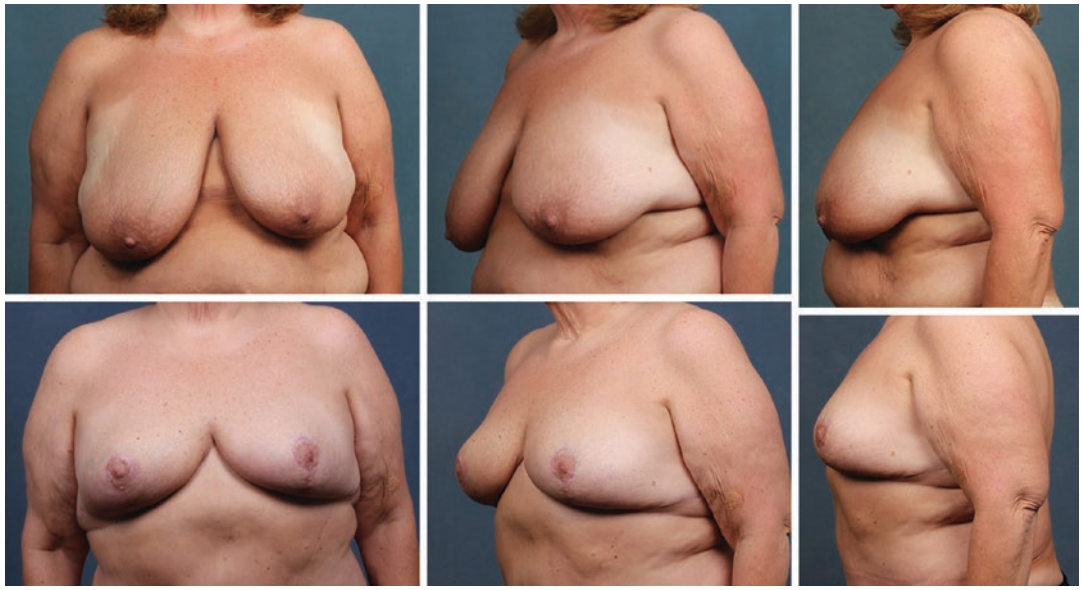


Fig. 2.38 Case 1: Sixty-four-year-old female with asymmetric grade 3 ptosis

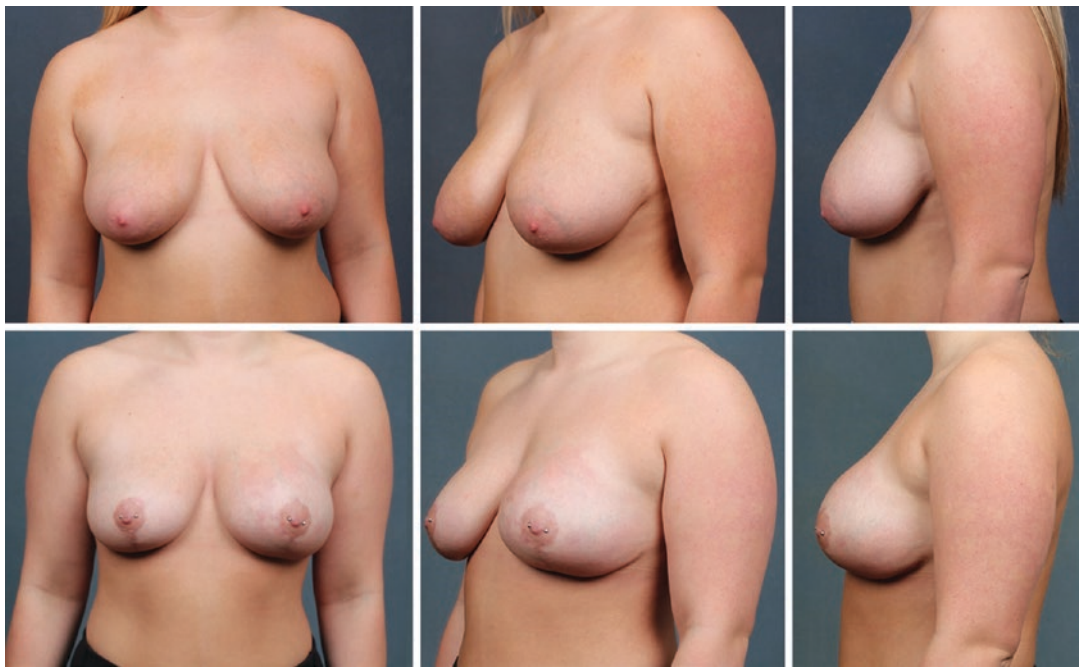


Fig. 2.39 Case 2: A 29-year-old female with 34 DD cup breasts desiring a smaller, more uplifted appearance

Case 4 Thirty-four-year-old female with breast asymmetry presenting with grade 3 ptosis on the left and grade 2 ptosis on the right (Fig. 2.41). She underwent a bilateral inferior pedicle inverted-T mastopexy. For symmetry, 37 g was removed from the right and 176 g from left. Six months' postoperative result reveals symmetric lifted breasts.

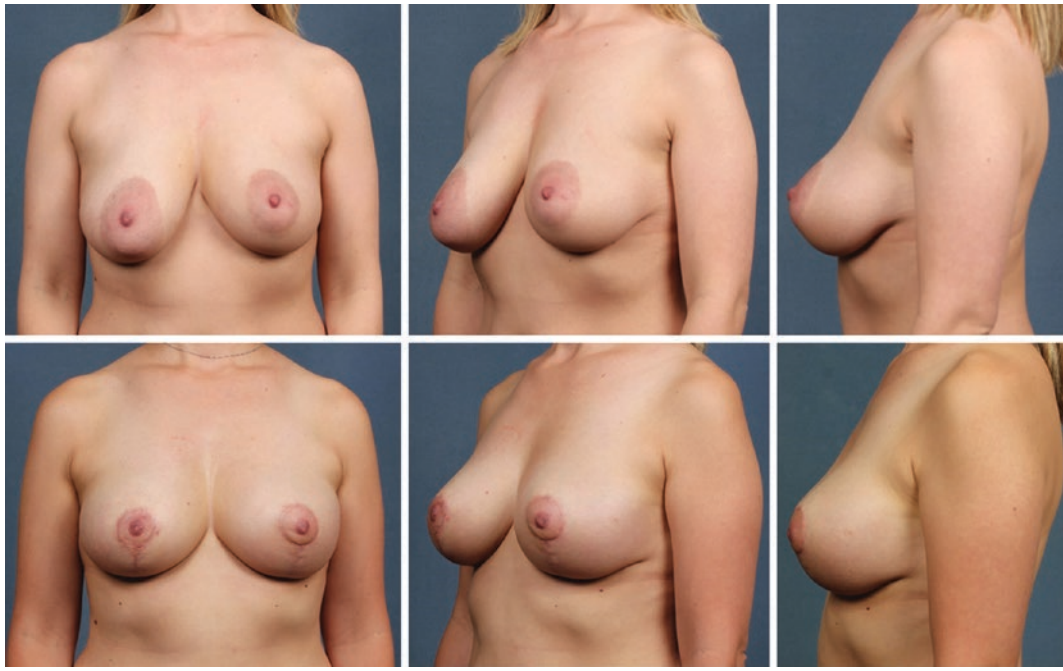


Fig. 2.40 Case 3: A 35-year-old wearing a 32 DD cup complained of saggy, heavy breasts

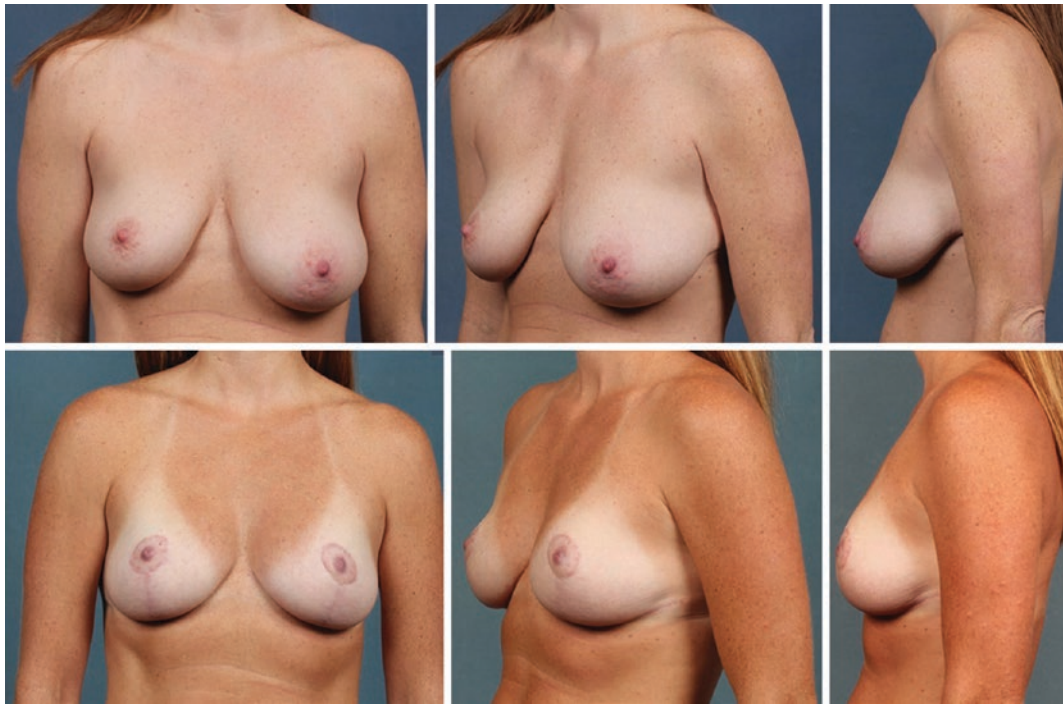


Fig. 2.41 Case 4: A 34-year-old female with breast asymmetry presenting with grade 3 ptosis on the left and grade 2 ptosis on the right

Augmentation Mastopexy

Patients with ptosis and volume deficiencies, or those desiring significant upper pole volume, require placement of an implant with the mastopexy to achieve their desired shape. The success of the augmentation mastopexy is multifactorial, but implementing the optimal surgical technique based on patient factors can significantly contribute to the long-term success of the procedure. The details, decisions, and experience-based pearls involved in this operation can provide guidance to perform this operation with expert precision.

To achieve these objectives, the breast augmentation and the mastopexy can be performed either simultaneously or as a staged procedure. Much controversy has existed over the years as to the safety of doing this procedure as one stage [50–52]. Detractors believe a two-stage procedure produces superior aesthetic results and is a much safer approach compared to a one-stage procedure. However, significant data and reports have emerged over the past few years demonstrating the safety and efficacy of these procedures being performed simultaneously [53–57]. However, there are patients for whom a staged procedure may be more appropriate, as listed below:

Relative Indications for a Staged Augmentation Mastopexy

- Obesity: BMI >30
- Large, pendulous breasts—need volume reduction
- Significant breast ptosis—NAC elevation >5–6 cm
- Vertical excess >8–10 cm (or possibly >6 cm)
- Unrealistic expectations (patient would not accept reoperation rate > 20%)
- Smoker refusing to quit >4 weeks
- Previous surgery impacting blood supply

Additional Considerations for a Staged Augmentation Mastopexy

- Significant breast asymmetry
- Borderline case—may be acceptable for mastopexy or augmentation alone
- Previous breast radiation
- Large implant volume or "augmented" look desired
- Massive weight loss patient
- Immunocompromised patient
- History of hypertrophic scarring
- Multiple medical comorbidities
- Surgeon uncomfortable performing a single-stage procedure based on the breast anatomy of the patient or surgeon inexperience

Blood Supply

To ensure the most reliable blood supply to the NAC and skin flaps in an augmentation mastopexy, the superior pedicle and occasionally the superomedial pedicles are utilized. The superficial position of these vessels in the upper pole allows the implant placement and mastopexy without interfering with the blood supply. However, these vessels take origin along the sternal border in the medial aspect of the implant pocket, and can be inadvertently sacrificed when aggressive medial pectoral muscle division is performed.

The inferior pedicle is not utilized in an augmentation mastopexy, as its blood supply through the deep fourth branch of the IMA is sacrificed with development of the implant pocket, and its secondary blood supply along the inframammary fold is divided with the mastopexy. Thus, an augmentation mastopexy with an inferior pedicle design is not truly supplied by pedicle blood supply in most cases, and the best one can hope for is random blood supply. If the remainder of the mastopexy is performed dividing deep into the flaps with an assumption that the inferior pedicle will provide circulation, the division of much needed superficial perforators both medially and laterally can lead to devastating consequences, including loss of NAC or breast flap viability, and resultant necrosis. Thus, the preferred pedicles enter the breast superiorly and superficially, providing a more reliable and robust blood supply (Figs. 2.42 and 2.43).

Additionally, implant and pocket selection affect the blood supply to the overlying breast.

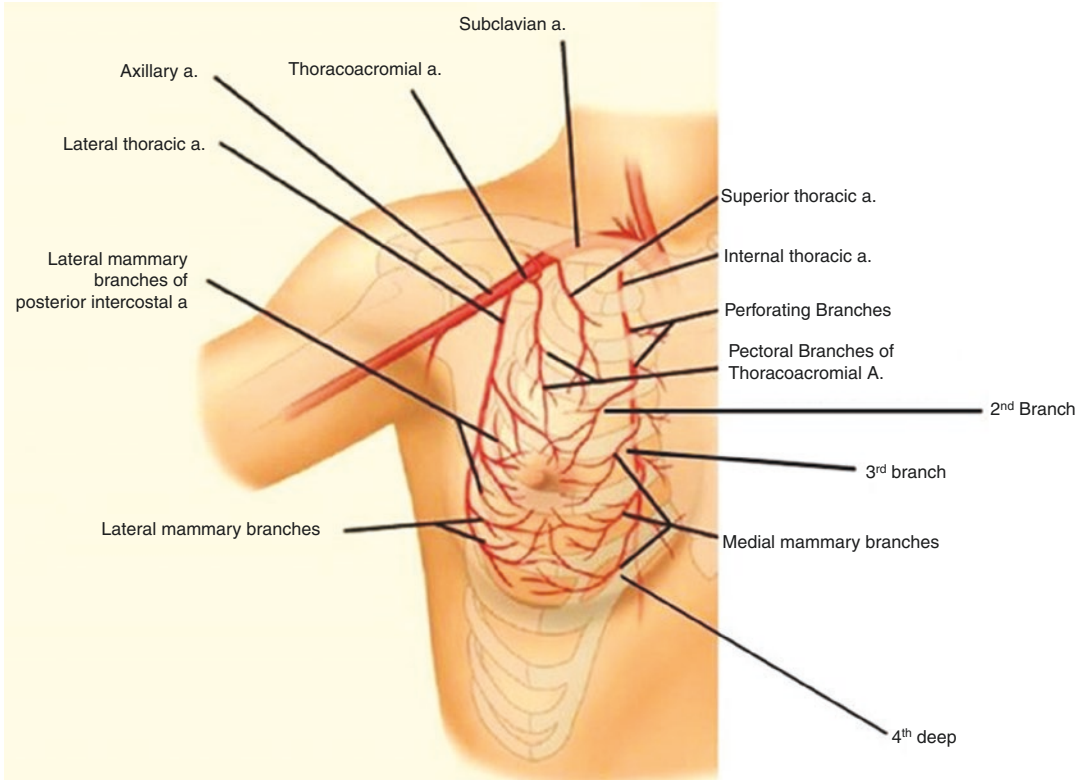


Fig. 2.42 Breast blood supply: the second branch of the internal mammary artery (IMA) supplying the superior pedicle; the third branch of the IMA supplying the medial pedicle; and the fourth branch of the IMA supplying the inferior pedicle

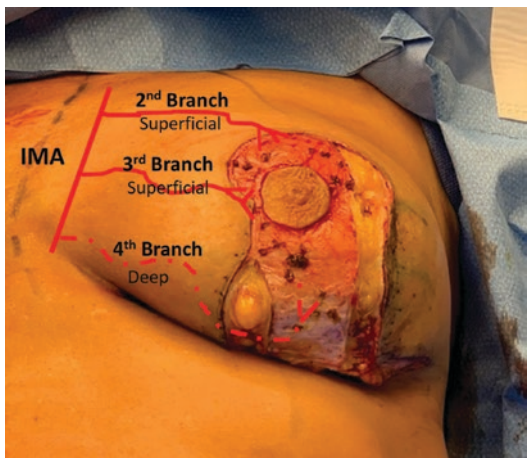


Fig. 2.43 Blood supply to the nipple-areola complex. Second branch of the internal mammary artery (IMA) running superficial supplies the superior pedicle. Third branch of the IMA coursing superiorly supplies the medial pedicle. The fourth branch of the IMA running in the deeper plane of the inferior breast is shown with the dotted lines and is cut during an augmentation mastopexy

The subpectoral pocket maintains the musculocutaneous perforators (unless an extensive dual plane is performed) and is less likely to interfere with the blood supply compared to a subglandular/subfascial pocket. Likewise, larger implants placed in any pocket, but especially the subglandular/subfascial pocket, may result in undue tension on the mastopexy closure that can also create vascular compromise to the NAC or overlying skin flaps, resulting in skin or NAC necrosis.

Implant Selection

In augmentation mastopexy, implant selection can significantly impact the final outcome in an augmentation mastopexy case. The implant selection in a one-stage augmentation mastopexy is of greater significance, as the augmentation is performed in the face of a mastopexy with soft

tissue envelopes that are more lax, stretched, thinned with stria, and less tolerant to the effects of the underlying implant.

Implant Profile and Size

Tissue-based planning proves very beneficial in augmentation mastopexy, just as it does in augmentation alone [56]. The base width of the breast provides a general guide as to the appropriate sizing of the implant for the breast. In considering implant width, critical to that calculation is determining how much the native breast itself will contribute to the final width of the breast. Optimal implant width is calculated by determining the desired final breast width (usually anterior axillary line to 1 cm from the midline of the chest) and subtracting the soft tissue contribution from the native breast using the medial and lateral pinch.

In a patient with ptosis but with a thin skin brassiere and minimal breast volume, the implant determination will be identical to a straightforward breast augmentation. In breasts with more significant volume, and heavier breasts, this calculation might lead to a smaller implant compared to a breast augmentation alone. When trying to achieve a desired volume with limited base width, a higher profile implant may be deemed as appropriate in these patients. However, the skin envelope laxity with the planned mastopexy must be taken into consideration. The effect of a high-profile implant on the skin envelope immediately on the skin flaps, and over time with potential for stretch deformity, must be balanced against the patient's desire for more volume [28]. In the heavier breasted patient requiring an augmentation and mastopexy, an implant is often selected with a lower profile and with greater height and width of the implant to add volume to the upper pole, but to minimize the impact on the overlying breast. Oversized implants not only create long-term effects, the undue tension created when mastopexy flaps are closed around a larger implant can impact circulation to the NAC and overlying breast skin flaps, leading to ischemia and necrosis. The pocket selection with these implants can also impact circulation. Because of stretch and weight of the implant on the overlying breast tissue, the authors prefer silicone implants over saline implants, as saline leads to greater lower pole stretch, palpability, visibility, and higher revision rates.

Smooth Versus Textured Implants

Smooth implants have several advantages, including a natural mobility and an extremely low risk of wrinkling or palpability. The implants tend to settle at the bottom of the breast pocket, and continue to descend with the overlying breast tissue naturally. When performing a mastopexy with the augmentation, the smooth implants can be translocated superiorly, taking the tension off the closure, and will naturally descend over time back into the newly lifted skin envelope. Due to the laxity of the skin envelopes, surgeons often cite the mobility of the implants as an advantage when there is instability in the overlying breast envelope.

In light of the issues related to textured implants, there has been a diminished use of textured devices, and if texture is selected, microtexture or nanotexture is utilized. Patients with sloping chest walls are also ideal for textured devices, as the texture stabilizes the implant and minimizes migration, especially lateral slip of the implant into the axilla. Textured implants also allow not only for placement of round implants but also the possibility of using an anatomic-shaped implant. The stability of texture, especially more aggressively textured implants, seems to create less lower pole stretch deformity over time. The less aggressively textured devices available today do not provide the level of stability and reduction in lower pole stretch, and may not prove advantageous in the augmentation mastopexy patient.

Shaped Implants

Shaped implants can provide advantages in certain types of patients and may be appropriate in an augmentation mastopexy. Shaped implants are uniquely beneficial when performing an augmentation mastopexy on patients with constricted breast or tuberous breast deformities. These augmentations are often performed in conjunction with a circumareolar mastopexy to optimize

results. The shaped implant provides a point of maximal projection lower than a round implant, allowing improved expansion and nipple positioning with the augmentation. The increased cohesiveness of the gel and the texturization of the implant provides stability that tends to improve the expansion of the lower pole. These qualities allow the implant to "shape" the tight, constricted tissue rather than the tight tissue restricting and "shaping" the implant.

Pocket Selection

Pocket selection for the augmentation mastopexy is often one of the most overlooked aspects, and may have the greatest impact on the final results. The pocket choices include the submuscular, subfascial, and subglandular. The very lax, loose breasts, such as those of the weight-loss patient, will need a greater level of dual plane to allow the lower pole to be subglandular, thus allowing greater expansion for correction. Whereas one might think this is not necessarily due to the overlying mastopexy that is capable of tightening the tissue over the implant, the very lax breast, even after a mastopexy, will often fall off of the underexpanded lower pole and implant, leading to a waterfall deformity. The ability of the implant to have some influence over the overlying breast tissue is an important, and yet often misunderstood, concept for achieving long-term success in augmentation mastopexy.

A subfascial/subglandular pocket is possible if the upper pole pinch is 2 cm or greater. Implants placed above the muscle have less coverage in the upper pole compared to submuscular implants. Thus, when above the muscle, implants with greater cohesiveness, optimal fills, and possible texture provide a more optimal implant for limiting lower pole stretch over time and maintaining upper pole volume.

Augmentation Mastopexy

When determined that a one-stage augmentation mastopexy is deemed appropriate, the approach to the mastopexy is based on the preoperative evaluation. The assessment of the level of ptosis guides the surgeon in assessing the need for NAC elevation, as well as skin envelope reduction and possibly parenchymal excision.

Circumareolar

Although performed less often, patients with borderline ptosis, grade 1 ptosis, or pseudoptosis (N-IMF under maximal stretch 10 cm), low NAC (such as constricted breast deformity), or tuberous breast deformity may benefit from a circumareolar mastopexy. This can elevate the NAC modestly (2 cm or less) and can reduce the areolar diameter. There should be minimal overhang of breast over the fold, and limited horizontal laxity. The circumareolar mastopexy should be used very selectively, as it can create widening and flattening of the breast, which may prove beneficial in a tuberous breast deformity but undesirable in a deflated, flattened breast. This approach mostly corrects the NAC and improves the shape of the NAC and breast, but with little ability to actually "lift" the breast.

Circumvertical

Patients with moderate ptosis, grade 1 or 2, requiring NAC elevation of usually less than 4 cm, with modest amounts of breast overhanging the fold, can be addressed with a circumvertical mastopexy with or without removal of a small amount of skin along the fold (horizontal wedge). These patients tend to have more horizontal laxity, requiring breast narrowing with only a modest amount of reduction in the vertical component.

Circumvertical with Inverted-T Skin Excision

For patients with more severe ptosis, grade 2 or 3, with significant vertical excess and overhang over the fold, a circumvertical with inverted-T skin excision is more appropriate to achieve opti-

mal results. The greater the vertical excess and laxity, the greater the horizontal wedge and the longer the incision becomes along the inframammary fold.

When planning the type of mastopexy, it is important to distinguish between the pedicle design and the skin excision design of the mastopexy [42]. In augmentation mastopexy, the design of the more ptotic breast is always a circumvertical approach, with the superior, or occasionally the superomedial, pedicle as the pedicle blood supply. The only difference in the approach is whether skin needs to be excised along the fold. Thus, even in the more ptotic breasts with significant laxity requiring an inverted-T skin pattern excision, the parenchymal and pedicle design is still a circumvertical approach with a superior pedicle. In these patients, if the breasts are heavy with excessive ptotic parenchyma, a lower pole parenchymal resection along with the skin excision is optimal to reduce the likelihood of recurrent ptosis postoperatively [27].

Lower Pole Mastopexy

There is an occasional patient, especially in secondary cases, in which the NAC is in satisfactory position, but a significant amount of glandular ptosis or pseudoptosis is present. These patients may benefit from simply an inframammary fold resection (smile mastopexy) or vertical-horizontal resection (sailboat mastopexy) without transposing the NAC [58]. This can address both vertical and horizontal laxity without jeopardizing NAC circulation and placing an unnecessary scar around the areola.

Operative Technique

Preoperative Markings

The augmentation mastopexy is based on a superior pedicle blood supply and is not dependent on the final skin excision pattern. Decision on nipple placement is performed based on the location of the fold and expectation on the location of the new lifted breasts with an underlying implant. This can be approximated by simulating the mastopexy and identifying the probable location of the NAC. The nipple position is marked along the breast meridian at or within 2–4 cm of the reflected inframammary fold.

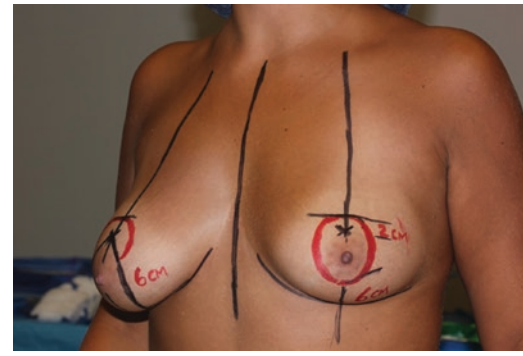
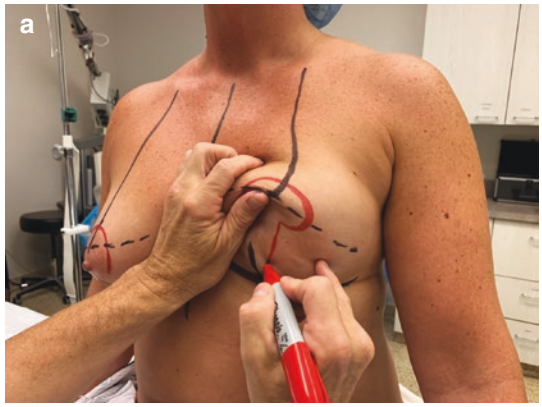


Fig. 2.44 Preop markings in an asymmetry case showing location of the new nipple position (black X), which is within 2 cm of the reflected inframammary fold. The red circles represent the proposed new NAC location. The left breast will be a periareolar mastopexy and the right breast will be a periareolar vertical with possible short horizontal along the IMF. Be sure to keep the distance from the IMF to new NAC 6–8 cm

In the circumareolar approach, the proposed location of the new areolar opening is marked, starting approximately 2 cm above the nipple position and 6–8 cm above the inframammary fold, based on implant size. An oval line is then drawn from the two points extending around the areola to create the desired shape and skin excision (Fig. 2.44).

Vertical Mastopexy

When a vertical or inverted-T mastopexy is planned, the areola is drawn from the planned superior areola opening, extending around the areola to produce an areolar opening of approximately 42 mm. The breasts are then rotated medially and laterally to mark the location of the vertical incisions, recognizing that the placement of the implant will add volume, thus requiring less skin excision than would be required with mastopexy designed without an implant (Fig. 2.45a, b).



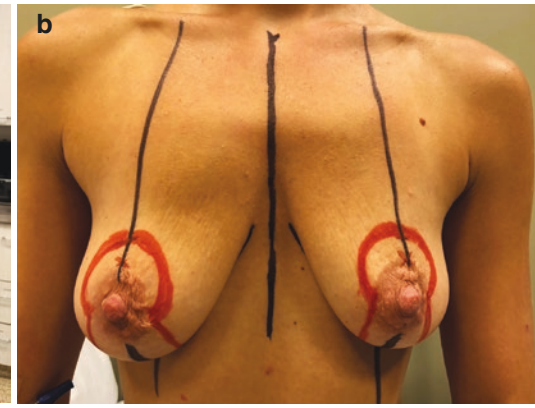


Fig. 2.45 (**a**) Medial rotation of the breast to mark the lateral vertical incision of the mastopexy. (**b**) Preoperative markings of a periareolar vertical mastopexy. The red X represents the new nipple position. Note the larger skin excision design of the patient's right breast based on the greater volume and ptosis of the breast compared to the left

If the vertical limbs are deemed excessively long, the design can be modified to include additional skin excision around the areola (circumvertical mastopexy) or along the inframammary fold (circumvertical with horizontal wedge excision).

Patients with greater ptosis will often require more significant excision of skin and elevation of the NAC. This can range from a long wise-pattern excision down to a very short horizontal wedge based on the amount of skin excess. These markings are made along the inframammary fold and intersect with a line drawn from the vertical limbs extending in a curved fashion down to the fold markings. When planning an augmentation mastopexy, these drawings should be conservative, allowing for adjustments once the implant has been placed. All the markings made preoperatively are made as a guideline for the operation, but the final NAC placement and skin excision required will be determined in surgery after the breast implant has been placed.

Surgical Technique

Each breast is placed under maximal stretch, and the areolas are marked with a 42-mm cookie cutter (range 38–45 mm depending on desired aesthetics) and incised with a 15-blade scalpel.

Once the areolas are incised, access to the breast pocket is determined. For circumareolar mastopexies, the access is either through the inferior areola in the area of planned deepithelization or through a counterincision in the IMF. The preferred access currently is with an IMF incision. This provides improved exposure and visualization of the pocket, which is associated with lower capsular contracture rates, and allows for IMF control sutures to be placed to stabilize the new fold position.

When a vertical or inverted-T skin incision is planned, access to the breast pocket can be made via the periareolar, vertical, or the inframammary approach. However, a vertical access approach (most typical) or the IMF is utilized in the majority of cases. The breast is divided down the midline extending from the inferior areola to at least 2 cm above the inframammary fold to gain access to the desired pocket (Fig. 2.46).

It is extremely important to not carry this incision all the way down to the fold, as this lower area of the breast, the "no-go zone," will provide a protective cuff of tissue during closure (Fig. 2.47).

Once through the breast tissue, the pocket is created based on preoperative decision-making, as described in the breast augmentation section. The level of dual plane required varies, and each surgery can be tailored to provide the optimal level based on soft tissue requirements and implant selection. In augmentation mastopexy, the breast-implant relationship is improved with

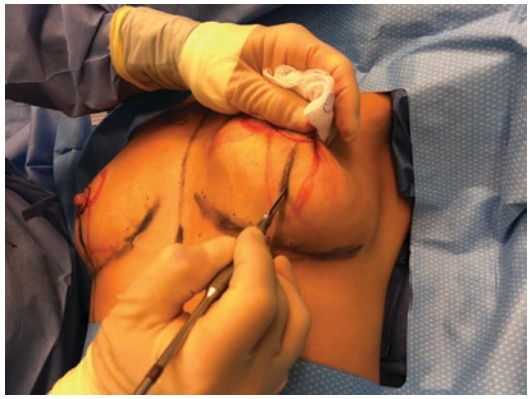


Fig. 2.46 Vertical incision made just inferior to the NAC, extending down to at least 2 cm above the IMF

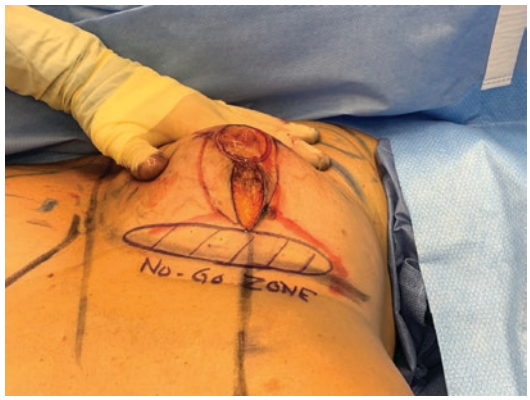


Fig. 2.47 The "no-go zone" is an area along the IMF that provides a protective cuff between the implant and the outside world. Stopping your vertical incision 2 cm above the IMF will preserve this area

the overlying mastopexy. However, even with a mastopexy, failure to optimize the breast-implant interface during surgery can lead to a waterfall deformity, with the breast sliding off of the implant. If the subglandular or subfascial pocket is used, the implant-breast interface is not affected by the interposing muscle, and pocket development is simply developed to accommodate the implant.

Implant Placement

The implant is then placed into the pocket with the assistance of an insertion sleeve such as the Keller funnel. The use of the insertion sleeve is even more beneficial in an augmentation mastopexy surgery, as the implant is passed through either the circumareolar or vertical incision in the vast majority of patients. These access incisions require the implant to pass through the bacteria-laden breast tissue. The insertion sleeve provides a "minimal touch" technique that is associated with lower capsular contracture rates [9].

Tailor Tacking

Once the implant is in the pocket and oriented appropriately, the final planning of the mastopexy is carried out. Tailor tacking is a critical step in designing the optimal breast shape. With the circumareolar approach, the areola is stapled to the outer circle and adjusted to create the desired shape prior to deepithelialization. In the vertical or inverted-T approach, starting usually at what will be the new inferior areola location (6 o'clock position), the medial and lateral vertical limbs are brought together and stapled in a descending fashion, adjusted by tightening a little more or a little less to create the desired lower pole breast shape. If a vertical approach only, the planned excision tapers down to the fold. The length of the lower pole skin (distance from the inferior areola to IMF) varies based on the size of implant and amount of breast parenchyma that is present. For most augmentation mastopexies, this length is generally 6–8 cm. If this distance is excessive when tailor tacking, two options exist: expand the circumareolar opening to encompass more of the vertical length (circumvertical approach), or remove a horizontal wedge of skin at the fold to shorten the vertical limb. This often is a small wedge of skin, leaving a short horizontal scar (has been referred to as owl's feet) or extended laterally as J-type mastopexy. If the vertical excess is significant, the horizontal wedge excision will create an inverted-T pattern. With the patient in the upright position and the arms extended at 45 degrees, breast shape and symmetry are confirmed. Adjustments are made if necessary, until the results are optimal (Fig. 2.48).

It is important to mention that once the tacking is complete, a final decision on placement of the NAC must be made. There is flexibility, as no

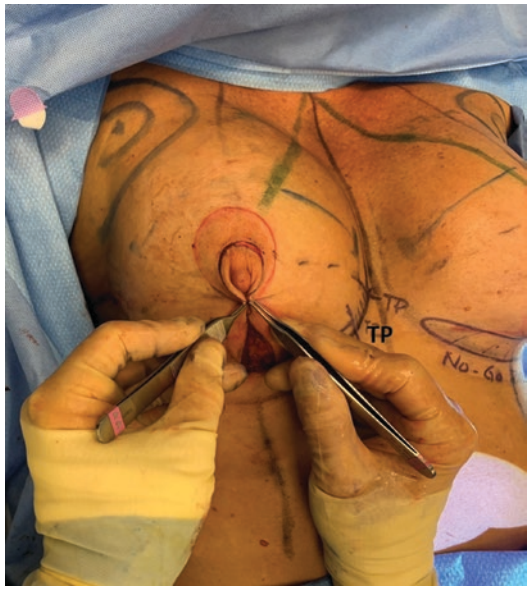


Fig. 2.48 Tailor tacking of the breast after placement of the implant. The IMF to the inferior border of the areola is marked at 6–8 cm

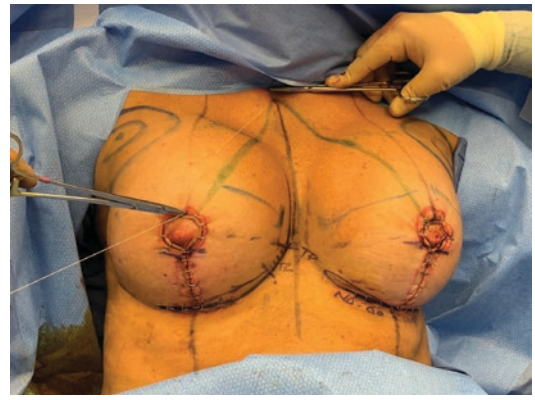


Fig. 2.49 Confirming the NAC placement is symmetrical using the "top-down" approach from the sternal notch to the top of the areola. Two needle drivers are used along with a suture tail to measure the symmetrical distance between the two sides

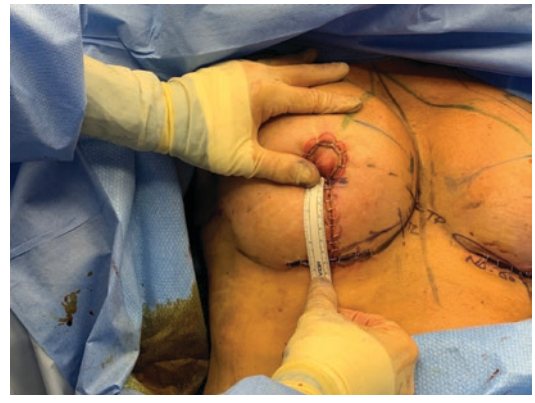


Fig. 2.50 Confirming the NAC is symmetric using the "bottom up" approach. Note the "bottom-up" distance of 6 cm from the IMF to the inferior edge of the NAC is confirmed bilaterally

skin has been excised at this time. The areola can be positioned higher or lower to optimize breast shape, placing the NAC centrally along the median of the breast at the point of maximal projection. When considering NAC placement, confirmation can be performed from bottom up, top down, or both. "Top down" refers to the distance from the sternal notch to the top of the areola (or nipple) and "bottom up" refers to the distance from the IMF to the inferior areola (or nipple). During tailor tacking, it is helpful to confirm NAC position and symmetry using both of these techniques (Figs. 2.49 and 2.50).

Once confirmed, the patient is placed supine and the tailor tacking is marked with methylene blue or permanent marker, identifying the planned incision lines.

Breast Flap and Pedicle Dissection

In the circumareolar approach, the area between the areola and outer circle is deepithelialized. Although an IMF counterincision is the preferred access for the augmentation, if the periareolar access was used, then the deep breast tissue must first be closed with an absorbable 2-0 Vicryl. The dermis is then cauterized for maximal shrinkage (Fig. 2.51). A purse string suture of 3-0 Gortex is placed in a wagon wheel pattern (Fig. 2.52).

In the vertical augmentation mastopexy technique, the superior pedicle is preferred. The incisions are outlined with a scalpel, ensuring not to cut deeply into the dermis. The periareolar region is deepithelialized. The incisions are then made full thickness through the dermis, along all of the scored skin. However, in the superior areola, the dermis is left intact (from 8 o'clock to 4 o'clock) as the superior dermal pedicle (Fig. 2.53a, b).

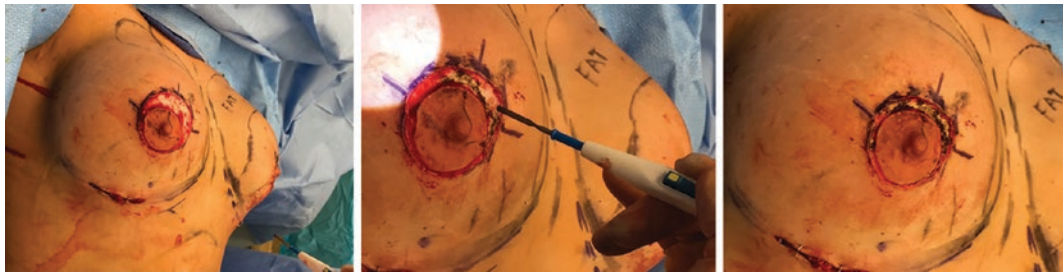
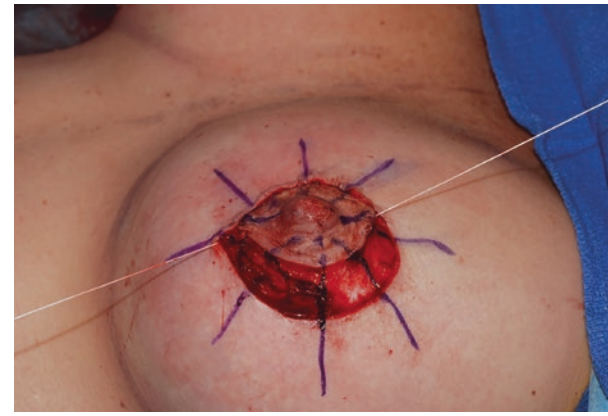


Fig. 2.51 The dermis around the areola is cauterized to shrink the tissue and facilitate a tension-free closure

Fig. 2.52 Wagon wheel closure of the NAC with a 3-0 Gortex



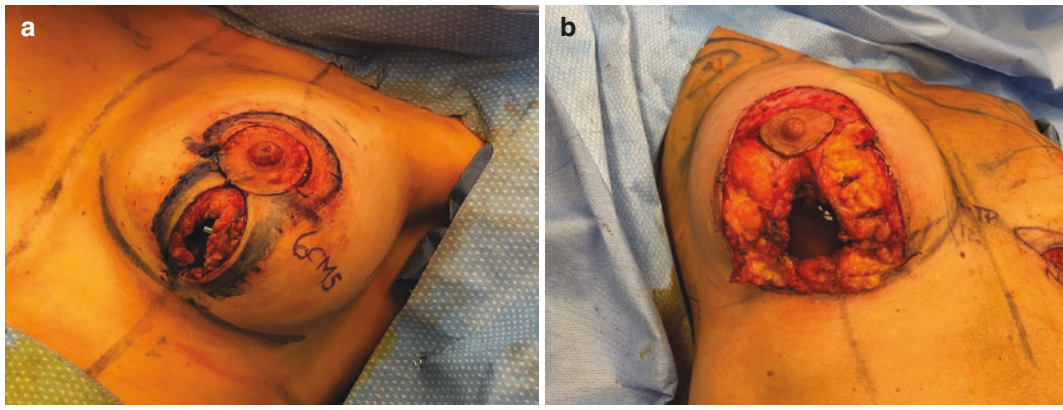


Fig. 2.53 (**a**) Once symmetry confirmed with the patient sitting upright, they are laid back supine, tailor-tacked staples removed, the incisions are demarcated with marking pen around the NAC and vertical limb. Note the distance from the IMF to NAC is 6 cm. (**b**) Periareolar and vertical limb are deepithelialized. Note that the superior dermis around the NAC is left intact from 8 to 4 o'clock to maintain NAC perfusion

Lower Pole Debulking

If the patient is extremely thin, such as in a revision surgery or a patient with paper-thin skin, the vertical skin +/- the horizontal skin is deepithelialized and maintained for additional coverage and support with the mastopexy. However, most patients with ptotic breasts have significant amounts of excess skin and breast tissue in the lower pole. In these patients, debulking of

the lower pole is probably the single most important step in the procedure to reduce the likelihood of recurrent ptosis. Breast flaps along the medial and lateral vertical incisions are initially created, staying approximately 2 cm or greater in thickness. Located centrally is the lower pole segment of breast tissue —located from the areola to the IMF within the vertical incisions. This tissue is aggressively debulked to reduce lower pole stretch over time with recurrent ptosis. It also reduces the tension on the lower pole mastopexy flap closure. When debulking the lower pole, the anterior tissue is removed, preserving a posterior lamellae of breast tissue and posterior breast fascia. It is especially important to maintain the "no-go zone" cuff of breast tissue located above the IMF, as this creates the floor for the implant and provides protection for the implant if skin breakdown occurs at the level of the IMF (Fig. 2.54).

Deep Fascial Sling

Once the pedicle has been developed and appropriate skin and breast tissue removed, closure of the breast pocket is performed. This step is extremely important to creating a lamellar closure over the implant and developing the shape of the lower pole. As in all mastopexy techniques, controlling the lower pole of the breast through parenchymal shaping—and not skin tightening—provides increased stability of the results over time. Starting inferiorly, which is just above the "no-go" cuff of breast tissue, the lateral and medial pillars are brought together at the most posterior aspect of the breast, just superficial to the implant, with a running 2-0 Vicryl suture (Fig. 2.55a, b).

This 2-0 Vicryl running suture carries the closure superiorly toward the NAC, continually tightening the lateral pillar and the medial pillar to create the desired lower pole shape. Therefore, this step is not just closing over the implant, it is parenchymal shaping in a vertical fashion to control overall breast shape and vertical projection. This closure additionally adds another layer of closure, protecting the underlying implant.

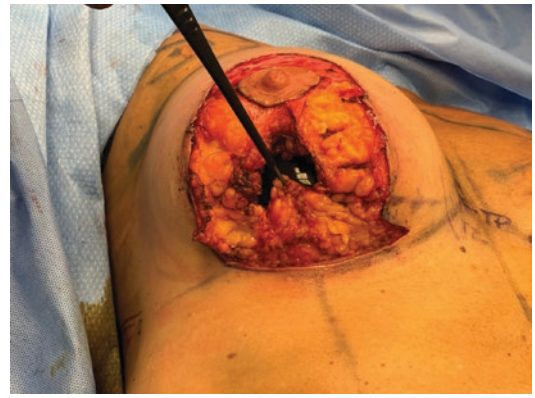


Fig. 2.54 "No-go zone" just above IMF shown in the tips of the forceps

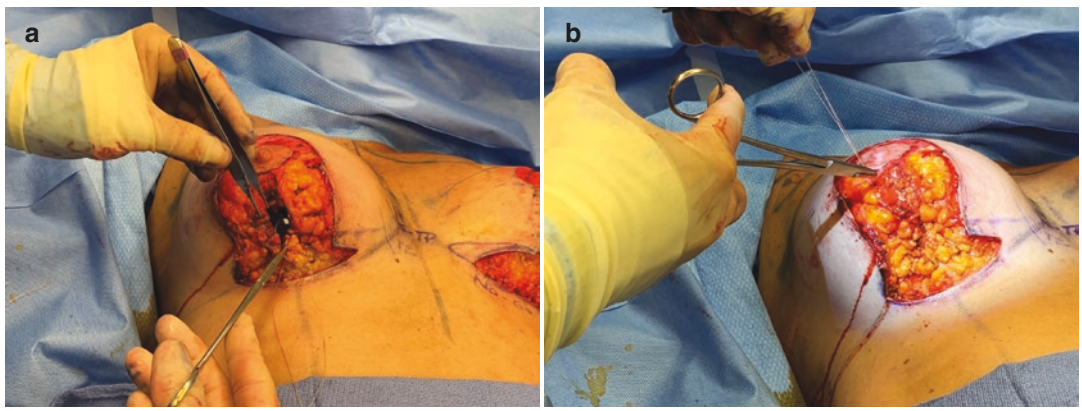


Fig. 2.55 (**a**, **b**) Closure of the posterior lamellae of the implant pocket with a running 2-0 Vicryl suture to provide an additional layer of closure

Closure

Deep parenchymal sutures of 2-0 Vicryl are then placed along the vertical incision, bringing the medial and lateral pillars together at the midline (Fig. 2.56). All incisions are then closed with interrupted 3-0 PDS dermal sutures. The vertical and horizontal scars are closed with a 4-0 monocryl running subcuticular suture. The areolas are then closed with 3-0 PDS interrupted dermal suture and a simple running 5-0 nylon suture (Fig. 2.57). Steri-strips are placed over the incisions. Contour tape is then placed along the lateral breast border and inframammary fold. The breasts are wrapped with a xeroform gauze, Kerlix, and ace wrap.

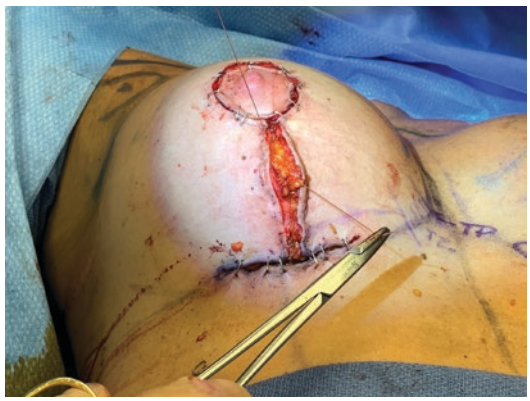


Fig. 2.56 Closure of medial and lateral breast pillars with a 2-0 Vicryl to provide final shape and support of lower breast pole

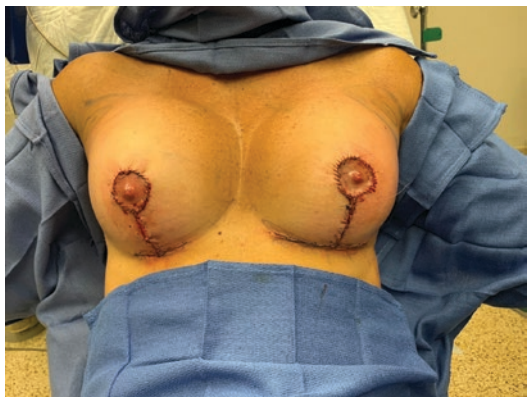


Fig. 2.57 Final closure of the breast with the patient sitting upright on the operating room table

Postoperative Management

Breast Augmentation

Patients are wrapped in an ace wrap for the first 24 hours, followed by a sports bra to be worn 23 hours a day for the next 4 weeks. Early range of motion beginning in the recovery room is initiated for all patients, which includes shoulder rolls in both directions as well as elevation of the arms outward to the sides and over the head. The contour tape is removed at days 4–7. With smooth devices, implant massage begins postoperative days 4–6 and includes displacing the implant upward and downward in the pocket, crossing the arms and pulling the implants inward to create cleavage, and downward pressure on the implants to stretch the lower pole. Implant massage is contraindicated with textured surface devices, as it can irritate the pocket and potentially create serous fluid around the implant. It is also advisable to limit strenuous exercise for 6–12 weeks with textured implants to avoid early seroma formation. Patients are allowed to resume wearing regular bras after 4 weeks, but should continue with sports bra during bedtime for an additional 2–4 weeks to limit lateral implant migration while recumbent. Normal activity resumes within a few days after surgery, but exercise and high-impact activity should be delayed for 4–6 weeks.

Mastopexy and Augmentation Mastopexy

The patients are instructed to leave all dressing on for 48 hours. The wraps are then removed, and a sports bra is worn for the following 4 weeks. Dressing changes with antibiotic ointment and gauze are used over incisions for 1 week. Patients are allowed to shower after 48 hours. Nylons around the areolas are removed 6–8 days postoperatively. The subcuticular monocryls are clipped on the ends as they exit the skin at 2 weeks. Scar management with silicone gel or silicone sheeting is initiated on all patients at 2 weeks. Patients are allowed to resume activities of daily living almost immediately. Exercise is usually allowed

at 4 weeks, with heavy lifting at 6 weeks. If implants are present, massage protocol is initiated once all incisions are well healed.

Management of Complications

Breast Augmentation

Hematoma The incidence of hematoma after a primary breast augmentation has ranged from 0.5% to 2.0%. The best prevention is achieving meticulous hemostasis intraoperatively. Blind or blunt pocket dissection without surgery for hemostasis after should be avoided, to limit the incidence of hematoma. Patients should likewise be counseled to avoid medications that increase bleeding or interfere with platelet function for at least 2 weeks prior to surgery. A hematoma is easily recognizable with a breast that is swollen, bruised, and exquisitely painful to palpation, or often arm movement. Treatment includes reoperation with evacuation of the hematoma, hemostasis, pocket washout, and drainage. Implant exchange is usually not necessary. A hematoma left untreated is discouraged, as it can lead to prolonged healing, wound problems, delayed healing, infection, possible long-term issues of asymmetry, and possible capsular contracture [59].

Infection Infection rates for primary breast augmentation can approach 2% [2, 60, 61]. It is well known that the breast parenchyma and associated breast ducts harbor bacteria that can be introduced into the operative field or breast pocket [8, 62]. Prevention is key, and many operative maneuvers can assist in minimizing this possibility. Current recommendations are for skin preparation with chlorohexidine, which covers most organisms including methicillin-resistant *Staphylococcus aureus* (MRSA). Likewise, perioperative antibiotics and pocket irrigation with 50% betadine reduce implant contamination and possible infection. The standard treatment includes operative exploration, irrigation, and debridement of the pocket with drainage. In most incidences, the implant is removed and reaugmented 6 months later. There is the possibility of implant salvage with prolonged antibiotic therapy if the patient is clinically stable and the infection is limited, but failure of a salvage procedure would mandate implant removal [63–65].

Sensation changes Alterations in nipple sensitivity can manifest as either hypoesthesia or hyperesthesia, and are often the result of traction injury, bruising, inflammation, or possibly even injury to the lateral intercostal cutaneous nerve that enters the breast laterally on the deep surface just above the pectoral fascia. Although the major innervation is the fourth, there is some overlap from the anterior and lateral branches of the third and fifth intercostal nerves. There is evidence that nipple sensitivity changes are no more likely with a periareolar incision when compared to an inframammary incision [66, 67]. The most common cause is aggressive pocket dissection laterally, especially with sharp dissection, with injury to the intercostal nerves.

Deflation and implant rupture It is important to inform breast augmentation patients that breast implants do not last a lifetime. Implant rupture and failure of the shell are dependent on implant style. Any disruption of the outer shell of a saline implant leads to complete failure of the implant, with the saline leaking out into surrounding tissue, and is harmless. Saline implant failure can be associated trauma or a spontaneous leak that involves either fold fatigue on the shell of the implant or valve incompetence. Silicone implant rupture rates have been quite variable between devices, and failures increase with the age of the implant. The fifth-generation silicone gel implants have more cohesive gels, and the silicone is less likely to egress from the implant shell, leading to a much lower rupture rate than earlier fourth-generation devices [1, 2, 20]. MRI imaging is currently the diagnostic technique of choice to discern a silicone implant rupture, although high-definition ultrasound has shown excellent utility in discerning ruptures, and will most likely play a role in identifying occult ruptures.

Capsular contracture Capsular contracture remains the number 1 complications of breast

augmentation, with incidence ranging as high as 15–30%, with the development of palpable and/or visible deformation of the periprosthetic capsule around the implant [1, 2, 68, 69]. The development of a capsule around an implant is always present due to the unique foreign body reaction by the surrounding breast tissue. A periprosthetic capsular contracture that is clinically significant is characterized by excessive scar formation with shrinkage and often thickening of the capsule, leading to firmness, distortion, and displacement of the breast implant. Baker proposed a clinical classification system for capsular contractures that is still widely used today [70]. While there are many factors identified that seem to contribute to the incidence of capsular contracture, the exact etiology is not known. The infection theory has been studied and appears currently to be the most cited explanation for capsular contracture development [3–8]. This theory entails a chronic subclinical infectious process located adjacent the implant shell within a microscopic biofilm that is protective of the infectious process and inaccessible to cellular and humoral immune function to combat the inflammatory process. Staphylococcus epidermidis, propionibacterium, enterobacter, bacillus, and other organisms have been implicated in this process.

There have been many techniques proposed to reduce the incidence of capsular contracture. Maneuvers to minimize tissue trauma, blood staining, and seroma formation during pocket dissection have been employed, as these may all contribute to capsular contracture formation. Periprosthetic fluid pockets generally resorb within the first week, and the use of topical antibiotic irrigation has been shown to decrease this rate [71]. Additionally, the use of an insertion sleeve (e.g., Keller funnel) for implant placement and placement of Tegaderm (nipple shield) over the nipple-areolar complex have been employed to reduce bacterial contamination of the implant and potentially biofilm formation [8]. Pocket irrigation with antibiotic solutions has proven beneficial in reducing the incidence of capsular contracture. Our current recommendation is the betadine-containing Adams' formula or 50% betadine alone. Leukotriene receptor antagonists which are used to treat asthma, such as zafirlukast (Accolate) and montelukast (Singulair), have shown some benefit in reversing the clinical signs of capsular contracture, but should be used with caution due to potential side effects [72, 73]. Treatment includes capsulotomies or capsulectomies (partial or total), with implant exchange and pocket exchange if possible. Recurrent capsular contractures can be more problematic to treat, but the use of an acellular dermal matrix, such as Alloderm or Strattice, has reduced the recurrence rate to 1–4% [74, 75].

Implant malposition/rotation Implant malposition is the second most common complication in most studies, and is rather a broad category, encompassing a wide range of complications. Most malpositions are preventable. Medial and lateral malposition are most often the result of overdissection of the lateral pocket or overrelease of the pectoralis sternal attachments, respectively. Inferior malposition is often due to mismanagement of the inframammary fold during lowering, or use of implants larger than the lower pole can tolerate, leading to stretch deformities. Superior malposition is usually due to underdissection of the lower pole, inadequate dual plane if submuscular, inadequate lowering of the inframammary fold, or the development of a capsular contracture. Implant rotation is a complication only applicable to shaped devices, and refers to the implant orientation becoming altered in the breast pocket. Because of this possibility, all shaped devices are textured to help maintain spatial orientation in the pocket. Creation of a controlled implant pocket that fits the implant accurately (hand-in-glove) is critical to minimizing this risk. Treatment includes correcting the implant malposition, either through manipulation of the capsule with capsulorrhaphy or capsular flaps, or creation of a new pocket, such as the neosubpectoral pocket. The use of acellular dermal matrices or mesh (such as Galaflex, Galatea Corporation) has been very useful in reducing the incidence of recurrence of the malposition.

Wrinkling/rippling Adequate soft tissue coverage takes priority in determining implant pocket

location and minimizing the risk of wrinkling, rippling, visibility, and/or palpability of the implant. Placement of the implant in the submuscular or dual-plane pocket provides the greatest coverage. Placement of an implant above the muscle requires at least a 2 cm upper pole pinch thickness. Even with adequate coverage, soft tissue atrophy and lower pole thinning and stretching are possible. Wrinkling is more likely with inadequate or thin soft tissue coverage, saline implants, textured implants, and underfilled gel devices. Treatment of wrinkling may include implant exchange to the retropectoral position, implant exchange to appropriate device with less wrinkling (e.g., saline to silicone and texture surface to smooth surface), fat grafting, and/or placement of a soft tissue matrix.

Animation deformity Implant distortion on muscular contracture is a phenomenon unique to implants placed in the submuscular position. It can be very noticeable, and especially bothersome for patients who exercise or lift weights frequently. In one study, although mostly mild, 15% of patient were noted to have moderate or severe distortion on animation [76]. Placement of the implant in the subglandular or subpectoral pocket is preventative, and may be a preferable pocket for those patients at risk, but must be weighed against the benefits of subpectoral placement. If a severe animation deformity is present, correction may include conversion to preferably a subglandular/subfascial pocket or to a dual plane with or without acellular dermal matrix in patients who are not candidates for subglandular placement.

Breast implant associated-anaplastic large cell lymphoma Over the past few years, there have been increasing awareness and questions raised concerning reported cases of BIA-ALCL in women with breast implants. Initial presentation has included the development of a late periprosthetic fluid collection, a mass attached to the capsule, tumor erosion through the skin, lymph node involvement, or discovered during a revisional procedure. These have been associated with saline and silicone implants. In the cases of ALCL where the patient's full implant history is known, most, if not all, are associated with having at least one textured implant in place as part of their history, the majority of these being of the "salt-loss" type of texturing. The Biocell textured implants (Allergan, Irvine, CA) were recalled globally in 2019. Whereas smooth implants have generally not been associated with BIA-ALCL, there is some early evidence that texture may be merely a passive potentiator and the real culprit may be a chronic immune response to a certain variety of bacteria [51]

In any patient presenting with a late seroma 1 year or greater after implant surgery, evaluation should include image-guided fluid aspiration and appropriate fluid evaluation for culture, cell count, and cytology [77]. All late seromas or capsular contractures associated with a mass should be evaluated, and BIA-ALCL should be considered and ruled out. Even if idiopathic, and not associated with infection or neoplastic process, surgical intervention is usually indicated and includes total capsulectomy with or without implant exchange. Appropriate staging is mandatory and dictates adjuvant treatment, including possibly chemotherapy and/or radiation therapy.

Mastopexy

Early complications Early complications are infrequent with mastopexy procedures. The most concerning complication is ischemia to the nipple-areolar complex or skin flaps. Ischemia may be due to the dissection of the pedicle, but often is secondary to excessive tension on the skin closure and underlying volume under the skin flaps. If recognized during surgery, all sutures should be removed to look for improved circulation, improved color, capillary refill, and pinprick bleeding. It is important to assure that the pedicle is free of tension and not twisted or compromised. Topical nitroglycerin or DMSO can be used to improve venous outflow. If the closure is too tight due to volume present under the flaps, consideration should be made to resect more volume in an attempt to reduce the closure tension. If any doubt exists, the NAC can be left

unattached and closed the following day in the clinic. Although conversion to a free nipple graft could be done if inadequate pedicle flow through all of the above-mentioned efforts, this is by far more common in a breast reduction, and should be extremely rare in a mastopexy procedure.

An occasional patient may develop a hematoma, usually within the first 24 hours, but a late hematoma at days 10–14 is also occasionally encountered, as activity level increases and the clots present on the ends of the cauterized vessels begin to dissolve. A very small hematoma can be allowed to resolve on its own, but any substantial hematoma should be explored, evacuated of blood, and drained. Small amounts of blood within the pocket in a mastopexy without a breast implant are generally less concerning, as there is not potential for capsular contracture. Seromas are generally managed conservatively with serial aspiration until resolved.

Delayed aesthetic issues Late sequalae include poor scarring, recurrent ptosis, bottoming out, asymmetry, contour deformities, fat necrosis, and loss of upper pole volume. These may require revisional procedures to improve the final aesthetic outcome. Most procedures are delayed at least 6 months or longer to allow for soft tissue remodeling and stabilization of the results. Scars are often the product of excessive tension on the closure and postoperative swelling, and can often be improved with scar revisions when the environment for scar maturation is more optimal. Lower pole stretch deformities and recurrent ptosis are managed with a revision of the mastopexy, with or without the addition of some additional support from a mesh or acellular dermal matrix. Fat necrosis is often simply monitored if it is small and not deforming the shape of the breast. If the area of fat necrosis impairs the shape or softness of the breast, or is interfering with cancer surveillance, excision of the involved area is appropriate.

Loss of upper pole volume is the most common late finding after a mastopexy, whether inferior pedicle or superior pedicle. Loss of the upper pole can be secondary to relaxation and loss of lower pole support, or simply due to the lack of stable, firm volume in the breast envelope. A breast augmentation is the most reliable procedure to provide stable upper pole volume and cleavage. Surgeons often will stage their procedure, performing a mastopexy as the initial procedure, followed by a breast augmentation 6 months or more postoperatively. Fat grafting can also be performed to improve volume in the upper pole and cleavage, but does little to improve breast projection and is less reliable than a breast implant.

Conclusion

With proper preoperative evaluation and employing accurate surgical techniques, excellent results can be achieved through breast augmentations, a superior- or inferior-based inverted-T mastopexy, or an augmentation mastopexy. The breast augmentation should follow a process that selects an implant and approach that optimizes results and adheres to tissue-based planning and the limitations imposed by the breast footprint and envelope preoperatively. As it relates to mastopexies, it is the authors' opinion that too much focus has been placed on avoidance of the inframammary scar in mastopexy procedures. This has often led to excessive vertical lengths in the lower pole and bottoming out of the breasts postoperatively. Whereas minimizing or eliminating the inframammary scar can be quite effective in the most experienced hands in appropriately selected patients, the inverted-T mastopexy can be mastered by most surgeons and leaves a postoperative appearance at the end of the procedure that most accurately predicts the final results of the mastopexy. The significant advantage of the superior pedicle technique in the appropriately selected patient is not the elimination of an inframammary scar, but rather the parenchymal shaping and lower breast pole unloading (either through resection or autoaugmentation) that is possible with this technique. The inferior pedicle technique is easy to master and quite versatile, but is generally reserved for those patients where superior or superomedial pedicle technique

is not as feasible, including the need for significant nipple-areolar complex elevation or potential loss of the superior pedicle blood flow from previous procedures such as a biopsy or mastopexy. When performing an augmentation mastopexy, the risks are greater to the viability of the tissues. The impact of the breast implant on the circulation of the NAC and skin flaps can be significant, and the decisions intraoperatively should be directed at minimizing these risks. Whereas short-scar mastopexies can be an excellent option in mastopexies, the expansion effect of the implant often mandates removal of excess skin to prevent long-term bottoming out and lower pole stretch deformities.

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Osteotomies in Rhinoplasty

3

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Introduction

Osteotomies for rhinoplasty have a long and varied history, marked by a wide variety of techniques. No single technique, approach, or instrumentation has completely dominated the surgical scene [1–4]. The surgical design of the osteotomy varies from low to low, low to high, high to low, medial, medial oblique, transverse, and double level [5]. Instrumentation is equally varied, from osteotomes to oscillating saws, and more recently to the Piezzo approach [6]. This latter technique may become the procedure of choice. Although it is an expensive tool, its popularity is increasing because it allows for very fine control.

The lack of consensus on all these osteotomy variables can be disturbing to the beginning rhinoplasty surgeon. We will present a technique that after many years of experimentation is admittedly personal in nature for the senior author. It is the result of trying almost every conceivable approach and instrumentation in hopes of finding the ideal operation. What we present is the best in our hands, but we readily acknowledge that each surgeon is an individual and will want to find what is best for him/her. If nothing else, we will be able to point out the potential pitfalls and provide a few pearls that should apply to almost all osteotomy techniques.

The Problem

Over the years, surgeons, ourselves included, have occasionally suffered from the following side effects and complications: (1) inability to reduce the nasal bone width (thick male bones); (2) step-off deformity of the lateral nasal bones; (3) rocker formation—a mobile bony fragment that cannot be put back in place from where it came; (4) overcorrection and excessive narrowing of the nasal bones; (5) failure to recognize that the problem was the dorsal width and cannot

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be corrected by just reducing the nasal base; (6) inability to reduce just the nasal dorsal width; and (7) excessive bleeding.

Principles of Osteotomy Surgery

1. Principle of independent osteotomies—a specific osteotomy for a specific part of the nasal bone that needs reduction.
   (a) Medial oblique osteotomy for the nasal dorsum
   (b) Lateral (low-to-low) osteotomy for the nasal base
2. Avoid dense nasal bone located medial to a line that goes from open roof to medial canthus; doing so avoids rocker formation.
3. Create an environment of homeostasis (proper local anesthesia, well timed, and possible DDAVP).
4. Proper size of osteotomes—3 mm width.

Indications

Almost all osteotomies are done for nasal bones that are too wide. A decision is made preoperatively if the dorsal width is excessive, as noted by the flow of the dorsal aesthetic lines (Fig. 3.1a) if the nasal base is too wide (Fig. 3.1b), or if both the dorsum and the nasal base are too wide (Fig. 3.1c). Imaging is invaluable to determine what should be done. Seldom is it necessary to plan on moving the bony septum (perpendicular plate) that is in between the bones in order to straighten crooked nasal bones (see cadaver Fig. 3.2 and discussion later in this chapter). That will be obvious when opening the nose, moving the nasal bones, and noting whether or not the bony septum is precluding proper positioning of those bones. For nasal bones that are too narrow and not corrected by onlay cartilage grafts, it will be necessary to create a "hanging chad" (Fig. 3.3). So doing allows the nasal bone to be green sticked, still attached cephalically, and mobile enough to be digitally manipulated into a wider stance with a pair of forceps.

Patient Example for Both Osteotomies

G.N. is a 28-year-old female. She complained of a large nose, one that is wide including the tip. Figure 3.4a shows *p*reop front view; Fig. 3.4c shows preop side view; Fig. 3.4e shows preop oblique view; and Fig. 3.4g shows preop basal view. Physical exam revealed: (1) a dorsal hump; (2) a round, ill-defined tip; (3) a broad dorsum; and (4) broad nasal base. At 15 months postop (Fig. 3.4b, d, f, g), there was considerable improvement in the width of the dorsum and the width of the nasal base. Figure 3.4a, b demonstrates the improvement in both the dorsal width and the nasal base width on front view at 15 months postop. The side views (Fig. 3.4c, d) do not, of course, reflect osteotomy results, but improvement is seen in this patient from the other maneuvers mentioned. Finally, the basal view (Fig. 3.4e, f) shows improvement from the tip plasty.

Surgical Technique in Detail

A mixture of Xylocaine/Marcaine 1/75,000 using fresh epinephrine is infiltrated into the nose. A total of 7–30 minutes is given before intended osteotomy. If there is any question of a bleeding issue preop, or if during the course of the rhinoplasty the field is not dry to one's satisfaction, the patient is given desmopressin (DDAVP) (0.3 mcg/kg) [7]. Systolic pressure should be approximately 80–100 mm Hg. We use a buccal sulcus approach because there is less tissue trauma to the nose from the entry site, and blood from the osteotomy track can exit the mouth instead of the nose. The buccal sulcus is injected followed by the underside of the nasal bones by entering the nose with the needle directly at the turbinate. This local injection is done at the very beginning of the case, but is done again at least 7 minutes prior to the osteotomy. There is no good way we know of to inject the underside of the dorsal nasal bones for the medial oblique osteotomy. Our experience

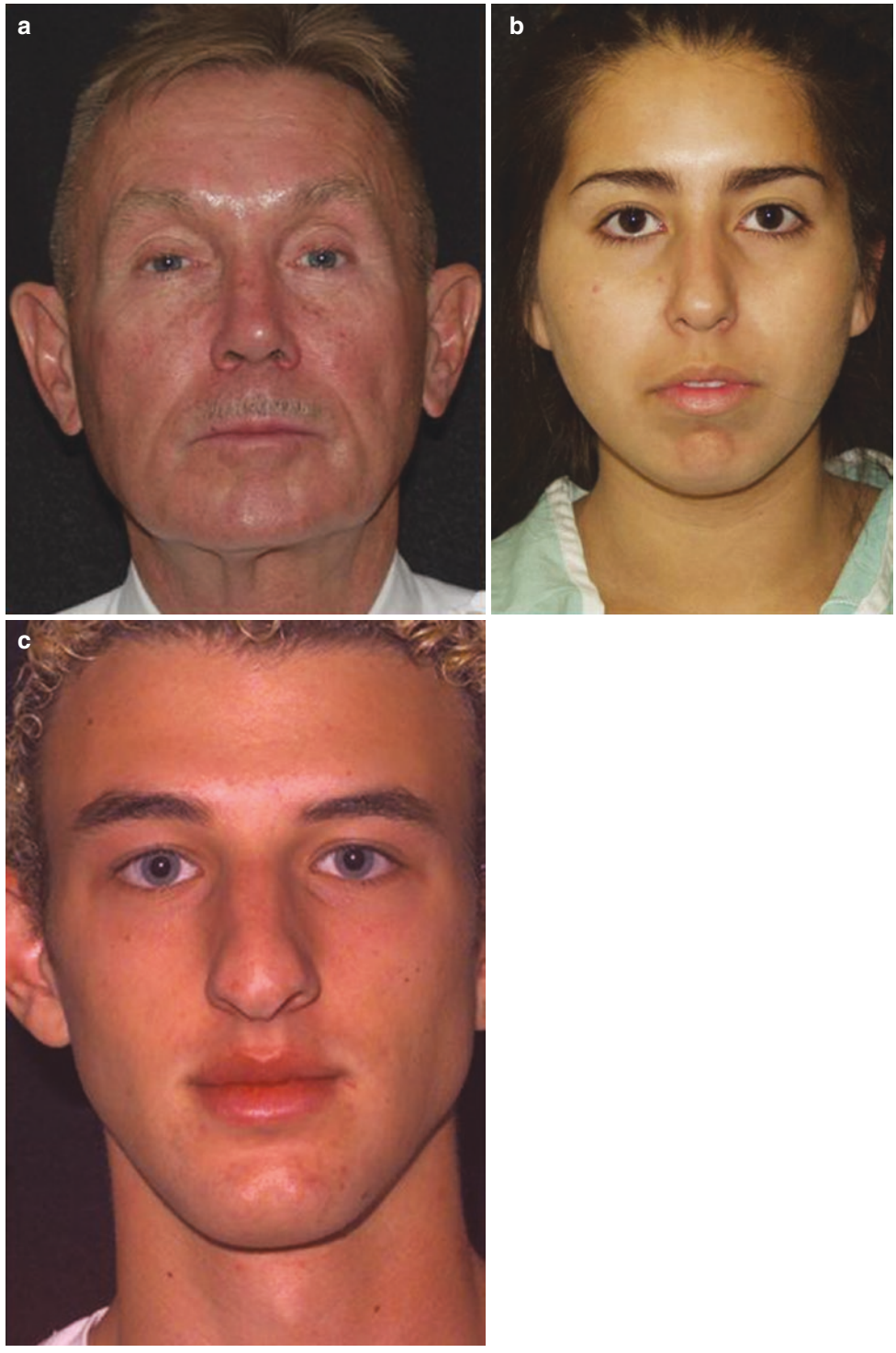

Fig. 3.1 (**a**) A male patient's front view demonstrating abnormally wide dorsum, but not base of nasal bones. (**b**) A female patient's front view demonstrating abnormally wide nasal base, but not abnormally wide nasal dorsum. (**c**) Male patient front view demonstrating wide nasal dorsum and wide nasal bone base

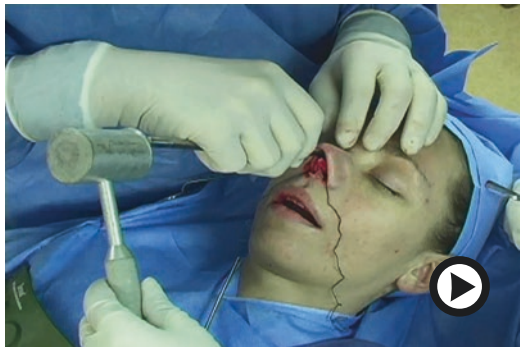

Fig. 3.2 Cadaver (▶ https://doi.org/10.1007/000-3th)

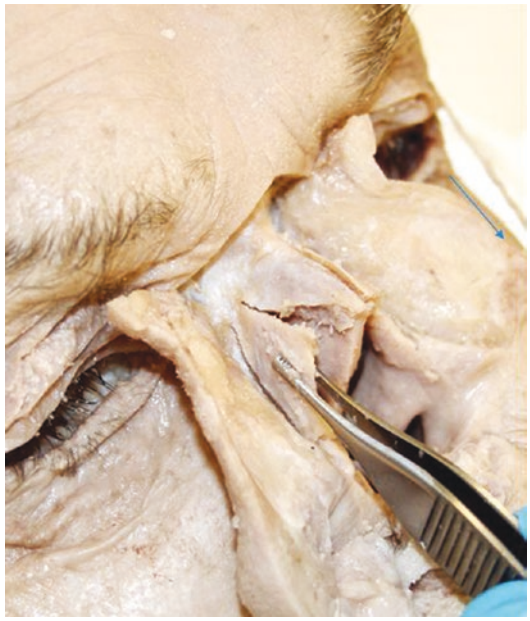

Fig. 3.3 Cadaver demonstration of "hanging chad." It is the lateral nasal bone that looks like a thin plate. Because of the medial oblique and low-to-low osteotomy, the nasal bony plate is still attached cephalically by a small remnant of bone or periosteum

with the above technique is a fairly dry operative field in most cases. A humpectomy is preformed next (which is described elsewhere) [8].

The osteotomes are approximately 3 mm wide [9] for minimal damage to the periosteum (Fig. 3.5). It is sharpened with a conventional hardware store stone (autoclaved) prior to each use.

Medial Oblique Osteotomy

The medial oblique osteotomy is intended to medialize the dorsal aspect of the nasal bones as high up as possible, yet avoid the dense and often bloody central nasal bone [1] (Fig. 3.6). It is for that reason we no longer use a saw to do an actual medial osteotomy. Although a medial osteotomy will narrow the dorsum by the width of the saw, it has been our experience that it is a bloody procedure.

The medial oblique osteotomy is invariably done first, as so doing destabilizes the nasal bones for a lateral osteotomy. Doing the lateral osteotomy first tends to create a slightly more unstable bone for a subsequent medial oblique osteotomy. The osteotome is placed on the outside (lateral) edge of the open roof so that the dorsal edge of the nasal bone is able to migrate medially (Fig. 3.7). Placing the tool flush up against the septum results in a bony plate that has nowhere to go, that is, cannot go beneath the dorsum. Once placed correctly in the open roof, the osteotome is aimed in the general direction of the medial canthus. It is acceptable to aim it perpendicular to the long axis of the open roof, if when taping the osteotomy, very dense bone is encountered. The extent of the osteotomy track is approximately 5 mm. Slight lateral prying with the tool is done before removal from the track. A Freer elevator is inserted into the track and wiggled to see how malleable the bony plate is. If the bone does not bend medially easily, the osteotome is reinserted and tapped in for 2 more mm. This is where the learning curve is located. Experience with five cases should be sufficient. The dorsal edge of the nasal bony plate will at some point after manipulation with a tool become malleable enough to stay in the medially placed position. Often it slips beneath the central solid nasal dorsum, which now has a dorsal overhang in the form of a spike (Fig. 3.8a). A Fig. 3.9 *of medial oblique osteotomy* is presented here, and also shown in Fig. 3.8b. That spike is rasped down very gently. The net result now is a narrower dorsal width without any

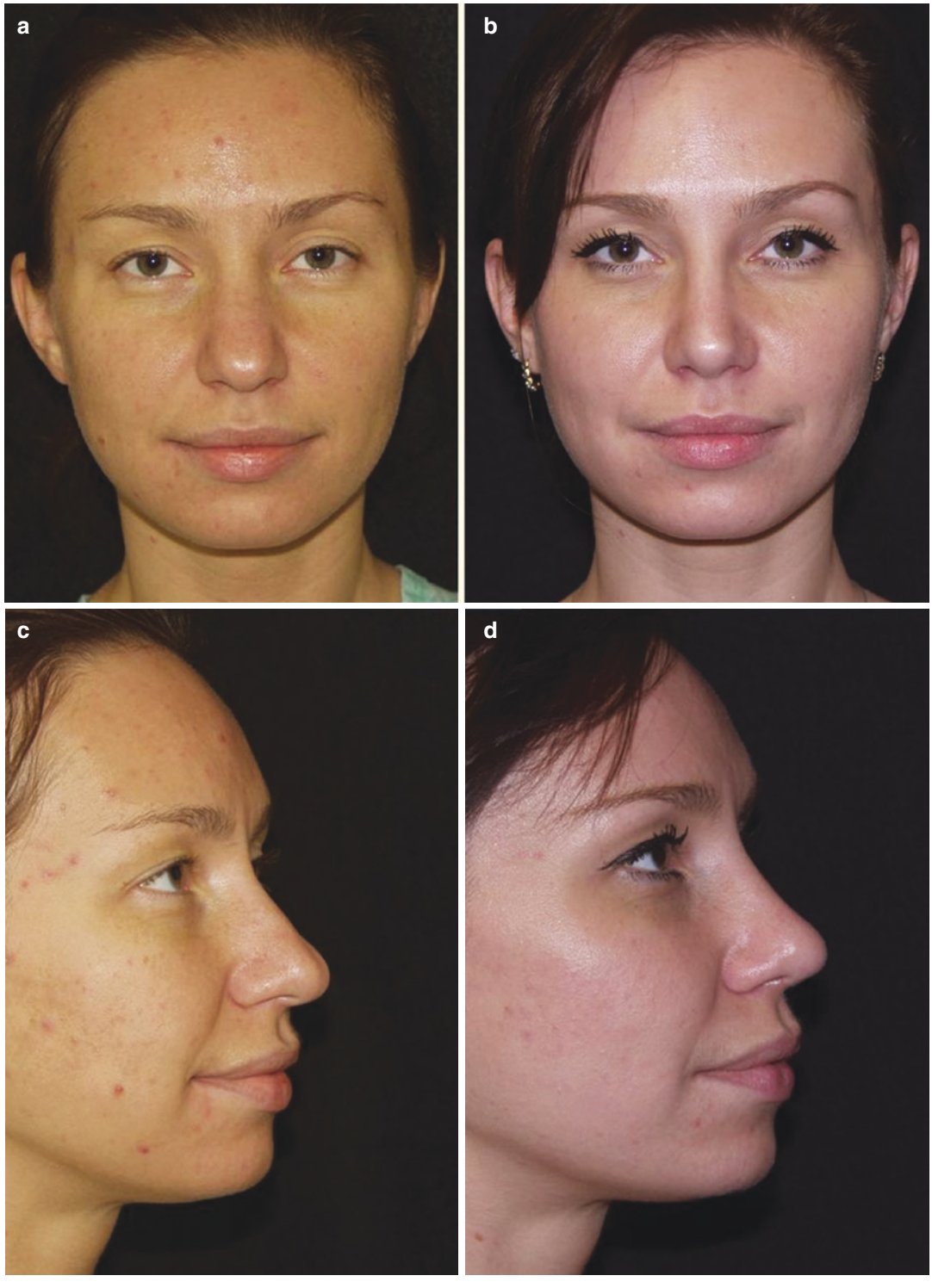

Fig. 3.4 A 28-year-old female with pre- and postop views following medial oblique and low-to-low lateral osteotomies. (**a**, **b**) front; (**c**, **d**) oblique; (**e**, **f**) lateral; and (**g**, **h**) basal. Other surgical maneuvers were, of course, performed

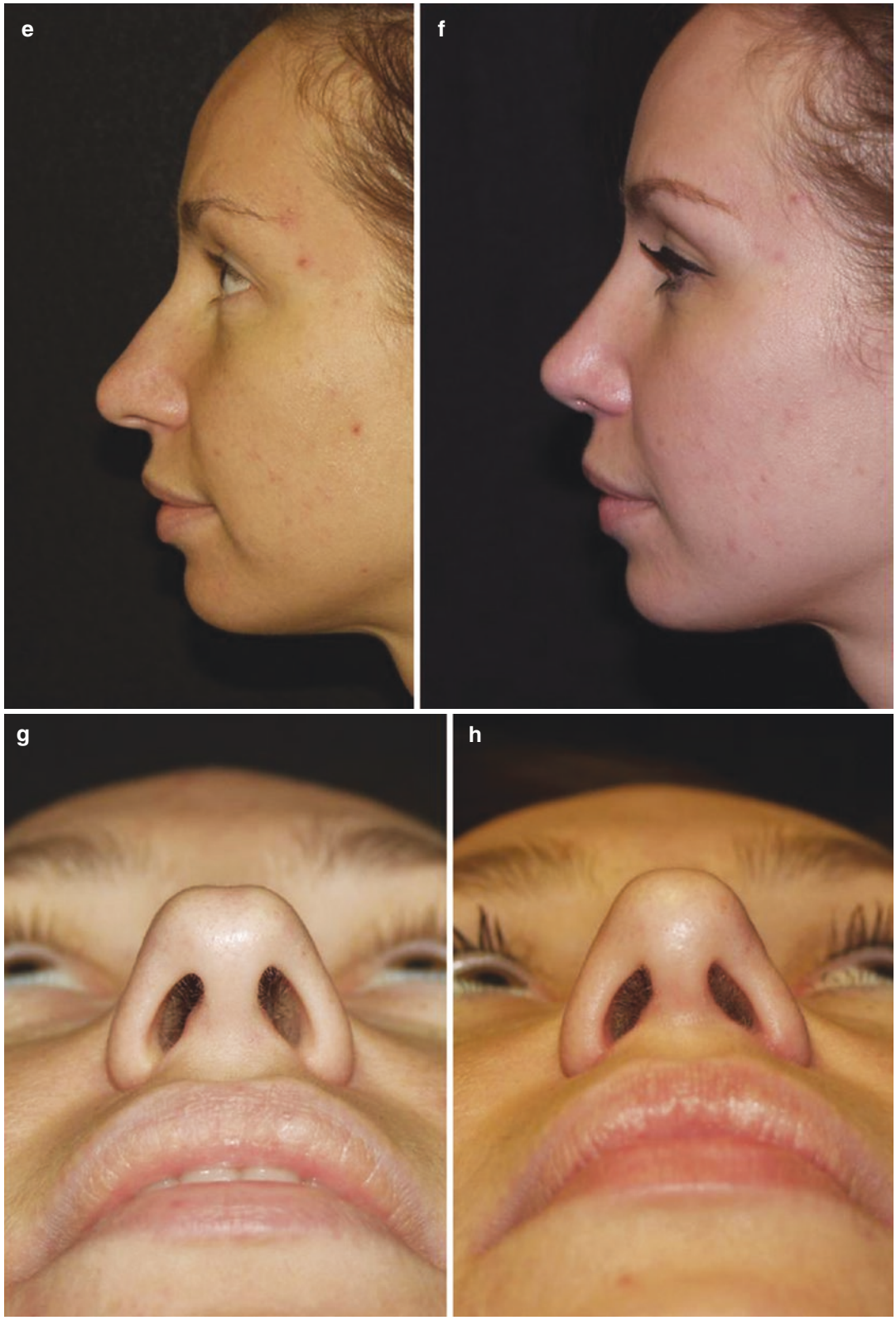

Fig. 3.4 (continued)

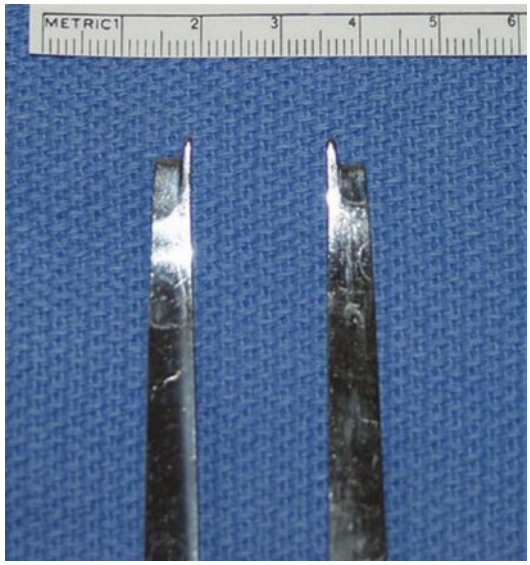

Fig. 3.5 Osteotomies that are 3 mm in width or less are associated with less periosteal tear and subsequent nasal bleeding

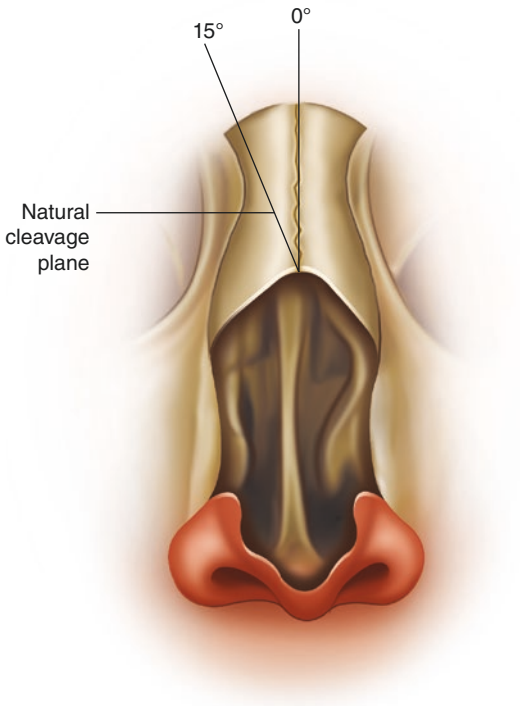

Fig. 3.6 Schematic showing zone of dense bone within a 30 degree border. Avoiding this unusually dense bone with its many blood vessels is beneficial

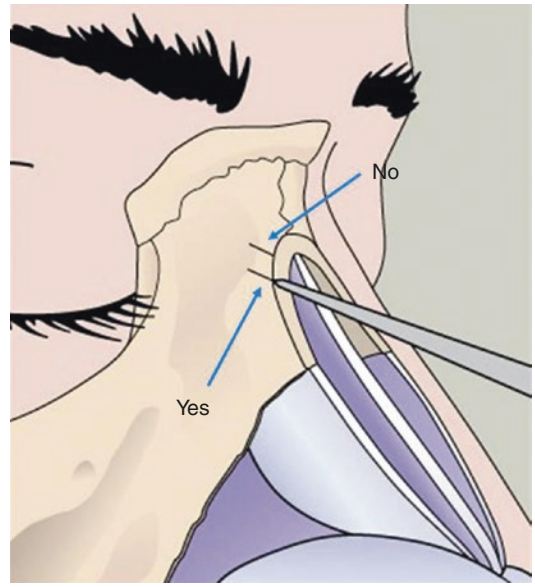

Fig. 3.7 Schematic for medial oblique osteotomy demonstrating where osteotome should be placed, that is, in the outer (lateral) aspect of the open roof so that the bony plate can migrate medially after medial oblique osteotomy is performed

changes to the nasal base width (the principle of independent osteotomies).

Lateral (Low-to-Low) Osteotomy

The low-to-low osteotomy begins with a small 3 mm incision of the mucous membrane of the buccal sulcus, where it is flushed up against maxillary bone (Fig. 3.10). It is located along a vertical line from the lateral edge of the ala and usually in line with the cuspid tooth. A small scissor spreads the hole to 1 cm. A Joseph periosteal elevator sweeps the periosteum off the maxilla up to the pyriform fossa. The tool is allowed to drop into the fossa to orient oneself. It is important to stay directly on bone and not create a subcutaneous tunnel, which would affect nerve fibers coming from the infraorbital nerve. The tool is then used to create a tunnel where one wants the osteotome to go. That direction is invariably on a line from the pyriform fossa running along the base of the nasal bone to a point 1 cm inferior and

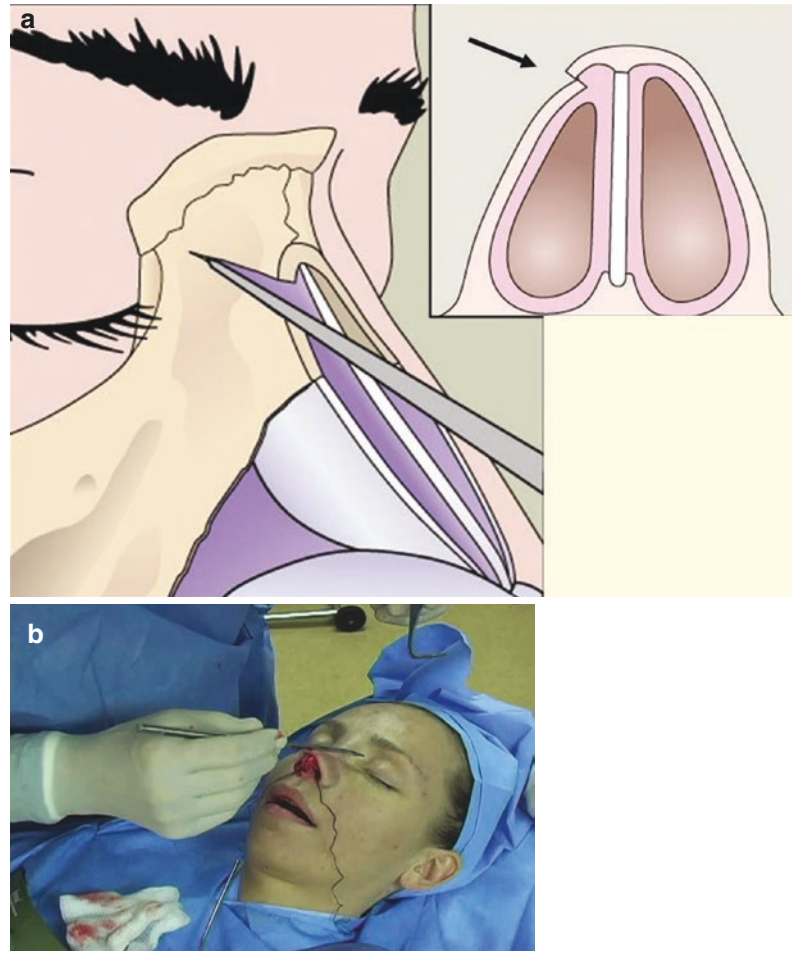

Fig. 3.8 (**a**) Schematic of medial oblique osteotomy demonstrating that prying downward (posteriorly) is beneficial to mobilize the bony plate. If done properly, the bony plate slides or can be made (with a Freer elevator) to slide deep to the dorsal bone, leaving a palpable spicule. That bony spicule is then rasped, and the result is a slightly narrower dorsal bony width. (**b**) Medial oblique osteotomy

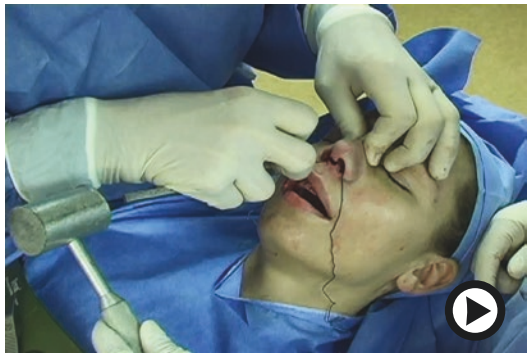

Fig. 3.9 Medial oblique osteotomy (▶ https://doi.org/10.1007/000-3tg)

slightly medial to the medial canthus (Fig. 3.11). For the beginning rhinoplasty surgeon, it is good to mark that line externally (Fig. 3.12). The tunnel is as narrow as the osteotomy. One purpose of marking it is to acquire a mock osteotomy. After creating that path (tunnel) with the Joseph elevator, the osteotome is inserted into the buccal sulcus opening. By palpation with the tool itself, the most inferior and lateral aspect of the pyriform aperture is found. It is not easy to find, but it is also not necessary to be in the precise part of the aperture. What is necessary is to set the best direction and be able to palpate the guard. The line on the skin externally is very helpful. The osteotomy is held firmly and the assistant gives it two taps to get a purchase of the pyriform aperture (Figs. 3.13 and 3.14).

Once the tool has taken a bite of the bone and the direction is set, wiggling should be avoided. The direction and location are already established for the surgeon by the trial with the Joseph elevator. The guard of the osteotomy is invariably pal-

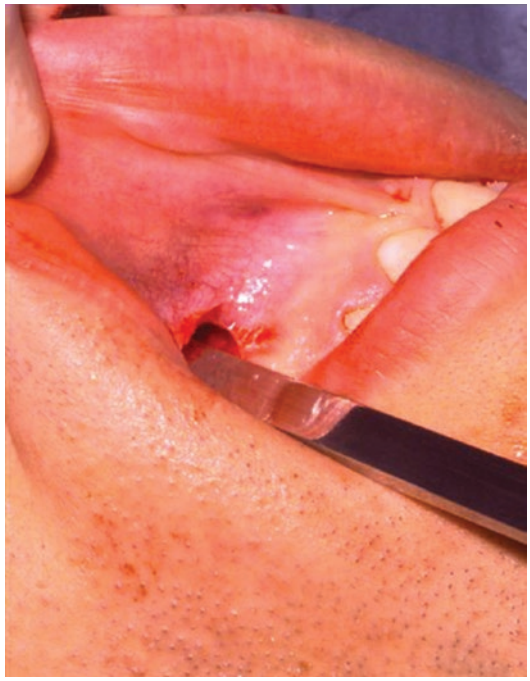

Fig. 3.10 The low-to-low osteotomy begins with a small 3 mm incision of the mucous membrane of the buccal sulcus where it is flushed up against maxillary bone. It is located along a vertical line from the lateral edge of the ala and usually in line with the cuspid tooth. A small scissor spreads the hole to 1 cm. A Joseph periosteal elevator sweeps the periosteum off the maxilla up to the pyriform fossa

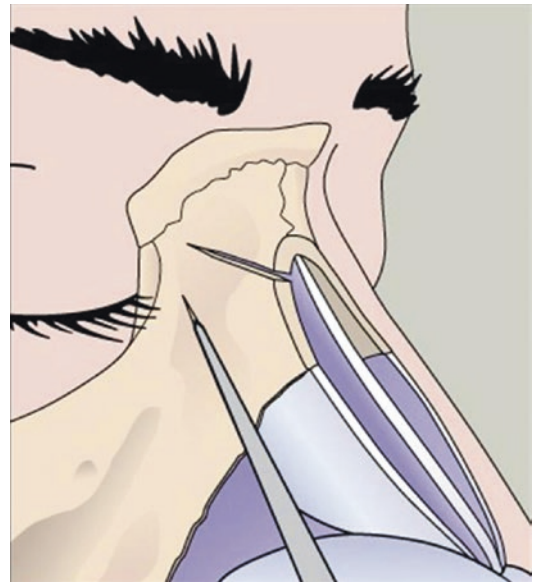

Fig. 3.11 Schematic showing location of medial oblique osteotomy having been done and also low to-low osteotomy being done with osteotome

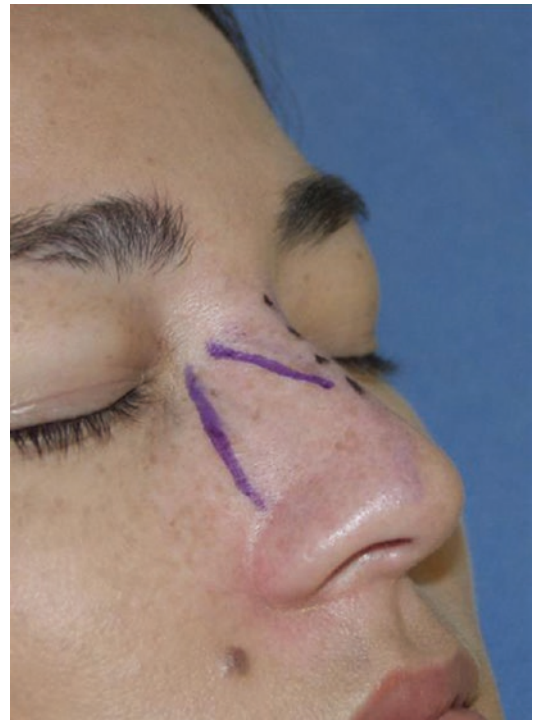

Fig. 3.12 The beginning rhinoplasty surgeon will find it useful to mark the skin with the exact location and direction of the medial oblique and low-to-low osteotomy sites

pable as the osteotome proceeds cephalically. The osteotome is held steady for the ride until there is a change in sound. Because nasal bones fan out from the nasion to the ala, the osteotome needs to be moved medially ever so slightly as it proceeds cephalically toward the medial canthal region. After hearing the change in sound (due to very dense bone), the osteotome is pried anteriorly, that is, ever so slightly (a few mm) before removing. The more prying is done, the more the base of the nasal bone plate moves medially. A conservative approach is used in that one can always reinsert the tool and pry anteriorly some more in order to allow the nasal bone to move more medially. Moving the bone back out (laterally) is to be avoided because the nasal bony plate may not stay out, as they have a tendency to move medially. The net result is a width reduction in

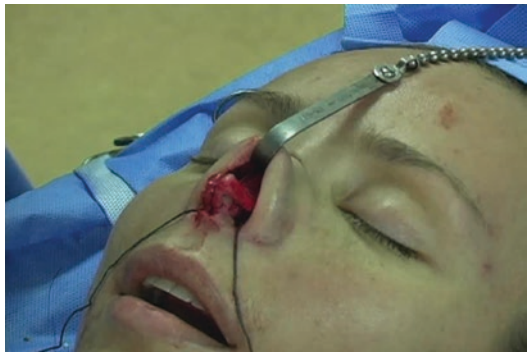

Fig. 3.13 Demonstration of the lateral low-to-low osteotomy

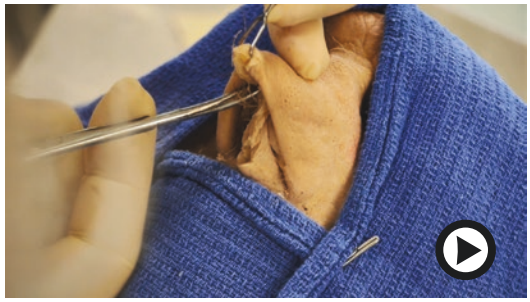

Fig. 3.14 Low-to-low osteotomy (▶ https://doi.org/10.1007/000-3tj)

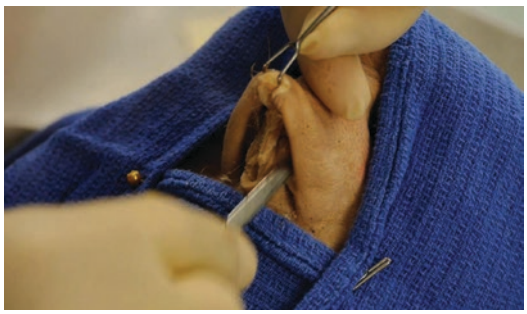

Fig. 3.15 Demonstration of a left-sided medial oblique osteotomy followed by a low-to-low osteotomy

the nasal base width with no change in dorsal width (the principle of independent osteotomies). If for some reason a significant step-off deformity is felt, suggesting that the osteotomy track was made too anteriorly leaving an incompletely narrowed nasal base, the entire procedure should be repeated, this time remarking the skin externally and placing the osteotome in a more posterior position at the pyriform aperture.

If a medial oblique osteotomy has preceded the low-to-low osteotomy (for noses with both broad dorsa and nasal bases), the entire bony plate will be mobile, with some unseen or impalpable bone attached cephalically where the two osteotomy tracks almost meet. This is referred to as the "hanging chad" osteotomy [10]. Even if the two tracks do meet, the hanging chad tends to be stable enough for mild digital manipulation. The periosteum below will not have been injured because 3 mm osteotomes were used. Despite that reassurance, one should not be aggressive in digitally mobilizing this segment. It should be possible with an Adson Brown forceps (shown earlier in Fig. 3.3) to grasp the entire bony plate and manipulate the "slope" of the nasal bony plate. This will be necessary in those few cases where the bones need to be widened. One may want to manipulate the nasal plate in order to get the dorsal edge to slip under the roof of the dense medial nasal bone, as shown earlier in Fig. 3.8a.

We do not worry about the turbinates when performing osteotomies because they do not seem to be a part of the nasal bony plate that is being medialized, as shown here in Fig. 3.15 and in the cadaver video later in this chapter. For that reason, we never perform a high-to-low osteotomy. Also, we do not concern ourselves with Webster's tubercle [11], which we consider to be irrelevant.

Crooked Bony Septum

Most often the location of the bony septum (perpendicular plate of the ethmoid) is irrelevant. Only the location of the nasal bone plates in this region is important. However, in those very few cases where it is noticed that the bony septum (or even the cartilaginous septum) is pushing on one nasal bone and thereby preventing its medial positioning, it will be necessary to mobilize the septum in this very cephalic region. To do so, an osteotomy of the cephalic most accessible part of the bony septum is performed. A cut in the bone (see cadaver video later in this chapter) is made directly downward on the bony septum for a distance of 5 mm. A Freer elevator is used to literally

push and bend the bony septum to one side. Complete centralization is not necessary. If the bony septum will not move, the track of the osteotomy has to be deepened a few more mm. There is little chance of causing a collapse of the entire bony septum if this is done in an incremental fashion. If the septum in this high-up region is cartilaginous, the cut is made with a knife instead of an osteotome and the cartilage is simply bent over until it stays put.

Other Maneuvers

This particular nose also required septoplasty, nasal shortening, tip plasty, and alar base excision. Mastisol and a half nasal taping was applied followed by a seven-layer superfast plaster splint which was removed 6 days later. Like for any fracture reduction, splinting must be precise and snug.

Cadaver Video Demonstration

The cadaver first demonstrates a left-sided medial oblique osteotomy followed by a low-to-low osteotomy. The cut (track) is admittedly somewhat anterior on this side. Note that the bony plate is quite thin. Note that the osteotomies are not in the region where the bone is known to be thick, that is, in the central region medial to a line 30 degrees off the midline [1]. On the right side, the two osteotomies were repeated; this time the low-to-low osteotomy was placed more posteriorly. Again, note that the nasal bone is basically a thin plate. An osteotomy of short length was made so that the central septum (whether it is of bone or cartilage) can be bent over so that it does not push on one of the nasal bones, preventing them from being medialized.

Summary

A series of principles for nasal osteotomy have been provided; in particular, the *principle of independent osteotomies*. An algorithm and detailed description of the procedure were also provided. The essence of our osteotomy approach is given in the tables below. In Table 3.1 we provide a list of advantages, disadvantages, limitations, and complications of our approach. In Table 3.2 we list advantages and limitations of the alternative methods. Finally, we list a series of pearls that should apply (to some extent) to all osteotomy approaches in addition to our own method.

Tips and Tricks (The Pearls)

1. Local anesthesia Xylocaine/Marcaine 1/75,000 ½ prior to osteotomy.
2. DDAVP PRN.
3. For medial oblique osteotomy, place the osteotomy on lateral aspect of open roof.
4. Test flexibility of bone after osteotomies gently with Freer and be willing to place osteotome back in the track to do more.
5. Rasp spike off central nasal dorsum after medial oblique osteotomy completed.
6. Use Joseph elevator to create a tunnel and to perform mock osteotomy.
7. Once osteotome is in the desired position, be firm and steady and do not waver as the taping proceeds.
8. Prying of the osteotome in the lateral osteotomy track causes the bony plate to migrate medially.
9. Medial oblique and low-to-low osteotomy achieve a “hanging chad,” which can be gently manipulated with an Adson Brown to adjust the bony plate slope.
10. Seven-layer superfast plaster split with forehead extension maintains bone position.

Table 3.1 Advantages, disadvantages, complications, and limitations

Independent osteotomy technique	1	2	3
Main advantages	Control is excellent Simple algorithm	Reasonably dry	
Disadvantages	Learning curve required	Not always easy for widening nasal bones	
Possible complications	Step-off deformity at nasal base	Dorsal collapse from extensive cut of bone	
Limitations	Severely curved nasal bones—rarely seen	Extraordinarily thick male nasal bones	

Table 3.2 Advantages and limitations of alternatives

Alternative techniques	Possible advantage	Possible limitation
Percutaneous	See osteotomy line better	Scar
Intranasal approach	Easier to palpable guard at the start	Intranasal trauma and bleeding
Piezzo	Cost	More extensive tissue dissection

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4 Facial Porous Polyethylene Implants

Petros Konofaos and Robert D. Wallace

Introduction

It is well established in the literature that facial augmentation using alloplastic materials is associated with low morbidity rates, although rates are material and site dependent [1]. Thus, it is useful to know the mechanical properties and nature of complications associated with the available materials. Ideally, the material should be cost-effective, be inert with the tissue fluids, be easily shaped in the operating room, maintain its consistency and shape in situ, and be permanently accepted but not toxic, carcinogenic, or antigenic.

Among the various alloplastic materials which have been used for facial augmentation, the use of porous polyethylene facial implants (PPFI) has received considerable attention. Porous polyethylene was developed in the early 1970s and has been available for clinical implantation since 1985 [2]. The porous surface of this biomaterial (range in size from 160 to 368 μm) allows tissue ingrowth and collagen deposition into the pores, and thus, relative implant incorporation, and forms a stable complex that is resistant to infection, exposure, and contractile forces [3, 4]. Moreover, PPFI are somewhat flexible at room temperature and when heated in hot water become malleable, strong enough to be used in nonload bearing areas, and readily available as sterile implants in various preformed shapes [4].

Although PPFI have gained popularity among providers as an excellent option for facial skeletal augmentation in the appropriate patient, there is limited literature regarding the indications, treatment results, and complications associated with its use. The aim of this chapter is to review the indications for PPFI use, patient evaluation, surgical planning, and its related morbidity and complication rates. Moreover, a description of the basic steps of surgical technique for PPFI placement, along with incision placement and intraoperative PPFI contour refinement, is provided.

Indications for PPFI

Augmentation of the facial skeletal can add angularity, definition, or balance to a face of normal dimensions or to a face with deficient and surgically/traumatically altered anatomy. Thus, the indications for alloplastic facial augmentation are classified as cosmetic or cosmetic/reconstructive based on the status of the facial anatomy.

For the first group (cosmetic), although skeletal relationships are ostensibly within the normal range, alloplastic facial augmentation is aiming on providing more definition and angularity to

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the patients' appearance. In some other patients, the aim of alloplastic facial augmentation is to "balance" facial dimensions.

For the second group (cosmetic/reconstructive), the presence of craniofacial deformities with aesthetic and functional sequalae (in vision, breathing, and mastication) usually requires the use of orthognathic surgical procedures for restoring anatomy and function. Alloplastic facial augmentation can be used either as an alternative to orthognathic procedures in patients with less severe skeletal deficiencies and without respiratory or ocular compromise, or as an adjunct to orthognathic procedures in patients with severe craniofacial skeletal deficiencies with functional sequalae in order to improve outcomes both aesthetically and functionally.

Preoperative Evaluation

Physical Examination

Physical examination includes assessment of life-size photographs, evaluation of skeletal and soft tissue asymmetries, and reviewing of previous surgical interventions. The recognition of facial asymmetries is important to the surgeon in planning, and to the patient in anticipating, the postoperative result. Moreover, in order to avoid operating in patients with unrealistic expectations, it is the surgeon's responsibility to discuss with the patient the aesthetic goals in relation to the patients' aesthetic concerns. This will help the surgeon in planning, and help the patient in anticipating the postoperative result.

Imaging Studies

Although preoperative radiology assessment is not necessary, and its use is based on surgeon's experience and case complexity, cephalometric X-rays and/or 3D maxillofacial CT scans can significantly contribute to achieving the optimal treatment of an individual patient. Cephalometric X-rays are usually used for planning mandible augmentation surgery due to their ability to define skeletal dimensions and asymmetries.

On the other hand, 3D CT scan imaging of the maxillofacial region is the best means of quantifying the deformity and planning treatment by viewing the craniofacial skeleton in different planes and in three dimensions. Moreover, it provides the ability of "mirroring," which is the ability to compare the affected side with that of its normal counterpart. This can help the surgeon to accurately determine the size and the shape of the implant needed.

Surgical Technique

Anesthesia

Facial implant augmentation is generally performed on an outpatient basis. Depending on the location and the severity of the skeletal/soft tissue deficiency, either local anesthesia supplemented with sedation or general anesthesia can be used for the implant placement. In general, general anesthesia with nasotracheal or endotracheal intubation is indicated when the implants will be placed through an intraoral approach. This assures protection of the airway and the best possible antiseptic preparation of the oral cavity.

Local anesthesia supplemented with sedation can be used for chin augmentation, if extraoral approach is used. It is important that the surgeon explains to the patient the potential advantages/disadvantages of this approach, and identify the patient's comfort level of pain that will occur during induction of local anesthesia.

Preparation

Following anesthesia induction, the incisions are marked and infiltrated (along with the operative field) with lidocaine 1–2% with epinephrine (1:200000) in order to minimize bleeding. The head and neck area and/or the oral mucosa are prepped with a povidone-iodine solution. The administration of IV antibiotics is a must-do step of the preparation; use of either cephalosporins or clindamycin is most common.

Incisions

Incisions are chosen based on the location of the skeletal/soft tissue asymmetries. Incisions over the location in which the implant will be placed should be avoided. For temporal and forehead skeletal deficiencies, coronal incisions are used. Transconjunctival incisions are used for placement implants at the infraorbital rim and internal orbit. The lateral extent of the lower-lid blepharoplasty incision provides access to the lateral orbit and zygomatic arch and usually leaves an inconspicuous scar.

The most commonly used incision is the intraoral sulcus (either maxillary or mandibular), with a generous labial cuff (of at least of 1 cm) that is used for placement of implants on the midface (infraorbital rim, malar, and piriform aperture) and/or on the mandible (including mandibular ramus, body, and chin). For chin augmentation, some surgeons use the submental incision, which leaves an inconspicuous scar. For placement of nasal implants, an open rhinoplasty incision is used.

Technique

Successful alloplastic facial augmentation is based on three principles: (1) adequate subperiosteal pocket dissection, (2) implant screw fixation to the facial skeleton, and (3) implant contouring. Moreover, handling of the PPFI with talc-free gloves and avoiding positioning of the implants on cotton-based towels and sheets are of paramount importance in order to avoid contamination.

Although there were some early reports which suggested placing the PPFI above the periosteum [5], strict PPFI subperiosteal placement has gained popularity among providers. The subperiosteal pocket dissection has several advantages: (1) the dissection proceeds faster due to the fact that the plane is relatively blood less and the local nerves are located superficial to the dissection plane, (2) elevation of the periosteum off the facial skeleton allows direct visualization of the deficient area and enhances more precise facial augmentation, and (3) exposure of the facial skeleton allows easier and more secure fixation of the implant on the facial skeleton. It is important to emphasize at this point the importance of adequate hemostasis, which is correlated with short convalescence and minimal morbidity.

In contrast to using smooth silicone implants to make the pocket just large enough to accommodate the implant and, therefore, guarantee its position, with PPFI the pocket should be larger than the selected implant. This is due to the fact that PPFI allow considerable fibrous tissue ingrowth instead of surrounding fibrous tissue capsule formation, thereby limiting movement and stabilizing fixation of the implant. Moreover, adequate soft tissue dissection and periosteal elevation eliminate tension over the implant and prevent implant migration or rotation.

Following unpackaging of the PPFI, the implant should be placed in a plastic container containing antibiotic solution. Before implant placement, the contour of the implant should be shaped in order to mimic the desired shape of the bone it is augmenting. This is the case especially if noncustom-made PPFI are used for facial augmentation. Carving of the PPFI is performed using a #15 scalpel blade in a specially made sterile plastic carving block to avoid contamination with lint or other particulate matter. It is advised to presoak the implants in hot saline in order to make carving easier. Carving aims to trim and shape the PPFI to fit the individual patient's needs. Moreover, the implant margins should be tapered imperceptibly into the native skeleton to avoid the implants being either palpable or visible, especially in patients with thin facial soft tissue envelope.

Fixation of the PPFI is an important step for a successful alloplastic facial augmentation. Screw fixation of the implant to the skeleton prevents any implant movement and, thus, avoids implant rotation or migration of the implant. Moreover, eliminating gaps between the implant and the facial skeleton by fixating the implant is important for two reasons. First, if there is any space between the implant and the skeleton, then the

asymmetry is not adequately addressed, which can lead to overaugmentation and further asymmetries. Gaps are also potential spaces for hematoma and seroma formation, which can lead to postoperative infections and additional surgical interventions. Second, screw fixation allows for final contouring with the implant in position. Implant fixation is not necessary if PPFI are used for augmentation of the nose or the chin. In these two areas, because of the thin soft tissue envelope, the implant's tissue ingrowth property with the aid of a soft tissue splint is able to stabilize the implant on the desired position.

Following insertion of the implant, densely spaced interrupted sutures are placed, in layers, in order to create a "watertight" pocket. This is necessary in order to prevent contamination of the implant with microorganisms that reside in either the mucosa or the skin. In cases of either chin or nasal augmentation with PPFI, a splint is applied over the soft tissue for a period of 7 days. Moreover, postoperatively the patients are administered a 7-day course of oral antibiotics and analgesics as needed. The patient is instructed to avoid significant talking and animation for the first 4 days and to follow a liquid diet for the same period.

Upper Face Augmentation

Forehead

The forehead is an aesthetically demanding area and any abnormalities (either congenital or acquired) of the frontal bone have a direct effect on the appearance of the upper third of the face. This section will address the use of PPFI for correction of contour deformities of the frontal bone (onlay cranioplasty). The main indications are either to refine the results of previously performed cranioplasties, or for posttraumatic frontal bone irregularities.

It is important to emphasize that the surgeon should be aware of the anatomy, surface landmarks, and especially of the aesthetic variables of the forehead (its inclination, its relation to the globes, and the relative prominence of its frontal sinus). Old or preinjury photographs of the patient's forehead help the surgeon to analyze the irregularities and avoid unnatural transitions (following implant placement).

PPFI placement is usually performed through a bicoronal incision with subperiosteal dissection. Carving of the PPFI should be considered in all cases, especially if a noncustom-made implant is used. The edges of the PPFI should be feathered, so that continuity between implant and bone is achieved and the edges are not palpable or visible. This may be the most important part of the procedure. Then, the implant is fixated over the irregular surface of the frontal bone with the use of titanium screws. It is important to emphasize that during fixation, special care should be taken so as not to fracture the implant and to ensure the screw is sufficiently well buried, so it will not be palpable through the skin. Closure of the incisions is performed in layers.

Temporal Area

Temporal area depression (Fig. 4.1a, b) is usually due to atrophy of the temporal muscle, which can cause significant aesthetic deformity, a matter of great concern to the patient. The cause of temporalis muscle atrophy can be iatrogenic, posttraumatic, or due to aging. PPFI have been used to restore the contour of temporal area in patients with temporal hollowing without complications [6].

The approach to the temporal fossa is through a unicoronal incision, and the dissection is carried down to the deep temporal fascia. If the temporalis muscle is intact, then it is split in the direction of its fibers and is elevated (with the periosteum) off the temporal fossa. If part of the temporalis muscle is missing, then the remaining part of the temporalis with the periosteum is elevated off the temporal fossa.

Then, the implant is carved to the required shape for contour augmentation. The deep surface of the PPFI should conform accurately to the contour of the underlying temporal bone. The

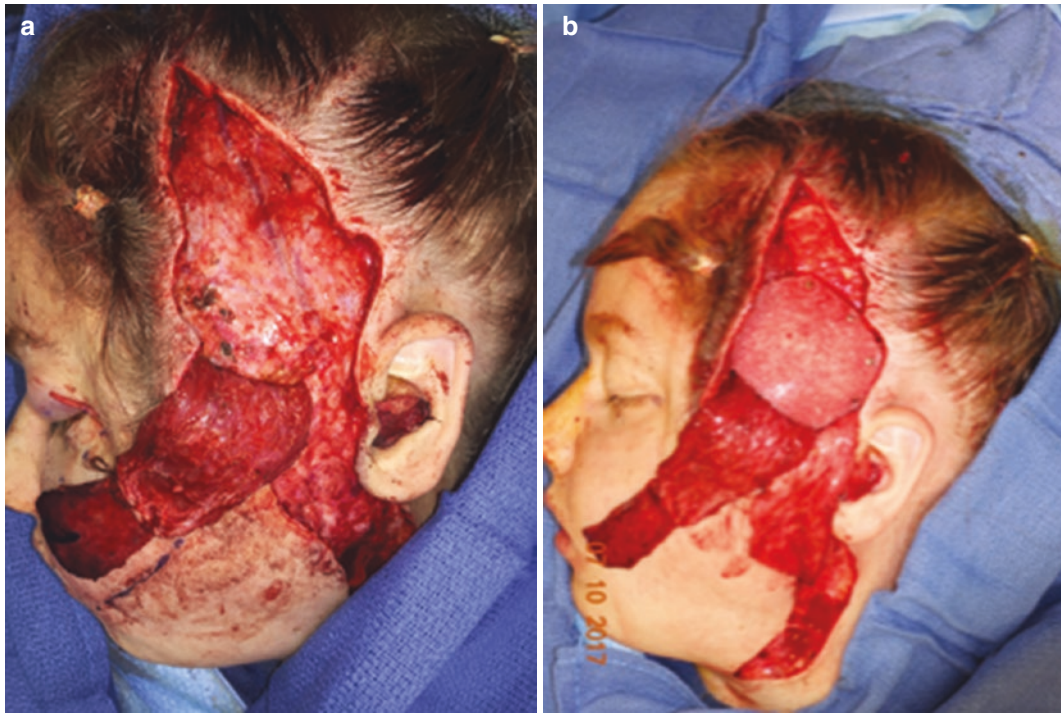

Fig. 4.1 (**a**, **b**) A female patient who underwent mini-temporalis muscle transfer for facial paralysis. A porous polyethylene implant was used for reconstruction of the donor site. (**a**) The defect of the donor site after the mini-temporalis muscle was raised in order to be transferred to the face. (**b**) The porous polyethylene implant was fixated in the temporal area

implant is fixated to the underlying temporal bone with screws. The temporalis muscle or its remaining parts are used to cover the implant, and the closure is performed in layers.

Midface Augmentation

The skeleton of the midface has direct and indirect correlation on the appearance of the face, particularly the eyes and nose. The midface is conceptualized as having four zones, alone, or in combination, for augmentation including the infraorbital rim, the malar area, the pyriform aperture, and the nose.

Infraorbital Rim

Infraorbital rim augmentation aims to improve the globe-rim relationship in patients with congenital deformities, or in "normal" patients with prominent eyes [7]. In young healthy adults, the supraorbital rim projects 10 mm beyond the anterior surface of the cornea, whereas the infraorbital rim lies 3 mm behind and the cheek prominence projects 2 mm. Augmentation of the supraorbital and/or infraorbital rims aims to restore the above-mentioned relationships.

Although subciliary skin or skin-muscle incisions can be used for the exposure of the infraorbital rim and adjacent areas, the same exposure, without the morbidity of subciliary incision, can be achieved through an upper gingival buccal sulcus incision with/without a transconjunctival retroseptal incision. It is important, during the pocket creation, to identify and spare the infraorbital nerve. Carving the implant and fixating to the skeleton with two self-drilling screws allow precise application of the implant on the surface of the skeleton.

Malar Area

The malar area is frequently augmented with implants, as prominent malar bones are considered attractive. Malar hypoplasia, submalar soft tissue insufficiency, and combined malar and submalar deficiency can be addressed through midfacial implant augmentation [8, 9]. On the other hand, malar skeletal augmentation is not a substitute for soft tissue volume loss. Once the "ideal" position of the malar mound is identified, then it can be determined if malar repositioning or augmentation is required. Once this is established, the soft tissues of the midface are evaluated. These considerations determine whether a malar, submalar implant, or combined malar-submalar (midface) implant is required.

Placement of the PPFI is relatively straightforward through a transoral approach and creation of a subperiosteal pocket, extending from the inferior orbital rim superiorly to the masseteric tendon laterally. If a submalar implant is placed, the pocket is smaller in order to avoid the upward displacement of the implant during wound contracture [9]. It is important to emphasize that during dissection over the zygomatic arch and malar eminence, the surgeon should proceed with caution to avoid injury to the buccal and frontal branches of the facial nerve and the infraorbital nerve (when dissection proceeds over the infraorbital rim area). Fixation of the implant is performed with screws, and water-tight closure of the pocket is always performed.

Piriform Aperture

Augmentation of this area improves the projection of the nasal base, the nasolabial angle, and the vertical plane of the lip. The cause of the deficiency can be congenital or acquired, especially after cleft surgery and maxillary fractures. Placement of the PPFI can be performed through an upper gingivobuccal sulcus incision just lateral to the piriform aperture. The dissection proceeds subperiosteal, and the borders of the piriform aperture, the infraorbital nerve, and the root of the canine tooth should be identified in order to provide bony landmarks for a precise implant placement. The implant should not be positioned beyond the bony edge of the aperture, in order to avoid airway compromise. The incision is closed in layers.

Nose (Figs. 4.2 and 4.3)

Trauma, infection, or prior nasal surgery can often render available septal cartilage inadequate for the degree of reconstruction required. While autologous tissue implants are the most desirable reconstruction option for use in rhinoplasty, they are not readily available, they are sometimes in limited quantity, and their harvesting is not without complications [10]. Among the various alloplastic materials which have been used for such reconstructions, PPFI are considered acceptable alternatives for nasal reconstruction when adequate or desirable autogenous grafts are not available [11, 12].

The use of alloplastic materials is indicated either in patients with inadequate cartilage stock who need either nasal dorsal and tip augmentation, as well as columella augmentation, or in those patients who have undergone rhinoplasty, with resultant nasal valve collapse, nasal tip bifidity, and a scooped-out nasal dorsum. There are prefabricated PPFI for use in patients who need a revision rhinoplasty, including columellar strut, nasal dorsal implant, and curved valve batten.

Placement of the selected PPFI is performed through an open rhinoplasty approach using an inverted V transcolumellar incision combined with a bilateral marginal incision. Dissection of the columellar skin over the medial crura and laterally is performed. Further dissection is carried out over the tip, the supra tip area, and the nasal dorsum, and is stopped at the nasion. Dissection is carried out in the submuscular plane and effort is made to stay below the periosteum of the nasal bone. The upper lateral cartilages are carefully dissected from the dorsal septum, and the mucosa is preserved. The septum is freed from the extrinsic forces of the deformed nasal bones and from the upper and lower lateral cartilages. The septal deformity then is evaluated and corrected.

Dorsal PPFI grafts are placed in a subperiosteal pocket as onlay grafts above the nasal bone and the upper and the lower lateral cartilages. The nasal dorsal implant is carved and shaped with a #15 scalpel blade.

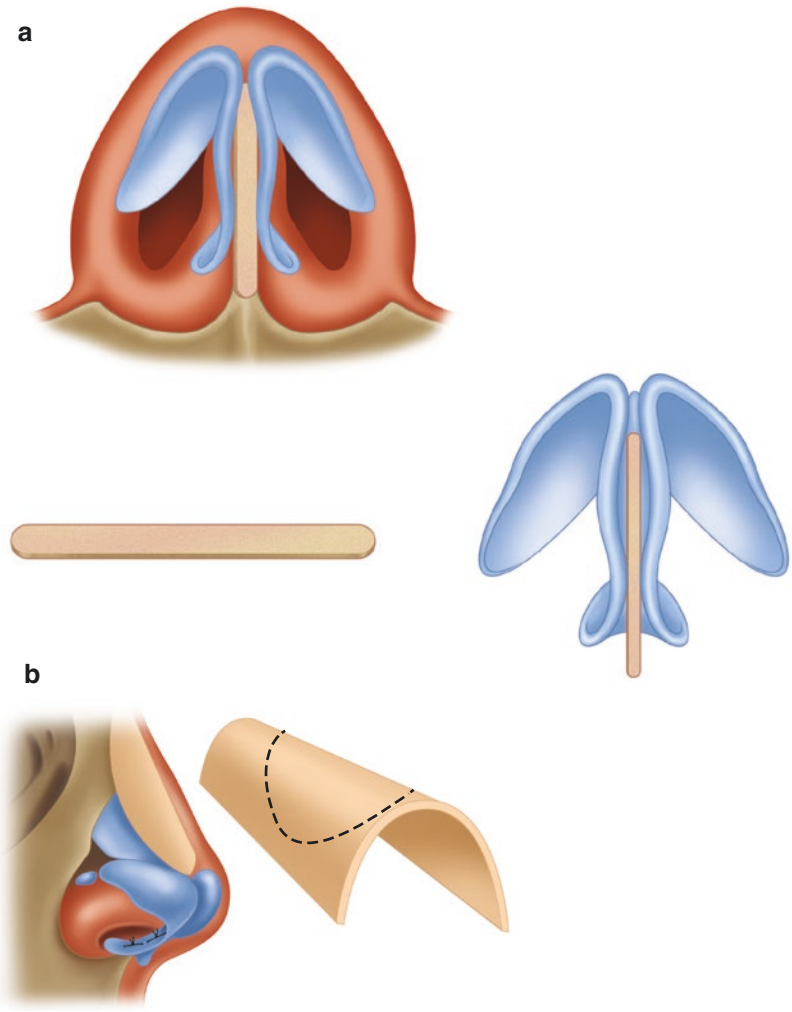

Fig. 4.2 (**a**, **b**) Nasal porous polyethylene implants. (**a**) A columellar porous polyethylene graft. (**b**) A nasal dorsum porous polyethylene graft

If there is significant alar collapse, the batten implant is used. The technique for placing the batten implant is slightly different in the lateral edge of the batten implant, which is placed over the edge of the pyriform aperture, and the medial edge of the implant is placed on top of the transected edge of the lower lateral cartilage.

Columellar grafts are secured, between the medial crura, into a columellar pocket using through-and-through horizontal mattress 5-0 monocryl sutures. Following insertion of the implants, the nasal tip and columella skin are redraped, and the incisions are closed with interrupted 6-0 nylon and 5-0 chromic sutures. A steri-strip splint is placed on the nasal dorsum.

Mandible Augmentation

Mandibular contour abnormalities occur from congenital deformities, traumatic injuries, disease, or previous surgery and may be located at the chin, angle, and/or ramus. Effective preoperative planning requires understanding of the patient's desires, detailed facial examination, and review of the previous facial surgery.

Chin

Augmentation of the genial area is indicated in patients with congenital mandibular retrognathia or those with contour deformities (due to previous surgery, traumatic injuries, or disease). These deformities affect the anteroposterior relationship

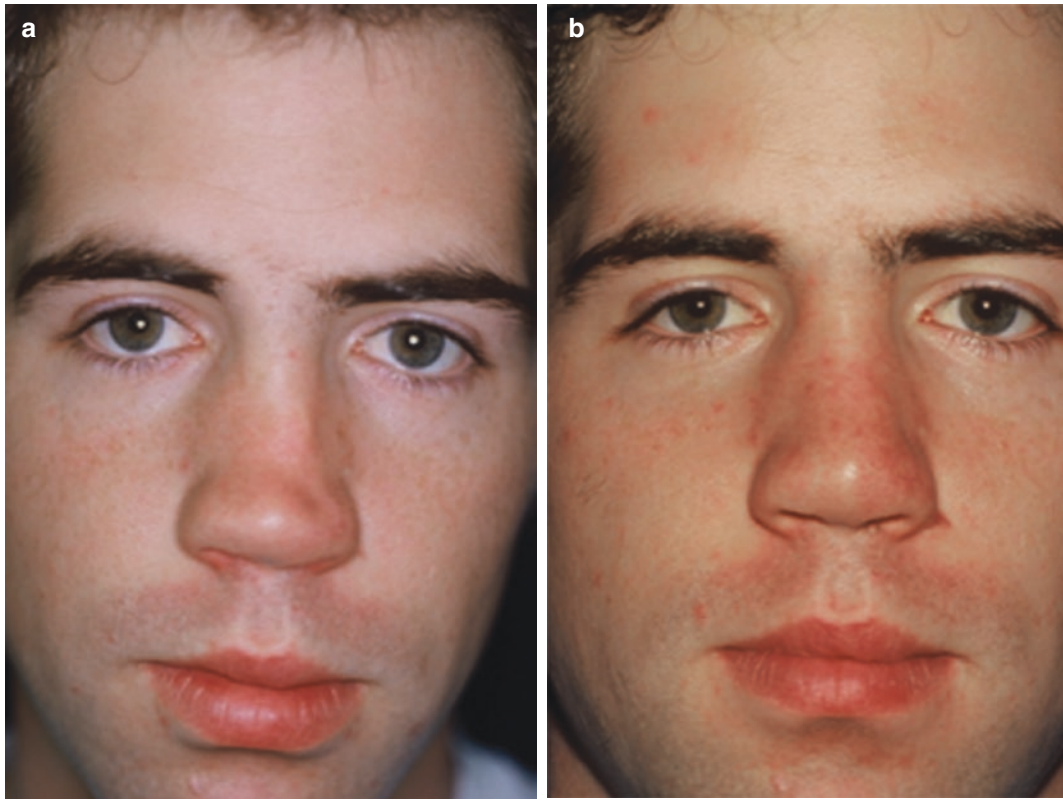

Fig. 4.3 (**a**, **b**) A male patient with a traumatic "saddle-nose" deformity, who underwent open rhinoplasty with cartilage grafts. The grafts were resorbed and the patient underwent a secondary rhinoplasty with porous polyethylene nasal implants. (**a**) Anteroposterior view of the patient before the porous polyethylene implant placement. (**b**) Anteroposterior view of the patient 8 years following the secondary rhinoplasty

of the chin to the lower lip and the vertical ratio of the lower lip to the upper lip with the lips in repose. In adult population, the chin should be positioned 3–4 mm behind the lower lip in repose and the vertical relation of the upper lip to the lower lip is about 1:2, with men having a slightly larger lower lip in comparison to the upper lip than women (men: 1:2.1–2.3). Thus, the goal of augmentation is to create an anatomically correct and stable mandibular contour.

General endotracheal anesthesia is used for PPFI placement for chin augmentation through an intraoral or an extraoral approach. The extraoral approach, through a submental incision, allows direct view of the chin contour deformity and, thus, precise implant placement. Moreover, mentalis muscle is preserved, the mental nerve is easily identified, and the scar is inconspicuous.

On the other hand, the intraoral approach provides limited exposure to the area of concern and is associated with implant malposition, paresis of the mental nerve, and lower lip dysfunction from mentalis muscle division [13]. Thus, the extraoral placement seems to be correlated with less morbidity and better aesthetic outcomes.

Through a submental incision, the soft tissue of the chin at the subperiosteal level is telescoped over the inferior border of the mandible. The middle of the chin is marked on the pogonion as a reference point. The subperiosteal dissection extends superiorly to the origin of the mentalis muscle, laterally 1 cm lateral to the mental foramen, and bilaterally and inferiorly below the inferior border of the mandible.

Fixation of the PPFI is not needed, as the soft tissue envelope with the aid of an external splint act as stabilizing forces for the implant, along

with the tissue ingrowth capability of the implant. The PPFI are placed on a subperiosteal pocket after the necessary contouring is performed. The submental incision is closed in layers, and external splint is placed for the first 4–5 days.

Mandibular Angle Augmentation

Patients with contour abnormalities in the mandibular angle do not usually have aesthetic concerns, unless there is a notable asymmetry or because of acquired factors such as an injury, previous surgery, or disease that cause a change in the patient's normal appearance. Females tend to have a reduced ramus height compared to males, which creates a more ovoid appearance, whereas the longer the ramus height is correlated with a more square face.

The use of 3D maxillofacial CT scan is especially useful in the diagnosis and for treatment planning for mandibular angle deformities because it creates a 3D facial soft tissue and skeletal model, which enables the surgeon to directly measure the extent of the deformity as well as quantify and establish the correct size and shape of the implant. Thus, it is possible to use custom PPFI, which can accurately augment the deformity, although the cost is always an issue.

Placement of the implant is usually performed through an intraoral approach, which is made at least 1 cm above the mandibular sulcus on its labial side. The periostium is reflected superiorly to the midportion of the mandibular ramus and inferiorly to the lingual surface of the inferior border of the mandible. It is important to achieve sufficient soft tissue relaxation to allow placement of the implant and prevent it from being displaced. The dissection is performed at the subperiosteal level and extends below the inferior border of the mandible, creating a pocket for passive placement of the implant.

Once the pocket is created, curving of the implant as needed is performed, and the implant is placed on the deformed/deficient area and is secured in place with one or two screws in order to prevent displacement of the implant during function or from soft tissue tension. It is also to emphasize the importance of softening any transitions between the implant and the mandible because any step offs in this area may be visible, especially in thin patients. The incision is closed in two layers with absorbable sutures.

Postoperative Protocol

In the immediate postoperative period, the patients are prescribed oral antibiotics for 10 days postoperatively. In cases in which a transoral incision is used for implant placement, a liquid diet is prescribed for the first 3 days postoperatively, then a soft diet for 7 days. The patient is instructed to perform frequent mouth washes for the first 5 days and careful tooth brushing thereafter. In cases in which a skin incision is used, the incision is to be cleaned every day with saline and application of antibiotic ointment, performed for the first 4 days postoperatively.

Complications

The rate of complications following application of PPFI in the upper face (temporal and forehead areas) is almost rare due to the thickness of the soft tissue and the vascularity of these areas. The only exception to this applies to cases with scars in these areas, previous infections, and possible communication of the defect with the airway (e.g., frontal sinus).

On the upper face (midface), potential complications include inadequate correction or overcorrection, malposition, implant migration, infection, extrusion, nerve hypesthesia/anesthesia, and facial nerve injury [14]. In general, mandibular angle and cheek implants are the most likely of all facial implants to result in postoperative asymmetry.

Careful preoperative analysis can be preventive in avoiding over-/undercorrection [15]. Meticulous surgical technique, knowledge of anatomy, and implant fixation can minimize problems of malposition, migration, and nerve injury. Finally, careful sterilization procedures, perioperative and postoperative antibiotics, intraoperative wound irrigation, and postoperative mouth rinses can reduce the incidence of infection and extrusion.

Complications of mandibular implantation are rare and generally preventable. Of those that occur, the most frequent include inadequate correction or overcorrection, asymmetry, malposition, bone resorption, infection, extrusion, and nerve hypesthesia/anesthesia [16, 17]. Inadequate correction, overcorrection, asymmetry, and malposition typically extend from improper implant selection and/or improper placement. All of the above can be avoided if there is appropriate preoperative planning and a tight subperiosteal pocket with rigid fixation of the implant. Subperiosteal dissection along the inferior mandibular border, in addition to screw placement that avoids tooth roots and the path of the inferior alveolar nerve, will prevent concomitant-related nerve injuries.

Conclusion

There are many factors that determine the success of alloplastic facial augmentation, including patient's health status and recipient tissue quality, and the expertise offered by the surgeon. PPFI are composed of an inert material, which is a type of porous polymer that allows tissue ingrowth into its pores, which prevents mobility; is hard and noncompressible; and easily carved to create the desired shape. PPFI are an excellent alternative for facial augmentation. Clinical judgment, thorough preoperative facial analysis, adherence to fundamental surgical principles, meticulous implant handling, avoidance of a contaminated operative field, and perioperative use of antibiotics are the backbone of a successful alloplastic facial augmentation.

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5 Treatment of Facial Aging—Minimally Invasive Surgical Procedures

Obaid Chaudhry, Ira Savetsky, and Alan Matarasso

Introduction

Signs of senescence are often most apparent in the face and are a frequent concern of patients. Consequently, it is not surprising that patients' desires for facial rejuvenation remain popular requests. In order to achieve an optimal result, a comprehensive approach to diagnosis and management of facial aging is utilized. This includes assessment of the various areas of the face including the brow, periorbital, midface, and neck, as well as the layers of deep tissue (superficial musculoaponeurotic system, or SMAS), subcutaneous fat, and skin.

Traditionally, it was believed that more invasive procedures would produce the best and longest lasting results. Although this concept may be true to an extent, many would argue that the invasive coronal brow techniques and complicated, "risky" deep plane facelifts provided no significant difference relative to less-invasive surgical approaches, which did not confer the increased risks associated with the former [1]. Nevertheless, substantial improvement is derived from more traditional facelifts (with some form of SMAS manipulation), neck lifts, brow lifts (subcutaneous vs. endobrow techniques), and blepharoplasty.

As with other forms of medical technology, plastic surgery has continued to evolve over the last decade. According to the 2018 American Society of Plastic Surgeons national survey, approximately 17.7 million cosmetic procedures were performed, which was up 2% from the previous year [2]. Out of these, 15.9 million procedures were minimally invasive, which was also up 2% from 2017. Compared to 2014, where 13.9 million procedures were nonsurgical, there has been a steady, substantial increase in minimally invasive surgeries [3]. Human nature is such that patients prefer dramatic results with the less-invasive approaches, and with minimal downtime. This has led a shift in treatment algorithms, where plastic surgeons are testing the limits with minimally invasive techniques to satisfy the demands of the patients who desire results that are dramatic and efficient. In this chapter, we will discuss the process of facial aging and the minimally invasive approaches that may be used to aid in facial rejuvenation.

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Patient Evaluation

A comprehensive, systematic approach to evaluating the patient should be utilized. This can be from the top down or vice versa, all the while dividing the face in thirds. Furthermore, one should realize that with facial aging, there are three major areas to be addressed: the surface skin, volume/fat atrophy, and deep tissue (SMAS) ptosis. The neck may also have platysmal laxity/bands and supraplatysmal/subplatysmal fatty tissue that may need intervention. Other specialized concerns, such as buccal fat, should be inspected, and removal may be warranted, depending on the patient's desires and anatomy.

The patient's anatomic findings should be reviewed along with the patient's desires regarding downtime, invasiveness, cost, and risk. As long as the patient is aware of the limitations of a lesser invasive procedure, then performing a minimalistic procedure is acceptable, despite their being alternative, longer-lasting solutions that result in more downtime. Nevertheless, all options should be presented, with the pros and cons emphasized, and then a mutual solution is agreed upon by both the patient and surgeon.

Facial Rejuvenation Techniques

Facial rejuvenation can be considered from the perspective of surgery, minimally invasive procedures, or nonsurgical methods. These procedures can be used alone or in conjunction with each other. When considering minimally invasive surgical techniques in facial rejuvenation, we can consider three major categories: liposuction of the neck and jowls, submentalplasty with liposuction, and short-scar facelift. Other minimally invasive facial rejuvenation techniques, such as a lateral subcutaneous brow lift for brow ptosis, and buccal fat removal for a full face, will be discussed briefly.

Neck

When neck laxity exists, the surgeon must assess a few key factors [4] (Table 5.1). These include degree of subplatysmal versus supraplatysmal fat, platysmal bands, severity of skin laxity and quality, submandibular gland enlargement/ptosis, and presence or absence of jowls. The decision on the ideal treatment plan depends on a few key factors [4] (Table 5.2). In the presence of mild-to-moderate skin laxity with supraplatysmal fat only, neck liposuction with multiple cannulas includes 2.4 and 1.8 mm Mercedes cannulas, as well as spatulated type cannulas. These will provide significant benefit via fat reduction and skin retraction [4, 5]. Furthermore, if jowls are present, these can be reduced via liposuction as well. Stab wound incisions are made near the base of the earlobe and in the submental region. The procedure can be done under systemic or local anesthesia, depending on the patient's health status and desires. The presence of severe skin laxity will likely benefit from a full neck lift; however, modest improvement may be with liposuction only [4–6] (Fig. 5.1a–f). It must be stressed that

Table 5.1 Related components to correct neck aging

Submandibular glands
Jowls
Marionette lines
Hypertrophic earlobes
Microgenia
Buccal lipodystrophy
Larynx[a]
Masseter muscle hypertrophy
Parotid gland enlargement

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[a]Potentially addressed in conjunction with neck surgery

Table 5.2 Decision analysis and patient education in treating soft tissue components in the aging neck

Fat	Muscle[a]	Skin	Treatment
+	No laxity	Adequate	Liposuction
+	+	Adequate	Submentalplasty
+/–	+	+	Neck lift[b]

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These components (fat, muscle, and skin) represent a framework for analyzing a range of neck deformities

[a]Visible or lax medial border platysma bands (submentalplasty) muscle treatments include resection, plication (Eiffel Tower), or incising

[b]Within neck lift, it often includes submentalplasty

Fig. 5.1 (**a**–**c**) A 41-year-old female shown preoperatively with moderate neck laxity. Neck liposuction only was performed under general anesthesia. (**d**–**f**) Postoperative results at 10 weeks show significant improvement of the neck with significant skin contraction. Neck liposuction can produce dramatic results in certain patients

Fig. 5.1 (continued)

the surgeon and patient must come to an understanding of the limitations of neck liposuction, and it may not fully address severe neck laxity. As long as the patient is aware, educated, and content with moderate improvement, this is an excellent solution for supraplatysmal fat and neck laxity.

Open platysmaplasty is considered in patients with less significant skin laxity [4, 7]. The surgeon starts with liposuction, as described above, to remove supraplatysmal fat; it also aids in creating a plane for subsequent wide skin undermining. In addition, the liposuction aids in subsequent skin contraction. After the liposuction is performed, an incision is made just posterior to the chin crease. Dissection is carried down to the cricoid and laterally. The extent of lateral dissection depends on the degree of skin laxity. Anteriorly, the subplatysmal fat, if substantial, may be melted under direct visualization with electrocautery. Care must be taken to not overresect, as this may cause a "hollowed out" anterior neck. The medial platysmal can also be addressed anteriorly and plicated in the midline, and any redundant platysmal tissue can be excised to aid in deepening the cervicomental angle (Fig. 5.2a–f).

Complications of neck liposuction may include contour irregularities, skin necrosis, pigment changes, cadaveric appearing neck (especially if there is injury to the subdermal plexus), and nerve injury (marginal mandibular nerve is at risk with liposuction of the jowls) [4, 8]; and neck lift complications include hematoma, seroma, cervical branch injury, and recurrent platysmal bands. Fluid collections should be aggressively treated to prevent contour irregularities. Nerve injuries usually resolve over 6–12 months [4].

New modalities utilizing radiofrequency-assisted liposuction (FaceTite, Inmode Aesthetic Solutions) have been described to aid in skin contraction under local anesthesia [9, 10]. This device utilizes bipolar radiofrequency to obtain

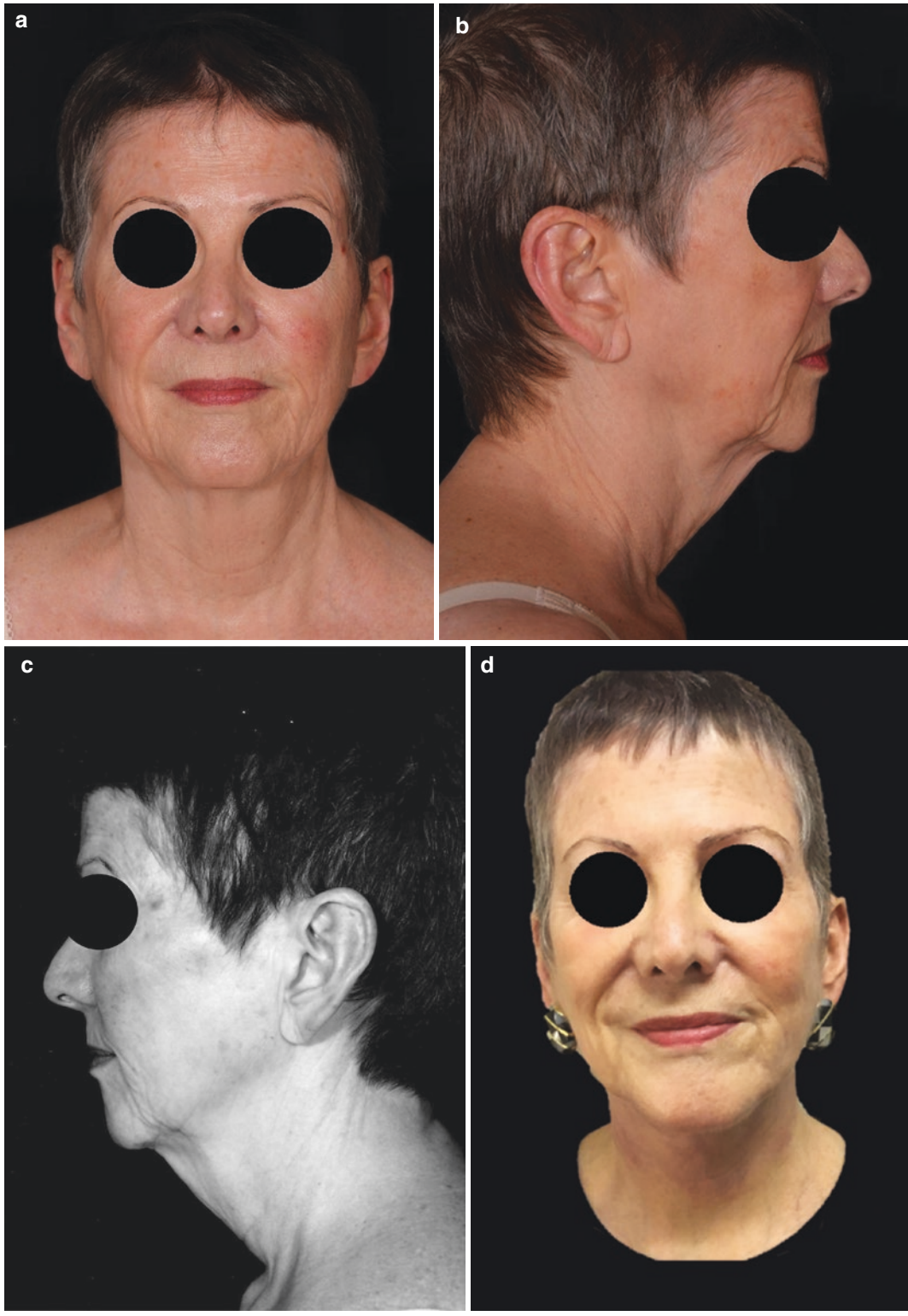

Fig. 5.2 (**a**–**c**) A 67-year-old female is shown preoperatively with significant neck laxity. A neck lift and periocular erbium laser were undertaken. (**d**–**f**) Postoperative results at 6 weeks show improvement in the patient's neck laxity

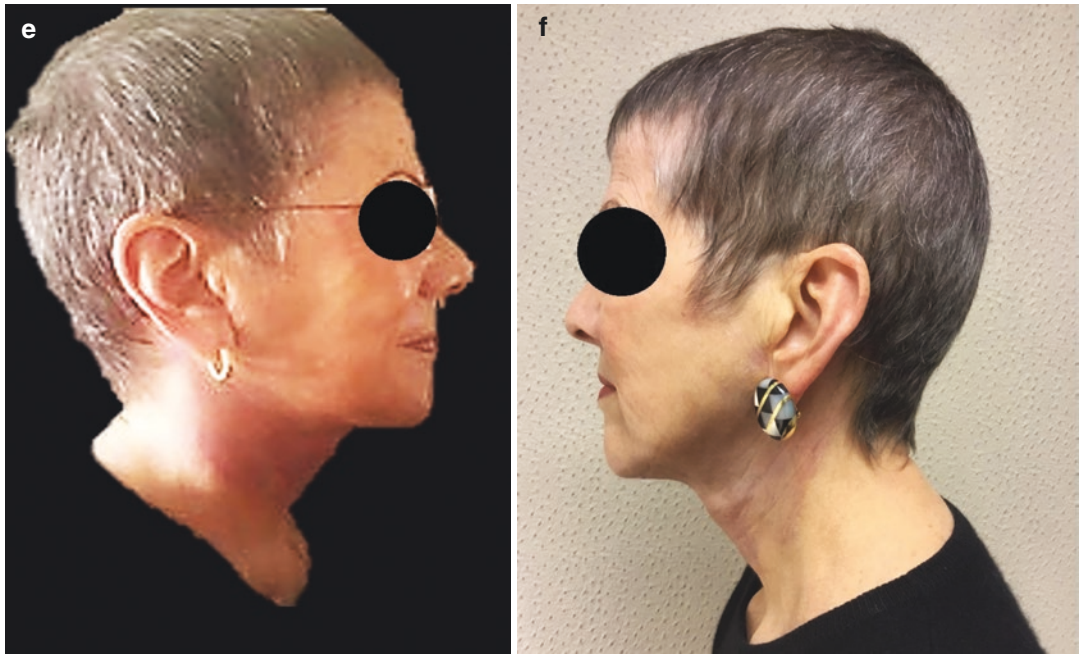

Fig. 5.2 (continued)

skin tightening by heating the reticular dermis, which leads to neocollagenesis. Radiofrequency microneedling devices, such as Morpheus8/Fractora, work in a similar manner to fractional lasers, and can be added to improve skin texture and quality [9]. The microneedling heats areas of skin and tissue, leaving islets of segments untreated to limit downtime. Radiofrequency has been shown to increase hyaluronic acid, elastin, and reticular dermal volume. Combined with the FaceTite, this modality may produce significant results in the neck without a neck lift [9, 10]. Ideal patients for these new treatment devices include the younger patients who do not desire the traditional scars and downtime, the "gap" cohort of patients who lie in a spectrum between needing an excisional procedure versus not minimal enough to rely on liposuction alone, and those patients with recurrent neck laxity who already have had full neck lifts [9]. Although the results seem promising with these new technological advances, more long-term data are required to make adequate conclusions.

Face

Common concerns from patients with regard to the face include jowls, deflation, and ptosis, as well as skin quality and rhytids. A traditional full facelift, with or without fat grafting, and either laser resurfacing or chemical peel, will produce more dramatic results at the expense of more downtime. A short scar, or 5-STAR approach (short scar transauricular rhytidectomy), however, will limit the scar burden and provide a significant result with a minimally invasive approach [7]. In a short-scar facelift, the incision does not extend in the temple or the postauricular area, the neck is addressed with liposuction, and wide skin undermining is performed along with changing the vectors of skin removal. The short scar facelift is typically reserved for patients with minimal jowling, skin and neck laxity, and those desiring a smaller scar burden. At times, the scar under the earlobe may need to be extended slightly to the postauricular area in order to prevent a standing cone, or dog ear. As with a traditional facelift, the

short-scar approach may be combined with facial fat grafting for volume deflation and laser resurfacing for deep rhytids. Advantages of a short-scar approach include a smaller, inconspicuous scar with no hair anomalies, shorter operative time, and a higher likelihood of patient approval, with the trade-off being a narrower surgical field with restricted access to the orbicularis and temporalis muscles. Potential disadvantages include transitory bunching of the skin in the postauricular and temporal areas that often flatten. It also limits the amount of pulling on the skin, which the senior author feels other modalities such as lasers, chemical peels, or radiofrequency may be more appropriate to address skin pathology [7].

The neck may be addressed with liposuction alone versus a submental incision with platysmaplasty, with or without resection. Direct fat removal is recommended in "fatty necks." In general, "fatty necks" tend to respond better to skin contraction and elasticity after fat resection than in older patients with "chicken skin" necks, where the skin lacks elasticity and tends to have inadequate collagen organization with a decreased amount of pilosebaceous components. The skin is widely undermined from each side of the sternocleidomastoid and across the jowls and malar elements to release any retaining ligaments. Superficial musculoaponeurotic system (SMAS) tightening is performed with plication, imbrication, or resection, with a vector usually conducted in a vertical fashion. After the SMAS is addressed, the skin flaps are excised and rotated in a posterior vector and closed with 5-0 nylon sutures. Drains are placed for 24–48 hours, and tissue glue may be utilized. Dressings include three layers of 4 × 8 gauze and a surginet dressing [7].

Perioral or other deep rhytids may be addressed with a chemical peel, laser, or dermabrasion. With regard to lasers, there are three factors that should be assessed prior to using lasers: wavelength, pulse duration, and fluence [3]. Wavelength is dependent on the type of laser used, while pulse duration is derived from thermal relaxation time, and signifies the length of therapy. Fluence is based on the amount of energy needed to denature the directed tissue without causing significant harm to adjacent tissue. Ideal results are attained when the intended tissue is heated quicker than the heat loss to the nearby tissue. Once a laser is utilized on the target tissue, it produces a heat injury to collagen, which stimulates collagen remodeling and synthesis. Laser resurfacing with an ablative laser tends to provide a more dramatic result, but at the expense of a longer downtime relative to other more superficial lasers. Ablative lasers may have worse adverse effects, such as hypo- or hyperpigmentation and poor scarring, which can be permanent. Intense pulse light (IPL), infrared, and pulse dye laser (PDL) are utilized for rejuvenation of the skin for different pathologies such as melisma, sun damage, acne scars, hypertrophic scars, hyperpigmentation, and facial rhytids, but results are usually moderate. Nonablative lasers induce selective thermal injury to the dermis, but spare the epidermis of significant heating. Postlaser erythema usually lasts 1–2 days for a nonablative device, rather than 7–14 days for an ablative laser. Multiple treatments may be required to obtain adequate results. A happy medium between the two categories is fractional ablative carbon dioxide and erbium lasers. These lasers improve facial rhytids, skin tone, and abnormal pigmentation, but without the prolonged downtime of a conventional ablative laser. Many devices exist that are multimodal in nature. The Inmode (Inmode Aesthetic Solutions, Lakeforest, CA) platform has numerous lasers and radiofrequency devices for skin improvement. The IPL (Lumecca) may be used for pigmentation issues, whereas skin contraction can be induced by a radiofrequency nonablative device (Forma). Forma may be used on the face and neck to improve skin quality and elasticity, whereas radiofrequency microneedling (Morpheus8, Fractora) can aid in tightening of the facial skin, and improve the fine rhytids. Depending on the severity of the rhytids and skin pathology, as well as the patient's goals with respect to downtime and efficacy, the surgeon

may offer a wide range of treatment modalities directed at the patient's specific concerns [3].

A patient with a full face who desires enhancement of their cheeks and reduction in their midface volume may be a candidate for buccal fat pad resection [11, 12]. Patients who suffer from pseudoherniation of the fat pad or buccal lipodystrophy will likely benefit from resection. Similar to orbital fat, the relative volume of this fat pad is consistent throughout weight fluctuations and gender. It may become more apparent, however, after a facelift or facial lipoplasty, and thus it is important to discuss these preoperative findings with the patient prior to any surgery. Patients can present with a small "marble shaped" mass in the cheek that has no identifiable cause.

The buccal fat pad has four parts, which are divided by Stensen's duct, and the facial nerve and vein in anterior and posterior lobes. To remove the fat pad, one may perform an intraoral or extraoral approach. The senior author prefers an intraoral approach that is performed at the beginning of the case prior to scrubbing. Likewise, the procedure has the potential to be performed under local anesthesia if done in isolation. The buccal extension and main body are resected to achieve the ideal contour, and it is important to not overresect the fat pad. Gentle pressure on the external cheek will expose the amount that is needed to be resected, and this can be done without excess traction. A Bovie and hemostatic clamp are used to resect the fat pad, and the mucosa is closed with absorbable sutures. The most common complication is overresection, whereas others, such as hematoma and nerve injury, are less likely. Buccal fat pad resection in the right candidates will produce dramatic facial contouring results with minimal downtime.

Brow

Numerous techniques have been described to correct brow aesthetics in facial rejuvenation [13, 14]. These include a coronal, anterior hairline, endoscopic, and temporal approach. In addition, different planes of dissection such as subgaleal, subperiosteal, and subcutaneous planes have been described. The senior author (A.M.) has evolved from using each of these to our current approach for eyebrow elevation utilizing a lateral subcutaneous brow lift and, when indicated, a medial subgaleal brow lift. The availability of neurotoxins, however, has changed the indications for the surgical treatment of forehead rhytids.

The senior author has performed more than 500 lateral temporal subcutaneous brow lifts for lateral brow ptosis. The senior author began utilizing a lateral temporal brow lift for lateral brow ptosis in the early 2000s, initially beginning with a subperiosteal dissection, then a biplanar; then subperiosteal and subcutaneous; and finally, for the last 15 years, solely subcutaneous. It became evident that there were no advantages to any other dissection plane other than the subcutaneous plane of dissection. The 4–5 cm × 2–2.5 cm dimensions gradually were noted to be applicable to the majority of patients. Fluid collections occurred in less than 1–2% of cases, and fibrin sealant was introduced in an attempt to reduce this. Numerous skin closure methods resulted in settling on bidirectional barbed suture skin closure. There have been no cases of asymmetry, pruritus, or infection. Overall, there was a high degree of patient satisfaction reported for all those who underwent this procedure (Figs. 5.3, 5.4a, b, and 5.5).

Fig. 5.3 A 65-year-old female before and 3 weeks after a facelift, lateral subcutaneous brow lift, and bilateral upper and lower blepharoplasty. Notice significant improvement in brow elevation

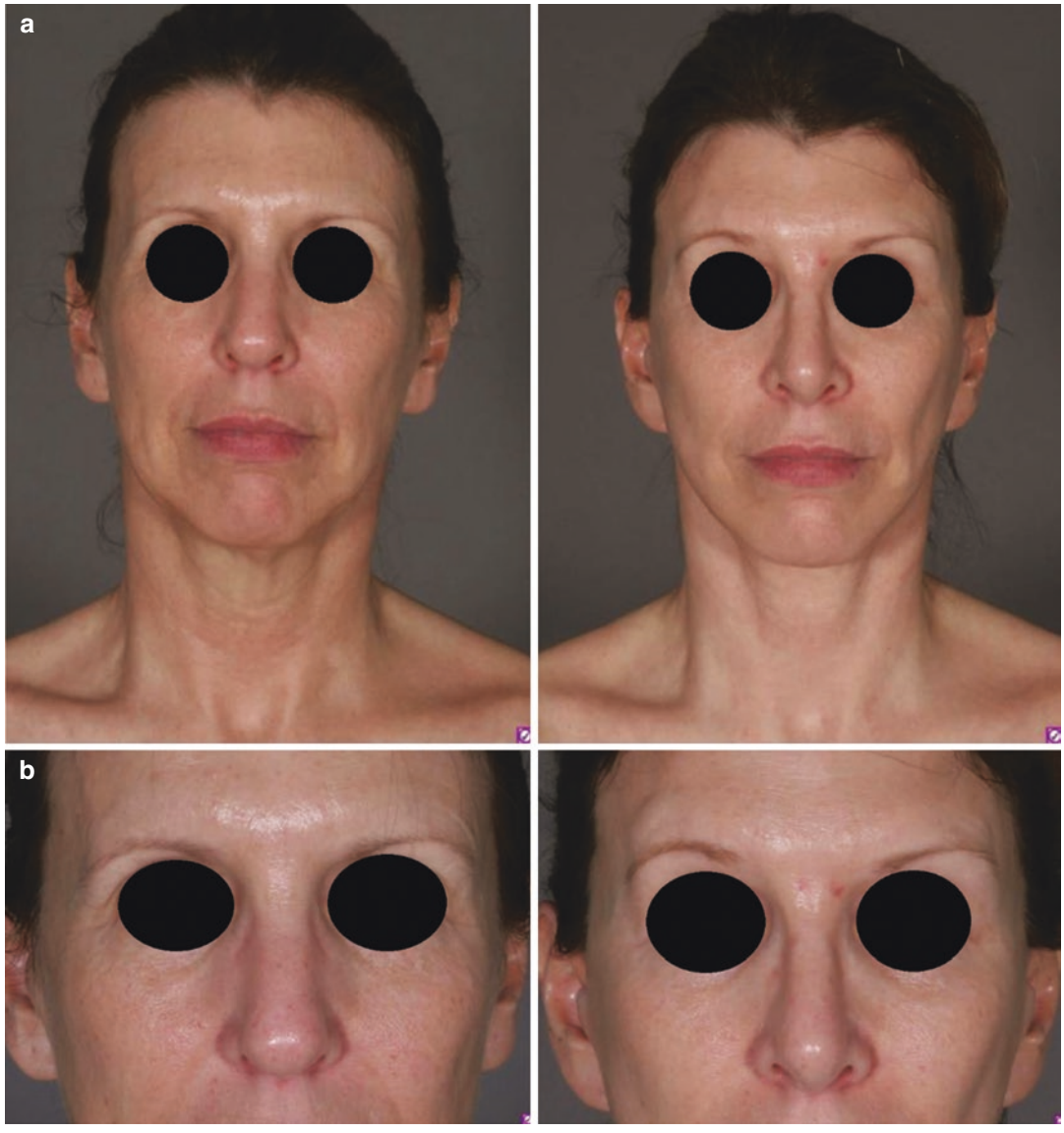

Fig. 5.4 A 58-year-old female (**a**) before, left, and 3 months after a facelift, lateral subcutaneous brow lift, rhinoplasty, and bilateral upper and lower blepharoplasty. (**b**) At 3 months, lateral brow elevation is improved and well maintained

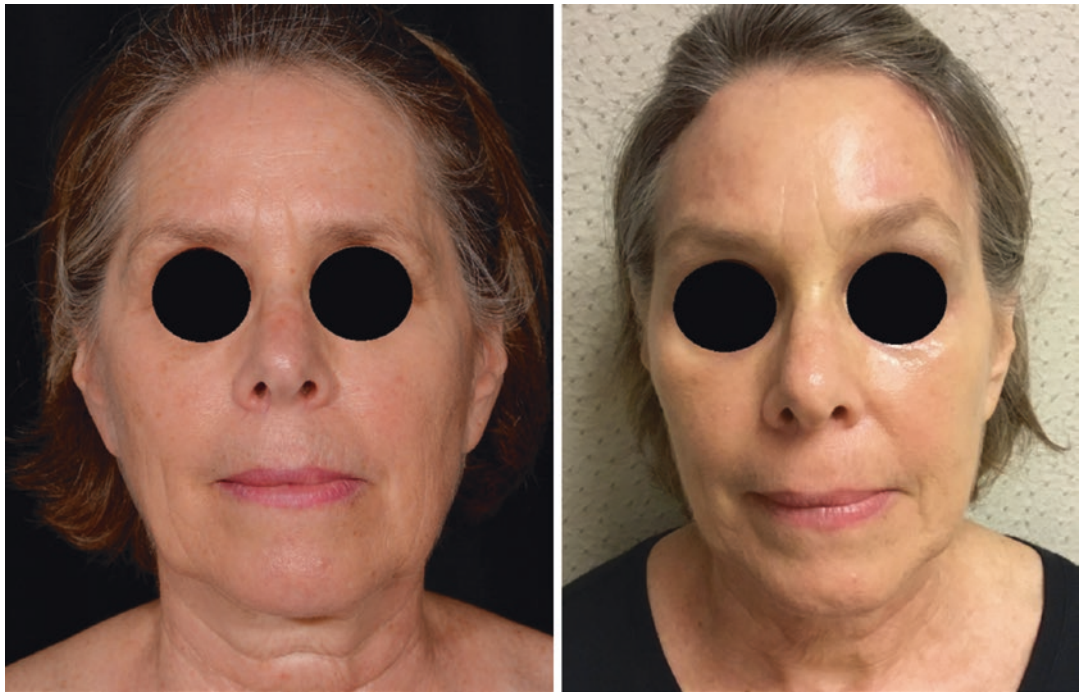

Fig. 5.5 A 62-year-old female shown before, left, and 6 weeks after a lateral subcutaneous brow lift and periocular laser treatment. Lateral brow position has dramatically improved to a more aesthetically pleasing position

Conclusion

The onus is on the surgeon to manage patient expectations and determine which treatment will be beneficial. Naturally, patients should recognize that surgical, minimally invasive surgical procedures, and nonsurgical treatments will each achieve different results. Combining them is often feasible and can be preferable to achieve optimal outcomes.

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6 Nonsurgical Facial Enhancement and Rejuvenation—Fillers, Neurotoxins, and Fat Transfers

David Kenneth Funt

Introduction

With good skincare and lifestyle habits, including daily sun protection, it is not generally until the third decade of life that the first aging-related changes to the face become apparent. It is then that expression lines start to appear, at first only with dynamic movement, but eventually also visible at rest. In the next decades, individuals may start to notice a change in face shape due to a loss and redistribution of facial fat and bone resorption. Skin also becomes more lax due to a loss of collagen and elastin as a result of genetics, sun exposure, nicotine usage, and other environmental stresses. Muscle tone increases as a result of the decreased tissue resistance of laxer tissues and lengthened resting position.

Continued research into the structural changes involved in face aging has led to the development of improved techniques for facial rejuvenation that target both soft and hard tissue facial volume loss. By combining treatments that act on multiple aspects of facial aging, physicians can address the visible signs of aging with an understanding of their underlying cause. In many patients this can be achieved with minimally invasive procedures using a combination of treatment modalities. Treatment with botulinum toxin A to remove mimetic wrinkles can also be used prophylactically in younger patients (prejuvenation) to prevent some aging changes resulting from muscular activity (i.e., brow ptosis, perioral rhytids, and down-slanting oral commissures). Dermal fillers and fat transfer can be used to restore facial volume, enhance contours, lift lax tissues, and soften rhytids and folds. Properly placed biostimulatory fillers can improve skin texture and fine rhytids, as well as improve skin quality. These treatments can be combined with light-based modalities such as intense pulsed light (IPL), lasers (CO_2, Erbium, and YAG), and energy-based modalities such as radiofrequency and ultrasonic devices.

Increasingly, individuals are searching for solutions that offer natural-looking improvements and that are affordable and with minimal downtime. However, when performing aesthetic treatments, practitioners should avoid a price-per-unit or syringe mentality. A global plan should be formulated that enhances the younger patient, and both rejuvenates and enhances the older individual. The plan must evaluate facial aesthetics from multiple angles at rest and in animation. The patient's skin quality (laxity, fine and deep rhytids, dyschromia, and actinic changes), volume, and contour must all be assessed. An "ideal" treatment plan should be discussed and the patient educated as to what treatments and procedures will yield the best results. Patients often require help in visualizing the cause for their dissatisfaction with their appearance. At that point, a patient's budget and desires can modify

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the "ideal" plan. It is certainly acceptable to not treat all concerns simultaneously, but using inadequate volume of material to treat multiple areas (because of budgetary concerns) will result in inadequate treatment of each. This will create an unhappy patient due to a combination of undercorrection and short duration treatment results. If a patient's finances do not allow for a satisfying correction, this should be explained to them and the treatment delayed. Furthermore, patients' desires may not always be achievable with a noninvasive approach, in which case appropriate surgery should be recommended. The physician's knowledge of facial anatomy, the anatomy of aging, facial aesthetics, suitability of a product for a particular indication, and injection technique are all essential for patient safety and optimal aesthetic results.

The stigma surrounding medical aesthetics continues to decrease as traditional, as well as social, media feature influencers and celebrities openly discussing their aesthetic treatments. As a result, minimally invasive aesthetic procedures have become popular with a much wider audience and there has been an increase in younger individuals seeking ways to maintain and enhance their appearance. Millenials are looking to enhance their real life as well as digital appearance and to prevent facial aging, and they offer clinicians the opportunity to forge long-term relationships.

Anatomy of Facial Aging

Facial aging involves multidimensional interactions between bone, muscle, fat, and skin that result in changes in quality, shape, and contour [1]. The craniofacial skeleton undergoes resorption, mimetic muscles increase their resting tone, fat compartments lose volume, deflate, and descend, and skin becomes thinner and less elastic, and demonstrates varying degrees of dyspigmentation and wrinkling [2, 3]. The face does not age as a homogeneous unit, but as many individual dynamic components. These changes vary based on hereditary as well as environmental factors.

The youthful face is full of well-supported facial fat, typically located overlying the masseter. This is associated with a concavity, or depression, overlying the buccal recess just anterior to the masseter [1]. The combination of fullness in the malar region and lateral cheek associated with a concavity overlying the buccal recess accounts for the angular, tapered appearance of the youthful face. This appearance has become known as the triangle of beauty. Aging faces are rectangular in their configuration, with little differential between malar highlight and midfacial fat (Fig. 6.1).

In the aging face, facial fat is situated more inferiorly, making the face appear visually longer [4]. Typically, the upper third of the face demonstrates forehead flattening, horizontal rhytids, brow ptosis, and temporal hollowing. In the middle third of the face, there is infraorbital hollowing and tear trough formation, and loss of prominence of the malar eminence, with a crescent or V-shaped deficiency extending along the maxilla to the zygoma [5]. The lower eyelid appears lengthened and distinct from the cheek. There is submalar hollowing, with deepening of the nasolabial folds. The lower one-third of the face demonstrates lengthening of the upper lip, with vermillion thinning, and decrease in projection, with flattening of the philtral columns and cupids bow [6]. Both lips develop vertical rhytids along with volume loss. The oral commissures slant downward and marionette lines form. There is loss of a distinct mandibular border, with scalloping of the jawline as jowls develop, increasing the apparent width of the lower face. The skin of the neck becomes lax, platysmal bands increase in visibility, and ringlet lines develop.

Skin Aging

The quality of our skin is a primary indicator of our age [7]. Histologic examination of aged skin demonstrates reduced numbers of fibroblasts, mast cells, and blood vessels [8]. Fibroblasts interact with collagen fibrils to maintain normal cell shape and mechanical tension [9]. In young human dermis, fibroblast binding to intact collagen fibrils allows the generation of traction forces that are necessary for maintaining normal cell size (Fig. 6.2a, b). However, in the aged dermis, fragmentation of the collagen dermal matrix

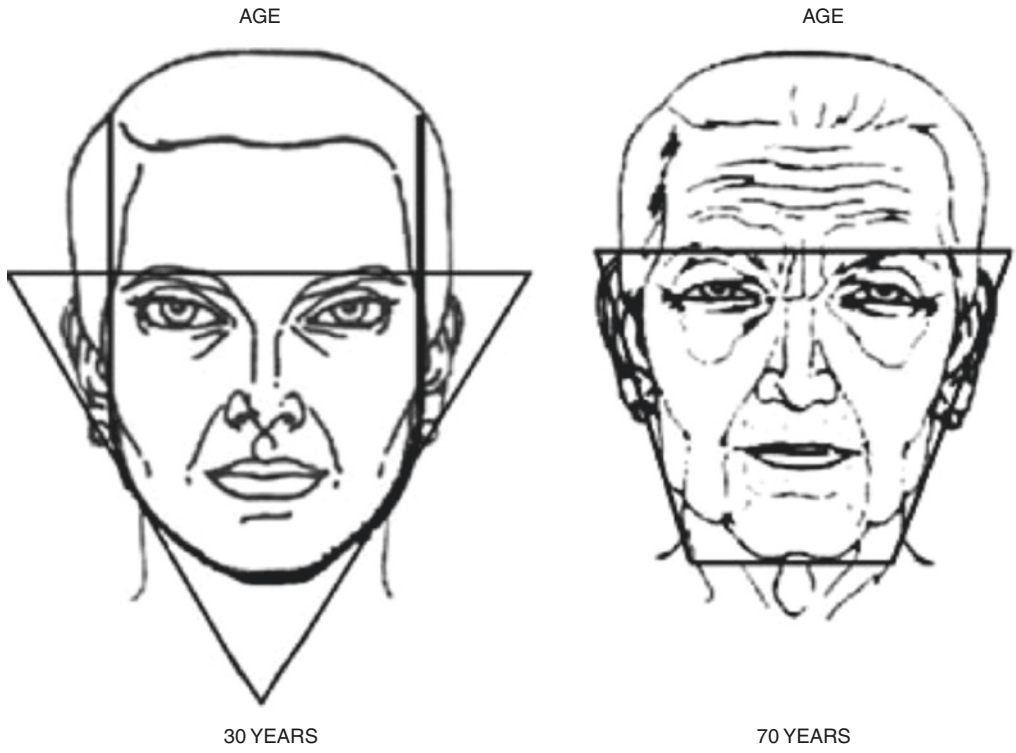


Fig. 6.1 Facial changes at various ages. (Reproduced with permission from Gonzalez-Ulloa [46])

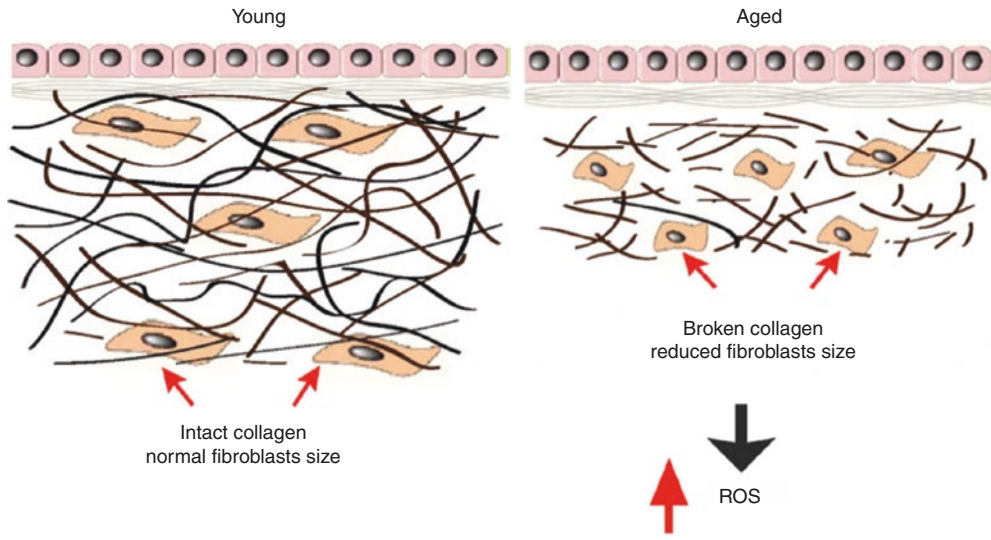
makes it harder for fibroblasts to attach. Unattached fibroblasts experience no tension stimuli, which is necessary for normal balanced collagen production. This produces a perpetuating never ending cycle of aging.

Fat in the Aging Face

A youthful face demonstrates smooth transitions between convexities and concavities, while aging causes individual fat compartments to appear as distinct entities. Rohrich and Pessa, through cadaver dissections, demonstrated that facial fat exists as well-delineated, separate compartments that have consistent relationships to each other [3]. These individual fat compartments age independently, and this is genetically predetermined. The compartments are defined by fibrous membranes that stabilize blood vessels and nerves [10]. Deep fat compartments are defined by fusion zones where fascial attachments tether muscles to bone as they cross unstable areas [11]. Folds, such as the nasolabial fold, occur at transition points between thick and thinner superficial fat compartments [12].

Changes in deep fat compartments are more causally related to the contour changes seen with aging, and are responsible for the anterior projection of the face. Fat in the superficial compartments is more metabolic and associated with a look of health and vitality. Loss of volume in these compartments makes us look tired and drawn.

Gierloff et al. used CT scans to measure midfacial fat compartments and to compare the anatomy between human cadavers of younger versus older age subjects. After examining CT scans of 12 cadaver heads, divided into two age groups (54–75 years and 75–104 years), Gierloff concluded that there was an inferior migration of the midfacial fat compartments and an inferior volume shift within the compartments during aging (Fig. 6.3) [13]. Descent and deflation of the buccal fat worsen the changes and add to the jowling.



Photoprotected or young skin		
Mechanical tension	**Procollagen synthesis**	**Collagenase levels**
Normal	Normal	Normal
Photodamaged or aged skin		
Mechanical tension	**Procollagen synthesis**	**Collagenase levels**
Low	Low	High

Fig. 6.2 (**a**, **b**) In young human or photoprotected skin dermis, intact collagen fibrils interact with cells to maintain normal cell spreading and size (**a**). In contrast, in aged or photodamaged human skin dermis (**b**), broken collagen fibrils are unable to support normal cell spreading, and this causes reduced fibroblast size. (Reproduced with permission from Tu and Quan [47]. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited)

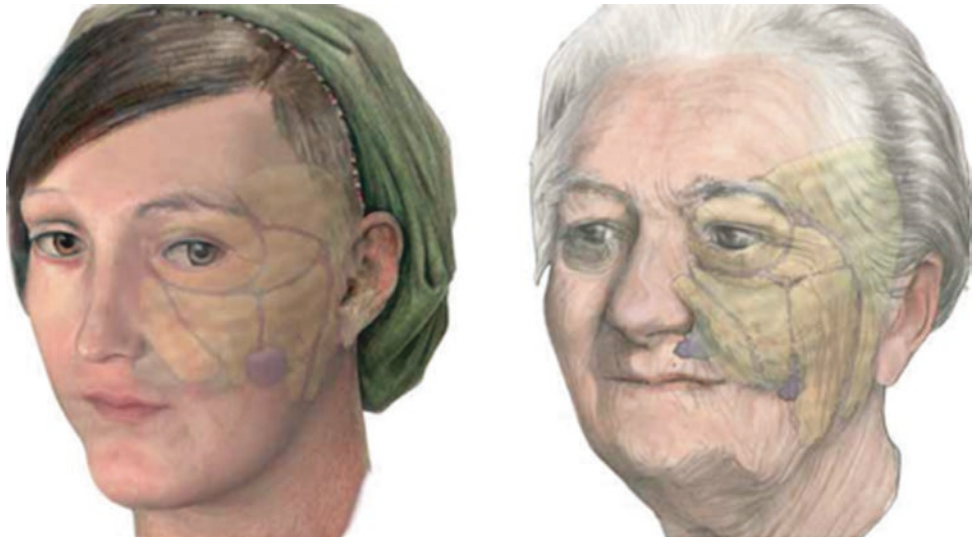


Fig. 6.3 Stylistic drawing of the facial fat compartments and their aging changes. (Reproduced with permission from Giefloff et al. [48])

Changes Resulting from Muscle Activity with Aging

Muscle tone and activity are responsible for many of the changes associated with facial aging. Over time, repeated contraction of facial mimetic muscles contributes to changes in the facial fat positioned above and below these muscles. Le Louarn, et al., showed an increased mimetic muscle tone with age, in contrast to the traditional view of increased facial muscle laxity with age causing downward displacement of tissue [14]. It is the author's opinion that this increased muscular activity against more lax aged tissue is responsible for some of the caricature-like changes that occur as we age. An example would be those affecting the mouth, where we see a widening of the smile; increased tooth show with smiling, talking, and laughing; down-slanting oral commissures; and a lengthened upper lip with a thinned vermillion. The author has also noted involuntary movement of perioral musculature at rest in aging patients, with significant aging changes in this area (more frequent in women than men). It is likely that this increased musculature activity is caused by increased muscle length as a result of bone resorption and decreased resistance offered by lax tissues.

Bone Aging

Craniofacial bony remodeling appears at age 50+ in both men and women, and also contributes to the facial aging process [15]. The facial skeleton undergoes a decrease in bone density similar to the axial skeleton, and this correlates with an overall decrease in volume and contour changes [16]. Examination of orbital aging using CT scans has shown that the width and area of the orbital aperture increases with age [17]. In both men and women, there is an increase in height of the superior orbital rim, and an increased distance to the inferior orbital rim; the orbit enlarges in a superomedial and inferolateral direction. Bony changes in the superior half of the orbit cause hooding, unmasking of medial upper eyelid fat, crow's feet, and, in combination with deepening of the glabella angle and descent of the medial brow, horizontal glabella skin creases form. In the lower half of the orbit (Fig. 6.4), tissues roll over the recessed inferior orbital rim, contributing to lid lag, descent of the lid cheek junction with infraorbital hollowing, and a deepening of the nasojugal groove [18].

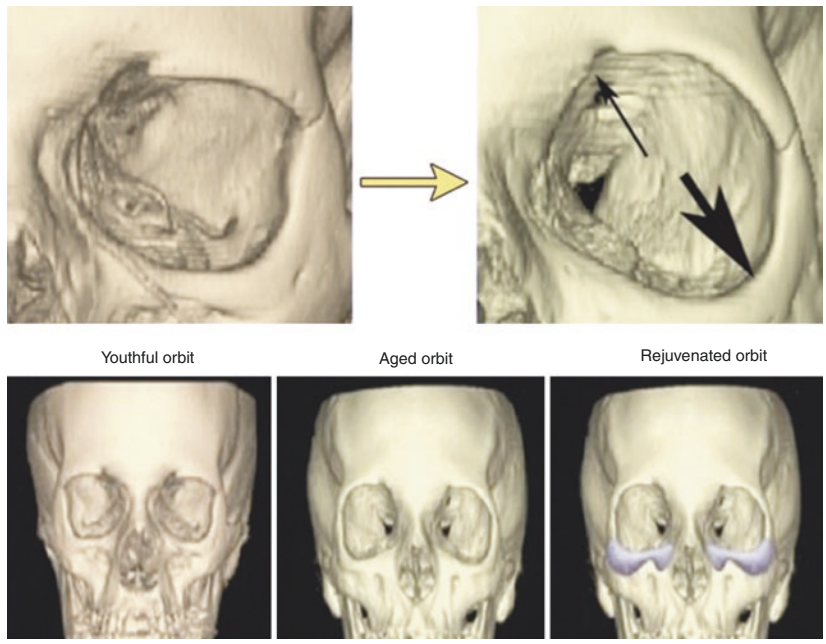


Fig. 6.4 Example images of the bony orbit of a young female subject on the left and an old female subject on the right (different subject). (Below) Changes in the orbital skeleton may be camouflaged with filler. (Reproduced with permission from Shaw et al. [18])

Such changes in the craniofacial skeleton are not limited to the orbit [19]. The midface skeleton also has a strong predisposition to resorption, particularly the maxilla, including the pyriform region of the nose. CT scans have shown an aging-related decreased midface vertical height with deepening of the glabella, pyriform, and maxillary angles [17]. Shaw and Kahn [16] found that the pyriform aperture enlarges with aging as the edges of the nasal bones recede (Fig. 6.5). Other changes in note include maxilla recession (Fig. 6.6), and loss of vertical height of the mandible, with posterior recession of the inferior alveolar ridge. As bone decreases in volume in key anatomical locations, the overlying skin and soft tissue are left with a gradually shrinking support base, contributing to the morphologic aging changes described above [18].

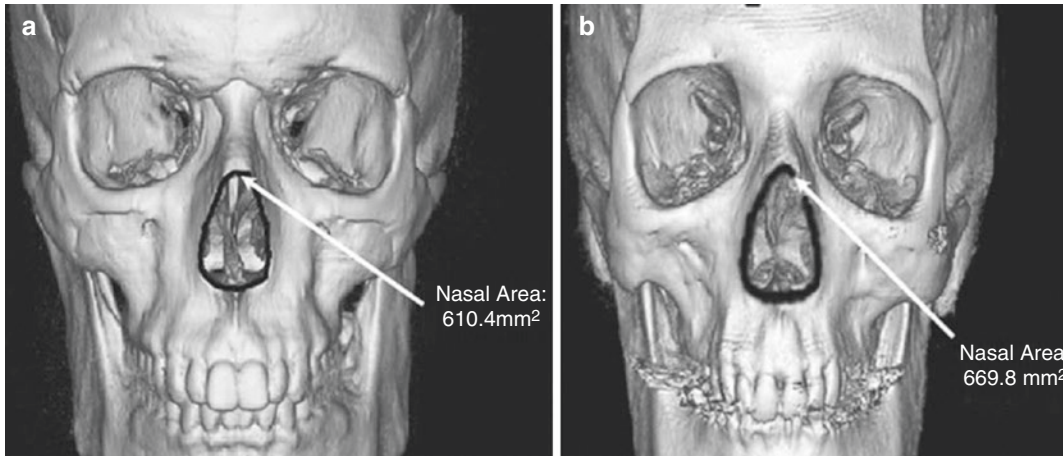


Fig. 6.5 Sample computed tomographic scans of (**a**) a male subject in the young age group and (**b**) a male subject in the old age group, with mean pyriform aperture area applied. (Reproduced with permission from Shaw and Kahn [16])

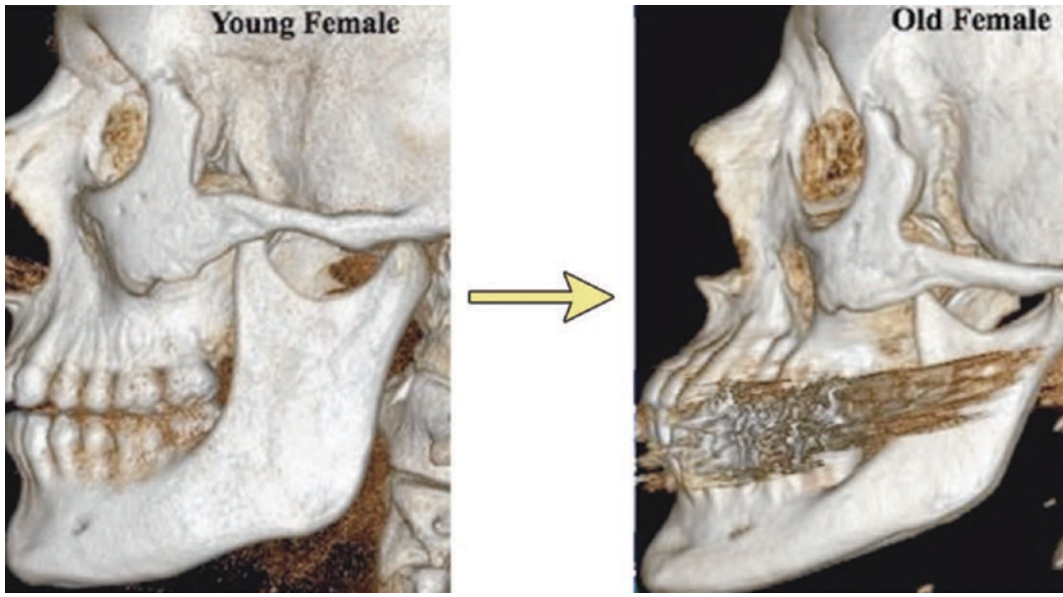


Fig. 6.6 Example images of the bony mandible of a young female subject on the left and an old female subject on the right (different subject). Decreased skeletal support of the overlying soft tissue results in morphologic aging changes. (Reproduced with permission from Shaw et al. [18])

Patient Examination and Treatment Plan

The goal of aesthetic medicine is to make clients look like the best version of themselves. Whether the patient is seeking enhancement of a particular area or considering facial rejuvenation, it is the provider's job to be able to accurately evaluate the patient's facial aesthetics and determine an appropriate individualized treatment plan. Communication skills are important at this stage, as many clients know they need something, but may not be sure exactly what. It is the clinician's role to understand the clients' needs and to formulate these into a treatment plan that all are agreed on. It is important that we as aesthetic practitioners guide our patients rather than vice versa, as their desires may not always be achievable, and their expectations must be managed tactfully and sensitively.

The practitioner can facilitate this education process by employing photographs, three-dimensional imaging, morphing software, pre- and posttreatment photographs, mirrors, and aging scales. At the time of consultation, the practitioner should determine the patient's complaints and desires. A thorough medical history as well as a history of all previous aesthetic treatments and surgery should be obtained. A careful examination should be performed from various angles, in animation as well as in repose. Asymmetries, both structural as well as those resulting from muscular action, should be noted and pointed out to the patient. A plan involving one or more treatment sessions should be formulated. Costs should be discussed, and all patient's questions should be answered. Standardized photographs should be taken to record the patient's pre- and post procedure appearance.

Regardless of the patient's age, ethnicity, or gender, the physician's role is to create a harmonious, balanced, and natural appearance. Though a patient's desires are always paramount, a physician should guide the patient because everyone has difficulty in properly assessing their own appearance. Whether invasive or noninvasive, all aesthetic procedures carry potential medical consequences and require informed consent so that patients understand the risks and benefits, and have realistic expectations of the results.

Treatment Options

Dermal Fillers

The selection of a dermal filler is dependent on the indication and site of placement, and largely determined by a product's rheological properties such as cohesivity, G prime, and viscosity, which allow physicians to match the individual properties of a dermal filler to its optimal use [20]. Fillers with high cohesivity combined with low G prime and viscosity give tissue expansion in a predominantly horizontal plane, providing tissue support with natural contours. These are a good choice for more superficial placement, and for mobile areas such as around the mouth or eyes. In contrast, fillers with high cohesivity and high G prime provide more tissue projection and expansion, and are most suited for deep volumizing. An understanding of the rheologic properties of the different fillers allows physicians to select the optimal product for the required indication. It is important to bear in mind that the rheological properties of a filler are determined in a laboratory, and they change when injected into the aqueous tissue environment. These properties serve as a method of comparison of the filler materials.

The anticipated duration of correction is another factor that must be considered. In addition to the hyaluronic acid (HA) fillers, other frequently used options include poly-L-lactic acid (PLLA; Sculptra) and calcium hydroxylapatite (CaHA; Radiesse). The clinical effect of PLLA is not related to its elasticity and viscosity at the time of injection, but depends on the neocollagenesis that it stimulates over a period of several weeks to months thereafter. CaHA has high cohesivity, G prime, and viscosity, as well as having stimulatory capacity to promote collagen synthesis.

Injection Techniques for Optimal Results and Complication Avoidance

Successful aesthetic treatment with dermal fillers is technique dependent. Adverse events and poor outcomes are a result of an interaction between the characteristics of the filler used, the patient's anatomy and physiology, and the injector's technique. Practitioners must have a thorough understanding of the characteristics of the available fillers, facial anatomy, potential adverse events and their etiology, and the techniques that can be employed to achieve the desired aesthetic enhancement.

Available injection techniques for each facial area will now be individually discussed (Table 6.1 and Fig. 6.7). Appropriate anatomic planes, danger zones, and treatment objectives and technique alternatives will be emphasized. Regardless of the technique and area of the face being treated, sterile technique must be employed. *Fillers are implant materials and must be treated as such*. Appropriate skin preparation with alcohol or chlorhexidine with alcohol (or other appropriate solution, i.e., hypochlorous acid, Technicare) should be employed, and the areas retreated if contaminated. Every time the site in the skin where the needle or cannula enters is touched by the injectors' unsterile gloves or gauze pad, the area should be wiped again with antiseptic. The needle or cannula used should be changed if no longer sterile. Never handle the needle or cannula with unsterile gloves or gauze pads. Intraoral injection technique is not recommended and will not be discussed here. If the fillers are mixed with local anesthetic, attention must be paid to avoid any contamination. Avoidance of bacterial contamination is essential to prevent not only infection but also inflammatory responses such as nodularity and granuloma formation. The presence of bacteria (not necessarily in sufficient quantity to cause a frank infection) enhances the body's ability to recognize the material as foreign and stimulate an inflammatory response.

Safety

Filler adverse events are multifactorial, representing a complex interaction between the filler characteristics, the patient's anatomy and genetics, and the technique employed. After selection of the appropriate filler, and taking a comprehensive medical and filler history (particularly to determine if the patient has experienced any previous filler reactions), the only remaining variable is the injector's technique.

Table 6.1 Dermal filler injection techniques: uses and advantages

Technique	Uses and advantages
Threading	Primarily used for line filling. Material can be placed antegrade or retrograde. When antegrade, the material is expressed as the needle or cannula is advanced. Amounts should be small 0.05 cc per thread. With retrograde product deposition, the needle or cannula is advanced in the desired plane to the distal most extent of the deposition location and material is expressed upon withdrawal. Again, amounts should be no greater than 0.05 cc per thread. The author prefers the retrograde technique because depth and location are determined prior to material deposition
Fanning	Variation on threading where multiple radial threads originate from a single skin puncture. Again the author prefers a retrograde technique. The injector should be cautioned to discontinue expressing material when coming close to the skin puncture site so that excess is not deposited at this location (can accumulate from each of the radial threads)
Depot	The needle or cannula is directed to a location and while stationary material is deposited. In most circumstances no more than 0.2 cc depot injections should be performed. This technique is not recommended unless in an avascular location such as the vermillion white roll or when directly in contact with bone
Pylon or tower technique	This is similar to threading but in a perpendicular axis. The needle or cannula pierces the skin and moves in a perpendicular direction (slightly obliquely is preferable) until in contact with bone. Material is expressed as a thread as the needle or cannula is withdrawn. Attempt to elevate the overlying tissue upon withdrawal to accommodate the filler

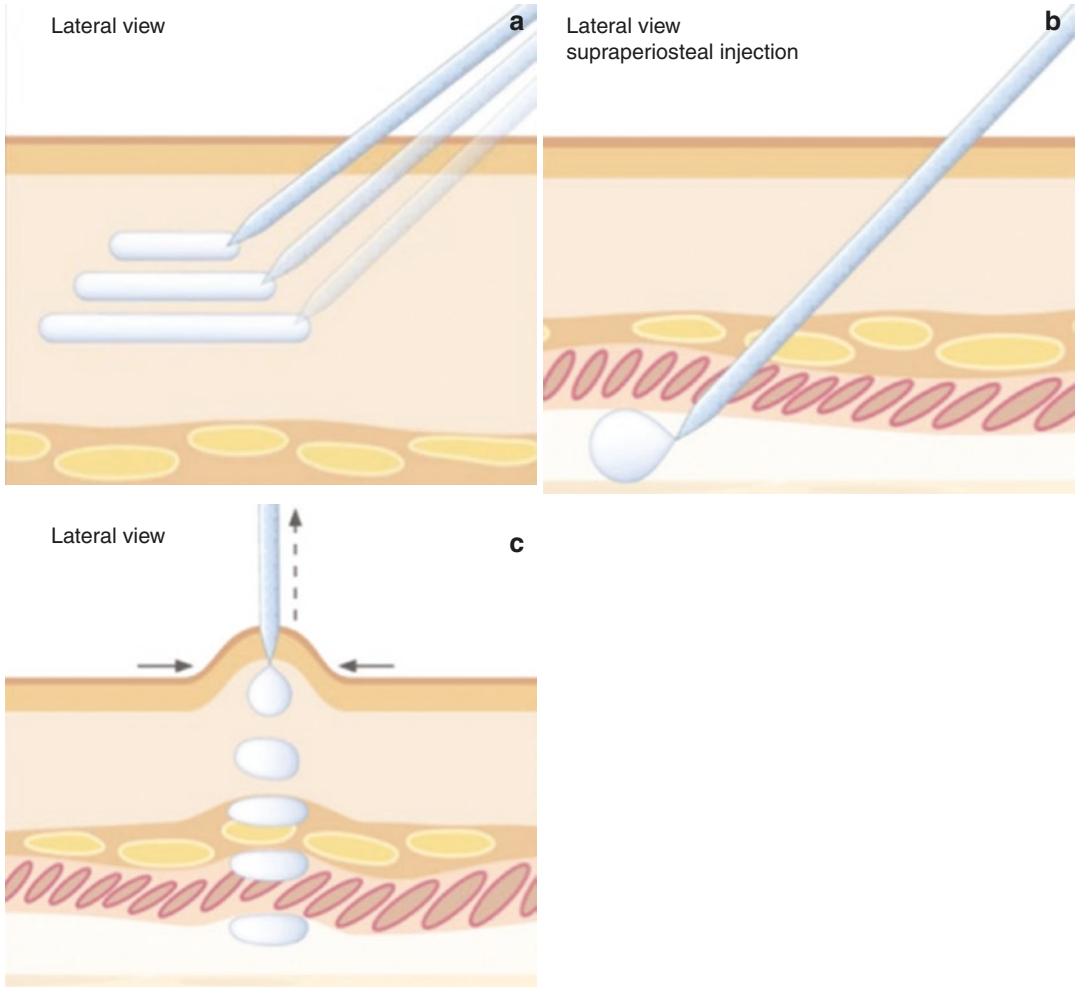


Fig. 6.7 Commonly used injection techniques: (**a**) linear threading, (**b**) depot injection, and (**c**) pylon or tower. (Reproduced with permission from Funt [49]. Copyright © 2017, © 2018 S. Karger AG, Basel)

Injectors should always use a sterile or the cleanest possible technique. Bacterial or fungal contamination can cause immediate infection, late chronic infection (biofilm), granulomas, or stimulate immune-related responses (erythema, edema, and nodules). The FDA-approved fillers are biocompatible and in most cases are not generally immune stimulators. Once bacteria are introduced, even if not in numbers sufficient to cause infection, they become immune stimulators.

Cleansing the skin and prepping (alcohol, chlorhexidine, chlorhexidine and alcohol, phenol-based solutions, etc.), and reprepping after each contamination of the treatment site (massage, molding, and intraoral contact) is essential. Injections should not be performed in areas where infection is present or in areas of traumatized tissue.

Before undertaking any aesthetic treatments, all injectors should obtain a thorough knowledge of facial anatomy, including facial bony architecture, location and action of facial musculature, location of facial sensory nerves and their sensory territories, and the vascular anatomy of the face. They should be aware of the danger zones, where intravascular filler injection resulting in emboli events are more likely. That being said, the face is highly vascular, so injectors should be vigilant at all locations.

Injectors should always use injection techniques that mitigate against neural or vascular injury. When using a needle, material should be injected directly on bone when volumizing in areas where bony support is present. The needle should enter at an oblique angle, as this avoids the unlikely event that the bevel remains in a vessel, and also limits filler moving retrograde following the path of the needle. If not in direct contact with bone, the needle should always be in motion with gentle plunger pressure. Have the path of the needle or cannula oblique or perpendicular to the path of major vessels rather than parallel to them. These measures reduce the volume of material that would be intraluminally injected into any vessel the needle or cannula penetrates. Though the facial vasculature varies significantly in its horizontal positioning, and there are numerous collateral vessels in addition to the named vessels, the location of these vessels in a vertical dimension (depth) is constant. The facial vessels lie at the level of the SMAS (subcutaneous musculoaponeurotic system), so, in general, injections should always be within the dermis, or in the immediate subdermal plane when fanning and threading. Depot injections should occur only in avascular locations, in contact with bone, within the dermis, or the vermillion white roll (when using a needle). When using a cannula, the injector must be aware that cannula thinner than 25 gauge can pierce a vessel as easily as a needle, and one should not have a false sense of security. The cannula should also be kept moving, and material injected at the bony level or superficially, as described above. Larger-gauge cannulae (25 g or thicker) reduce the risk of intravascular injection, but the injector sacrifices some ability to control its position, particularly in fibrotic previously injected areas.

Injectors should avoid injecting highly cross-linked, high G prime HA fillers into the dermis, as these can be more reactive. PLLA and CaHA should not be injected intradermally either. At this injection depth, PLLA will have an increased nodule rate and CaHA particles may be visible.

Malar edema can best be avoided by a careful examination of the patient to look for a history of intermittent malar edema. Material is best placed at the periosteal level and should be in small aliquots. The G prime of the filler used is less important than the patient's degree of preexisting lymphatic compromise. In the area of the infraorbital hollow, an HA filler should be employed so that hyaluronidase may be used to break down the filler should malar edema occur, but a highly hydrophilic HA material should be avoided in this region.

Finally, injections into the facial musculature should be avoided, as these are more prone to granuloma formation.

Facial Volumizing and Contouring

When thinking about facial soft tissues, think of them as a mask that is stapled to the face by a series of ligamentous attachments that lie in a vertical line in the midportion of each side of the face. As a result of the orientation and location of these attachments, filler placement medial to this line volumizes, while material placed laterally volumizes, but also lifts the tissue, correcting the descent of the tissue caused by aging [21]. These attachments are at the temporal crest, the zygomaticocutaneous ligament, and the masseteric and mandibular ligaments.

Forehead

The objectives of treating the forehead include softening horizontal forehead rhytids that are not corrected with neurotoxin treatments; volumizing a skeletonized forehead; correcting volume deficiency resultant from bone resorption; altering the frontal angle and shape; and achieving brow elevation, particularly laterally.

The forehead area may suffer from lines that are present at rest, or volume depletion, both of which can be treated with dermal filler. Fine lines can be treated by superficial injection within the dermis with a low G prime filler (sequential, superficial depot injection can be employed). Deeper volumizing is performed by placing the tip of a needle or cannula on the periosteum (in the subgaleal space) and placing small depot aliquots or threads of filler. Placement of retrograde

threads with a moving cannula is the author's preferred technique.

Danger zones The supratrochlear and supraorbital arteries travel beneath and within the corrugator and frontalis muscles, arising from their bony foramina, and become increasingly superficial as they course through the frontalis muscle until they become subcutaneous. Due to the lack of collateral blood supply (axial pattern) in this area, dermal filler occlusion of these arterial vessels is likely to lead to ischemia, followed by necrosis.

Tips and Tricks
To create space for injection of filler, the forehead tissues can first be elevated by injection of dilute lidocaine or saline. This technique allows for a more uniform placement of filler in patients who have adherence of their soft tissue to the frontal bone. It also reduces the potential for intravascular injection, as the vessels are lifted anteriorly prior to the filler injection.

Brows

The lateral brow can be elevated by placing a high G prime filler at the periosteal level using a needle or cannula. Material can be deposited as threads or depots (0.1–0.2 cc each). When injecting using a depot technique with a needle, the tip should be in contact with bone at an oblique angle, walking the tip along the bone without withdrawing it from the skin. When using a cannula, start laterally and keep the cannula in contact with the bone. Stop injections when the midpoint of the brow is reached, to avoid vessel and nerve injury. Molding to smoothness is essential. Care should be taken not to inject too much volume, as this can masculinize a female face by creating a prominent supraorbital ridge. Treating the temporal hollows will also elevate the lateral brow (see below).

Danger zones They include the supratrochlear and supraorbital neurovascular bundles, branches of the superficial temporal artery, and the frontal branch of the facial nerve.

Temporal Hollows

In the temporal hollows, preperiosteal injection is performed with a needle in contact with bone using a depot technique, and is the author's preference for the medial hollow near the temporal crest. Begin at a point 1 cm superior to the orbital rim and 1.5 cm lateral to the temporal crest. Here, the volumes are 0.2–0.5 cc. Injections are directed medially. Additional injections superior to this point can be placed in a similar fashion. Alternatively, using a threading technique with a cannula, filler can be placed in the loose areola plane above the deep temporal fascia. This plane can be entered either medially or laterally, but it is easier to find the proper plane from a lateral entry point. This is the author's preferred technique for correction of the more lateral temporal hollow using a high G prime, high-viscosity filler. Remember that the temporal fossa is a large bony concavity containing the temporalis muscle. It is shallowest at the edge near the temporal crest and is most efficiently filled in this area. Lifting of the facial tissues can also be accomplished by placing filler subdermally with a needle or cannula posterior to the superficial temporal artery, beneath the sideburn and temporal hairline, using a needle or cannula (cannula is preferable).

Danger zones They include the superficial temporal artery, zygomaticotemporal artery, and the deep temporal arteries. Avoidance is by injecting at the periosteal level with the needle tip in contact with bone when injecting using a depot technique, or retrograde threads with a moving cannula in the relatively avascular plane on the surface of the deep temporal fascia. The zygomaticotemporal artery is a terminal branch of the ophthalmic artery, and an embolic event here may result in blindness.

Tips and Tricks
The temporal fossa is like a shallow bowl, with the depth reducing at the edges. Less volume of filler will be required if the filler is placed preperiosteally near the temporal crest. A surprising amount of facial elevation can be accomplished by the subcutaneous injection mentioned above when combined with lateral cheek augmentation along the zygoma. Injection of the temporal hollow generally also results in some degree of lateral brow elevation.

Infraorbital Hollows and Tear Trough

Infraorbital hollow refers to the curvilinear depression under the eyes that comprises the tear trough, as well as the nasojugal fold and palpebromalar groove [22]. Anatomically, it is related to the underlying bony anatomy, amount of fat present, and the tethering effect of the orbitomalar and zygomaticofacial ligaments. With thin skin overlying bone, little to no subcutaneous fat, and thin orbicularis oculi muscle in this region, the infraorbital hollow can be a challenging region to treat. Injections should be performed at the preperiosteal level with the needle tip in contact with bone when injecting using a depot technique, or using retrograde threads at the same plane with a moving needle or cannula. Depot technique is preferred by the author. A lower G prime HA filler is recommended by many injectors (though the author uses more longer-lasting fillers in this location to decrease the need for frequent injections). It should be placed in small volume aliquots to reduce the incidence of visible material and malar edema, and to allow correction with hyaluronidase if a complication occurs. In stubborn cases, the skin can be subcised, and subcutaneous microdroplets placed to correct a persistent skin crease.

Danger zones The skin and soft tissue in this area are thin and translucent and, as a result, HA fillers can cause a bluish hue (Tyndall effect), and other materials can be visible. All materials can cause contour irregularity in this area. The tear trough area is highly vascular, and the injector must inject atraumatically to reduce the risk of bleeding and bruising. The infraorbital neurovascular bundle lies in a vertical line with the lateral limbus of the iris and between 5 and 7 mm inferior to the inferior orbital rim. Embolic events are not uncommon here, and injury to the infraorbital nerve can result in dysesthesia or anesthesia of the ipsilateral cheek and upper lip. Injection in this area can also result in lymphatic compression and malar edema. The incidence of malar edema can be reduced by proper patient selection (patients must be examined for any degree of pre-existing lymphatic compromise), by limiting filler volume, and by placing filler material deep to the malar septum (orbitomalar ligament) directly on periosteum [23]. Malar edema is likely more related to the patient's pre-existing degree of lymphatic compromise and the degree of correction more than the physical qualities of the injectate. It can occur with a low G prime filler if the patient has existing lymphatic compromise.

Tips and Tricks
The author strongly recommends only using an HA product in this area so that if lymphatic compromise occurs, it can be corrected with the use of hyaluronidase, and the malar edema resolved within 24 hours.

Cheeks

Midfacial volume restoration and contour enhancement using fillers are performed laterally to medially, with smaller volumes used medially in the infraorbital hollow. If the nasolabial folds are to be treated, the midface should be volumized first, as expansion of the midfacial soft tissue will in itself soften the nasolabial folds and reduce filler volume required for their correction. Using a high G prime filler, injections are performed at the level of the periosteum using a depot technique employing small aliquots of material. Alternatively,

a tower technique with a needle or threading preperiosteally with a cannula can be employed. As mentioned earlier, the injections placed laterally cause lifting and contour change, and medially more of a contour change.

Danger zones They include the infraorbital neurovascular bundle, zygomaticofacial artery, and angular artery. An embolic event into the zygomaticofacial artery, or angular artery (anastomosis with the dorsal nasal artery), can result in blindness.

Nasolabial Folds

This area is most frequently treated using immediate subdermal and subcutaneous threads placed with antegrade or retrograde fanning using a needle or cannula. In patients who have deep folds with significant amounts of soft tissue lateral to the fold, correction is best achieved by augmentation of the maxilla at the pyriform aperture. These patients have significant recession of the maxilla and will achieve the most natural correction employing this technique. This is accomplished using a high G prime filler placed directly on bone using a depot technique.

Tips and Tricks

Look at the cheek globally—infraorbital hollow, medial cheek, malar eminence, zygomatic arch, temporal hollow, and submalar hollow. Fill the area of greatest deficiency first, then proportionately fill all other areas. The high point of the cheek is more lateral on a female than a male. Have the treatment extend laterally along the zygomatic arch as far as necessary (to the hairline in many cases) to achieve smooth blending. Increasing the projection of the malar eminence will make deficiencies in the temporal hollow and submalar hollow appear more apparent. These areas may need to be treated in order to create a harmonious and natural-appearing volumization (otherwise the effect is to create a skeleton-like effect). Whether performing enhancement or rejuvenation, the objective is not to create "apple" cheeks, but rather increase midfacial projection and definition. There is no other area of the face that when corrected gives the patient a more rejuvenated, refreshed appearance than the midface. Patients frequently present with an oblique line of volume deficiency extending from the tear trough inferiorly. This line is parallel with the nasolabial fold and the marionette line. These three lines draw the eye downward and outward, creating a tired, older appearance. When corrected, an appearance of vitality is restored to the face.

Danger zones The facial artery runs at the level of the SMAS in this area, and vascular-adverse events are common here. In the area of the pyriform aperture, the facial artery is large and tortuous and no material should be deposited unless the needle is directly in contact with bone or immediately subdermal or intradermal. When using a threading technique in the treatment of the nasolabial fold, avoid deeper subcutaneous injections in the fat layer and keep the needle moving at all times. Cannula injections should also be placed as threads in the subdermal plane while moving.

Tips and Tricks

The nasolabial fold is a correction site frequently requested by patients, but is a site that, when corrected, usually does not make the patient look significantly better. In almost all cases, midface correction will serve the patient better (and will cause effacement of the nasolabial fold). When observing a patient with nasolabial folds, the viewer anticipates seeing a trough medial to the fold. When excessively obliterated, it can result in an unnatural appearance. The injector must guide the patient, and not the other way around.

Submalar Hollow

This area is frequently neglected by injectors when treating the midface. It is technically more difficult to achieve smooth and natural results here because there is no underlying bony support and the surface area to correct is large. The area is best treated by superficial subcutaneous threads placed retrograde using either a needle or cannula. A high G prime HA filler or CaHA mixed with lidocaine will yield good results. Use of a stimulatory filler such as PLLA is also ideal here. The material is placed in linear threads in the superficial subcutaneous plane and then molded to smoothness. Replacement of the lost superficial fat pad in this zone in the aging patient can make them look softer and healthier.

Danger zones The transverse facial artery, a branch of the superficial temporal artery, and the superficial temporal artery should be avoided by injection in the proper plane. The superficial lobe of the parotid gland lies deep to the injection plane and should also be avoided, as intraglandular injection can result in parotitis.

Tips and Tricks
In patients with deficiency in this area, augmentation of the malar eminence and zygoma will exaggerate the deficit and make the patient look skeletonized. The same is true for temporal hollowing. In patients with volume deficits in these two areas, augmentation in the malar area should be conservative unless adequate submalar and temporal blending is performed at the same time.

Perioral Area and Lips

Aging of the perioral region involves lengthening of the upper lip, down slanting of the oral commissures, loss of prominence of the vermillion border, vertical lip rhytids, marionette lines, and volume loss anterior to the jowl. In addition to rejuvenation, the lips are also an area where enhancement is frequently requested. Patients also present for correction of lip asymmetry.

Vertical Lip and Fine Lines

These are best treated using a depot, blanching technique with a low G prime HA filler formulated for fine lines. Placement of the needle is almost parallel to the skin, to ensure superficial, intradermal placement of material, using a 30-gauge needle and entering either perpendicular or axially to the lines [24]. Multiple punctures are injected very close to each other, leading to deposition of tiny aliquots that are visible for a short period under the skin. Postinjection molding of the area should be completed to ensure a smooth final correction. This technique is the same as that which is employed for fine lines in other facial areas.

Upper and Lower Lips

Augmentation of the vermillion white roll is accomplished using a lower G prime filler that is injected using a needle inserted almost parallel to the white roll. If the needle is properly placed into the potential space of the vermillion white roll, the filler will track along the roll, extending across that hemi lip. Alternatively, a needle or cannula can be placed along the vermillion white roll and then filler injected retrograde. The tubercles of the lip are then augmented using a threading or depot technique in the submucosal plane. The injector should be intimately familiar with the anatomy of the lips and capable of balancing the three tubercles of the upper lip and the two of the lower lip (Fig. 6.8). The location of the labial arteries is quite variable, and placement of filler is safest in the immediate submucosal plane rather than within the muscle. The philtral columns also need to be recreated and/or augmented. This is most expeditiously accomplished by pinching the column

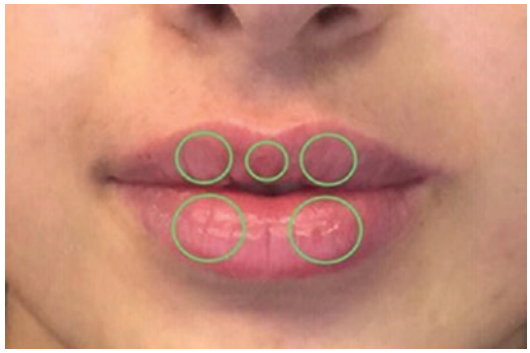


Fig. 6.8 The tubercles of the upper and lower lips are natural areas of prominence that should be enhanced during lip augmentation

between the nondominant thumb and index finger and threading the needle from the vermillion white roll superiorly toward the nasal sill. Product is then deposited as the needle is withdrawn (retrograde). Do not exaggerate the philtral columns in older patients, as it creates an artificial appearance.

Danger zones Injection procedures in the perioral area can lead to reactivation of herpes virus infections. If the individual has a history of cold sores, consider prophylactic treatment with valacyclovir (500 mg BID for 2–3 days) to be started immediately prior to injection. The use of particulate fillers in highly mobile areas with concentric muscular action such as the lips should be avoided as early-onset, noninflammatory nodules may develop. The injector should also be aware that intramuscular injection of any product increases the likelihood of foreign body granuloma development.

The superior and inferior labial arteries travel within the body of the lips in the orbicularis oris muscle and are at risk for embolization. Their location with the muscle is very unpredictable. Deep injection into the lip should, therefore, be avoided, and the location of the arteries understood by all injectors [25, 26]. A moving needle or cannula in the submucosal plane is less likely to result in a significant vascular event.

Tips and Tricks

Injectors should remember the balance between the upper and lower lip: upper lip 40% and lower lip 60% (1:1.6 in Caucasians, 1:1 in Africans, and in-between in Asians). The lower lip should be either slightly protruding or vertically in line with the upper lip. Make sure that the lip volumes enhance and are in harmony with the patient's other facial features, and are age appropriate. Most middle-aged and elderly patients appear cartoonish with excessive lip volume. The delicate architecture of the lip must be respected, and lips should never have a sausage-like appearance. Neuromodulators can greatly enhance the results of lip enhancement by pouting the lip edge and reducing the appearance of vertical lip rhytids. The closer the neurotoxin is placed to the lip vermillion, the more the pout. Vertical rhytids are treated with toxin placed more superiorly. Toxin will also extend the clinical correction achieved with fillers by reducing lip motion. Not all patients tolerate that reduction of motion, however.

Marionette Lines and Oral Commissures

The injector should visualize the marionette lines and prejowl sulcus as a single unit. When visualized in this way, the opposing triangles of deficiency can be appreciated (Fig. 6.9). The upper triangle should be treated with a fanning approach in the subdermal and immediate subcutaneous plane. The initiation points should be immediately lateral to the oral commissure, followed by injections beginning within the marionette line inferiorly, allowing for crosshatching to occur. The lower triangle of the marionette line that forms in the area of the prejowl sulcus may be treated with preperiosteal depot injections, as well as a fanning technique in the immediate subcutaneous plane.

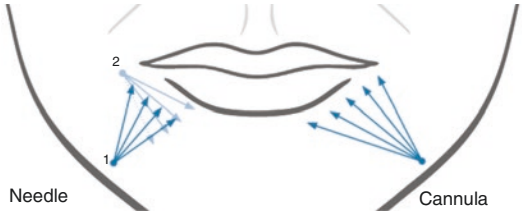


Fig. 6.9 Injection technique for marionette lines

Down-slanting oral commissures represent the uppermost part of the marionette lines. Down-slanting oral commissures can be treated by placing a small aliquot of filler within the vermillion white roll at the commissure. This injection is accomplished by placing the needle perpendicular to the commissure and injecting filler in the immediate submucosal plane. Alternatively, filler can be placed using linear threads beginning immediately lateral to the oral commissure and immediately adjacent to the upper and lower lip vermillion white rolls. The material increases tissue structure and supports and elevates the commissure.

Danger zones When treating the inferior aspect of the marionette lines and the prejowl sulcus, bruising is frequently seen. The mental and inferior labial arteries must be avoided by keeping material subdermal or preperiosteal.

Tips and Tricks
Evaluate the amount of lax skin lateral to the marionette line. If significant redundant skin is present, then this skin can be driven laterally by the filler, causing the appearance of a pouch lateral to the fold. Lifting from the temple and lateral cheek should accompany the marionette line correction in these cases.

Jawline

With aging, the jawline loses its definition and becomes scalloped as jowls develop. Individuals will frequently be aesthetically enhanced by increasing their jawline definition. Younger individuals may present with genetic weakness and asymmetries of the mandible and overlying soft tissue. When injecting over the parotid gland, immediate subcutaneous threading using a fanning technique will yield good results. A needle or cannula can be employed. These injections can be continued superiorly into the preauricular area, following the ascending ramus of the mandible. The angle is sharper in a male (90–100°) and more obtuse (110–120°) in a female. The mandibular angle is most easily defined using a depot injection on bone (0.2–0.3 cc). These techniques can be used to either widen or define the jawline, and/or to camouflage the jowl and restore the more youthful distinction between the jawline and neck. Alternatively, all injections can be placed directly on bone using a depot technique. Laterally, this will involve passing through the masseter and parotid gland. The material will be compressed by the masseter muscle, resulting in less longevity of the correction. The author uses subcutaneous placement of mixed CaHA (0.8 cc Lidocaine with 1.5 cc CaHA) with a single on-bone depot injection at the angle of the mandible. Avoid aggressive molding if using the depot technique to prevent material tracking back into the parotid gland.

Danger zones In the preauricular area, the superficial temporal artery is at risk for embolization, as is the facial artery, as it crosses the mandibular border immediately anterior to the masseter muscle. As mentioned above, injections should not be placed within the parotid gland. Parotitis from intraglandular injection has occurred and can be longstanding.

Tips and Tricks
These techniques restore the distinction between the cheek and neck and camouflage the jowl in the aging patient, and can greatly enhance the appearance of select younger patients. Widening the lateral jaw along the mandibular angle is particularly useful in the male patient. Threads should be of small volume placed evenly to avoid irregularity of the jawline contour.

Chin

Filler injections can be used to reduce chin ptosis, as well as to enhance chin projection. Injections are placed either at the periosteal level using a depot technique, or alternatively, immediate subcutaneous threading can be employed, beginning laterally on either side of the chin. Female chins should not be overly squared, and injections should be primarily confined to the area between two vertical lines originating from the alar cheek junction. In men, a square chin masculinizes the face, and is defined by two vertical lines extending inferiorly from the pupil.

Danger zones The mental neurovascular bundle lies approximately 1 cm superior to the mandibular border, in line with the canine tooth. The artery is at risk for embolic events, and injury to the mental nerve will result in anesthesia or dysesthesias of the lower lip. The vessels lie in the muscular layer.

Tips and Tricks
This procedure can be used in conjunction with a nonsurgical rhinoplasty to reduce the appearance of an overprojecting nose. It can also be used to show a patient the effect that a permanent surgically placed implant would have.

Nonsurgical Rhinoplasty

It is the author's opinion that this area should be reserved for the experienced injector with a thorough knowledge of anatomy. This area and the glabella are true danger zones, with a significant risk of vascular events with the potential for blindness and soft tissue loss.

This procedure, which can be exceptionally gratifying for injector and patient, can be used to mask the appearance of a dorsal hump, reduce the apparent nasal width by increasing height, elevate a drooping tip by increasing tip projection, correct asymmetries, and correct postsurgical deformities. Injections are placed at the skeletal level with a needle or cannula. Vascularity is again in the SMAS layer. Surgeons visualize the filler as they would visualize the placement of cartilage grafts. Insertion points are in the midline on the nasal dorsum and lateral to the midline in the tip. Injectors should use an HA filler and make sure hyaluronidase (at least 1200 units) is immediately available.

Danger zones They include the lateral nasal, dorsal nasal, columella, and angular arteries. Skin necrosis and blindness can result from embolic events. Injectors must have hyaluronidase (minimum 1200 units) present and watch for blanching.

Improving Skin Texture and Tone

Stimulatory fillers such as CaHA and PLLA can be used not only for volume restoration but also to improve the texture and tone of the skin. Small aliquots of HA filler injected into large areas of the dermis have been shown to induce neocollagenesis and enhance skin turgor and firmness, leading to skin that looks smoother and refreshed [27]. Perhaps the most studied product in this field is CaHA, which when mixed with lidocaine or saline and injected superficially in the subdermal plane appears to promote dermal remodeling through stimulation of collagen and elastin [28–30]. Guidelines have recently been published for this novel off-label use of CaHA for biostimulation in the face and body [31]. This application extends beyond the face to areas such as the neck, décolleté, medial upper arms, elbows, knees, supraumbilical skin, and neck. The ideal amount of lidocaine or saline added to the product is still unknown, but when using CaHA a 2:1 or 3:1 ratio is common. It is known that the greater the amount of CaHA particles present, the greater the amount of fibroblastic response. In most circumstances the author employs a 1:1 dilution using 1.5 cc of CaHA per 10 cm^2.

Tips and Tricks

When deciding on the dilution, the author recommends setting objectives as to how much volumizing versus stimulating effect is required, with less dilutent resulting in more volumizing, and more dilutent resulting in less volumizing and a more stimulatory effect. These techniques are also the basis for using PLLA and CaHA for buttock augmentation and cellulite correction (with subcision).

Aesthetic Applications of Botulinum Neurotoxins

It is now well established and common to prevent and treat unwanted expression lines for people from their third decade (even younger for preventative maintenance) with botulinum neurotoxins. Years of experience and use in therapeutics and aesthetics have proven their efficacy and the safety, and a number of consensus recommendations on the use of botulinum toxin for aesthetic indications have been published [32, 33], including in combination with other treatment modalities [34].

Careful patient evaluation and setting realistic expectations at the time of consultation are essential for patient satisfaction and success with botulinum toxin treatments. A number of patient characteristics and anatomical features help define their suitability for botulinum neurotoxin injection. The positions, strength, and insertion points of the facial muscles can be determined by inspecting them at rest, by observing their movements while the patient makes varying facial expressions, and by palpating them. Signs for areas of stronger contraction include greater dynamic movement, deeper lines, and larger apparent mass during use. Patients with dynamic rhytids show the most dramatic improvements from botulinum toxin injection, and are ideal candidates for treatment. Deep static lines due to loss of skin elasticity, environmental injury, and aging are not responsive to botulinum toxin injection. When evaluating a patient, look for specific clinical findings such as preexisting brow ptosis, lid ptosis, pattern of frontalis muscle motion, brow shape, poor lower lid tone, and malar edema. Evaluation should be done with the patient at rest and then in animation, smiling, then squinting, frowning, elevating their eyebrows, and pursing their lips. Asymmetries should be noted and pointed out to the patient prior to treatment. The aim of treatment is to eliminate lines when the patient is at rest, but to leave the ability for some movement, and minimal wrinkling, when the patient is animated or actively expressing emotion.

Tips and Tricks

When treating the periorbital area, the goal is to change the balance of muscular action toward brow elevation by eliminating the depressor and opposer muscle actions, while maintaining a degree of frontalis strength. This will reduce the effect of gravity on the brow and reduce the development of brow ptosis. If one fully paralyzes the frontalis muscle, the only brow elevator, the preventative maintenance aspect of this treatment is diminished.

Until recently, three products were approved for aesthetic use in Western markets: onabotulinumtoxin A (Botox®/Vistabel®; Allergan Inc., Irvine, CA), abobotulinumtoxin A (Dysport®/Azzalure®; Ipsen, Paris, France), and incobotulinumtoxin A (Xeomin®/Bocouture®; Merz Pharmaceuticals GmbH, Frankfurt, Germany). In 2019, these were joined by prabotulinumtoxin A (Jeuveau®; Evolus Inc., Santa Barbara, CA), which received FDA approval in February 2019 for the temporary improvement in the appearance of moderate-to-severe glabellar lines associated with corrugator and/or procerus muscle activity in adults. There are also a number of BoNT products approved in Asian countries. Licensed indications for use vary, and are specific for each country.

Glabellar Frown Lines

Vertical lines between the eyebrows seen at maximum frown are a result of contraction of the paired corrugator supercilii, and horizontal lines are the result of contraction of the procerus muscle. Injection points are determined by observing muscle contraction both visually and by palpation. The body of the corrugator supercilii is deep to the frontalis muscle, becoming more superficial at its tail; depth of injection needs to be tailored accordingly. The injection points should be to the medial end of the corrugator just lateral to the frown line, and then 1–1.5 cm lateral to this toward the end of the corrugator muscle, 1 cm above the bony orbital rim. Injection into the medial part is deep, as the muscle originates from the bone. The lateral injection point, verified by muscular contraction, is more superficial. During injection, the nondominant hand delineates the location of the superior orbital rim. The fifth injection point is into the belly of the procerus muscle. The optimal injection pattern will be achieved by adapting the injection points to the individual anatomy of the patient.

Tips and Tricks

To avoid medial brow ptosis, when treating the corrugator muscle, do not inject greater than 1 cm superior to the super orbital rim, to avoid excessive paralysis of the frontalis muscle that overlies the corrugator muscle. Drift of the neurotoxin onto the levator palpebrae muscle with subsequent ptosis is prevented by the superior orbital rim retaining ligament that lies 2–3 mm superior to the orbital rim. Do not inject inferior to the ligament, and avoid injection in the axis of the supraorbital neurovascular bundle, as this pierces the ligament and provides a pathway for toxin to drift inferiorly. It is the author's experience that duration of effect is directly related to the dosage administered, with inadequate dosing leading to short duration of action.

Horizontal Forehead Lines

Horizontal forehead lines are produced by contraction of the muscle fibers of the frontalis, which elevates the eyebrows. Rhytids created by muscles are always perpendicular to the axis of their fibers. By weakening the middle and upper portions of the frontalis, the horizontal lines can be softened or eliminated. To avoid worsening of existing brow ptosis, the muscle fibers of the frontalis must remain functional 1.5–2.5 cm above the brow (the maximal excursion of frontalis muscle is in its inferior portion, superiorly it becomes increasingly aponeurotic).

When treating horizontal forehead lines, the number of injection sites and dose should be tailored to the patient. The degree of existing brow ptosis is the limiting factor in reduction of forehead rhytids. Some patients may have many rows of fine forehead wrinkles, whereas others may have one or two rows of deeply set lines. The number and dosage of injections will, therefore, depend on many factors, including the number and depth of the wrinkles; the size, shape, and strength of the muscle; and the height, width, and shape of the forehead [35]. This has led to the development of techniques such as Grid 21 (developed for use with incobotulinumtoxin A), which allows treatment to be tailored to the individual. Grid 21 identifies the individual's unique structural and functional anatomy to determine the optimal protocol for predictable eyebrow shaping and forehead treatment. The technique identifies anatomically defined vertical lines based on the midpupillary line, inner and outer canthus, and medial facial line (Fig. 6.10). The horizontal lines of the grid are functionally defined, starting with the lowest horizontal frown line. The intersection of these lines defines 21 potential injection points, each of which has a different influence on the individual treatment outcome. Dosing is determined by the force of the muscle at each injection point.

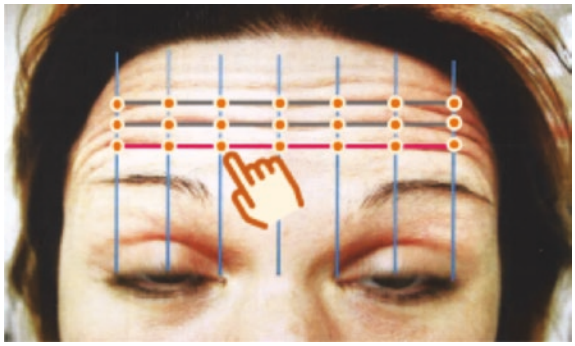
Tips and Tricks

It is essential that the injector observe the pretreatment brow shape, excursion, and asymmetry. Individuals who naturally peak their lateral brows will have this exaggerated by the neurotoxin, and so a 2 U injection of toxin should be placed at the second forehead crease in the axis of maximal peaking to prevent this. Patients who have no medial brow excursion are more likely to have medial brow ptosis after treating the corrugators, and medial frontalis injections should be avoided. Injections should be placed in the superficial subcutaneous plane.

Using a 30–33G needle (0.2–0.3 mm diameter and 13 mm long), the standard dose is 1–4 U intradermally divided among five or six (or more) injection points; up to 20 U (10 average) may be required in some patients. Do not overinject the frontalis muscle. When in doubt, inject less and bring the patient back in 7–10 days for reassessment. Always assess for existing brow ptosis, and avoid injecting the inferior frontalis muscle in these patients.

Lateral Periorbital Lines

The orbicularis oculi is a circular muscle that functions to close the eyelids. Its fibers are vertically oriented at its medial and lateral-most aspects, where they also function as depressors of the eyebrow. Medially, at the level of the eyebrow, this portion of the orbicularis is known as the depressor supercilii. Laterally, contraction of the vertically orientated fibers produces lateral periorbital lines or crow's feet. The application of neurotoxin to the lateral portion of the orbicularis oculi muscle will, therefore, prevent or soften the appearance of these lines. Using a 30–33G needle (0.2–0.3 mm diameter and 13 mm long), the recommended dose is 12 U per side. The first injection should be at the level of the inferior aspect of the brow, approximately 1 cm lateral to the orbital rim to avoid unwanted treatment of the muscles of ocular motion, which are inside the orbital rim, resulting in the side effect of diplopia. Two further injections are placed at 1 cm intervals inferior to the first, following the curve of the lateral orbital rim. As the periorbital skin is thin, the needle must be inserted at an acute angle to the skin and the botulinum toxin will diffuse to the underlying muscle.



Dosing: depending on the force of the muscle (0)–1–2–3 units

- 3 units: high pressure needed to predict paralyzing effect on very high muscle force
- 2 units: medium pressure needed to predict paralyzing effect on intermediate muscle force
- 1 units: little pressure needed to predict paralyzing effect on muscle force
- 0: no muscle force paipated – no toxin needed

Rule of thumb for th Grid21 dosing:
It is as simple as (0)–1–2–3!

Fig. 6.10 Grid 21 forehead injection protocol for use with incobotulinumtoxin A

Tips and Tricks

Injections into the orbicularis oculi muscle can be extended into the lower eyelid to reduce rhytids. If injections are performed too close to the lid margin, this may result in scleral show, or even ectropion, in patients with lax lid tone. If patients have pseudoherniated fat in their lower eyelids or malar edema, these may become worse, as the tone in the orbicularis oculi is diminished. If injections are placed too inferiorly, the smile can be affected by inadvertent paralysis of the zygomaticus major and /or minor muscles.

Nasal Rhytides

Nasal rhytides (bunny lines) may form on the lateral and dorsal aspects of the nose as a result of contraction of the levator labii superioris alaeque nasi muscle (not the nasalis, as is commonly thought, since the nasalis compresses the nasal sidewalls). The levator can be treated with two injection points, one into each side of the nose where the bunny lines are found. When treating this area, it is important to avoid excessive injection into the levator labii superioris, as chemodenervation of this muscle will cause the upper lip to droop (as in treatment of a gummy smile).

Gummy Smile

A common cause of a gummy smile is hyperfunctional upper lip elevator muscles (levator labii superioris alaeque nasi, levator labii superioris, levator anguli oris, and zygomaticus minor), which result in excessive upper lip retraction during smiling. It is often associated with deep nasolabial folds. Injection is achieved with 2–3 U at the pyriform aperture 1 cm lateral to the alar crease. Correction should be conservative so as not to create an unnatural appearance where the central upper lip is too low in smiling.

Perioral Lines

For the treatment of perioral lines, the target muscle is the orbicularis oris. Unbalanced dosing or asymmetrical injection can lead to dyskinetic movement when pursing the lips. The sites of injection will depend on the wrinkle pattern, but in the upper lip the central aspect should be avoided to maintain the integrity of the Cupid's bow, and should be at least 1 cm medial to the oral commissure (nine muscles attach at the oral commissure). Injections placed close to the vermillion border will evert the lip edge, while those placed overlying the midportion of the rhytids are required for wrinkle reduction. Typical doses are 1–2.5 U per injection site divided across four to six sites. Injections are performed using a 30–33G needle (0.2–0.3 mm diameter and 13 mm long) and should be superficial, subcutaneous, and symmetrical.

Tips and Tricks

This is an area where dyskinetic movement occurs when injections are not evenly spaced, resulting in toxin "hotspots." The author places his toxin injections using a retrograde threading technique, which distributes toxin evenly over the treatment area, eliminating this problem.

It is essential that you discuss the weakness that results from these injections with the patient, as those with the deepest rhytids, who purse the lips the most, are most disturbed by inability to make this motion.

Masseter Hypertrophy

The masseter muscle is one of the four principal muscles of mastication and also plays an important role in facial aesthetics [36]. In women, enlarged masseter muscles can have a negative aesthetic impact, creating a square masculine face shape. They may also create facial asymmetry if hypertrophy is unilateral. Thinning of the

masseter gives the lower face a slimmer appearance. Masseter hypertrophy is more prevalent in the Asian population. Patients with bruxism and temporomandibular joint pain benefit greatly from this treatment.

Injecting neurotoxin into the masseter muscles is an effective nonsurgical approach to reduce lower face width [37]. The masseter muscle is located by asking the patient to clench their jaw. A line is then drawn from the corner of the lip to the tragus, and injections are kept below this line. Using a 30–33G needle (0.2–0.3 mm diameter and 13 mm long), 10–25 U per side is injected low into the masseter just above the mandible, with three to five injection sites. Doses can be increased to 25–50 U if required, but before reinjecting the patient, an interval of at least 8 weeks is recommended for the bulk of the muscle to diminish. Injections should be both superficial and deep to effect both the superficial and deep portions of the masseter.

Platysmal Bands

The platysma is a thin sheet of muscle originating from the fascia over the clavicle, and inserting into the inferior border of the anterior mandible. It distends the skin of the neck and pulls it downward and laterally, lowering the corners of the lower acting in synergy with the depressor anguli oris. The vertical bands become more evident with age as a result of repeated action, resulting in hypertrophy, skin laxity, and thinning of subcutaneous tissue.

The patient should be asked to tense their platysma by trying to expose their lower teeth to expose the bands. Treatment is typically with three to six injection points along each band, spaced 1–2 cm apart, with a total dose of no more than 15–25 U per band. The number of injection points will depend on the length and prominence of the band. Treatment of the platysma along the jawline can sharpen the mandibular definition (known as Nefertiti lift). Injecting over a prominent submandibular gland can increase its prominence (but injecting into the gland can shrink it).

Tips and Tricks

Ringlet lines in the neck can be treated by subcutaneous injection into the platysma, but frequently need filler for more complete correction. Avoid injections into the sternocleidomastoid, as the patient will have difficulty elevating their head, and if excessive dosing or deep injection is placed medially, dysphagia can result due to relaxation of the strap muscles. Injections are placed in the superficial subcutaneous plane.

Oral Commissures

The depressor anguli oris (DAO) depresses the oral commissure while frowning. The oral commissure can be elevated by injecting into the belly of the muscle at least 1 cm lateral and 1.5 cm inferior to the oral commissure (5 U). Alternatively, follow the nasolabial fold inferiorly and inject 5 U into the muscle immediately superior to the mandibular border. Injection into the depressor labii inferioris, which underlies the medial aspect of the DAO, must be avoided.

Chin

Chin dimpling when lips are pressed together is caused by the action of the mentalis muscle. This can be corrected with a single 5 U injection of neurotoxin in the midline of the chin at the mandibular border. Alternatively, two 2.5 U paramedian injections can be employed, but injections into the depressor labii inferioris must be avoided.

Tips and Tricks

As patients age, the muscles become hypertonic, most likely due to bone resorption and lack of resistance from the lax tissue they elevate. The author has noted a significant

degree of spastic motion at rest in patients with significant perioral aging (more common in females). Injection of neurotoxin into the orbicularis oris, mentalis, and depressor anguli oris can result in a change in the pattern of their movement, slowing further motion-induced aging changes.

Other Aesthetic Toxin Uses

- Excessive sweating (hyperhidrosis) in axilla, palms, soles, or any other area such as the forehead.
- Improvement of skin texture when placed in solution with HA and delivered via microneedling (Aquagold) or direct injection of dosages at multiple sites.
- Reduction of acne.

Aesthetic Applications of Fat Transfer

Fat transfer or fat grafting is the transfer of adipocytes from one part of the body to another to act as a natural filler. It involves the removal of varying amounts of fat from a location such as the abdomen, thighs, or inside of the knee, which may or may not be processed before being reinjected into the face. Fat transfer is increasingly being used for rejuvenation or augmentation of the face [36, 37]. It has the benefits of being biocompatible, feels like normal tissue when touched and, once vascularized, offers a long-term, even permanent, treatment approach.

In addition to lipofilling, fat transfer has also been gaining attention for its observed regenerative properties and overall skin texture improvement [38, 39]. The introduction of microstraining techniques to filter, purify, and reduce particle size has also resulted in the development of nanofat transfer techniques [40]. Although the exact mechanism of action is unclear, these are thought to work by the action of adipose tissue-derived stem cells and growth factors upregulating collagen and elastin production [40]. Indications for the use of nanofat include intradermal injection for the correction of fine wrinkles, intra- and subdermal injection for the correction of sun damage, and intra- and subdermal injection for the correction of skin discoloration (e.g., in the lower eyelid) [40]. The treatment is particularly effective when combined with a microneedling technique [40, 41].

Any area successfully treated with injectable dermal fillers is potentially treatable with fat transfer, but it is particularly valuable in areas where volume loss is most pronounced, such as around the cheeks and jawline. How the fat is harvested, processed, injected, and the condition of the tissues receiving the fat will all influence the amounts needed and eventual fat retention. Patients who are smokers or previous smokers and patients who have undergone previous noninvasive radiofrequency and ultrasonic skin tightening procedures are likely to have compromised subdermal microcirculation and microlymphatic vessels, and as such are not optimal candidates for this procedure. Autologous fat transfer can play a crucial role in facial rejuvenation as a stand-alone procedure or in combination with traditional facial rejuvenation procedures.

Tissue volume loss after fat transfer can lead to unpredictable outcomes and is influenced by the techniques used for tissue harvest and processing. Gentle harvesting of adipose tissue is important for maintenance of viable fat cells and tissue volume. For small volumes, the use of a closed-syringe lipoaspiration system featuring disposable microcannulas offers a safe and effective means of harvesting adipose tissue in a suspension form.

It is essential to remove the nonviable, proinflammatory components of lipoaspirate, including blood cells, damaged tissue, and debris, before reimplantation. The three most common preparation techniques described in the literature are gravity separation alone (which requires the least user handling and manipulation), centrifugation, and washing of the fat graft prior to gravity separation [42]. For larger volumes, the author uses the Revolve® system (LifeCell; Bridgewater, NJ), which incorporates the harvesting, filtering, and washing steps into a single unit, thus simplifying fat processing [43].

The most common complication of fat transfer is the unpredictable degree of transplant resorption. This occurs because a proportion of the injected adipocytes suffer hypoxic injury before revascularization can occur, resulting in necrosis of the cells, resorption of their lipid content, and loss of volume at the injection site [44]. The practitioner should, therefore, explain to the patient that there is likely to be some loss of volume and a repeat procedure or touch-up may be required. Visibility is another adverse effect, and is most common in the lips and periocular area. If a patient has been previously treated with an HA dermal filler, it is important to wait until all filler material has been resorbed prior to grafting, as filled areas will not be able to provide the graft with vascular ingrowth, and the area will have future volume loss as the filler is metabolized.

It has been suggested that neurotoxin injection may enhance survival of adipocytes after fat transfer in the face. It is hypothesized that the temporary muscle immobilization provided by the neurotoxin preserves graft viability [45].

Infections are rare, but some practitioners prescribe patients with a 1-week course of antibiotics postoperatively as a precaution. As with all injectables, there is the risk of embolism if the fat is injected directly into a vessel. The use of a blunt-tipped cannula and injecting only when withdrawing the cannula reduce the risk of such complications.

Conclusion

The tissue layers into which dermal fillers, botulinum neurotoxin, and fat transfer are placed, and the manner in which they are injected, can have a significant effect on treatment results. Based on anatomical landmarks, specific treatment techniques are suggested to reduce the risk of serious adverse events and optimize patient outcomes, with the aim of making patients look the best version of themselves.

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Rhytidectomy

7

Sarah E. Hammond and Jim M. Stuzin

Introduction

With facelifting, as with most surgical procedures, the best outcomes occur when in-depth knowledge of anatomy is combined with close attention to details. Facelifting requires a surgical method that is at once defined and delicate. While there are no actual tricks to achieving good postoperative results in facelifting, a detailed knowledge of facial anatomy combined with meticulous slow dissection will always give superior results. The following tips can guide the plastic surgeon as they analyze the patient's anatomy, visualize the desired aesthetic destination, and rejuvenate the aging face.

Anatomy

The soft tissue anatomy of the face is at once challenging and simplified. A successful rhytidectomy begins with accurate knowledge of facial anatomy. This includes knowledge of where it is safe to manipulate that anatomy.

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- The soft tissues of the face are organized in a series of concentric layers. These layers are the skin, subcutaneous fat, superficial musculoaponeurotic system (SMAS), mimetic muscles of the face, loose areolar tissue, and parotidomasseteric fascia. This knowledge allows the surgeon to confidently dissect within one anatomical plane without fear of injury to structures within another anatomical plane.
- The SMAS layer is continuous with the superficial cervical fascia inferiorly and the galea superiorly.
- The parotidomasseteric fascia is continuous with the superficial layer of the deep cervical fascia inferiorly and the periosteum superiorly.
- Below the parotidomasseteric fascia is the plane of the facial nerve, parotid duct, and buccal fat pad.

Facial Aesthetics

The "ideal" proportions and angles of the face have long been debated and attempted to be defined. In actuality, individual perceptions of what is attractive, as well as what can be done to achieve those perceptions, must be discussed between the surgeon and the patient, so expectations are clearly set. Despite the individuality of what is deemed attractive, there are historical

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psychological reference points for what is universally pleasing to the eye [1].

- The face is evaluated for horizontal symmetry by dividing it into five vertical regions, with each region equivalent to the intercanthal distance.
- The face is evaluated for vertical symmetry by dividing it into three horizontal regions—from the hairline to the brow, from the brow to the nasolabial angle, and from the nasolabial angle to the menton.
- The lower third of the face is further divided into thirds, with the nasolabial angle to the oral commissure constituting one-third, and the oral commissure to the inferior mandibular border constituting two-thirds of the lower face.
- The level of the cervicomental angle at the hyoid bone should be 90–120 degrees.

Facial Subunits

The anterior face has a complex topography; areas of increased volume are evidenced by convexity and highlights, while areas of decreased volume result in concavity and shadows. This topography of highlights and recesses combines to give either a youthful or aged appearance.

- The midcheek area can be divided into subunits based on the underlying ligamentous anatomy.
- The lid-cheek subunit overlies the inferior orbital rim. The junction of the pretarsal and preseptal portions of the lower lid is known as the infratarsal groove, and is typically not apparent in the youthful face. When the lid-cheek junction is "high" and located above the inferior orbital rim, the resultant pretarsal bulge is considered youthful.
- The malar subunit overlies the zygomatic body and is an important area for volume in the midface. The highlighted convexity over the malar eminence with submalar concavity over the buccal recess suggests youthfulness [2].
- The nasolabial subunit overlies the anterior maxilla.
- The preparotid subunit is a dense fusion of ligaments extending from the preauricular area anteriorly for approximately 25–30 mm. This is a nonmobile area of the face.
- The neck is functionally and aesthetically divided into two subunits that are divided by the hyoid bone into the submental area and the anterior neck.

Facial Ligaments

The skeletal framework provides shape to the face by a series of retaining ligaments running from the deeper structures to the overlying skin. These ligaments generally separate the different facial compartments or spaces. They also often contain branches of the facial nerve traveling from deep to superficial to innervate the mimetic muscles.

- The temporal ligamentous adhesion, more specifically the inferior temporal septum, contains or is just superior to the temporal branches of the facial nerve.
- The lateral orbital thickening and lateral brow thickening are extensions of the periorbital septum, which extends along the lateral orbital rim, retaining the orbital spaces.
- The tear trough ligament is an extension of the orbicularis retaining ligament, and is an osteocutaneous ligament extending from the maxilla to the dermis.
- The zygomatic osteocutaneous ligament contains the zygomatic branches of the facial nerve.
- The masseteric cutaneous ligament is a condensation of deep and superficial fascia anterior to the masseter muscle.
- The mandibular ligament extends from periosteum to dermis and sets the level of the jowls.
- The parotid cutaneous ligament is a diffuse and dense attachment of dermis, subcutaneous tissue, SMAS, and parotid capsule layers.
- The retaining ligaments in the neck travel through fibrous subplatysmal fat, connecting

the hyoid and thyroid cartilage to the overlying platysma. These bands retract the muscle to the submental triangle, mandibular border, and anterior neck to create an acute cervicomental angle.

Facial Compartments

The soft tissues of the face are divided by the retaining ligaments into separate compartments or spaces: [3]

Upper temporal space This space is contained by the inferior temporal septum and the superior temporal septum, extensions of the temporal ligamentous adhesion. The superficial border of this space is the temporoparietal fascia and deep to it is the deep temporal fascia investing the temporalis muscle. There are no significant structures within this space, and it provides ready access to the lateral brow and upper malar area.

Prezygomatic space This triangularly shaped space overlies the zygoma and is bounded deeply by the zygomatic muscles and superficially by the orbicularis oculi muscle and suborbicularis oculi fat (SOOF). The superior border is the orbicularis retaining ligament and the inferior border is the zygomatic ligament.

Premaxillary space This space is medial to the prezygomatic space. It is quadrangular in shape and covered superficially by the orbicularis oculi muscles, which it separates from the lip elevator muscles forming its deep border. Superiorly it is contained with the tear trough ligament extension of the orbicularis retaining ligament.

Premasseteric space The large lower premasseter space overlies the fascia of the inferior half of the masseter muscle. This space is covered by platysma. The middle premasseteric space is cephalad to this and is covered by SMAS but not by platysma. The premasseteric compartment is bounded posteriorly by the anterior border of the parotid gland and anteriorly by the masseteric ligaments. This space has no definable inferior border other than where it meets the mandibular ligament anteroinferiorly.

Buccal space This space lies deep to the parotidomasseteric (deep) fascia (and thus the buccal branches of the facial nerve), superficial to the buccinator muscle, and medial to the masseter muscle. It contains the buccal fat pad.

Danger Zones

Multiple studies have been done to determine the location of the facial nerve branches. The exact lengths and number of rami are variable, but their location within the fascial planes is not.

Frontal Nerve

Facial anatomical landmarks can be used to anticipate the course of the frontal nerve.

- A line drawn from 0.5 cm below the tragus to 1.5 cm superolateral to the lateral brow was first described by Pitanguy and Ramos [4] and later refined by Tzafetta and Terzis to be at the level of the lateral brow 1 ± 0.5 cm superolateral [5].
- There is a sentinel vein, the medial zygomaticotemporal vein, that consistently runs caudal from the frontal nerve, an average distance of 6.8 mm [6] and 2–3 cm from the lateral orbital rim at the level of the lateral canthus [7, 8].
- The palpable portion of the zygomatic arch is an important landmark as the temporal branch travels in the periosteum over the middle third of the arch. More importantly, the arch also defines the frontal nerve location within the layers of the face. Above the zygomatic arch, the nerve is deep to the temporoparietal fascia. At the zygomatic arch, the frontal nerve is deep, usually traveling adjacent to the periosteum in the middle third. The frontal nerve becomes more superficial as it travels superiorly; however, it always stays deep to the tem-

poroparietal fascia, and eventually innervates the frontalis muscle from its deep surface.
- If dissecting above the lateral orbital rim, the inferior temporal septum will be seen as interdigitating fascial fibers at the inferior portion of the zone of fixation. This fascial fusion connects the superficial and deep temporal fascias lateral to the orbital rim. This orbicularis-temporal ligament should be avoided, as the temporal branches usually travel either parallel or just inferior to it, [9] separating the inferior temporal septum and the sentinel vein.

Buccal and Zygomatic Branches of the Facial Nerve

The buccal and zygomatic branches have significant arborization with each other, but they should nevertheless be anticipated and avoided.

- In dissections of Tzafetta and Terzis, [5] approximately 70% of the buccal and zygomatic nerve branches had significant arborization with each other or the marginal mandibular branch.
- Because of this arborization, injured nerve branches usually spontaneously recover; however, any loss of motor function, even if temporary, is distressing to the patient.
- Zones of highest risk are in areas with a higher density of retaining ligaments—just inferior to the zygoma, lateral to the zygoma, and between the zygomatic and masseteric cutaneous ligaments. In these areas, the nerve branches can be less than 1 mm deep to the SMAS [10].

Marginal Mandibular Branch of the Facial Nerve

This branch can also be identified and avoided if facial landmarks are noted.

- The marginal mandibular branch travels deep to the parotidomasseteric fascia after it exits the parotid gland. It then continues on the surface of the posterior digastric muscle and submandibular gland. It can be injured in this area if a submandibular gland excision is performed.
- The nerve can also be injured as it crosses the facial vessels traveling up over the mandibular border. Dissections done by Hazani et al. show that this occurs approximately 3 cm anterior to the mandibular tuberosity [11].
- Another useful landmark is the insertion of the masseteric retaining ligaments along the caudal masseter border. Caution should be taken here, as dissection deep to the platysma can injure the nerve.

Cervical Branch of the Facial Nerve

The cervical branch is at risk of injury due to its superficial location within the layers of the face and neck.

- The cervical branch is very superficial and intimate with the platysma, placing it at high risk of injury.
- During the lateral dissection inferior to the mandible, the platysma and the sternocleidomastoideus are more intimately attached, thus making dissection and avoidance of the cervical branch more difficult.

Great Auricular Nerve

The great auricular nerve is also at risk of injury during the more superficial portions of its path.

- The great auricular nerve travels deep to the sternocleidomastoid muscle until it pierces the midportion of the muscle belly to travel in the superficial muscular fascia. This transition from deep to superficial occurs approximately 6.5 cm inferior to the external auditory canal.
- The transition from the superficial investing fascia of the sternocleidomastoideus to the thin layer of SMAS in this area makes dissection more challenging.
- Stay superficial to the cervical fascia overlying the sternocleidomastoideus to prevent injury to the great auricular nerve.

Patient Factors

Certain patient factors can increase the surgical dissection risks in some situations.

- Thin patients with minimal subcutaneous fat make dissection more challenging.
- Secondary or revisional rhytidectomies have scarring, which blurs the anatomical planes.

- Likewise, patients who have had a significant amount of fillers or deoxycholic acid injections have scarring, which can make dissection more difficult.

Safe Zones

It is prudent to approach a riskier anatomical space from a safer zone of dissection. The compartments of the face are considered to be safe spaces for dissection, as they generally do not contain significant structures.

Frontal Nerve

- It is safe to dissect deep to the loose areolar tissue layer/sub-SMAS fat/ROOF pad just above the deep temporal fascia.
- When dissecting cephalad to the zygomatic arch, stay superficial to the temporoparietal fascia. If deeper dissection is needed, stay in the plane just deep to the superficial layer of the deep temporal fascia.
- The frontal nerve can be avoided above the inferior temporal septum.

Zygomaticobuccal Branches

- When approaching a retaining ligament, gradually approach the ligament by dissecting both cephalad and caudal to it to establish the correct plane.
- Stay superficial to the SMAS and slowly progress toward the ligament until it can be divided.

Marginal Mandibular Branch

- Stay superficial to the platysma-SMAS layer.
- Pay attention here, as this layer can be very thin naturally and become even more atrophic and lax with age.
- In the lateral cheek, beyond the parotid tail, perform limited blunt dissection as needed.

Cervical Branch

- Stay superficial to the SMAS.
- To avoid injury to the cervical branch of the facial nerve, incisions in the lateral SMAS as it transitions to the platysma should be 15 mm posterior and 45 mm inferior to the mandibular angle [12].
- Any subplatysmal dissection outside these parameters should be performed carefully and under direct visualization, staying superficial to the sub-SMAS adipose layer, which contains the nerve branches.
- Use blunt dissection beyond the tail of the parotid, which is easily done as there are no retaining ligaments in this area.
- Directly over the zygomatic eminence is a safe zone of dissection.

Physiology of Aging

In order to perform a facelift that results in a natural, youthful appearance, one must understand the anatomical changes that occur with normal aging. Many of the stigmata of an aged or a "tired" appearance are the direct results of the degenerative changes that occur at every tissue plane.

- Skin changes occur from external environmental exposure, hormonal changes, and exposure to nicotine or other chemical substances. Dermal elastosis, skin laxity, and photodamage result. Levels of collagen and elastin decrease [13], which further decreases the skin's ability to restore itself.
- Subcutaneous fat atrophies. Loss of fat volume causes the topography of the face to change, developing distinct concavities associated with an aged appearance. The most noticeable areas of lipoatrophy are the malar fat pad, nasolabial fold, and infraorbital rim.
- Skeletal muscle atrophies with age. This can be seen to affect the temporalis and masseter muscles, giving a hollowed appearance synonymous with age or ill health.
- Attenuation of the retaining ligaments of the face and neck causes the most pronounced stigmata of aging. With age, the fibrous system connecting the mimetic facial muscles to the dermis attenuates, grows lax, and inadequately supports the fat compartments in the face.
- The skeletal bone resorbs with age [14]. This can cause significant changes in the overlying soft tissue anatomy, particularly if there is pronounced maxillary retrusion.

Overall, the physiological effects of aging correlate with three general principles which should be used to guide the evaluation and treatment plan for rejuvenation of the aged face. It is important to remember that the signs of aging do not develop at the same rate throughout all the layers of the face.

Volume Loss

- The youthful face is characterized by fullness and roundness in the upper portions, tapering with a smooth mandibular line to end in a gentle point at the chin.
- The youthful face has volume in the malar area, preparotid region, lateral and infraorbital rim, and lateral chin. The youthful face is characterized by a smooth blending among all these areas of volume, giving a fuller, rounder appearance.
- With age, fat atrophies and ligaments attenuate, causing volume loss and a sharp demarcation among the aesthetic subunits of the face.
- In the midcheek, the once-smooth appearance of the midface becomes divided by the nasojugal, palpebromalar, and midcheek grooves.

Ptosis

- The youthful face is angular and tapered, with a well-defined mandibular border. The fat compartments of the face are well supported.
- The youthful face is known by highlights over areas dense with retaining ligaments (malar, preparotid, orbital rim) supporting soft tissue volume, juxtaposed with areas of concavity (submalar, buccinator muscle, and buccal recess).
- With age, the fascial ligaments become attenuated, causing volume descent anteriorly and inferiorly in the cheek. This ptosis leads to loss of volumetric highlights, a squarer shape, and a face that appears longer in the vertical dimension.
- In the lower face, the once-smooth mandibular border develops jowling, labiomandibular grooves, and a blunted cervicomandibular angle.
  - The labiomandibular groove deepens as ptosis displaces the buccal fat pad inferiorly, while it is still held in place by the masseteric and mandibular grooves.
  - The jowls develop from tissue ptosis while held in place by the mandibular retaining ligaments.
  - Cervical obliquity develops as the cervical retaining ligaments to the platysma become attenuated, causing the muscle to descend inferiorly. Platysmal banding occurs and the cervicomandibular angle blunts.

Radial Expansion

- In youth, dense retinacular fibers originate from the deep fascia, facial muscles, and skeletal structures of the face and travel to insert in the skin, subcutaneous fat, and superficial fascia. Over time, the mimetic muscles cause their superficial overlying tissues to be repeatedly pushed lateral and deep to those retinacular attachments. This leads to a gradual attenuation and a slow outward prolapse from the facial skeleton.
- Radial expansion leads to deepening of nasolabial folds, marionette lines, oral commissure lines, and jowling.
- This is a difficult element of aging to change; full correction would require diversion of the retinacular attachments from their skin and subcutaneous insertions, or their deeper structure origins.

Preoperative Points

Patient Assessment

History

A full up-to-date patient history will reduce avoidable complications.

- A complete past medical history should be obtained. Many systemic disorders can impact a patient's perioperative course, especially hypertension, coronary artery disease, chronic

obstructive pulmonary disease, obstructive sleep apnea, asthma, diabetes, and autoimmune diseases.
- The surgeon should be aware of all medications and supplements, especially immunosuppressants, chemotherapeutic agents, corticosteroids, and agents affecting the coagulation cascade.
- The patient should stop all nicotine use at least 4 weeks prior to surgery, and continue to abstain until fully healed.
- The surgeon should obtain a full history of the patient's injectable use, including placement and timing of all neuromodulators, fillers, and fat lysing agents.
- A complete past surgical history, including any complications and wound healing issues, should be elicited.

Physical Exam

A detailed facial examination is critical to achieve consistent favorable results.

- Perform a full sensory and motor exam of the face and note any abnormalities.
- Analyze the face as a whole—the condition and quality of the skin, signs of solar exposure, and the depth and location of rhytids.
- Evaluate facial width and facial length of each side, keeping in mind that often patients' faces age asymmetrically, with one side longer and the other side wider. This is important, as it can equate to different vectors of lift on each side.
- Evaluate the patient's bizygomatic diameter and amount of radial expansion. Examine the underlying skeletal structure of the zygomas, inferior orbital rims, and mandible. Determine the fixed versus mobile areas of the cheek.
- Assess areas of convexity and concavity, malar volume, and soft tissue atrophy, as well as ptosis. Determine the vector of the skin and soft tissue descent in order to reverse it and restore a youthful shape.
- Measure the brow position and level of ptosis if present.
- Encourage patients to bring old photographs to better assess the amount of soft tissue atrophy and vectors of ptosis.

Set Patient Expectations

- It is important to clearly communicate to the patient that the surgeon cannot make them look exactly as they did in youth.
- The term "facelift" is itself misleading, as it is not the entire face that will be lifted, but only the midface and jowls. It is important that the patient understands the facelift alone will not address signs of aging in the upper third of the face, around the eyes, or immediately around the mouth.
- The objective of a facelift is to restore a more youthful facial shape in all dimensions while avoiding an unnatural postsurgical appearance.

Preoperative Markings

- Markings should be done with the patient upright.
- Mark the fixed and mobile lateral cheek.
- Mark the areas of volume loss.

Surgical Prophylaxis

- Clonidine is given preoperatively for blood pressure control. In addition, patients are instructed to take their regular blood pressure medications the morning of surgery as prescribed.
- Deep venous thromboembolism (DVT) is prevented by physically exercising the patient every 2 hours during surgery.
- Hematoma prevention includes tight blood pressure control, strict hemostasis throughout the operation, and postoperative drains. These measures are even more aggressively attended to in the male facelift patient.
- Perioperative antibiotics covering *S. aureus*, *S. epidermidis*, and external ear canal flora are given for infection prevention. Hair in the field is included in the sterile prep solution. Drapes are secured for the duration of the procedure. The temperature in the operating room is controlled.
- A Foley catheter is utilized throughout the procedure.

Anesthesia

- Labetalol is given intraoperatively to maintain a systolic blood pressure < 120 mmHg.
- This procedure can be done using local anesthesia via infiltration of a lidocaine-bupivacaine mixture. In the senior author's operating room suite, induction with fentanyl and versed as well as intravenous ketamine is performed, with propofol and valium given as needed for deeper sedation.
- IV sedation provides the benefit of a lower risk of DVT, along with sequential compression devices and early ambulation. The possible risk is the lack of absolute airway control, so it is important to have an experienced anesthesia provider if this type of anesthesia is used.
- Glycopyrrolate can be given to limit secretions as an adjunct to patient comfort while under sedation.
- The anesthesia provider should be aware that if a platysmaplasty is performed, the airway is often slightly narrowed when the plication sutures are placed, as evidenced by a small increase in CO_2 and blood pressure.

Operative Technique

There are multiple facelifting techniques with satisfactory results. The most influential consideration in determining which technique to use is the aesthetic destination desired and the most long-lasting, precise solution to attain it.

- Skin flaps should never be the "vehicle" to reshape the face or remedy facial fat descent. This will lead to stigmata of surgery such as a mask-like appearance, distortion of the temporal hairline, and a vector that is too superior.
- Performing a SMAS dissection and release from the retaining ligaments provides greater surgical control. SMAS fixation and stabilization provide greater result longevity.
- Although it would seem that staying superficial to the SMAS would prevent nerve injuries, the incidence of nerve injuries with subcutaneous or sub-SMAS techniques has not been reported to be different [15–17]. Typically, when a skin-subcutaneous flap is raised, it is done bluntly, at varying thicknesses, not in an anatomical plane, and by surgeons of varying experiences. In contrast, sub-SMAS dissections are usually done under direct visualization, using anatomical landmarks to stay cognizant of the exact depth and location of dissection, thus preventing injury.
- The extended SMAS technique gives greater versatility as to where facial fat can be repositioned. This technique is a balance, trading greater operative time and more careful dissection for longer lasting, more precise results that are at the same time natural in appearance.
- Each patient has a unique skeletal structure and pattern of aging which must influence planning preoperatively. Factors to consider include the extent of SMAS release required, the vector of facial fat repositioning needed, and the location for SMAS fixation.
- More dissection is not necessarily better. Rather, limited precise dissection to release the fascia where it is specifically needed gives the best results. More dissection decreases aesthetic control while increasing risk of morbidity.
- Patients typically have some degree of asymmetry between the right and left sides of their face, with one side typically longer and the other side typically wider. Often malar highlights are located more superiorly on the long side of the face [2].
- Patients also tend to age differently based on their underlying skeletal morphology; facial fat often falls in a more vertical manner on the long side as opposed to the wide side. Thus, it follows that the vector for SMAS elevation can be different between the right and the left sides, and should be specific to the underlying anatomy and physiology of aging.
  - Vertical SMAS elevation will reposition fat volume over the malar eminence and enhance concavity of the submalar region for a more tapered face and sculpted appearance.

  - An oblique vector of SMAS elevation will reposition fat volume more in the submalar region with less enhancement of the malar eminence. This can be done in a patient with a gaunt face or exaggerated buccal recess for a fuller appearance.
- Patients with longer faces typically benefit from a more extensive SMAS dissection, elevating all the way medial to the lateral orbital rim, in order to restore malar volume and increase facial width on the frontal view [2].
- In patients with wider faces, adequate malar volume, and little malar fat pad ptosis, SMAS elevation is limited to the lateral aspect of the malar eminence in order to correct submalar fullness and restore youthful highlights over the malar eminence.

Cutaneous Flap Elevation Tips

- Skin subcutaneous tissue flaps should be raised sharply and precisely, taking care to leave some subcutaneous fat intact. Dissection should be superficial to the SMAS layer and limited to areas where the SMAS will be elevated. This will assist SMAS elevation and plication in the case of thin tenuous fascia.
- Incision is done intertragally, extending superiorly into the temporal area. Inferiorly it continues retroauricularly and partially into the hairline.
- Transillumination and correct retraction are critical to prevent injury to the skin flap or underlying SMAS.
- Dissection continues lateral to medial (from the lateral compartment to the middle superficial fat compartment), to the anterior border of the parotid gland, at which point dissection will become easier.
- The zygomatic-cutaneous and masseteric-cutaneous ligaments merge at the inferior border of the anterior zygoma. Branches of the transverse facial artery are often encountered here. Staying above the SMAS in this area will prevent injury to the nerve branches underneath.
- The midcheek is dense with ligaments as it transitions from the middle to the superficial malar fat compartments. It is sometimes difficult to find the right plane; change the direction of dissection if the plane becomes difficult to identify.

SMAS Flap Elevation Tips

- Facial fat descent is individual, and so the vector for re-draping the SMAS should be individualized.
- Use methylene blue to mark a line from the tragus to the lateral brow, to avoid the frontal nerve. Mark 1 cm below the zygomatic arch and continue forward until the point where the arch meets the zygomatic body. Angle superiorly over the malar eminence toward the lateral canthus 3–4 cm, then continue at a 90-degree angle inferiorly toward the nasolabial fold. Mark a vertical incision in the preauricular region extending 5–6 cm below the mandibular border along the lateral edge of the platysma.
- It is important to maintain the correct plane from the beginning, which is easiest to find in the anterior auricular area. Maintain a plane superficial to the orbicularis oculi, zygomaticus major, and zygomaticus minor muscles, as the facial nerve branches lie deep to these muscles. A natural plane exists here.
- Elevate the SMAS layer with careful needle tip electrocautery dissection, beginning laterally.
- Past the parotid tail, dissection can be done bluntly, but gently, to avoid injury to the marginal mandibular branch. Continue carefully, as the SMAS often becomes tenuous overlying the parotid gland and zygoma, and it is easy to tear here.
- Extend the dissection through the zygomatic ligament to completely free the fascia and release the overlying tissue. This is important for elevation of malar fat. Beyond the accessory lobe of the parotid gland, all retaining ligaments have been released, and continued dissection returns minimal benefit for increased risk.

- Release of the masseteric ligament provides more complete mobility and resolution of oral commissure lines and jowling. Take care in this area—after division of the masseteric cutaneous ligament, the buccal fat pad and nerve branches to the zygomaticus major will be visualized.
- If soft tissues continue to be restricted after this, the retaining ligaments medial to the zygomaticus minor can be divided for greater mobilization. This dissection can be done deep to the SMAS without undermining the overlying skin flap further [9]. This can be done with minimal resistance if in the right plane: insert scissors in the plane between the malar fat and upper lip elevators and bluntly dissect, spreading the scissors along a line parallel to the nasolabial fold.
- Place traction on the SMAS flap to redrape it in the appropriate vector, which is typically a more superior one than the skin flap vector. Pay attention to where the malar fat pad ends up.
- Mark the redraped SMAS as if it were going to be excised. A minimal SMAS excision can be performed; however, more often it is better to turn the edge of the SMAS onto itself for a thicker tissue layer and more secure purchase with the suture. Interrupted non-absorbable figure of eight sutures can be used except in areas where they are palpable; in those areas use absorbable suture. The lateral platysmal edge is sutured posteriorly to the mastoid fascia. Fixation of the SMAS flap is done prior to the platysmaplasty.
- We recommend placing the majority of tension on the SMAS and platysma rather than the skin flaps, so that facial reshaping relies on deep fascial support instead of a skin envelope. This will improve facial contour, as well as postoperative healing and scarring, by minimizing tension on the skin incision.
- Trim and sculpt fat on the SMAS to contour as needed
- Meticulous hemostasis is required.
- A drain is placed under the plastysma-skin flap and crossing the face.

Surgical Closure

- The medial dissection sets the course for the lateral excision—once the central portion is released, the lateral vector can be better applied.
- The SMAS-platysmal dissection and possible excision allow release and movement for conformity to the underlying structural support. The new facial shape is determined by the underlying skeleton and by the location of the sutures.
- It is important to redrape the skin flap with the correct vector and very little tension.
  - Often the skin and SMAS layers will redrape with different vectors. For example, a patient may require a lateral and slightly oblique vector of the skin but a more cephalad vector of the SMAS.
  - A vertical SMAS vector will increase malar eminence volume and submalar hollowing.
  - An oblique SMAS vector will give more submalar volume.
- Place tacking sutures at the helical root, mastoid, anterior lobe insertion, tragus, and the most superior postauricular point.
- Excise skin from the flap edges with a scalpel or scissors and close without tension using fine non-absorbable sutures.
- Fat grafting can be a useful adjunct in facial rejuvenation to improve the volume lost in the aging process. If fat grafting is done prior to the facelift, edema and possible secondary miscalculations are avoided. However, fat grafting at the conclusion of the facelift can afford more precise shaping overall.

Postoperative Points

- Transdermal clonidine is given postoperatively for BP control.
- A light head dressing is placed, minimizing pressure; this will be removed in 24 hours.
- Hydration is encouraged and is a key element in the postoperative recovery.

- Drains are closely monitored and typically can be removed after 4–5 days.
- Antibiotics are given for 5–7 days postoperatively.
- Prescriptions are given for pain control and antiemetics.
- Ice can be applied for 20-minute intervals every hour for the first 24–48 hours.
- Sutures are removed over the course of postoperative days 5–10, with preauricular sutures removed earlier.
- It is important to closely monitor the patient with frequent office visits in the initial 2 weeks.
- Activity limitations such as head-of-bed elevation, no strenuous activity, and limited neck flexion and extension are strongly recommended to the patient.
- Kenalog can be injected into any areas of induration or prominent scarring in the later phases of healing.

Surgical Complications

- The most common complication reported in the literature is hematoma, usually within the first 12 hours. Some hematomas are small enough to be self-limited and unnoticeable until edema resolves, at which point they can be a difficult problem to solve. It is essential to recognize the complication early and intervene immediately to prevent skin flap ischemia and necrosis.
- The next most common complication is skin necrosis, which is usually retroauricular. Common causes of skin necrosis are underlying hematomas, thin or damaged skin flaps, tension on the skin flaps, or patient-dependent factors such as smoking or dehydration.
- Nerve injury is probably the most serious complication in facelifting.
  - The most commonly injured nerve is the great auricular nerve; thus, it is important to take care when elevating the cervical skin flap from the underlying sternocleidomastoid muscle to avoid this complication. If an injury is noted intraoperatively, primary repair should be done at the same time, using magnification.
  - Facial nerve injury reported in the literature ranges from less than 1% to 20% [10, 18], which is likely an underrepresentation, given that most published reports are retrospective reviews of cases done by experienced surgeons. Injury can also occur to the seventh cranial nerve's branches, most commonly the buccal branch [2]. Injury to the buccal branch occurs with minimal consequences due to arborization; temporal or marginal mandibular branch injuries produce longer lasting weakness.
  - Superficial sensory nerves are divided during cervicofacial flap elevation, causing temporary change or loss of sensation in areas of dissection. Innervation typically returns spontaneously within 6 months.
- Hypertrophic scarring, usually retroauricular, is another possible complication. If encountered, one can inject intralesional steroids, or even excise if necessary.
- Skin slough can occur due to excessive tension, pressure from edema or dressings, or other causes of superficial skin necrosis. These areas should be monitored closely and treated with local wound care.
- Infections are treated with oral antibiotics if limited; IV antibiotics are used if the patient develops cellulitis. If infection becomes suppurative, surgical drainage and irrigation are necessary.
- Dehiscence can occur but is uncommon.
- Other common sequelae of rhytidectomy are listed below. These are typically mild without long-term consequences; however, it improves the postoperative experience if patients are counseled beforehand to expect them:
  - Congested skin flaps
  - Edema
  - Ecchymosis
  - Contour irregularities from fat or sutures
- There are also very undesirable effects when poor surgical technique is executed:

- Tight mask-like appearance from excessive skin excision and tension
- "Joker" smile from excessive lateral tension at the oral commissure
- Pixie ear deformity from incorrect tension and closure at the base of the ear lobule

These sequelae can be avoided with attention to detail, awareness of the patient's individual anatomy, and adherence to core plastic surgical principles.

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Blepharoplasty

8

Henry M. Spinelli, Andrew L. Weinstein, and David E. Janhofer

Introduction

In everyday life, our eyes play a central role in social interaction and the perception of facial beauty. We make eye contact when communicating as a sign of engagement, and use our periocular soft tissues to convey a variety of telling facial expressions. As we age, these periocular tissues, which include the upper and lower eyelids, eyebrow, and cheek, undergo a series of anatomical changes typically producing a "tired" appearance. As a result, blepharoplasty, or eyelid surgery to restore a youthful appearance, has become one of the most common cosmetic surgical procedures performed by plastic surgeons in the United States [1].

Traditionally, blepharoplasty techniques focused on aggressive resection of skin, muscle, and fat. Over time, however, it was recognized that these approaches led to aesthetic and functional issues, such as a periocular hollowing and incomplete eyelid closure, termed lagophthalmos, effectively worsening the problems they aimed to address [2–5]. In response, a paradigm shift has occurred, and current blepharoplasty management involves more conservative resection of soft tissues, with an emphasis on fat preservation, and complementary eyebrow and midface procedures when indicated.

The purpose of this chapter is to provide the reader with a road map to better understand the periocular anatomy affected by the aging process, key considerations when evaluating a patient for blepharoplasty, and proven upper and lower eyelid blepharoplasty techniques to achieve optimal and long-lasting results in periocular rejuvenation [6, 7].

Periocular Signs of Aging and Anatomical Changes

In considering a patient for blepharoplasty, an in-depth knowledge of the periocular anatomy and how it changes with aging serves as the foundation for safely and successfully selecting the right procedures for each patient. However, the eyelids do not function in isolation and are directly affected by their anatomical neighbors—the upper lid is interconnected to the eyebrow and lower lid to the cheek. As we age, these tissues and the soft tissues underneath undergo a predictable pattern of anatomical changes related to a loss of intrinsic support and Newtonian forces, namely gravity [3].

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Beginning cephalad, the eyebrow is comprised of skin, five muscles (procerus, corrugator supercilii, depressor supercilii, frontalis, and orbicularis oculi), galea, and brow fat pad, which in this region is the retro-orbicularis oculi fat (ROOF). With aging, the eyebrow's ligamentous attachments to the frontal bone become attenuated, leading to eyebrow ptosis and descent of this skin onto the upper eyelid, thereby worsening the appearance of upper eyelid skin redundancy, termed dermatochalasis [3, 8].

The eyelids may be conceptualized as a trilamellar structure with the outer lamella consisting of skin and orbicularis oculi muscle; middle lamella of orbital septum; and inner lamella of tarsoligamentous sling and conjunctiva [3, 9]. In the outer lamella, the eyelid skin is the thinnest in the body, with virtually no subcutaneous tissue. The orbicularis oculi muscle consists of three portions. The pretarsal orbicularis overlies the tarsal plates and assists with both blinking and tear movement, the preseptal orbicularis covers the orbital septum and helps with blinking, and the orbital orbicularis voluntarily closes the eyelids around the eyes. Additionally, orbicularis oculi movement facilitates tear drainage wherein muscle contraction (eyelid closure) draws tears into the lacrimal sac and relaxation (eyelid opening) empties them through the nasolacrimal duct into the nasal sinus.

In the upper eyelid, behind the orbicularis oculi muscle and orbital septum in the post-septal/preaponeurotic space, lay two superior orbital fat pads in the medial and central compartments, separated by the superior oblique muscle. Laterally, the lacrimal gland sits in the lacrimal fossa and contributes to a trilaminar tear film, composed of a middle aqueous layer for eye lubrication, inner mucin layer for homogenous distribution, and outer oily layer to minimize tear film evaporative loss. With aging, the orbital septum develops laxity and the orbital fat pads protrude anteriorly, termed steatoblepharon, thereby lowering the upper eyelid fold position. The ligamentous attachments to the lacrimal gland (Soemmering's ligaments) may also become attenuated, leading to gland ptosis. While a low or absent upper eyelid fold is a component of age-related pathophysiology in Caucasians, it is anatomically physiologic in Asian individuals, wherein the levator fibers insert into the pretarsal skin more caudally, if at all**.**

Upper lid elevation occurs voluntarily by the levator palpebrae superioris muscle and involuntarily by Müller's muscle, which insert into the superior tarsal plate (6–10 mm high). Whitnall's ligament, located about 14–20 mm above the superior tarsus, acts as a fulcrum over which the horizontally oriented levator muscle converts its contractile force onto the eyelid into a cephalad direction. Though contrasting theories do exist, the upper lid fold is formed by insertion of the levator fibers into the pretarsal skin, with its position variable with age, gender, and race. With aging, the levator aponeurosis may attenuate or dehisce from its insertion site in the skin, leading to upper eyelid drooping, termed blepharoptosis, associated with elevation or loss of the upper eyelid fold. As levator muscle has tethering attachments to the overlying orbital fat pads, dehiscence of the levator aponeurosis can result in concomitant fat pad retraction and the classic superior sulcus deformity (Fig. 8.1).

In the lower eyelid, the thin skin is similarly prone to developing dermatochalasis with aging due to the proportionally low levels of collagen and elastin, which provide skin firmness and elasticity, respectively. Located in the post-septal/pre-capsulopalpebral fascia space, the lower eyelid has three orbital fat pads in the medial, central, and lateral compartments, with the medial and central fat pads separated by the inferior oblique muscle. With aging, the orbital septum develops laxity and the inferior orbital fat pads protrude anteriorly. The suborbicularis oculi fat (SOOF), which is located in the pre-septal/suborbicularis space and thickest laterally, may also contribute to lower eyelid fullness above the orbitomalar ligament.

The lower eyelid is stabilized in position by superior and posterior forces from the medial and lateral canthal tendons acting through the inferior tarsal plate (4–5 mm high) balanced against down-

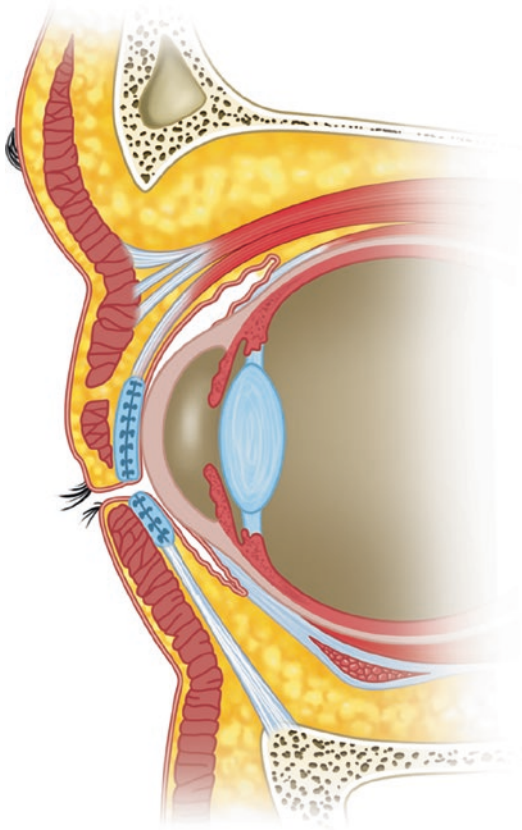

Fig. 8.1 On lateral view, the analogy between upper and lower eyelids is clear. The upper and lower septum merging with the periosteum externally and the periorbital internally. The levator aponeurosis merges with the septum and the preaponeurotic fat is linked to the levator and only accessible by violating the septum. Muller's muscle is sympathomimetically innervated and is the flight/fright elevator of the upper lid, responsible for approximately 1–2 mm of excursion. The capsulopalpebral fascia or lower eyelid retractor system arises off the inferior oblique and rectus muscles. Therefore, the lower eyelid "gets out of the way" when the globe is depressed, as when reading the newspaper. The conjunctiva reflects on itself, covering the undersurface of the eyelids and then onto the eyeball. This is similar to visceral and parietal layers found elsewhere in the body. The fat in the lower orbit is behind the septum but in front of the retractor system. Hence, it may be termed pre-capsulopalpebral fat. All orbital fat is linked by septae so that traction placed on anterior extra-conal fat produces a disturbance in the deep extra- and intra-conal fat. Note the coalescence of the inferior orbital septum with the capsulopalpebral fascia well below the inferior tarsal plate. This zone of coalescence is a favored access route to the important potential space I term the post-orbicularis pre-capsulopalpebral fascial space, which is important in deftly executing both the transconjunctival and transcutaneous blepharoplasties. (Modified from *Atlas of Aesthetic Eyelid and Periocular Surgery* © 2004 Henry M. Spinelli, M.D. All rights reserved)

ward distraction forces from the cheek. The lateral canthal tendon has anterior and posterior limbs, which insert on the lateral orbital rim andvWhitnall's tubercle (located 6 mm below lacrimal fossa and 2 mm within orbital rim), respectively, and join with the lateral horn of the levator aponeurosis, inferior suspensory (Lockwood's) ligament, check ligaments of the lateral rectus muscle, and Whitnall's ligament to form the lateral retinaculum [13, 14]. The medial canthal tendon is tripartite with anterior, posterior, and superior limbs, which are intertwined with the lacrimal sac, and together with the orbicularis oculi muscle aids in tear drainage with blinking movement. Though racial differences exist, the lateral commissure is generally inclined 10–15° compared with the medial commissure, so-called "positive canthal tilt." With aging, attenuation of the medial canthal tendon leads to inferior and lateral displacement of the lacrimal puncta, and that of the lateral canthal tendon leads to inferior and medial descent, thereby decreasing the lateral canthal inclination.

Descent of the lateral canthal tendon also shortens the intercommissure distance leading to horizontal lower eyelid laxity. Over time and exacerbated by downward distraction forces from the cheek, the lower eyelid may develop malposition including scleral show, ectropion (eyelid margin eversion), or entropion (eyelid margin inversion). Eyelid malposition due to retraction or lagophthalmos is often due to some underlying etiologies such as Graves' disease, but further discussion is outside the scope of this chapter (Fig. 8.2).

The lid-cheek junction is formed medially by the tear trough ligament and laterally by the orbitomalar ligament, continuous osteocutaneous ligaments that extend from the maxilla to the skin between the palpebral and orbital portions of the orbicularis oculi muscle [3, 10]. With aging, atrophy of the SOOF and malar fat pad in the nasojugal groove and protrusion of inferior orbital fat pads lead to the development of tear trough deformity, which may continue laterally as a prominent lid-cheek junction. Attenuation of the tear trough-orbicularis retaining ligament may also contribute to the appearance of an increased lower eyelid height [11, 12].

Lastly, with aging of the midface, descent of the malar fat pads may result in inferior orbital

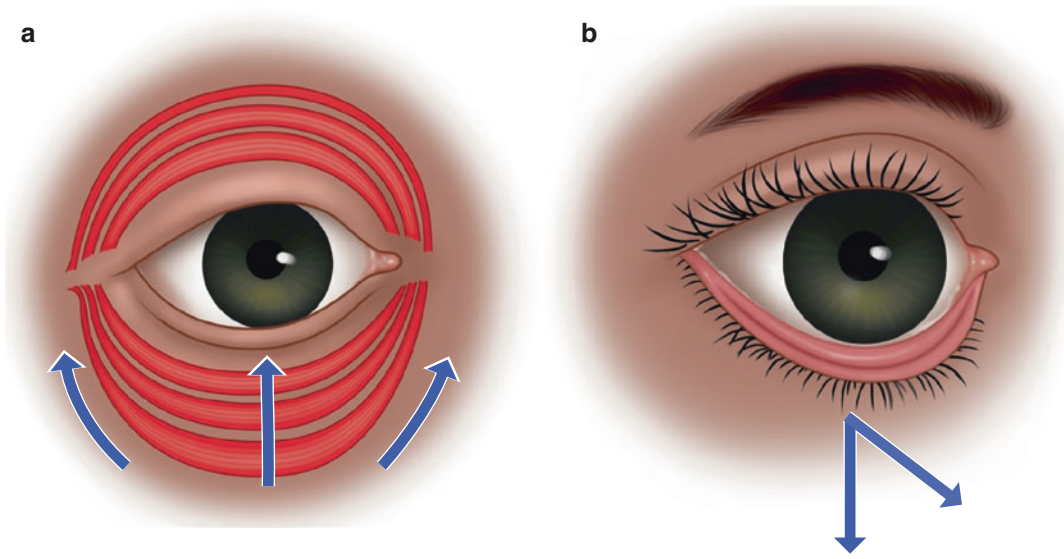

Fig. 8.2 (**a**, **b**) The adnexa, and especially the lower eyelid, is held in normal anatomic position against the globe by intrinsic support (IS) provided by the tarsal plate, the canthal tendons, and the orbicularis muscle sling. These elements provide a net vector that is posterior and superior. There are also forces acting on the lid in opposition to its intrinsic support. These extrinsic distraction (ED) forces provide a net vector that is inferior and anterior from the globe. The lid will maintain a functional anatomic position as long as IS at least as strong as the extrinsic distraction forces. An unfavorable imbalance can be created by weakening the IS as in senescence, or by strengthening the distraction forces as occurs from surgery, lasers, or trauma. This tips the scale in favor of a lid that no longer provides an anatomic and functional position. (Modified from Atlas of Aesthetic Eyelid and Periocular Surgery © 2004 Henry M. Spinelli, M.D. All rights reserved)

rim prominence, the so-called "orbital rim in relief," a term this senior author (HMS) believes is most appropriate [3, 7]. The prezygomatic space is bordered superiorly by the tear trough-orbicularis retaining ligament and inferiorly by the zygomaticocutaneous ligament, and contains fat and orbicularis oculi muscle. With aging, the prezygomatic space may bulge from edema (malar mounds) or orbicularis oculi muscle redundancy (festoons). The latter two entities are most difficult to satisfactorily treat and serve as a great source of consternation for the patient and treating clinician.

History and Physical Exam

Patients desiring blepharoplasty are often fixated on cosmetic concerns and may be unaware of any senescent changes to their eyelid function. As eyelid function is paramount to ocular health and visual acuity, surgeons must keep this priority at the forefront of their minds, starting at the initial consultation. A thorough history and exam will allow for accurate diagnosis and risk stratification for the development of blepharoplasty complications, such as corneal exposure and lower eyelid malposition. Ultimately, this information can be used for patient selection and surgical decision-making, with the goal to minimize blepharoplasty risks and maximize patient satisfaction. Sometimes, as in many aesthetic procedures, cosmesis and/or patient perception of an appropriate approach diverges from a good function goal.

The history should involve eliciting ocular and periocular problems including, but not limited to, visual impairment and use of corrective lenses; dry eye syndrome or excess tearing, termed epiphora; eyelid inflammatory diseases or infections, such as ocular rosacea; chronic blepharitis or recurrent herpes infections; thyroid or Grave's disease; and risk factors for corneal injury

following blepharoplasty were lagophthalmos to occur.

Tip
Patients with a history of ocular problems should be evaluated by an ophthalmologist and medically optimized prior to undergoing blepharoplasty.

Tip
Early on, identify what would optimize function in each patient and incorporate that into your decision paradigm.

A relevant surgical history should also be elicited, including previous eyelid surgery or corneal surgery, such as LASIK refractive eye surgery or cataract surgery.

Tip
Blepharoplasty should be delayed at least 6 months after any corneal surgery (refractive, etc.) to allow for corneal healing and return of protective sensation.

Moving on to the physical exam, both functional and cosmetic features must be evaluated, and it is recommend that a systematic approach be followed. Beginning with the eyes, baseline visual acuity and extraocular muscle movement should be established, as visual impairment and strabismus are possible complications of blepharoplasty. Next, the eyelid margins and palpebral fissure shape may be observed. The upper eyelid margin should be located midway between the superior corneoscleral limbus and pupillary aperture. An upper eyelid margin below this point suggests the presence of blepharoptosis, which may be graded as mild (<3 mm), moderate (3–5 mm), and severe (>5 mm). For patients with blepharoptosis, levator muscle excursion should also be measured and generally graded as normal (>12 mm), good (10–15 mm), fair (6–9 mm), and poor (<5 mm). The lower eyelid margin should be located at or just above the inferior corneoscleral limbus. Inferior displacement of the lower eyelid margin with scleral show indicates lower lid malposition and any ectropion or entropion should be identified. The palpebral fissure shape reflects the overall relationship between the eyelids and eye, and should be noted and/or a photograph from youth viewed in order to preserve or restore it during surgery.

At this point, a series of physical examination techniques may be employed to assess the risk factors for developing corneal exposure and lower lid malposition after blepharoplasty (Tables 8.1 and 8.2).

Table 8.1 Risk factors for developing corneal exposure

Risk factor	How to asses
Any lagophthalmos or lid lag (even if asymptomatic)	Have the patient look down and gently close both eyelids and observe for a space between upper and lower eyelid margins
Absent or weak Bell's phenomenon	Have the patient close his or her eyelids against forced manual opening and observe for a lack of superior rotation of the eye to a protective position covered by the upper eyelid [15]
Absent corneal reflex	Lightly touch the patient's cornea and observe for a failure to blink both eyelids
Low tear film quantity	Perform the Schirmer test and observe a result of less than 10 mm distance wetting on the standardized filter paper within 5 minutes
	Tip: The senior author (HMS) recommends performing this test in a dark room to reduce the effect of ambient light on tear production, and with topical anesthetic (e.g., tetracaine) to avoid reflex lacrimation
Poor tear film quality	Perform the fluorescein break-up test and observe a fluorescein stained pre-corneal tear film losing its uniform integrity (breaking up) in less than 20 seconds under direct observation with eyelids immobilized. Added assistance may be provided with cobalt blue filter lighting

Table 8.2 Risk factors for developing lower eyelid malposition

Risk Factor	How to Asses
Negative canthal tilt	Observe the position of the lateral commissure inferior to that of the medial commissure position
Negative lateral orbital vector	Observe the position of cornea anterior to the malar prominence
Prominent eyes	Using a Hertel exophthalmometer, observe for a distance of greater than 18 mm or a difference of 3 mm from each side from lateral orbital rim to cornea
Increased lower lid distraction distance	Manually distract the lower eyelid anteriorly and observe for a distance greater than greater than 6 mm
Increased lower lid snapback time	Manually distract the lower eyelid anteriorly and then release it and observe for a time of greater than 1 second or requisite blink until the eyelid returns to its starting position

As the primary goal of blepharoplasty is periocular rejuvenation, the focus of the physical exam should now be turned to cosmetic considerations. Fitzpatrick skin type should be determined, and skin quality evaluated for the presence of fine rhytids and hyperpigmentation, both of which may require nonsurgical adjunctive procedures, such as chemical peels or laser treatments, for optimal management.

Again, beginning cephalad, the eyebrow should be located above the superior orbital rim and follow an arch with peak at the lateral corneoscleral limbus in women, and located at the superior orbital rim and follow a flatter course in men [16]. The eyebrow-upper lid lash distance should be approximately 10–25 mm at the mid-pupillary line. With the frontalis muscle blocked, an eyebrow position below the aforementioned bony landmarks and a reduced brow-upper lid lash distance is suggestive of eyebrow ptosis.

Upper eyelid dermatochalasis should be evaluated, with the frontalis muscle blocked and the eyebrow and sub-brow fat pad held in anatomical positions, in order to control for the brow's contribution, especially in the lateral third where there may be hooding.

Tip

Dermatochalasis (excess eyelid tissue due to the senescent process) should not be confused with blepharochalasis (excess eyelid tissue due to recurrent edema from an underlying medical etiology).

Particular attention should be paid to the degree and distribution of skin redundancy, as well as the presence of rhytids.

Tip

The surgeon should do his or her best to discriminate the thick brow and thin eyelid skin in the planning phase ahead of execution.

Next, the superior orbital fat pads and lacrimal gland may be assessed. The degree and distribution of fat pad protrusion should be noted, and lateral upper eyelid palpated for a ptotic lacrimal gland, which presents as a mass that is sharply demarcated and easily reducible on palpation. Eversion of the upper eyelid gland can sometimes assist in discriminating lacrimal gland from fat.

The presence and location of an upper eyelid fold are dependent on a patient's age, gender, and race and may be best visualized in downward gaze. In Caucasians, the fold may be found 6–9 mm above the upper lid lash line and expose about 3–6 mm of pre-tarsal skin, so-called "pretarsal show." In Asian patients, the fold may be minimal or absent, and replaced by protruding superior orbital fat. However, elevation or loss of this fold suggests attenuation or dehiscence of the levator aponeurosis, which may warrant surgical repair during blepharoplasty.

As with the upper eyelid, dermatochalasis in the lower eyelid should be evaluated, with particular attention paid to the degree and distribution of skin redundancy, as well as the presence of rhytids. Next, the degree and distribution of

inferior orbital fat pad protrusion should be assessed, especially the lateral pad, whose prominence is often underappreciated and consequently undertreated. The lower lid-cheek junction should also be examined for the presence and severity of the tear trough deformity with lateral extension.

Lastly, the midface should be assessed for signs of aging, including malar fat pad descent with subsequent inferior orbital rim prominence, and malar mounds/festoons in the prezygomatic area.

Upper Eyelid Blepharoplasty

For surgical rejuvenation of the upper eyelid, it is essential to recognize the presence and contribution of eyebrow ptosis to upper eyelid skin redundancy in order to characterize the degree of true blepharochalasis, which is the area of skin redundancy that will be resected during blepharoplasty. As blepharoptosis from levator aponeurosis attenuation or dehiscence is also a common sequela of the aging process, blepharoptosis should be identified and addressed at the time of the upper lid blepharoplasty [3, 17]. If the patient has lagophthalmos, even if minimal and asymptomatic, or any of the aforementioned risk factors for developing corneal exposure, it is critical that skin and fat resection be conservative to avoid postoperative complications.

Beginning with markings, the inferior incision is marked either in the upper eyelid fold, if visible, or a curvilinear line drawn at the junction between pretarsal and preorbital skin where there is a notable change in quality—about 6–8 mm above the lashes in Caucasians, higher in women, and lower in Asians—from above the medial canthus and extending laterally to about 6–7 mm above the lateral canthus and ending, ideally, within a periorbital rhytid.

With the frontalis muscle blocked and the brow and sub-brow fat pad held in anatomical position, the superior incision is then determined by pinching with a smooth forceps the skin redundancy above the upper lid fold until the upper lid lashes are only slightly everted, keeping in mind that the brow-to-upper lid lash distance should be less than 10–15 mm (Fig. 8.3).

Tip
An important guiding principle is the tissue removed is less important than the tissue left behind. Given a patient's particular anatomy and desires, asymmetric skin excisions should be performed to optimize the final result.

The curvilinear design of the superior and inferior incisions should be such that the medial aspect is convex superiorly and the lateral aspect convex inferiorly, which is especially important to avoid a narrow skin bridge if performing a simultaneous transcutaneous lower lid blepharoplasty.

The upper eyelid blepharoplasty procedure starts with infiltration of the marked area, with local anesthetic preferably containing epinephrine in the subcutaneous plane. The superior and inferior skin incisions are made, and either the skin only, or the skin and orbicularis oculi muscle resected, depending on the patient's anatomy and surgeon's preference. The orbital septum is then tented with forceps and opened as cranially as possible to avoid injury to underlying structures, such as the levator aponeurosis, and preaponeurotic fat pads exposed.

With light digital pressure applied to the superior tarsus against the globe, medial and central fat pads can be manipulated as appropriate and sub-brow fat pad sculpted using an insulated needle cautery.

Tip
The medial fat pad is often the more prominent and can be identified intraoperatively by its pale yellow to white appearance.

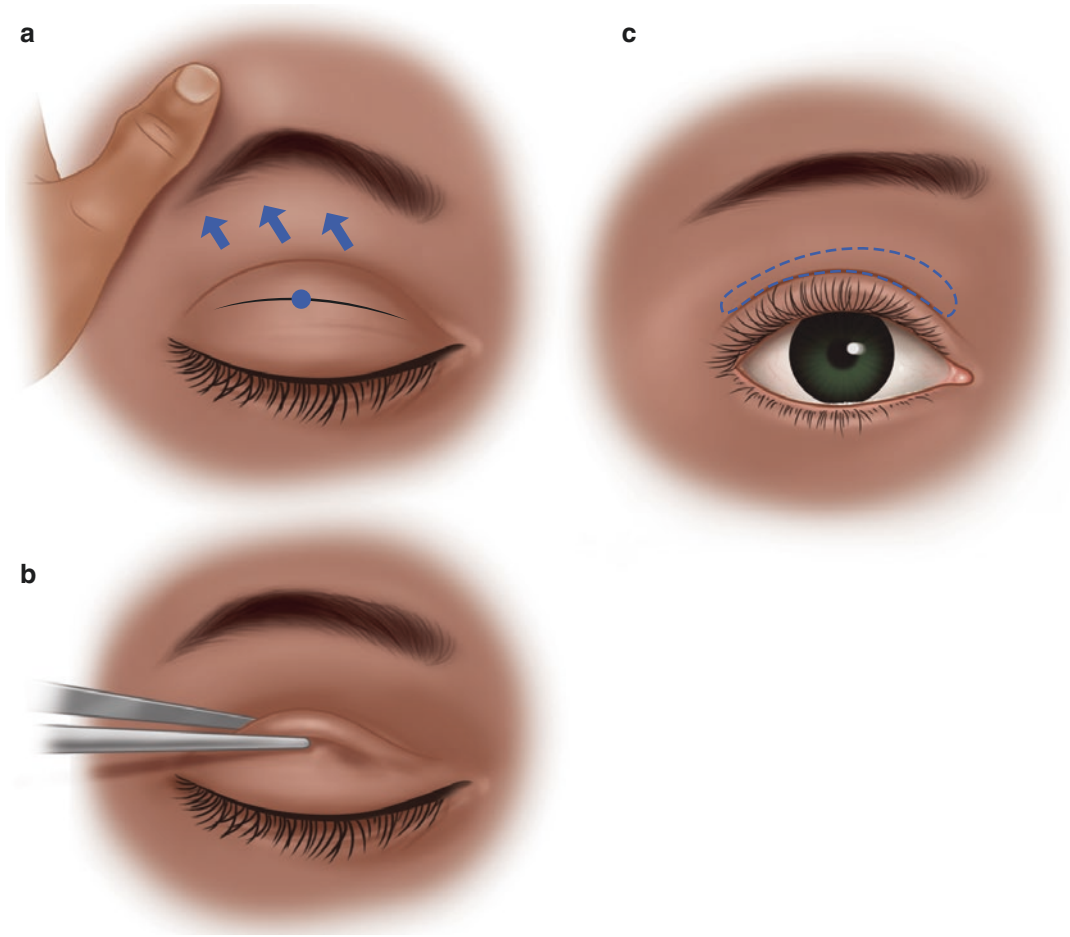

Fig. 8.3 (**a**, **b**) Determination of the endogenous lid crease, or height at which to create a new lid crease (if different than the existing crease). The later would require supratarsal fixation. The level of this crease will serve as the lower limb of the blepharoplasty incision and the height of supratarsal fixation, should that be necessary. The width or extent of skin excision is determined by pinching the lid skin between forceps using slight lash line eversion as the endpoint. This superior point will determine the location for the superior limb of the skin incision (**b**). (**c**) Determination of the extent of lateral eyebrow ptosis and, hence, the amount of lateral upper eyelid hooding. The degree of lateral hooding will dictate the point of the lateral extension needed to treat the hooding. The greater the hooding, the more lateral the extent of the incision (top drawing, dark to lighter shades color). In general, incisions which extend beyond the orbital rim are not well tolerated. The unequal length of the upper and lower limbs is effectively Burrow's triangles to eliminate dog ears, and must be exaggerated as one widens the lateral skin excision. Also, a brow which lacks stability may be pulled down by tension induced by wide lateral excision. Here, a balance must be made between the extent of lateral hooding and the drive to maintain incision lines within the confines of the orbital rim. Once the lateral extent of the incision becomes excessive, then a lateral brow suspension should be entertained. (Modified from *Atlas of Aesthetic Eyelid and Periocular Surgery* © 2004 Henry M. Spinelli, M.D. All rights reserved)

Tip

Fat pad resection in the upper lid should be conservative in order to minimize the risk of a postoperative superior sulcus or A-frame deformity, defined as a deep notching of the soft tissues between central and medial fat pads.

If lacrimal gland ptosis is present, it should be corrected using suspension techniques, and clinically significant blepharoptosis should be addressed with either levator plication or advancement techniques, depending on the degree of ptosis and levator function.

Attention should next be turned to the brow, as blepharoplasty can actually worsen brow ptosis in the context of a mobile senescent brow. Browpexy or brow lift can be performed through the upper blepharoplasty incision to address brow instability or ptosis, respectively, or alternative techniques may be employed [18, 19].

Tip

For patients with mobile, ptotic brows, a transpalpebral technique can be performed and fixation of the brow accomplished, either to the suprabrow periosteum or directly to the bone, using a suture-anchoring device of choice.

Tip

Performing a browpexy or brow lift before upper lid skin resection may lead to irregularities in the final incision line.

If a position change of the upper lid fold is desired, a supratarsal fixation may be performed by securing the levator aponeurosis to the overlying skin at the appropriately determined location using three or four absorbable interrupted sutures of choice. Lastly, the skin is closed using a 5-0 nonabsorbable monofilament intracuticular suture from medial canthal region to just medial to the lateral canthal region, and 6-0 nylon interrupted sutures laterally.

Postoperatively, sutures should be removed after 5–10 days to decrease the risk of purulent incision cyst formation.

Lower Eyelid Blepharoplasty

For surgical rejuvenation of the lower eyelid, it is essential to look for the presence of midface soft tissue descent, as a simultaneous midface lift and lateral canthal tendon anchoring procedure may be indicated in order to adequately restore lower eyelid position and tone against the globe. As with upper eyelid blepharoplasty, if the patient has lagophthalmos, even if minimal and asymptomatic, or any of the aforementioned risk factors for developing corneal exposure of lower eyelid malposition, it is critical that skin and fat resection be conservative, to avoid postoperative complications.

There are two main approaches for lower eyelid blepharoplasty: transconjunctival and transcutaneous [20, 21]. Generally, patients with protrusion of their inferior orbital fat pads or prominence of the lid-cheek junction and minimal dermatochalasis or lower lid laxity may be treated using a transconjunctival blepharoplasty alone. However, individuals with substantial dermatochalasis or any degree of lower lid malposition are better managed using a transcutaneous blepharoplasty or combination of transconjunctival blepharoplasty and marginal skin excision. Alternatively, true skin redundancy and/or rhytids may be treated with topical agents or lasers to invoke contracture. For patients with clinically significant lower lid laxity, lateral canthal tightening procedures may be indicated as well.

Transconjunctival Approach

Beginning with the transconjunctival approach, no markings on the conjunctival surface are required. However, if applicable, the specific areas for fat resection, redistribution, or even grafting can be marked with the patient awake and in the upright position.

The lower eyelid transconjunctival blepharoplasty procedure starts with instillation of topical anesthetic into the conjunctival sac and application of protective contact lenses. Alternatively, if the surgeon is comfortable, an autogenous con-

junctional protective "lens" may be employed. The surgical area may then be infiltrated with local anesthetic containing epinephrine through the transconjunctival route. With the fornix of the lower lid conjunctiva engaged with a 5-0 fast-absorbing gut traction suture and lower lid retracted, a transconjunctival incision is made at the inferior border of the inferior tarsus using needle cautery and dissection carried through the lower lid retractors and into the post-orbicularis/pre-septal plane down to the inferior orbital rim. At this juncture, the tear trough-orbicularis retaining ligament may be released.

If fat transposition is planned, preperiosteal dissection is carried out in areas of soft tissue deficiency. The orbital septum is subsequently incised and the medial, central, and lateral fat pads as well as inferior oblique muscle visualized.

Tip
Care should be taken to observe the lateral fat pad, which is often fixed in its compartment and difficult to fully appreciate. This fat pad may be better visualized for manipulation by teasing it out of the lateral compartment using forceps or light digital pressure applied to the globe. If pressure is applied to the globe, the surgeon should be mindful of the oculocardiac reflex that causes bradycardia.

Depending on the patient's anatomy and surgeon's preference, the fat pads can be manipulated by resection, repositioning, grafting or a combination thereof, and guided by preoperative markings. As with the upper lid, fat resection should be conservative, limited only to that which herniates anterior to the inferior orbital rim with light digital pressure applied to the globe, in order to minimize the risk of a postoperative concavity and the "sickly" postoperative appearance.

Tip
Due to having greater skin elasticity, younger patients generally tolerate less fat resection than do older patient.

Instead of resecting excess fat, however, fat can be moved to areas of soft tissue deficiency, for example, set over the inferior orbital rim or tunneled into the nasojugal groove, while preserving its blood supply. It can be fixed into position using loosely tied transcutaneous sutures or other means of immobilization. If the excess fat is inadequate to reach areas of soft tissue deficiency, then it can be detached from its pedicle and transferred as a fat graft. Alternatively, fat may be harvested from a distance donor site such as the abdomen or medial thighs and injected as micrografts using small cannulas into the areas of deficiency, either under direct visualization into the orbicularis oculi muscle or through separate stab incisions following skin closure. The senior author (HMS) has used deep orbital fat grafts placed under direct vision, but we only recommend this technique in experienced hands.

The traction suture is then removed and conjunctiva reapproximated with a single 5-0 fast-absorbing gut buried interrupted suture placed lateral to the cornea.

Tip
Only the conjunctiva should be reapproximated with this suture, as including underlying structures increases the risk of pyogenic granuloma formation.

If a small amount of dermatochalasis is present, a marginal skin trim and closure with a 6-0 silk suture may be performed, or other skin resurfacing techniques, such as chemical peel or laser treatment, may be used. Lastly, topical antibiotics

containing a corticosteroid may be applied when not contraindicated.

Postoperatively, ophthalmic drops and ointments may be continued for 5–7 days. If a marginal skin trim was performed, the silk suture may be removed after 3–5 days and, if fat repositioning was performed, transcutaneous sutures removed after 1 week.

Transcutaneous Approach

Beginning with markings, the lower lid transcutaneous incision is marked 2–3 mm below the lower lid lashes from a point lateral to the medial punctum and extending laterally across the lower lid and ending within a periorbital rhytid. If applicable, the areas for fat resection and/or redistribution should also be marked with the patient awake and in the upright position.

The lower eyelid transcutaneous blepharoplasty procedure starts with infiltration of the marked area with local anesthetic containing epinephrine in the subcutaneous plane. A small incision is made at the lateral aspect of the planned incision through skin and orbicularis oculi muscle, and curved small scissors are inserted into the post-orbicularis/pre-septal plane (potential space) to undermine the myocutaneous flap. The remainder of the lower lid incision is then made with an Iris scissor in a stairstep fashion, first through skin at the delineated location, and then through orbicularis muscle at the inferior border of the inferior tarsus for the preservation of the pretarsal orbicularis muscle, which is responsible for eyelash orientation (Riolan's muscle) (Fig. 8.4).

Tip

The key dissection is defining the post-orbicularis/pre-septal space.

Tip

Use of an Iris scissor to make subciliary incision has the added advantage of more control to preserve the eyelid lashes.

Tip

Transcutaneous lower eyelid blepharoplasty can also be performed using a skin-only flap, which may be more effective at treating lower lid rhytids, but at the risk of postoperative skin contracture and potential for lower lid malposition due to decreased vascularity.

Tip

If midface lift is planned, then this dissection is carried out in the subperiosteal plane across the midface, and all encountered retaining ligaments of the face are released to achieve complete mobilization of the cheek.

As in the transconjunctival approach, the orbital septum is incised and the three fat pads and inferior oblique muscle visualized. Again, care should be taken to observe the lateral fat compartment. The fat pads can then be manipulated by resection, repositioning, grafting, or a combination thereof, as previously described.

At this point, lateral canthal tendon anchoring procedures, such as canthopexy or canthoplasty, can be performed as informed by patient history, physical exam, and the operative plan [22]. Canthopexy, defined as tightening or suspension of the lateral canthal tendon without division of one or more of its elements, is performed either by plication of the lateral aspect of the inferior crus of the lateral canthal tendon or the common canthal tendon, or by fixation of the tendon directly to the lateral orbital rim periosteum. The utility of canthopexy is limited to treating mild degrees of lower eyelid laxity and providing lower lid support to counteract distraction forces from edema or less aggressive skin treatments during the postoperative period.

For more severe lower eyelid laxity or in cases of failed prior canthopexy, a canthoplasty, which involves division of part or all of the lateral can-

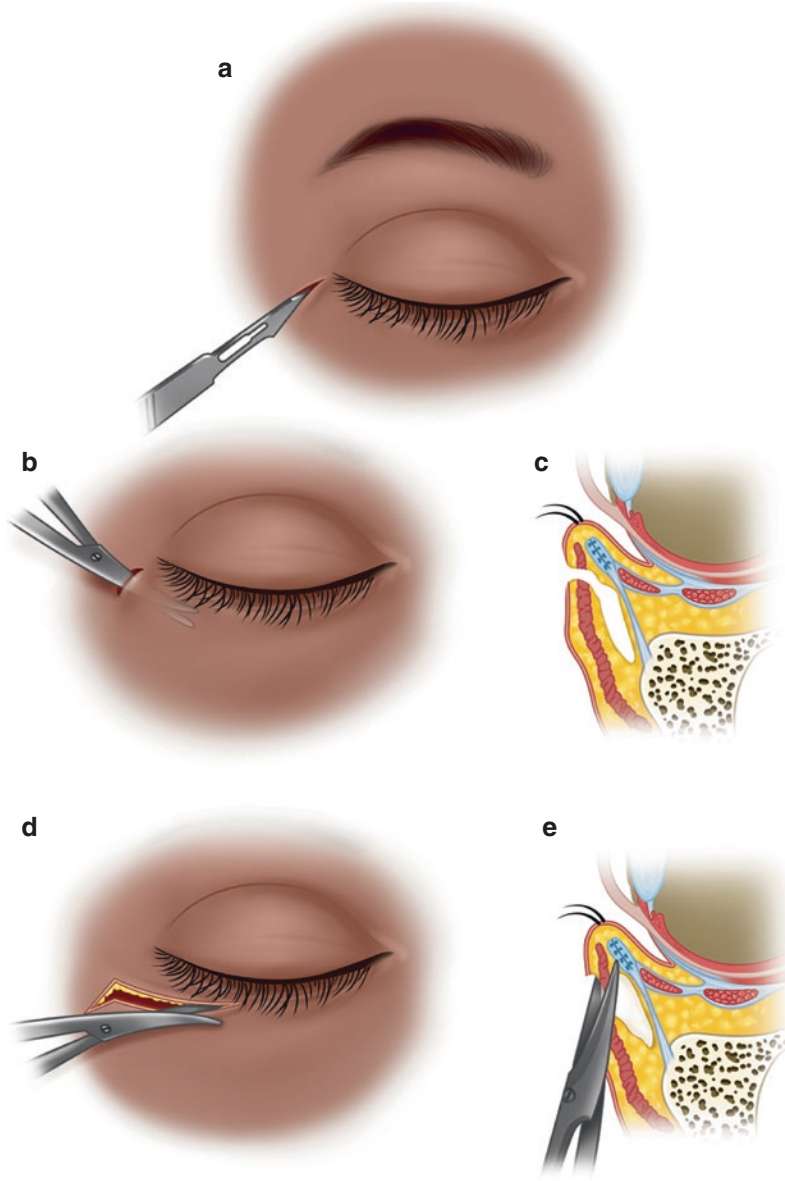

Fig. 8.4 As with the upper lid, the successful completion of the lower lid blepharoplasty requires a few technical steps which will simplify and speed its execution. The anatomy of the lower eyelid can be advantageous to the surgeon in properly performing these steps. (**a**) The primary incision should be in a desired fold or potential fold at and lateral to the lateral canthus. The incision should be limited, but be able to admit a small curved scissor. The scissor should be passed through the incision into the suborbicularis preseptal space. (**b**, **c**) This plane is developed from lateral to medial while gently pushing and spreading the scissor. Once this plane is developed, the myocutaneous flap can be mobilized with ease. The scissors are withdrawn and only one limb is inserted into the preseptal post orbicularis plane, with the other over the skin surface. The scissors may be beveled toward the eyeball (less skin, more muscle). (**d**, **e**) The second incision is completed lateral to medial with the assistance of inferior digital traction, ending just lateral to the lower lid punctum. The flap should be mobilized to the orbital rim without violating the septum. This is best achieved with a combination of digital cheek traction inferiorly and instrument elevation of the myocutaneous flap. (Modified from *Atlas of Aesthetic Eyelid and Periocular Surgery* © 2004 Henry M. Spinelli, M.D. All rights reserved)

thal tendon with a canthotomy, appropriate shortening of the lax lower lid, and then fixation to the lateral orbital rim, can be performed [23]. Canthoplasty is a powerful procedure that can be used to tighten the lower lid against the globe, as well as alter the position of the lateral canthus in order to accommodate varying degrees of eye prominence and different fissure shapes. Release of the lateral retinaculum and proper canthoplasty execution will allow the surgeon to position the lateral canthus and commissure virtually anywhere around the clock.

Tip
Lateral canthal tendon anchoring procedures, canthoplasty in particular, is capable of altering palpebral fissure shape. As a result, it is prudent to discuss, as part of the informed consent process, the potential effects of such techniques on eyelid aesthetics.

Tip
As with many repositioning procedures in canthoplasty, the key is in the release.

One such technique the senior author (HMS) believes should be in everyone's armamentarium is the modified lateral tarsal strip canthoplasty, wherein a lateral canthotomy is first performed and lateral canthal tendon inferior crus and other retinacular elements tethering the lower lid are divided. Once the lower lid is completely mobilized, a tarsal strip is created by circumferentially de-epithelializing the redundant segment of lateral lower lid, which is back-cut under the tarsal plate. This neocanthal tendon can be trimmed as needed for proper positioning of the lower lid margin and anchored to lateral orbital rim periosteum at Whitnall's tubercle using a double-armed braided nonabsorbable 4-0 suture on a spatulated semicircular needle. In conjunction with either canthopexy or canthoplasty, a temporary tarsorrhaphy, so-called "Frost suture," may also be placed to provide support to the eyelids during the period of maximal postoperative edema.

Tip
The inherent shortcoming of the tarsal strip canthoplasty is lower lid-to-upper lid length discrepancy.

Tip
Should insufficient periosteum be available for fixation, a hole can be drilled through the lateral orbital rim at that location and used as the anchor point.

Following lateral canthal tendon anchoring procedures, if applicable, a commissuroplasty is performed by precisely reapproximating the upper and lower eyelid margins using a single 6-0 Vicryl interrupted suture.

Tip
Successful lower lid positioning may be facilitated by preplacing the canthoplasty suture, but not tying it down until the commissuroplasty is complete.

The myocutaneous flap is then redraped in a superolateral direction and a triangular area of skin lying lateral to the lateral canthus, and no more than 2–3 mm of orbicularis muscle, should be resected based on surgeon judgment.

Tip
To avoid overresection, the patient may elicit downward distraction forces on the lower lid by looking up with mouth open.

The orbicularis muscle is resuspended to the periosteum of the lateral orbital rim at the level of the lateral canthotomy with one or two 5-0 Vicryl interrupted sutures. Lastly, the skin is closed using a 6-0 silk running suture from medial canthal region to just medial to the lateral canthal region, and 6-0 nylon interrupted sutures laterally.

Postoperatively, ophthalmic drops and ointments may be continued for 5–7 days. The silk and nylon sutures may be removed after 3–5 days postoperatively and, if fat repositioning was performed, transcutaneous sutures removed after 1 week.

Finally, the senior author (HMS) prefers common canthal repositioning in canthoplasty wherever possible. Basically, like other canthoplasty procedures, the importance of the lateral retinacular component release cannot be overstated. The advantage, of course, is that by positioning the entire canthus and commissure, one eliminates the lower-to-upper lid length discrepancy.

Blepharoplasty Complications

Overall, blepharoplasty is a well-tolerated procedure with high patient satisfaction [24]. As described above, there are a number of principles that should be followed to safely and successfully select the right procedures for each patient. However, despite the surgeon's best efforts, postoperative complications inevitably occur and, when they do, early identification and prompt intervention are paramount for effective resolution with minimal morbidity [3, 25]. While the most common complications are minor and will heal with supportive care, persistent or severe complications warrant close and careful care and referral to an ophthalmologist for further evaluation and additional specialized management [26, 27].

Retrobulbar Hematoma

Retrobulbar hematoma is the most feared complication of blepharoplasty, due to potential for vision loss. Signs and symptoms include severe retrobulbar pain, sudden pupillary changes, proptosis, loss of ocular motility, and ultimately progressing to vision impairment, beginning with a decline in red color perception, and blindness. Acute hemorrhage presents with rapid onset of proptosis and requires emergent treatment that includes performing a lateral canthotomy with cantholysis and re-opening all incisions for decompression and hematoma evacuation and hemostasis. This is followed by medical management with systemic corticosteroids, and topical β-adrenergic blockers (e.g., timolol) and systemic hyperosmolar agents (e.g., mannitol) to reduce intraocular pressure. Evaluation by an ophthalmologist is also indicated. Preventative measures include medical optimization of hypertension and any coagulopathies perioperatively, meticulous hemostasis intraoperatively, and early recognition of symptoms postoperatively.

Chemosis

Chemosis, or bulbar conjunctival edema, is thought to occur from conjunctival dryness leading to inflammation and edema. Treatment includes lubricating eyedrops and ointments in mild cases and temporary lateral tarsorrhaphy and/or conjunctivotomy in more advanced cases [3, 28]. Preventative measures include keeping the conjunctiva moist with lubricating eyedrops and ointments intraoperatively, and placement of a temporary lateral tarsorrhaphy in patients at high risk of developing postoperative chemosis such as those with lower lid malposition.

Eye Dryness

Blepharoplasty surgery may widen the palpebral fissure and thereby increase surface area of the exposed bulbar conjunctiva, leading to eye dryness. Treatment includes lubricating eyedrops and ointments and, if persistent, referral to an ophthalmologist for further evaluation. Preventative measures include conservative skin excision,

appropriate canthal anchoring, and liberal use of eyedrops and ointment perioperatively.

Corneal Injury

Corneal injury from abrasion can be a major source of patient discomfort after blepharoplasty surgery. Treatment includes antibiotic ointment and corneal protective coverage. Most abrasions will heal within 24 hours, but topical anesthetics may delay healing and risk neurotrophic corneal ulcer formation. Preventative measures include use of a protective contact lens that is rinsed with balanced saline and coated with ophthalmic lubricant prior to application. Sometimes pressure patch or temporary tarsorrhaphy is necessary in more severe cases.

Eyelid Malposition

Scleral show, ectropion, entropion, lagophthalmos, and A-frame deformity can all occur from a number of causes, including overresection of skin and/or fat and overaggressive tissue dissection. Blepharoptosis can occur from injury to the levator complex. Treatment depends on the type and severity of lid malposition and discussion is outside the scope of this chapter. However, it is worth mentioning that most cases of lid malposition improve considerably over time, some resolving completely. Consequently, watchful waiting may be the best initial approach. Preventative measures include conservative skin and fat resection, careful dissection, appropriate canthal anchoring, and identification and protection of the levator complex.

Tip

Many to most postoperative eyelid malpositions can be obviated with judicious application of preoperative history taking, examination, and, above all, planning and surgical execution.

Extraocular Muscle Injury

The inferior oblique muscle is located between the central and medial inferior orbital fat pads and is at risk of injury during fat pad manipulation in lower lid blepharoplasty. Less commonly, the superior oblique muscle can be injured during upper lid blepharoplasty from damage to the trochlea. Extraocular muscle injury may result in temporary or permanent diplopia and strabismus. Preventative measures include identification and protection of the inferior oblique muscle and minimal cautery in the area of the trochlea.

Infection

Infection is a rare complication of blepharoplasty, but can be dangerous, especially if it progresses through the orbital septum and causes a deep orbital cellulitis or abscess. Treatment includes and ranges from topical and oral antibiotics for early simple cellulitis, to systemic antibiotics and evaluation by an ophthalmologist for deep orbital cellulitis, with severe cases necessitating operative intervention.

Tip

The orbital septum is already violated and compromised in blepharoplasty procedures which address fat. Therefore, one's threshold for aggressively treating the rare postoperative infection should be low.

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9 Body Contouring: New Technology and Technique for Contouring the Lower Torso

Dennis J. Hurwitz and Lauren M. Wright

Introduction

Tips and tricks are shorthand for concepts and techniques acquired through thoughtful experience. While confirmable through anatomical study and retrospective clinical review, they are impossible to scientifically validate. Reliable tips and tricks are the means by which we improve our craft and teach.

The plastic surgery subspecialty of body contouring surgery has been the focus of the senior author (DJH) for the past 20 years. As applied to challenging massive weight loss (MWL) patients, body contouring has been a playground for innovation. DJH has designed the following operations: for sagging upper arms, L-Brachioplasty [1]; for ptotic breasts, Spiral Flap [2]; for sagging upper body, Transverse Upper Body Lift [3] and J Torsoplasty [4]; for ptotic gynecomastia, Boomerang Correction of Gynecomastia [5]; for ptotic mons pubis, Three-Sided Picture Frame Monsplasty [6]; for sagging medial thighs, Spiral Vertical Thighplasty [7]; for saddlebag deformity, High Tension Lateral Thigh Closure [6]; and for comprehensive body lift, single-stage Total Body Lift [8, 9]. These techniques have been published in peer-reviewed journals, with subsequent updates in journals and textbooks that include numerous tips and tricks that need not be repeated here [10–12]. This chapter is limited to the tips and tricks that relate to a new approach to lower body contouring.

Patient Considerations

The practitioner needs to appreciate their patients' functional and aesthetic concerns. The patients' expectations need to be realistic as related to their adiposity, skin laxity, and underlying musculoskeletal and visceral anatomy. Other considerations are general and psychiatric health and nutrition.

The recently harnessed technology of bipolar radiofrequency skin tightening [13, 14] and the surgical technique of Oblique Flankplasty [15] have been game changers. An informal review of over 100 patients during the past 4 years permits the authors to glean the following 18 tips and tricks related to surgery on the lower torso:

1. Preoperative 6-week Human Choriogonadatrophin (HCG)/500 calorie diet.

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2. Liposuction followed by BodyTite® for mild to moderate skin laxity.
3. Descriptive surface anatomy, not zones.
4. Pushing up ptotic buttock better defines flank excess.
5. Bulging flanks after LBL are not improved by transverse upper body lift.
6. Sagging or massively oversized flanks are not corrected by liposuction.
7. Plastic surgeons accept inadequate aesthetics when they expect no more.
8. Surgical innovation is often initiated by patient dissatisfaction.
9. When an innovator analyzes results, further advantages are discovered.
10. Dense adherences make Flankplasty long-lasting.
11. Flanks are the keystone of the torso.
12. VASERlipo for least traumatic form of liposuction.
13. BodyTite® treats mild skin laxity.
14. Lower body lift (LBL) for hip, buttock, and lateral thigh skin and adipose excess
15. Oblique Flankplasty for flank, buttock, lateral thigh, low back, mid back, abdomen, and lower lateral chest skin and adipose excess.
16. A large gel roll placed along the spine permits VASERlipo and BodyTite of flanks.
17. Lateral gluteal closure is a poor anchor.
18. Measure hatch marks of Oblique Flankplasty closure.

Preoperative 6-Week HCG/500 Calorie Diet

Overweight and obese patients with visceral adiposity, especially with diastasis recti or a hernia, who are unable to lose additional weight to reduce risk and achieve desirable recontouring, are offered a preoperative 6-week HCG/500-calorie-a-day diet [12, 16]. Case 1, shown in Fig. 9.1 is an

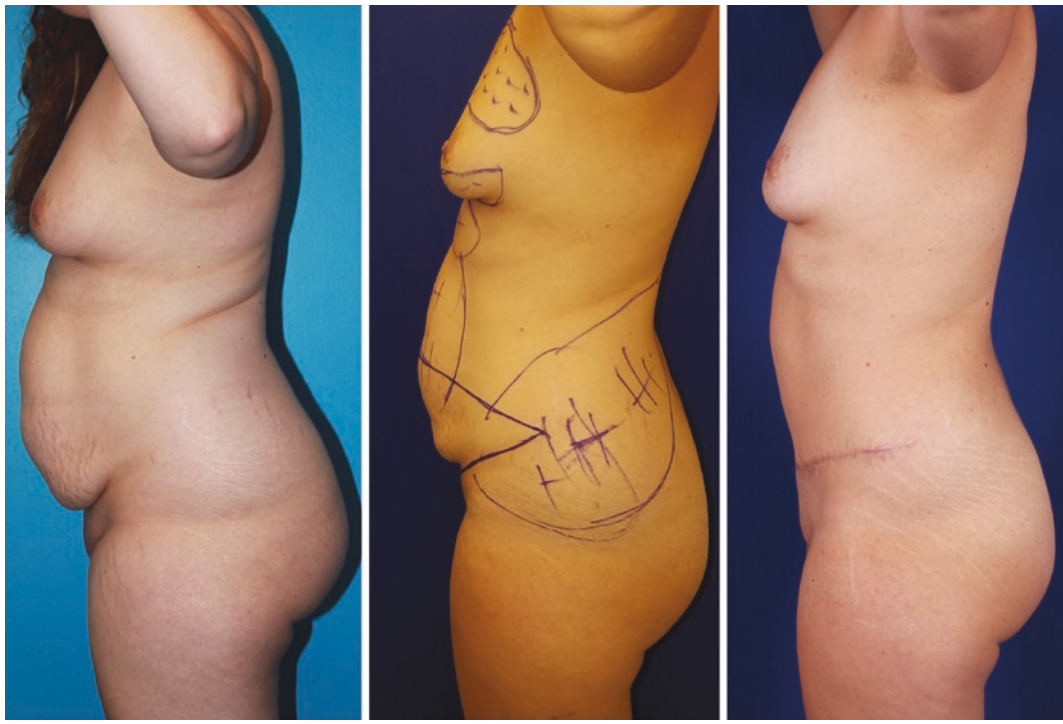

Fig. 9.1 Six-week HCG/500-calorie-a-day weight reduction prior to body contouring surgery. (Left) 35-year-old presenting with 31 BMI, skin laxity, diastasis recti, and umbilical hernia. (Middle) After losing 30 pounds on a 6-week HCG/500-calorie-a-day diet, she is marked for her lipoabdominoplasty with repair of diastasis recti and hernia, 1400 cc. VASERlipo of the flanks, and 800 cc. lipoaugmentation of her breasts prior marking of her lipoabdominoplasty with repair of umbilical hernia and Diastasis Recti, 1400 cc. Result, 2 years later, shows the maintenance of her pleasing results, with only a 10-pound weight gain (right)

example of a 35-year-old female with a BMI of 31 who lost 30 pounds with the HCG diet prior to lipoabdominoplasty, VASERlipo of flanks, and lipoaugmentation of breasts. Two years postoperative result shows the maintenance of desired outcome. Over the past 12 years, the senior author has administered this unique weight loss program at a charge of $1500 to over 400 patients who would otherwise not be surgical candidates. The HCG diet has a success rate of approximately 80% through to scheduled surgery, no complications, and high patient satisfaction.

Liposuction Followed by BodyTite® for Mild to Moderate Skin Laxity

On the other end of the spectrum of lower body contouring surgery, patients of BMI <30 with mild to moderate skin laxity may not benefit from, or wish to avoid, operations and instead elect liposuction followed by BodyTite® for quicker recovery and no visible scars (Fig. 9.2).

Descriptive Surface Anatomy Lower Body Contouring descriptive surface anatomy

The remainder of this chapter is devoted to operations on the posterior torso. When analyzing deformity and results, descriptive surface anatomy of critical areas of the posterior torso should be used instead of arbitrarily numbered zones. Figure 9.3 left shows the preoperative markings for Oblique Flankplasty, liposuction (+), and lipoaugmentation (−) labeled. The flanks lie between the tapering lower posterior ribs and the pelvic crest, with extension laterally and at times overlapping the hips. The hips are the soft tissue covering the posterior iliac crests. Manual upward push of both the buttocks and hips may be necessary to accurately define the flanks. The buttocks are the two adipose-filled convexities overlying the gluteus maximus, separated by the intergluteal crease. The lateral gluteal region lies inferior to the hip prominences and is often unaesthetically depressed. The lateral buttock bulge extends no lower than the inferior gluteal fold. Immediately inferior being the lateral thigh bulge, which overlies the greater trochanter with possible expansion to a saddlebag deformity.

The infamous waist-hip ratio, recently optimized at 0.65, relates to the widest extent of the buttocks (not the hips) to the narrowest width of the flanks adjacent to the lower ribs (drawn in blue, Fig. 8.3) [17]. While relevant to population studies, the waist-hip ratio reduction is just one of many factors in analyzing aesthetic improvement after surgery. Figure 8.3 right shows the 1-year postoperative scars and aesthetic improvement after an Oblique Flankplasty, revision of abdominoplasty scar, and vertical thighplasty. Figure 9.4 demonstrates oblique views of the patient in Figs. 9.3 and 8.3. Figure 9.4 left top and bottom and Fig. 9.4 right top and bottom are before and 1-year postoperative, showing aesthetic improvement of entire torso and thighs.

Bulging Flanks After LBL, Sagging or Massively Oversized Flanks, and Accepting Inadequate Aesthetics

Persistent bulging of the flank after LBL, which is not improved and possibly emphasized by a subsequent transverse mid back lift, is a rarely acknowledged disappointment of an LBL. Likewise, sagging or massively oversized flanks are not adequately improved by liposuction. Like other authoritative plastic surgeons, the senior author has not only ignored these shortcomings, but even failed to recognize them. Plastic surgeons and their patients accept an inadequate aesthetic result when they do not expect more than what they anticipate.

Surgical Innovation and Analyzing Results

The senior author's first flankplasty was revision surgery at the insistence of a discontented body contoured, MWL patient. After the failure of LBL and secondary liposuction to adequately reduce her sagging flanks, she demanded a direct oblique

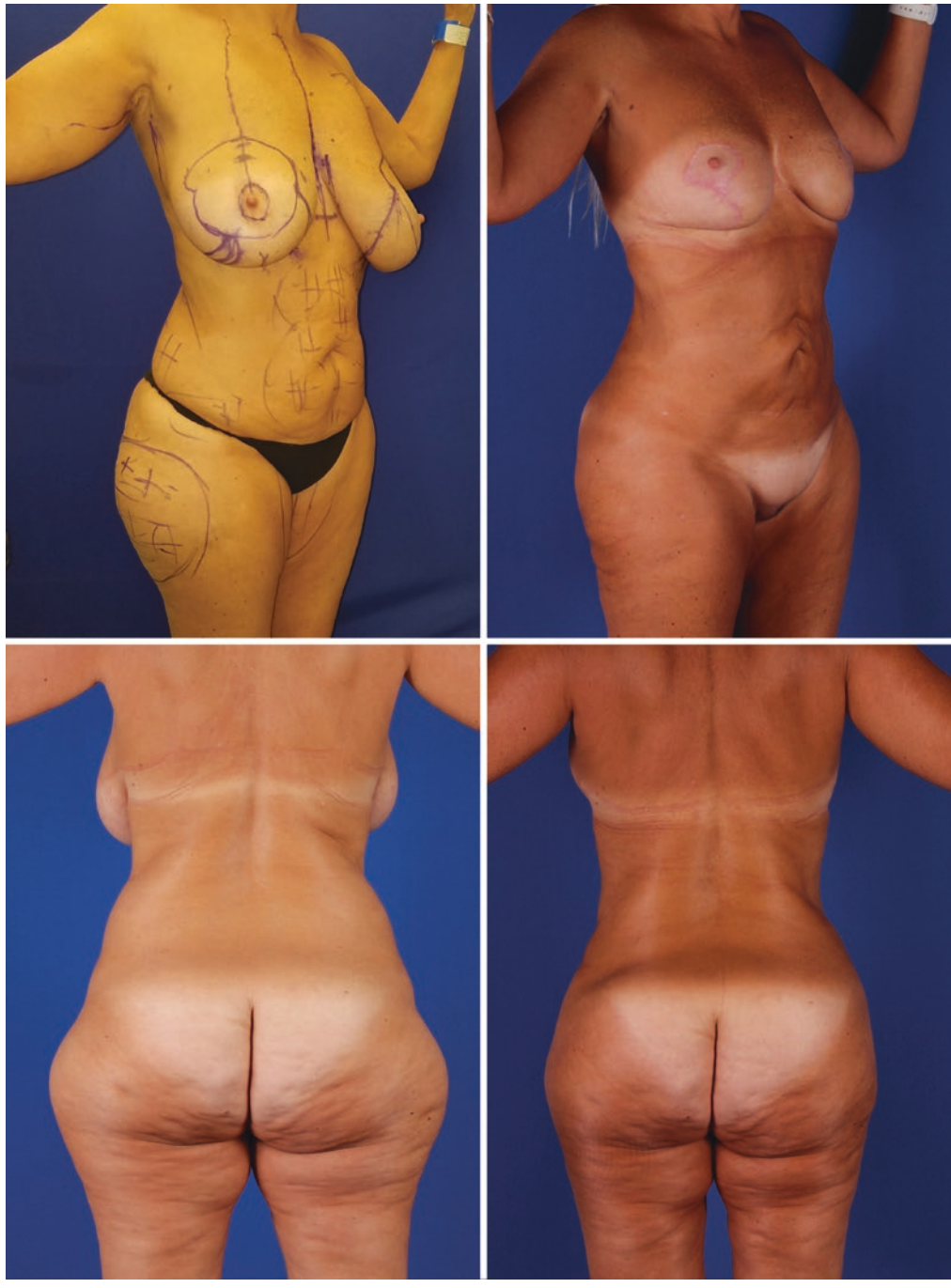

Fig. 9.2 Frontal and posterior views of body contouring with VASERlipo with BodyTite®. (Left) before with operative planning, and (right) 8 months after. Patient is a 54-year-old woman requesting scarless sculpturing of her torso and upper thighs at the time of her functional breast reduction. She does not have the pain tolerance, money, or time for recovery entailed in a lipoabdominoplasty. Her disturbing adiposity is tightly packed, with mild abdominal skin laxity. (Right) The operative plan of her superior pedicle, Wise pattern breast reduction, and VASERlipo followed by Bodytite® of the abdomen and upper thighs. BodyTite® was preemptively performed on the deflated saddlebag and medial thighs. By positioning a gel roll along her spine, the entire liposuction and radiofrequency treatment was efficiently performed supine. With two surgical teams, the operations were completed under 3 hours as an outpatient. (Right) Eight-month result shows hoped-for new contours. With only days of recovery, her residual abdominal skin wrinkling is preferred to weeks of recovery and a long abdominoplasty scar

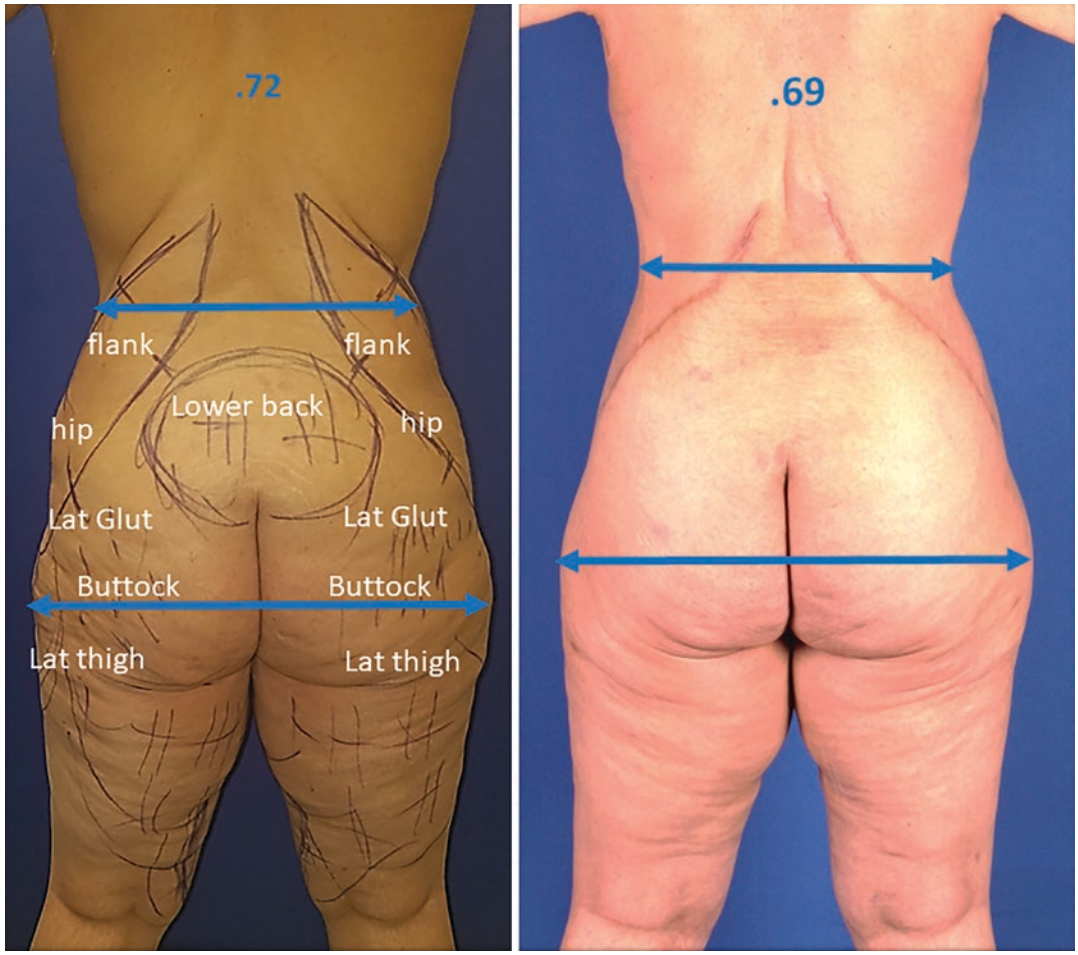

Fig. 9.3 (Left) Posterior view of the torso and thighs shows pertinent anatomical labels with preoperative markings for Oblique Flankplasty, VASERlipo of the low back and posterior thighs (pluses), superficial lipoaugmentation of the buttocks (minuses), and blue lines for measuring waist-hip ratios along the narrowest subcostal line divided by the widest buttock distance. Not seen are the markings for revision vertical thighplasty. (Right) One year later, see immature scars from the Oblique Flankplasty and aesthetic improvement of executing the complex surgical plan. The minimal change in the waist-hip ratio belies the dramatic aesthetic change. The flanks are broadly deeper and smoothly transition from the tighter skinned lower chest and raised well-defined hips. The lateral gluteal region and buttocks are suspended and fuller. Thigh skin wrinkling is reduced

excision. With full thickness excision down to lumbodorsal fascia, the flanks were deeply sculptured, and the lateral buttocks elevated. Her smoothly transitioned waist healed with faint scars. The patient's refusal to accept her sagging flanks after LBL was like the contrary boy in Hans Christian Anderson's parable *The Emperor's New Clothes*. He ignored the crowd's approval of the imaginary suit to proclaim the obvious, the King is wearing no clothes. My patient forced DJH to acknowledge the poor contours of her posterior waist and to reject plastic surgeon dogma that LBL closures be hidden. Surgical innovation is often initiated by patient dissatisfaction of the status quo, followed by demands for original surgery that ignores taboos and accepts uncertainty. Furthermore, when an observant innovator analyzes results of their technique, advantages never anticipated are often discovered.

That initial limited Oblique Flankplasty would probably have been forgotten, like so many other ad hoc operations, had not soon after two young,

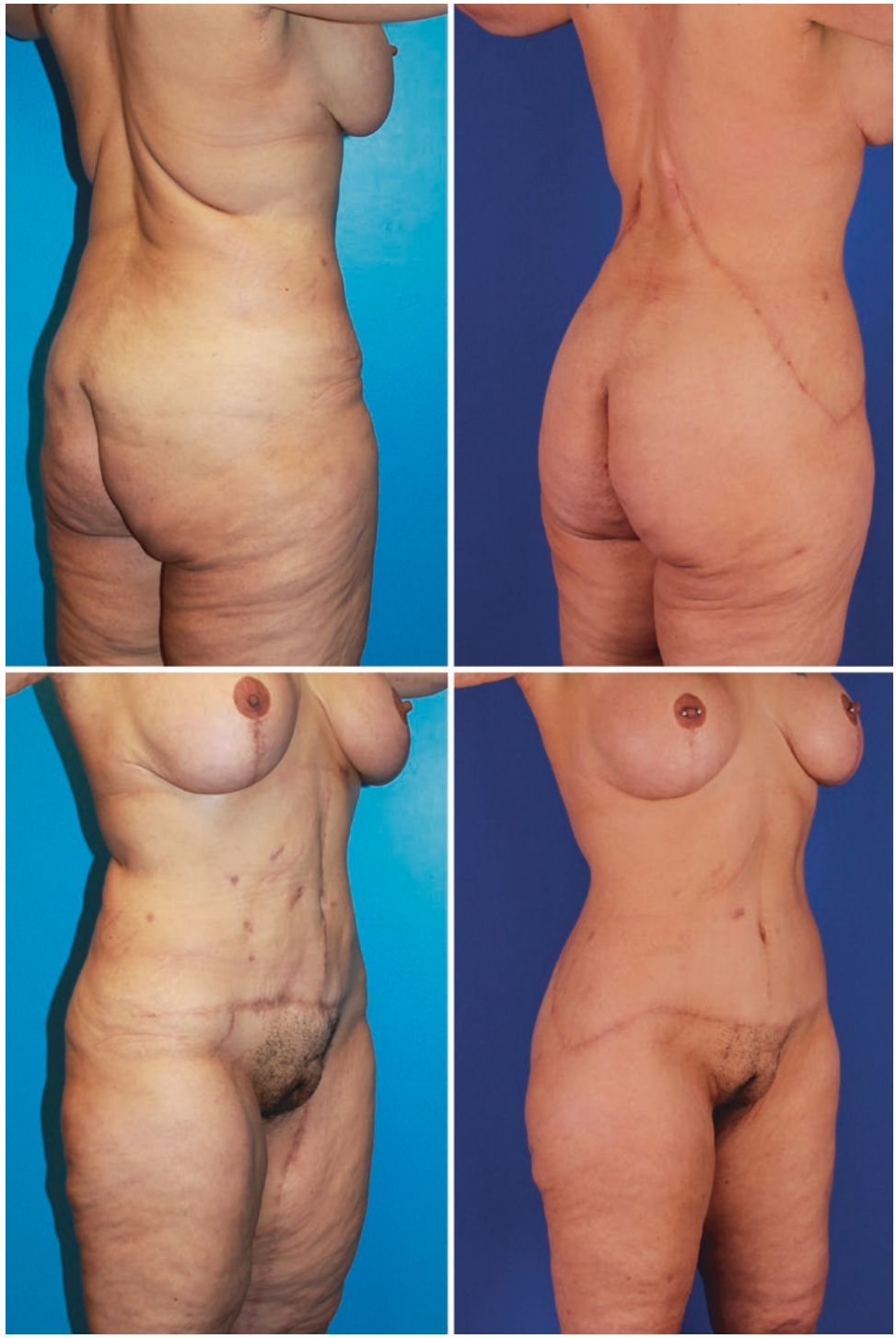

Fig. 9.4 (Left) Before oblique views shows the patient of Fig. 9.3 lower torso skin laxity and scars from her prior abdominoplasty and vertical thighplasty. (Right) Oblique views 1 year after her outpatient surgery show that Oblique Flankplasty and revision of her abdominoplasty and vertical thighplasty scars not only smoothly deepen the posterior waist but also correct skin laxity of the mid back, abdomen, and lateral buttocks and thighs

overweight, MWL patients with boxy torsos requested body contouring that included optimal narrowing of their waists. Oblique Flankplasty was combined with lipoabdominoplasty to fashion attractive waists, where there had been none. Their faint lower back oblique scars were a non-issue.

Dense Adherences Make Flankplasty Long-Lasting, and Flanks Are the Keystone of the Torso

Eighty Oblique Flankplasty patients later, we marvel at its incredible impact on shaping the entire torso. The closure is firmly sutured to dense adherences from the lumbodorsal fascia and, consequently, not only are the hips, lateral thighs and buttocks raised, but also skin laxity of low and mid back and abdomen reduced. The result is extensive and long-lasting because beyond deepening the flanks, oblique flank excision removes the most adherent skin of the torso beyond the midline. Flanks are the keystone of the torso.

The senior author's favorable experience with Oblique Flankplasty and bipolar radiofrequency for scarless minor skin tightening has altered the approach to contouring the posterior torso. The indications for the basic four contouring options are the following:

1. VASERlipo for least traumatic reduction of adipose [12]
2. BodyTite® treats mild skin laxity or after liposuction [13].
3. LBL for hip, buttock, and lateral thigh skin and adipose excess [14]
4. Oblique Flankplasty for flank, buttock, lateral thigh, low back, mid back, abdomen, and lower lateral chest skin and adipose excess [15]

VASERlipo reduces dense adipose with little to no residual sagging, due maximal preservation of neurovasculature and structural connective tissue.

Use a Large Gel Roll Along the Spine

Mild preoperative and anticipated secondary subcutaneous laxity after evacuation of adipose are immediately contracted with BodyTite®, involving multiple strokes of bipolar radiofrequency (Fig. 9.2). By positioning a large gel roll vertical along the patient's spine, VASERlipo and BodyTite® of the flanks and lateral thighs were performed under direct visualization without turning the patient prone.

Lateral Gluteal Closure Is a Poor Anchor

LBL treats loose posterior thigh skin and ptotic buttocks with minimal to no flank deformity, but often leaves an abnormally long intergluteal cleft (Fig. 9.5). As demonstrated by this patient, it is the evolution for many patients to suffer descent of the lateral buttocks, with deep lateral gluteal depressions and saddlebag deformity. Since this deterioration has also been seen in our LBL patients without MWL, the etiology is not poor quality of the MWL connective tissue, but more likely due to the lateral gluteal area being a poor anchor for advanced lateral thigh skin. Recent anatomical studies confirm the lack of adherences for closure stability in the lateral gluteal region [18]. Nevertheless, patients who refuse flank scars are offered LBL.

The evolution, details of technique, aesthetic evaluations, and 7% rate of minor complications of Oblique Flankplasty with lipoabdominoplasty (OFLA) were recently published [15]. The width of each flank resection is a gathering of the excess tissue over the flanks, while the ptotic lateral buttock and thigh are fully pushed superiorly. OFLA smoothly deepens the flanks along with tightening adjacent skin clear across the abdominal midline.

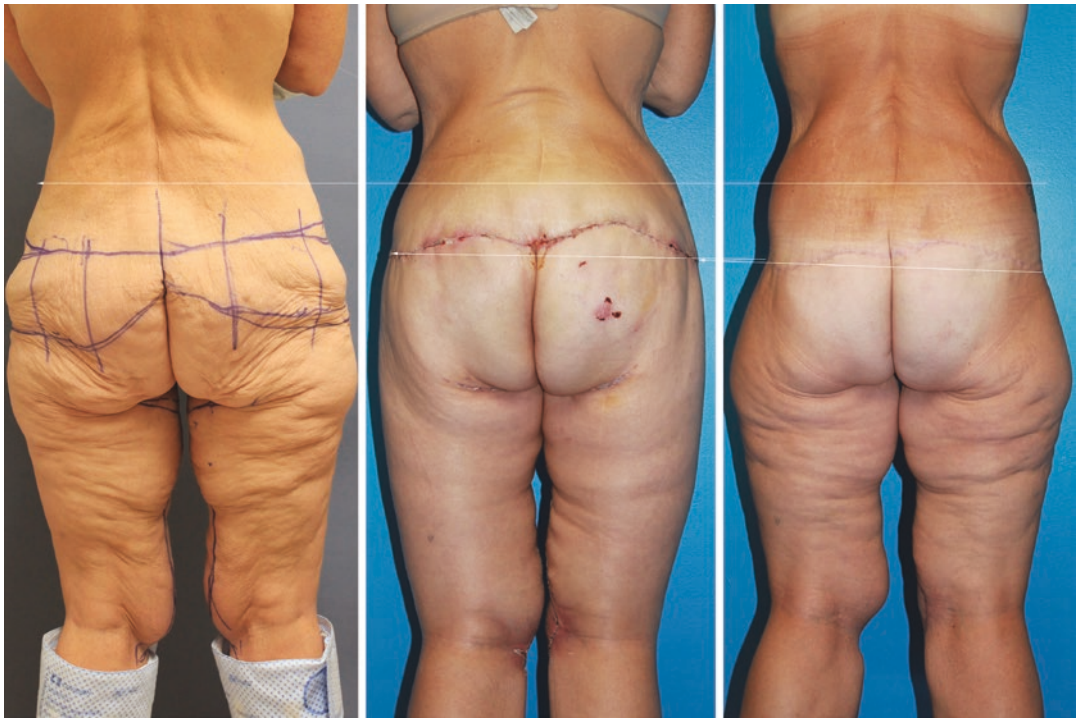

Fig. 9.5 Posterior views of LBL for loose posterior thigh skin and ptotic buttocks with minimal flank deformity. (Left) 34-year-old after losing 180 pounds has deep flanks and considerable excess skin and buttock laxity. (Middle) Two months after LBL shows hoped-for new contours of the hips, lateral gluteal, buttock, and lateral thighs, with no excess skin. She has an abnormally lengthened buttock crack. (Right) However, by 6 months, there is descent of the hip and buttocks, with lateral gluteal depressions and saddlebag deformity

Measure Hatch Marks of Oblique Flankplasty Closure

Measured hatch marking of Oblique Flankplasty closure allows a symmetric retraction of abdominal skin posteriorly and tapered redraping of the flanks. Figures 9.6 and 9.7 are oblique before-and-after views of the patient with measured hatch marks presented in the video 9.2. Left is before OFLA. Middle is 2 months after OFLA with VASERlipo of mid back roll and 200 cc. lipoaugmentation of lateral gluteal regions. Right is 1 week after J Torsoplasty upper body lift, Wise pattern Mastopexy, and Spiral flap breast reshaping, and addition 100 cc. lipoaugmentation of lateral gluteal region. The two stages work synergistically to create the best possible curvaceous torso contours.

The following two clinical examples of OFLA span the range of adipose presentation (BMIs 33 and 24, respectively). Both OFLA cases exhibit tapered narrowed waists; elevation of the hips, lateral buttocks, and thighs; and tight lower torso skin. Figure 9.8 demonstrates the effectiveness of adding VASERlipo of the low back/sacrum, mid back, lateral chest, and abdomen. Figure 9.9 shows that the skin redraping is tight enough to reveal underlying muscularity.

The following tips apply to Oblique Flankplasty as seen in our clinical examples:

1. Removes all flank excess tissue
2. Addresses vertical/horizontal waist excess
3. Removes watershed adherence of mid torso
4. Secure anchored closure
5. Tightens adjacent skin
6. Reshapes entire torso
7. Smoothly tapers waist
8. Excision site fat donor if needed
9. Sculpture by selective adipose removal and retention

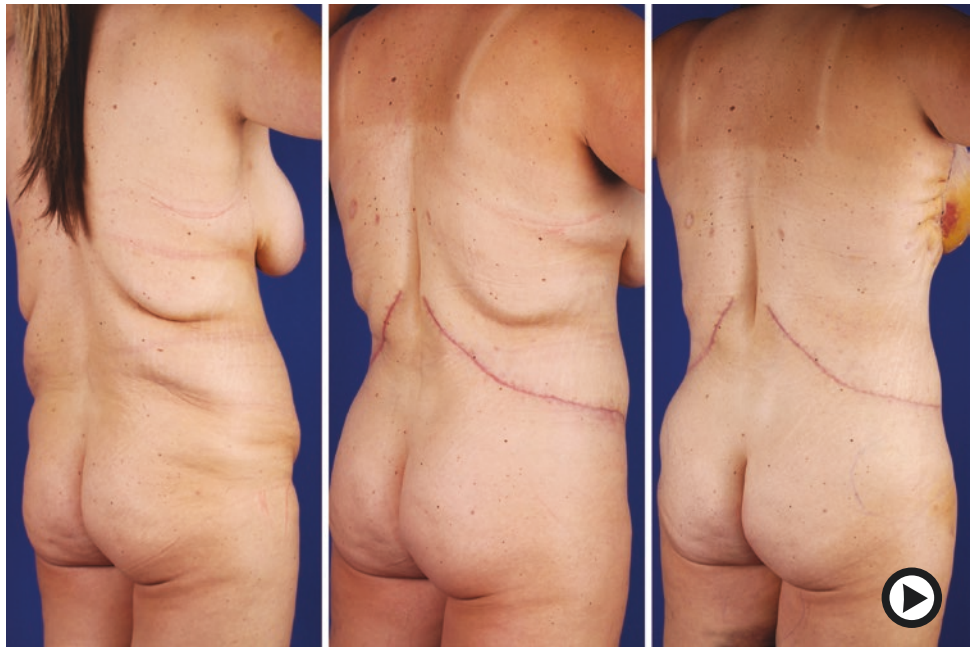

Fig. 9.6 Posterior right oblique views of patient with measured hatch marks presented in **Video**. (Left) before OFLA, (Middle) 2 months after OFLA with VASERlipo of mid back roll and 200 cc. lipoaugmentation of lateral gluteal regions. (Right) One week after J Torsoplasty upper body lift, Wise pattern mastopexy, and spiral flap breast reshaping (▶ https://doi.org/10.1007/000-3tk)

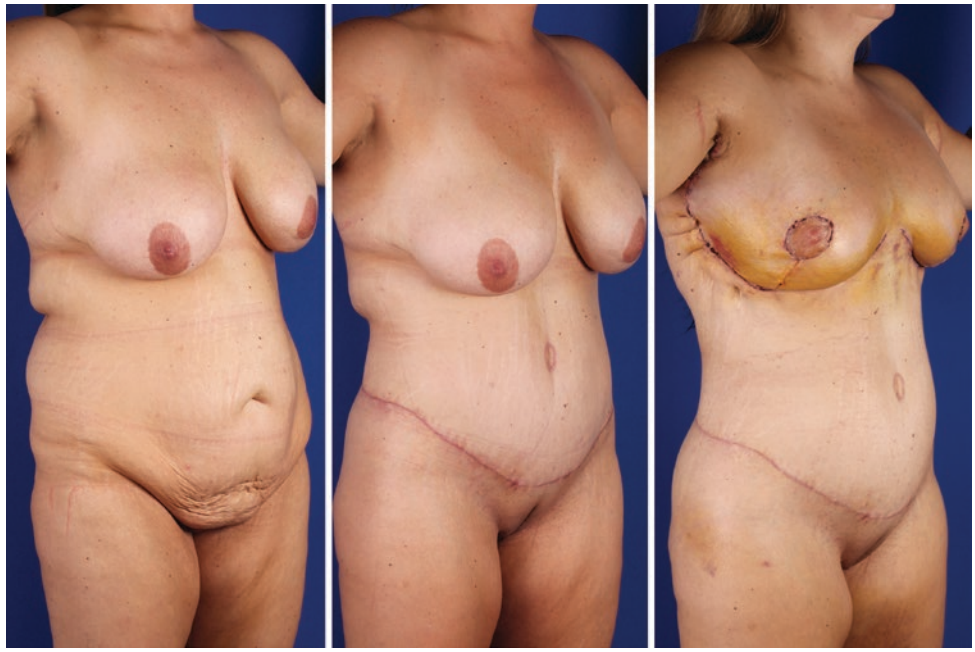

Fig. 9.7 Anterior right oblique views of patient with measured hatch marks presented in **Video**. (Left) before OFLA, (Middle) 2 months after OFLA with VASERlipo of mid back roll and 200 cc lipoaugmentation of lateral gluteal regions. (Right) One week after J Torsoplasty upper body lift, Wise pattern mastopexy and spiral flap breast reshaping. The two stages work synergistically to create the best possible curvaceous torso contours

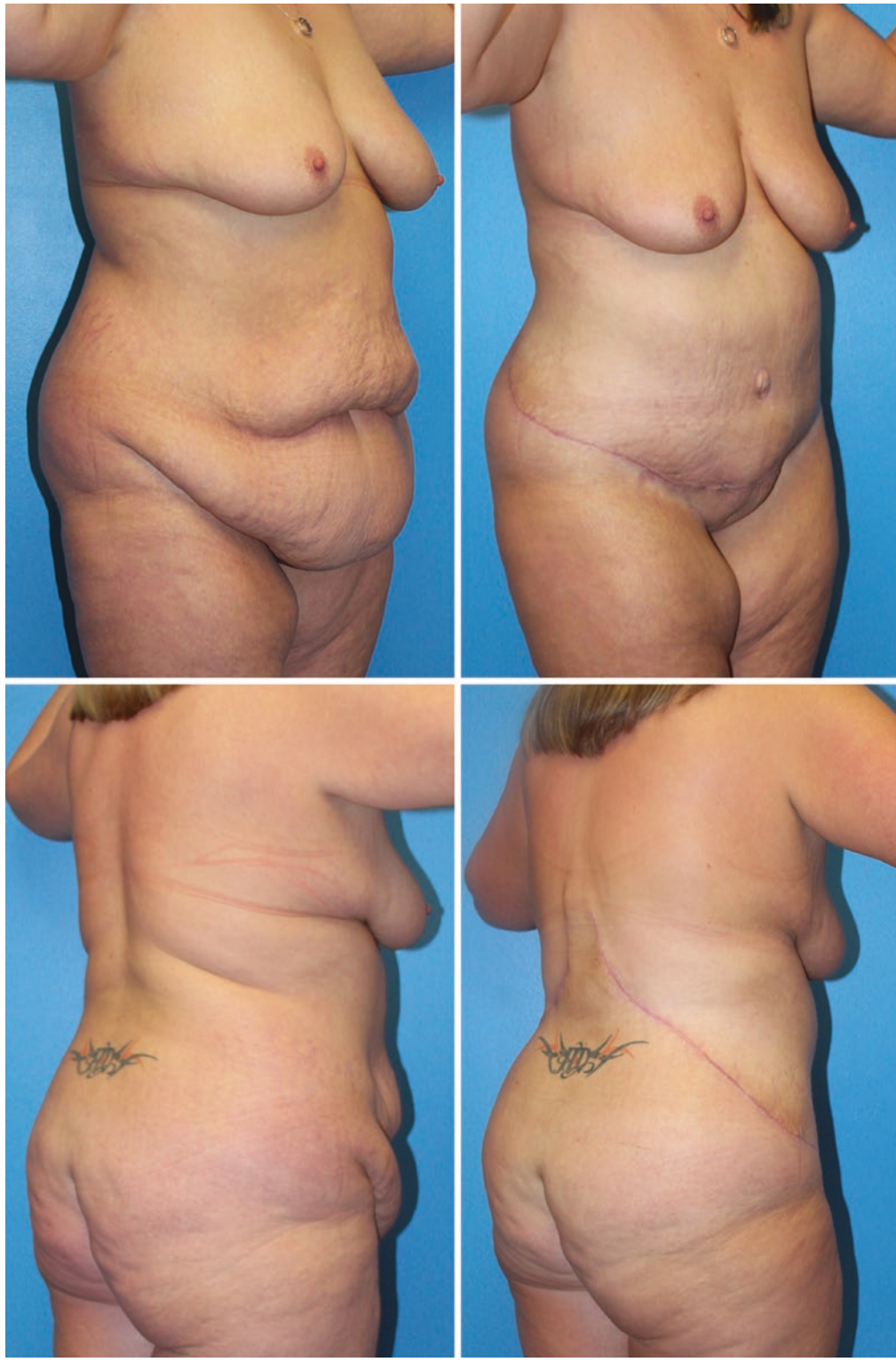

Fig. 9.8 Oblique views of a 42-year-old, BMI 34, before (Left) and after (Right) OLFA. Beyond the tapered deep waists, adjacent bulging rolls are effaced

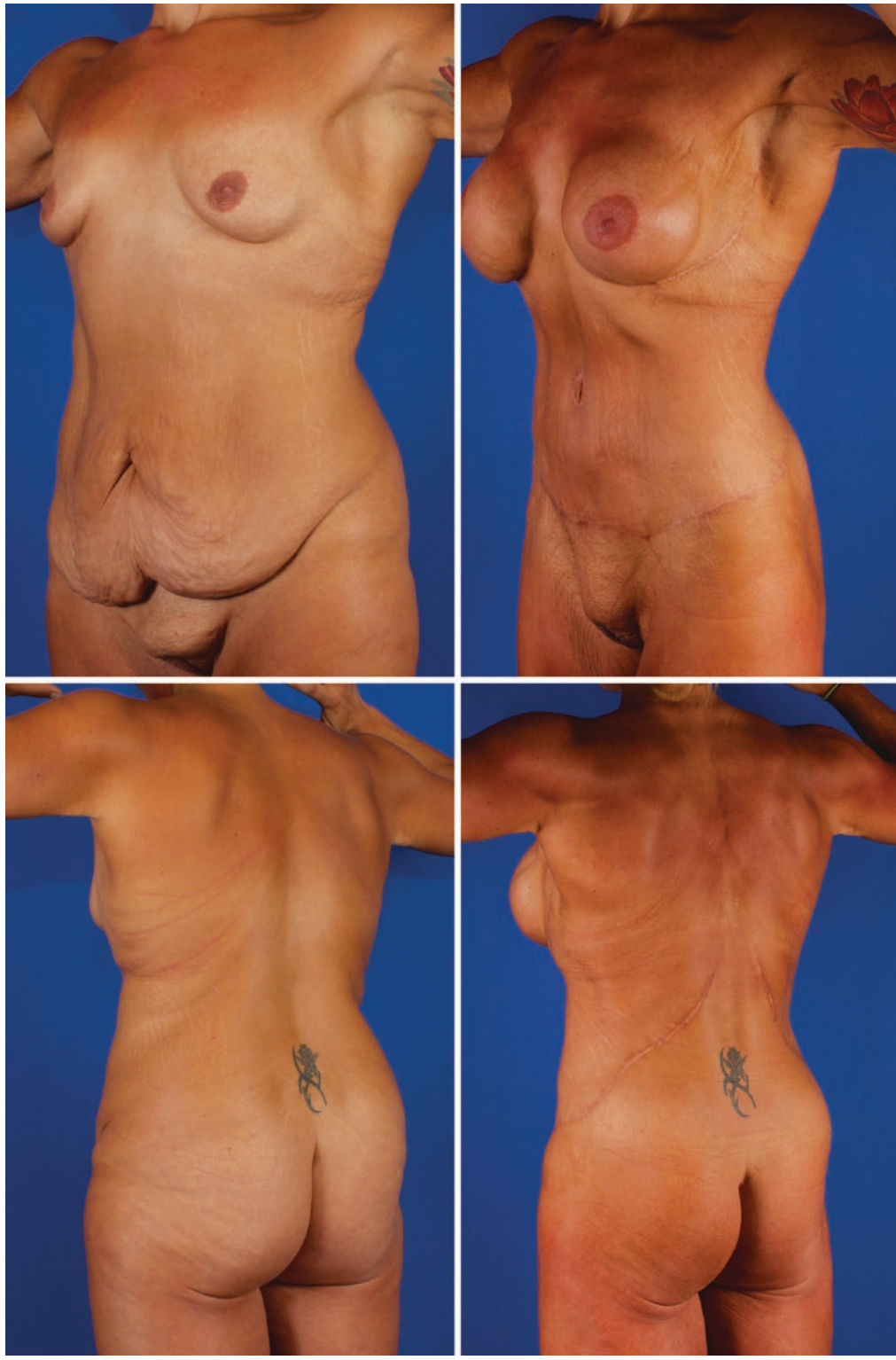

Fig. 9.9 Oblique view of a 32-year-old after losing 120 pounds (Left) and then 6 months after OFLA and breast augmentation with J Torsoplasty (Right). Tightly wrapped skin reveals underlying muscularity

10. Extends and improves lipoabdominoplasty
11. Corrects lateral buttock and thigh sagging
12. Rounded lateral buttock lift
13. Intergluteal cleft unchanged
14. Preserves para sacral dimples
15. Closure not over boney sacrum
16. Explained as a modified LBL
17. Bulging hip reduced
18. Smaller and rounded hip
19. No lateral gluteal depression
20. Saddlebag correction
21. Permits coincidental liposuction low and mid back
22. Faint scars
23. Easily planned and executed
24. Two teams
25. No transfusions in first 60 patients
26. Outpatient surgery
27. Less pain than abdominoplasty
28. Reduces epigastric excess
29. Alternative to Fleur de Lys abdominoplasty
30. Restores lumbodorsal musculofascial mechanical advantage
31. 7% minor complications
32. No secondary deformity
33. Compliments J Torsoplasty
34. Revises prior unsatisfactory LBL and/or liposuction
35. Predictable

Conclusion

The discovery and development of Oblique Flankplasty as a tool for contouring the torso have led the senior author to reflect on the process and share a myriad of observations and technical details. VASERlipo and BodyTite® combine for the treatment of localized adiposity with minimal to moderate skin laxity. Together, these advantages in lower body surgery take their rightful position in sculpturing the torso.

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Suction-Assisted Lipectomy and Brazilian Butt Lift

10

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Introduction

Suction-assisted lipectomy (liposuction) remains one of the most common aesthetic surgical procedures performed by surgeons in the United States. Both, the American Society of Plastic Surgeons (ASPS) and the American Society for Aesthetic Plastic Surgery (ASAPS), rank liposuction as the second most common surgical procedure reported by their members, and each society reported more than 250,000 cases performed in 2018 [1]. Brazilian butt lift (BBL) procedures, although less common, have seen over a 60% increase in cases over the past 5 years. More than 26,000 BBL procedures were reported by the ASAPS members in 2018 [2].

Consultation

Our initial consultations for body-contouring surgery, in particular liposuction or BBL procedures, involve the use of the TouchMD system (Cedar City, Utah). This system creates an electronic patient file that allows the patient's photos to be marked via a smart screen. All the preoperative markings are first performed on the patient's photos and saved while the patient is observing the screen. The specific areas marked for contouring are reviewed with the patient, so as to avoid misunderstandings as to what areas will be involved in the surgery. Any preexisting contour deformities are also highlighted and discussed with the patient (Fig. 10.1). The system allows the patient to access their personal file from their own computer, so they have the opportunity to review their consultation from home. The high-definition images are dated and saved by the system and are used on the day of surgery to guide the preoperative markings. We have found that employing this system as part of our liposuction and BBL consultations has significantly improved patient education.

Suction-Assisted Lipectomy (Liposuction)

Preoperative Preparation

Appropriate patient selection remains one of the most important factors in achieving acceptable results in any type of liposuction surgery [3]. Prudent surgeons practicing traditional liposuction, that is, suction-assisted lipectomy (SAL),

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Fig. 10.1 TouchMD consultation

typically limited their patient selection to fairly young, healthy patients, with well-defined areas of lipodystrophy, relatively close to their ideal body weight and with good skin tone [4]. Currently, plastic surgeons have been able to expand the patient selection criteria by employing larger volumes of wetting solutions and using ultrasound-assisted liposuction (UAL) and, more recently, VASER-assisted liposuction (VAL) [5]. Since the advent of VAL, the senior author (OG, Jr) has frequently performed high-volume liposuction with acceptable results on healthy but overweight patients with moderate skin tone [6].

Liposuction is still an elective, aesthetic surgical procedure, and even though we have expanded the patient selection parameters, one criterion that remains unchanged is that the patient needs to be in good health to undergo the surgery. One must take note and preoperatively discontinue commonly used nonprescription medications that may affect clotting or platelet function. The patients also need to be evaluated for risk factors that could potentially lead to deep vein thrombosis (DVT) or pulmonary emboli (PE). A 33/100,000 incidence of DVT and 12/100,000 of PE following liposuction surgery was reported by Teimurian and Rogers [7] in a survey of over 75,000 major liposuctions. A mortality rate of 19/100,000 for patients undergoing liposuction was reported by Grazer and DeJong [8] in a survey of the American Society for Aesthetic Plastic Surgery (ASAPS). Pulmonary emboli accounted for 25% of the reported deaths. It is the opinion of the senior author (OG, Jr), based on thousands of liposuction procedures personally performed, that proper patient selection, use of intermittent pneumatic compression boots, appropriate hydration, and early ambulation should result in virtually zero DVT-related complications following liposuction.

Preoperative markings are performed with the patient in the standing position. Waterproof markers of different colors are used to outline the specific areas planned for contouring, incision sites, and preexisting contour irregularities which are marked in red.

The senior author (OG, Jr) has been performing liposuction surgery since 1984; however, for the past 17 years, the great majority of these surgeries have all been performed using VASER-assisted liposuction. There are significant advantages to using this technology, including less blood loss, less postoperative bruising, better skin retraction, decreased postoperative discomfort, and a low complication rate, in experienced hands [9–12].

Anesthesia and Wetting Solutions

The dermatology literature contains numerous publications on the safe use of local anesthesia for liposuction surgery [13–15]. At the time that tumescent local anesthesia (TLA) was introduced for liposuction, the majority of the dermatologists in the United States were not able to perform inpatient liposuction because they lacked the necessary hospital privileges to perform the procedure. So, the original motivation behind TLA was to perform liposuction on an outpatient basis [16].

After over three decades of performing liposuction, we have come to the conclusion that general anesthesia works best for the great majority of my liposuction cases. Many of our cases are moderate- to large-volume aspirations performed circumferentially. With the patient in the lateral decubitus or prone position, having an endotracheal tube in place with proper control of the airway is of paramount importance.

Our general anesthesia protocol involves intravenous induction with propofol in combination with fentanyl and the anesthetic agent employed is sevoflurane.

Zofran (4–8 mg) is administered intravenously for 30 minutes before the end of surgery, since about one-third of patients undergoing liposuction experience postoperative nausea and vomiting [17].

Hypothermia, ranging from 33 to 36 °C, is commonly experienced by patients undergoing liposuction as a result of the effects of anesthesia, infiltration of large volumes of wetting solution, and the large body surface areas exposed during the procedure. Preoperative warming of the patient helps reduce the hypothermia associated with anesthesia induction. Employing a Bair Hugger (Arizant Inc., Eden Prarie, MN) before, during, and after the procedure is extremely helpful in maintaining the core temperature. Warming the intravenous fluids is helpful in minimizing hypothermia; however, we do not recommend warming of the wetting solutions. Infiltration of warm wetting solutions into the subcutaneous tissues is associated with an initial increase in vasodilation, with rapid absorption of the wetting solution into the intravascular space.

The VASER system (Solta Medical, Bothell, WA) delivers significantly less ultrasound energy to the tissues than the ultrasonic liposuction devices mentioned earlier; however, they perform more efficiently in a significantly wet environment. Since VASER liposuction requires higher volumes of wetting solution infiltrated into the tissues, it is associated with higher unquantifiable losses via the access incisions from the infiltrate backleaking under pressure. It was originally proposed that since only about 30% of the wetting solution infiltrate was aspirated in the liposuction aspirate, the other 70% would stay in the subcutaneous tissues and eventually be absorbed. My observation during numerous large VAL procedures is that close to a third of the infiltrate is lost through the access incisions both during the procedure and in the early postoperative period. That leaves only about a third of the wetting solution infiltrate behind that eventually gets absorbed. Since most of our circumferential cases are moderate- to high-volume, our preference is to place an indwelling Foley catheter to monitor the urine output, and we recommend beginning the intravenous fluids at a rate of 2 ml/kg/hour. This rate is adjusted in accordance with maintaining a urine output of close to 1 ml/kg/hour. This protocol for fluid replacement has served us well in many hundreds of patients who have undergone higher-volume liposuction, without experiencing fluid overload or hypovolemia.

Pulmonary edema complicating a tumescent liposuction was described by Gilliland and Coates [18]. Although the early presumption was that the high-volume infiltrate resulted in the pulmonary edema, Pitman [19] in his discussion attributed the complication to excessive parenteral fluids administered during the case. Typically, healthy individuals can tolerate high volumes of intravenous fluids (up to 2000 ml/hour), since these fluids usually enter the extravascular tissues within 15 minutes. However, when there are large volumes of tumescent infiltrate within the tissues, the hydrostatic pressure of that fluid in the subcutaneous space does not allow a gradient for the intravascular fluid to diffuse out of the vessels. This is another good reason to run the intravenous fluids at a very low rate during these surgeries, and adjust accordingly with the vital signs and desired urine output.

Jeffrey Klein, a dermatologist from California, began performing liposuction procedures using a tumescent local anesthesia formula in 1985. When Klein performed his first case, he used 35 mg/kg of body weight as the maximum dose for lidocaine. Since then, other published authors have written about formulas that employ higher total doses of lidocaine, some of which exceed 50 mg/kg of bodyweight [20]. Even lidocaine that is administered within the accepted maximum limits may result in toxicity [21]. Factors, such as obesity, oral contraceptive use, cigarette smoking, impaired renal function, impaired hepatic function, or cardiac disease, can affect the protein binding of lidocaine. Certain medications such as anorexiants, tricyclic antidepressants, histamine-2-blockers, and beta-blockers also affect the protein binding of lidocaine. Taking cytochrome p450 inhibitors may result in

lidocaine toxicity, even when the total dose of lidocaine administered is within the accepted safe range [22]. Absorption rates can vary significantly, so the total amount of injected lidocaine sometimes is a poor predictor of the potential for toxicity. Peak plasma lidocaine levels have a significantly better correlation with the potential for toxicity. Using lidocaine as part of the wetting solution formula in higher-volume, outpatient, tumescent-liposuction procedures carries significant risks. Lidocaine absorption can peak 10–12 hours after infiltration, hours after these patients are typically discharged from the surgical facility [23, 24]. Peak plasma levels of lidocaine in the 3 μg/ml are considered in the toxic range.

For most of my liposuction surgeries that are circumferential and moderate- to high-volume, my preference is general anesthesia. It not only improves patient comfort significantly, but also provides a safe airway in the prone and lateral decubitus position. My preference for wetting solution in these cases is 1 mg of epinephrine 1:1000 in a liter of Ringer's lactate solution at room temperature. I do not use lidocaine for general anesthesia cases, since its effect on postoperative pain is clinically irrelevant [25]. In the occasional small surface area case where general anesthesia is not utilized, 30 ml of 1% lidocaine is added to each liter of my standard wetting solution. Many proponents of tumescent local anesthesia for liposuction will disagree; however, we strongly believe that the total dose of lidocaine when used in a wetting solution should not exceed 35 mg/kg bodyweight. Since most major circumferential liposuctions require general anesthesia, they do not need lidocaine as part of the wetting solution formula. Smaller liposuction procedures without general anesthesia do not require such high volumes of wetting solution, so there really is no good reason to push the limits of lidocaine toxicity in these patients undergoing elective, aesthetic surgery.

Epinephrine is an important component of wetting solutions for liposuction. The vasoconstrictive effects of this drug have significantly decreased the blood loss in the aspirate during liposuction cases. Common effects of toxicity include an increase in blood pressure, tachycardia, and arrhythmias. A total dose of 10 mg has been proposed by some authors [26]. The University of Texas Southwestern has reported administering up to 12 mg in some cases, without associated complications. The senior author (OG, Jr.) has personally administered up to 14 mg in an intermittent fashion, throughout the course of a high-volume extraction case, without signs or symptoms associated with exceeding the toxic dose. It goes without saying that these patients require a proper monitoring of their vital signs during the surgery. It is important to note the importance of infiltrating the wetting solution at room temperature. Warm wetting solutions are associated with initial vasodilation and early rapid absorption of the wetting solution components. If there are concerns about hypothermia, the intravenous fluids can be warmed in conjunction with warmed forced air via a Bair Hugger. The common wetting solution formulas are depicted in Table 10.1.

Liposuction procedures, particularly high-volume extractions, present distinct challenges for the anesthesiologist. There is the potential for hypothermia, hypovolemia, fluid overload, and toxic effects from lidocaine or epinephrine. Of particular concern is the fact that peak plasma lidocaine levels can present 10–12 hours after infiltration, so toxicity may not manifest itself until hours after the patient has been discharged from the outpatient surgery facility. Position changes on the operating table can lead to postoperative sequelae of pressure-related injuries. For these reasons, an experienced anesthesiologist is preferred for the high-volume cases in which large amounts of wetting solution are employed. Strict adherence to fluid replacement guidelines, close attention to patient positioning, proper padding of all pressure points, and not exceeding the total recommended doses for both lidocaine and epinephrine will help avoid serious complications.

Table 10.1 Common wetting solutions for liposuction

Garcia's formula	*Fodor's formula*
Ringer's lactate solution 1 liter (room temperature, 21 °C)	Ringer's lactate solution 1 liter Small volume (<2000 ml)
Epinephrine 1:1000, 1 ml	Epinephrine 1:500, 1 ml
For local anesthesia cases	Moderate (2000–4000 ml)
Add 30 ml of lidocaine 1%	Epinephrine 1:1000, 1 ml
Total lidocaine dose not to exceed 35 mg/kg bodyweight Large volume (>4000 ml)	Epinephrine 1:1500, 1 ml
Klein's formula	*Hunstad's formula*
Normal saline 1 liter	Ringer's lactate solution 1 liter
Lidocaine 1%, 50 ml	(38–40 °C)
Epinephrine 1:1000, 1 ml	Lidocaine 1%, 50 ml
Sodium bicarbonate 8.4%, 12.5 ml	Epinephrine 1:1000 1 ml
Hamburg formula	*University of Texas*
Normal saline solution 1 liter	*Southwestern formula*
Lidocaine 2%, 10 ml	Ringer's lactate solution 1 liter (room temperature, 21 °C)
Prilocaine 2%, 10 ml	
Sodium bicarbonate 8.4%, 6 ml	Epinephrine 1:1000 1 ml
Epinephrine 1:1000, 0.7 ml	(<5000 ml) Lidocaine 1%, 30 ml
Triamcinolone 10 mg, 1 ml	(>5000 ml) Lidocaine 1%, 15 ml

Room temperature is used for all formulas except the Hunstad Formula, which warms the solution. The University of Texas Southwestern Formula specifically defines room temperature as 21 °C (70 °F). In the authors' formula (Garcia's Formula), we specifically mention room temperature to highlight the importance of not warming the tumescent fluid for ultrasound-assisted liposuction cases

Contouring of the Neck

Neck contouring by means of VASER-assisted liposuction (VAL) is a relatively common procedure. Most frequently, it is performed as a standalone procedure; however, in the authors' experience, about one-third of the cases are performed in combination with other liposuction procedures. Also, the techniques for submental and neck contouring can be performed by themselves or as an adjunct to open procedures such as facelifts [27]. The great majority of the fat extraction involves the neck and submental area.

Patient selection is imperative to achieving successful aesthetic results with neck contouring, since one should never trade fat for loose skin, particularly in a visible area like the neck. An accurate assessment of skin elasticity is mandatory, particularly in older patients or those with significant amounts of submental fat. Some patients with extensive submental fat may need to accept a secondary open procedure if prominent platysma bands are exposed following the neck defatting. Although complications are rare with this procedure, the informed consent for neck contouring with ultrasonic liposuction should include the possibility of postoperative contour deformities, asymmetry, prolonged edema, exposed platysma bands, thermal injury, pigmentation changes, neck skin paresthesia, and vascular injury.

The instrumentation used for neck and facial VAL is highly precise. The probes and cannulas are much smaller than those employed in body contouring, typically 2.4 mm in diameter (Fig. 10.2). Occasionally, 3-mm cannulas are employed for larger submental extractions; however, diameters greater than 3 mm are not recommended in the face and neck areas.

Three access incisions are commonly used for neck and facial contouring; one behind each earlobe and one in the submental crease. These incisions avoid placing torque on the ultrasound probes and provide good lineal access to the

Fig. 10.2 VASER-lipo facial instrumentation

entire neck. It is important to treat the whole surface area of the neck below the mandibular border in order to achieve better skin retraction. Involving the whole neck in the contouring yields a more harmonious result than spot suctioning. This is particularly important in cases that involve higher-volume submental extractions.

Our standard wetting solution (Garcia's Formula) [28] is modified for neck and facial contouring. When using general anesthesia, the formula consists of 1 liter of lactated Ringer's solution at room temperature, defined as 21 °C, plus 2 ml of epinephrine 1:1000. This is double the concentration of epinephrine recommended for body-contouring procedures where the wetting solution is dispersed in larger volumes over a large surface area. Obtaining good tumescence in a relatively small surface area such as the neck requires much less fluid and, in the authors' experience, the higher concentration of epinephrine results in a highly efficient vasoconstriction in the area, which results in minimal postoperative bruising. For intravenous sedation and local procedures, 50 ml of 1% xylocaine is added to the wetting solution. Infusion rates are 150 ml/minute for local procedures and 200–250 ml/minute for general anesthesia procedures. This is the rare surgical procedure where local anesthesia may not be the safest alternative. It is the authors' preference to perform large-volume submental liposuctions under general anesthesia. The large amounts of fluids that are infused into the neck tissues to create tumescence may lead to airway complications in patients under intravenous sedation.

For a typical neck-contouring procedure, the lead author (OG, Jr.) employs a 2.4-mm three-ring or five-ring VASER probe at 60% energy levels in pulsed (VASER) mode for approximately 3 minutes. Aspiration is performed with 2.4- and 3-mm VentX cannulas. Postoperatively, TopiFoam is contoured to precisely fit the area treated, and a commercially available head and neck compression garment is applied (Fig. 10.3). Patients are asked to maintain head elevation for several days, avoid high sodium intake, and avoid strenuous physical activity. Moisturizing massages are begun several days after surgery, as tolerated.

Contouring of the neck and submental area by means of VAL is a safe and efficient technique associated with a high patient satisfaction rate [29]. A significant advantage of VAL for contour-

Fig. 10.3 Typical head and neck compression garment

ing the neck is less postoperative bruising, resulting in decreased down time for the patient.

A 44-year-old woman requested improvement in her neck contour during her consultation (Fig. 10.4a–c). She had moderate pre-platysma lipodystrophy assessed by the pinch test. A VAL of the neck and submental area was recommended. The outpatient surgery was performed under intravenous sedation and local anesthesia. Retroauricular and submental incisions were used for access. The authors' recommended wetting solution formula for local cases was infused at 200 ml per minute to a total volume of 275 ml. A 2.4-mm five-ring VASER probe at 60% energy level was utilized for 2 minutes and 30 seconds in pulsed mode. Aspiration was accomplished with a 3.0-mm VentX cannula. Incisions were closed with buried absorbable sutures. A facial compression garment over a shaped TopiFoam sheet was applied immediately following the procedure. A total aspirate volume of 92 ml was extracted. Surgical results at 5 months are depicted in Fig. 10.4d–f.

Fig. 10.4 (**a–c**) A 44-year-old preoperative neck and submental contouring. (**d–f**) Five months post-VASER-assisted liposuction contouring of the neck and submental area

Contouring of the Trunk

The trunk is one of the most common areas for which patients seek liposuction. When contouring the trunk—either with traditional suction-assisted lipectomy (SAL) or with VASER-assisted liposuction (VAL)—a circumferential approach typically results in a more harmonious aesthetic result than "spot" liposuction. In all these cases, the patients will need to be repositioned on the operating table during the surgery in order to gain access to all the areas involved in circumferential contouring, which leads to lengthier surgeries and longer anesthesia times.

The approach to contouring of the trunk varies from females to males, and from younger patients seeking a more athletic appearance in a swimsuit to older patients just seeking improvement in physical proportions and better-fitting garments. For example, when contouring the posterior trunk in males, a "V" shape is desired. This is created by the musculature of the back tapering down to a straight, narrow waist. On the other hand, females require a more feminine back contour, which begins at the top of the posterior axillary crease and tapers down to a small curved waistline, which again widens at the level of the hips. Extensive flank liposuction in females creating narrow waistlines without addressing the upper back can create a masculine contour. For this reason, the authors recommend addressing the entire surface area of the posterior flanks and upper back during circumferential trunk-contouring procedures. The abdomen is not a flat surface, and as such, attempts should be made to highlight the normal anatomical landmarks, thus creating a more natural-appearing result devoid of liposuction surgery stigmata.

It is imperative to make a realistic assessment of the amount of fat that can be removed without adversely affecting the skin tone. For the experienced body-contouring surgeon, sometimes a pinch test and visual provide the information needed to create a treatment plan. The surgeon with less experience in body contouring may find a modification of the Matarasso classification, proposed by Rohrich, Beran, and Kenkel [30], helpful in assessing these patients and formulating a treatment plan. Prospective patients for abdominal contouring should be evaluated for the presence of rectus muscle diastasis, abdominal hernias, abdominal scars, skin elasticity, location of the fat, supraumbilical or infraumbilical, and how much of it is intraperitoneal vs extraperitoneal.

Preoperative markings are performed in the standing position. In females, the abdomen is usually marked first, making sure to address both the linea alba and linea semilunaris with your markings (Fig. 10.5). The anterior superior iliac spine is marked, since creating a shadow effect in that area provides a very athletic appearance. The areas of extraperitoneal fatty deposits are mapped out, aided by the pinch test. In the typical female patient undergoing VASER-assisted liposuction of the abdomen, the idea is to evacuate as much extraperitoneal fat as the skin turgor allows, and to create the natural shadow effects of the anatomical landmarks. In males, the markings are slightly different. The midline is marked mostly above the umbilicus, the lateral edges of the rectus muscles are marked, and the suboblique tri-

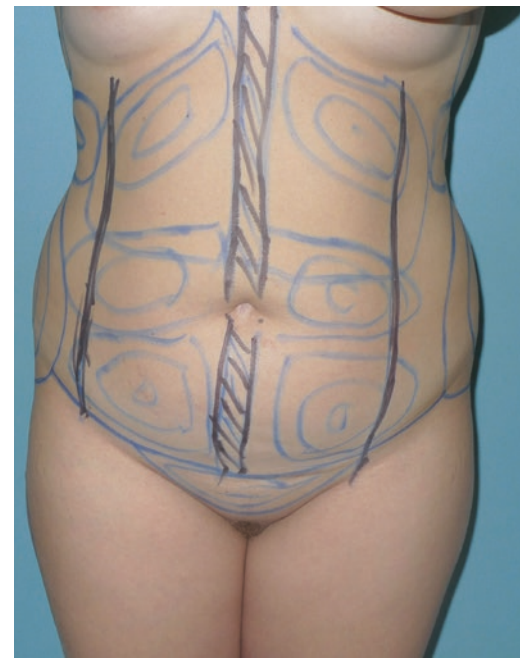

Fig. 10.5 Preoperative markings for VASER-assisted liposuction of abdomen

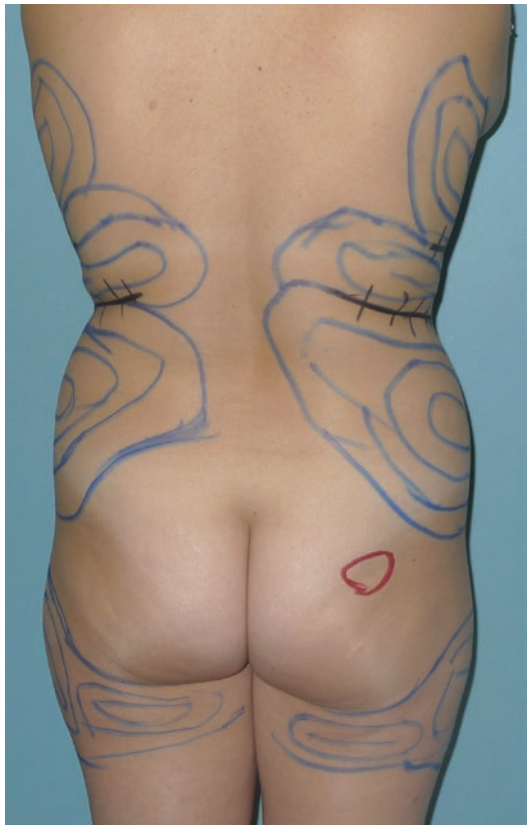

Fig. 10.6 Preoperative markings for VASER-assisted liposuction of posterior trunk

angle described by Hoyos [31] is also marked. Markings of the posterior trunk are depicted in (Fig. 10.6) and include the location of the back roll creases.

When performing circumferential contouring of the trunk, we typically begin with the back and flanks. For contouring of the posterior trunk, the options for positioning the patient on the operating table are prone or lateral decubitus, and both have pros and cons. The prone position requires meticulous padding of all pressure points from bony prominences, and proper protection of the face and breasts. When starting out in this position under general anesthesia, it is useful to perform the anesthesia induction and endotracheal intubation on the stretcher adjacent to the operating table and then transfer the patient directly to the table in the prone position over the hip rolls and axillary rolls. The operating table is then flexed slightly to provide better lineal access for the VAL probes. This maneuver minimizes torque on the probes, as they pass over the curved anatomical areas of the back and flanks. The prone position provides a fairly good access to the back and flanks, and the position makes it easier to access symmetry, since the surgeon is visualizing both sides simultaneously during the surgery. Another advantage of the prone position in circumferential contouring is that it requires only one additional patient repositioning to the supine position in order to complete the abdominal areas. In spite of these advantages, many experienced body-contouring surgeons, including the lead author (OG, Jr.), prefer contouring of the posterior trunk in the lateral decubitus position [32]. This position also requires an axillary roll and padding of the bony prominences. Although this position for liposuction requires an additional repositioning (side-side-supine versus prone-supine), many, including the authors, feel that the lateral decubitus position provides better access for UAL cases with less trauma. The position is extremely helpful when evacuating large volumes from the back and flanks, and in the creation of small, aesthetic waistlines. Once both sides of the posterior trunk are completed, the patient is then turned to the supine position for completion of the abdominal contouring.

Even large-volume VASER aspirate is relatively bloodless (Fig. 10.7).

Immediately following the surgery, with the patient still under anesthesia, TopiFoam is applied, followed by a compression garment (Fig. 10.8a, b).

A 46-year-old female was seen in consultation regarding the contouring of her trunk and extremities (Fig. 10.9a–c). Circumferential VAL of these areas was performed under general anesthesia as an outpatient procedure. Positioning included right lateral decubitus to left lateral decubitus to supine. Wetting solution consisted of 1 ml of epinephrine 1:1000/ liter Ringer's lactate solution infused at 400 ml/minute. Three liters was infused into the abdominal area and five liters was infused into the posterior trunk. The abdomen was treated with a 3.7-mm, five-

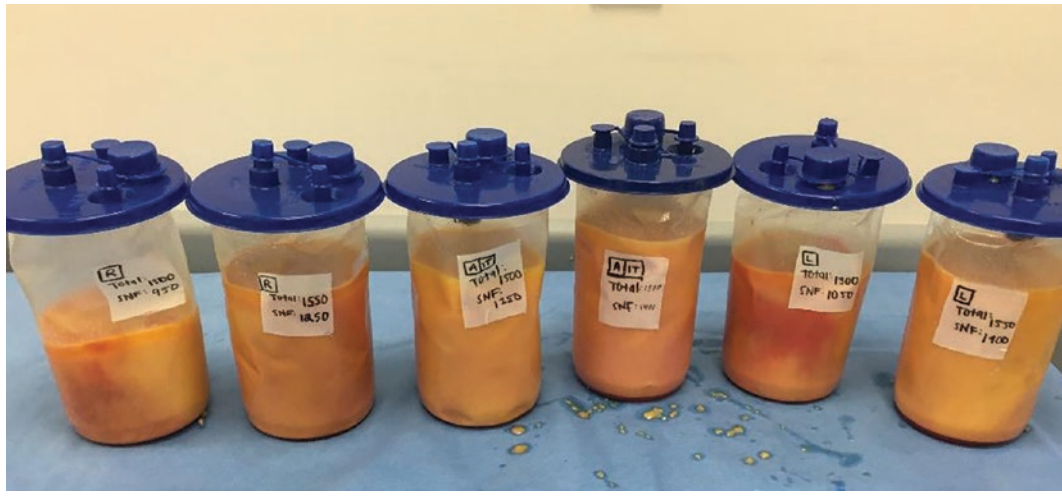

Fig. 10.7 Typical bloodless VASER-assisted liposuction aspirate

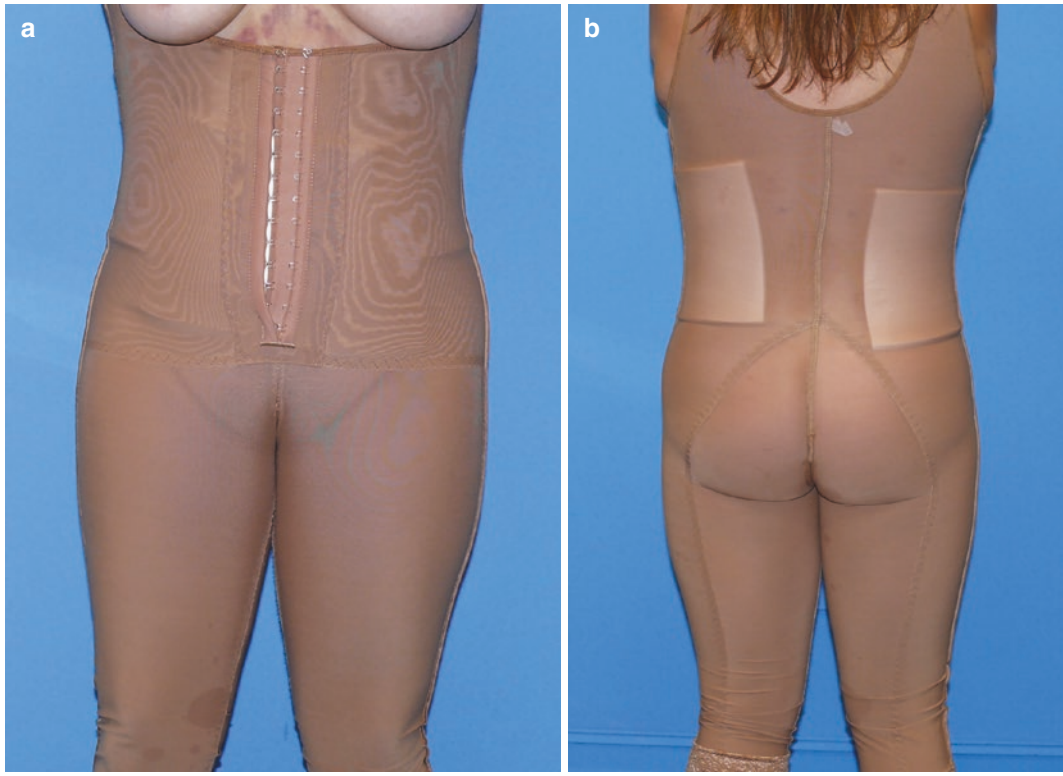

Fig. 10.8 (**a, b**) Body compression garments

ring VASER probe at 80% energy level for 8 minutes in pulsed mode, and the posterior trunk was treated with a 3.7-mm, two-ring probe at 80% energy level for 11 minutes in continuous mode. Aspiration was performed with 4.6-, 3.7-, and 3.0-mm VentX cannulas. Total volume extracted was 6400 ml. Surgical results at 1 year are depicted in Fig. 10.9d–f.

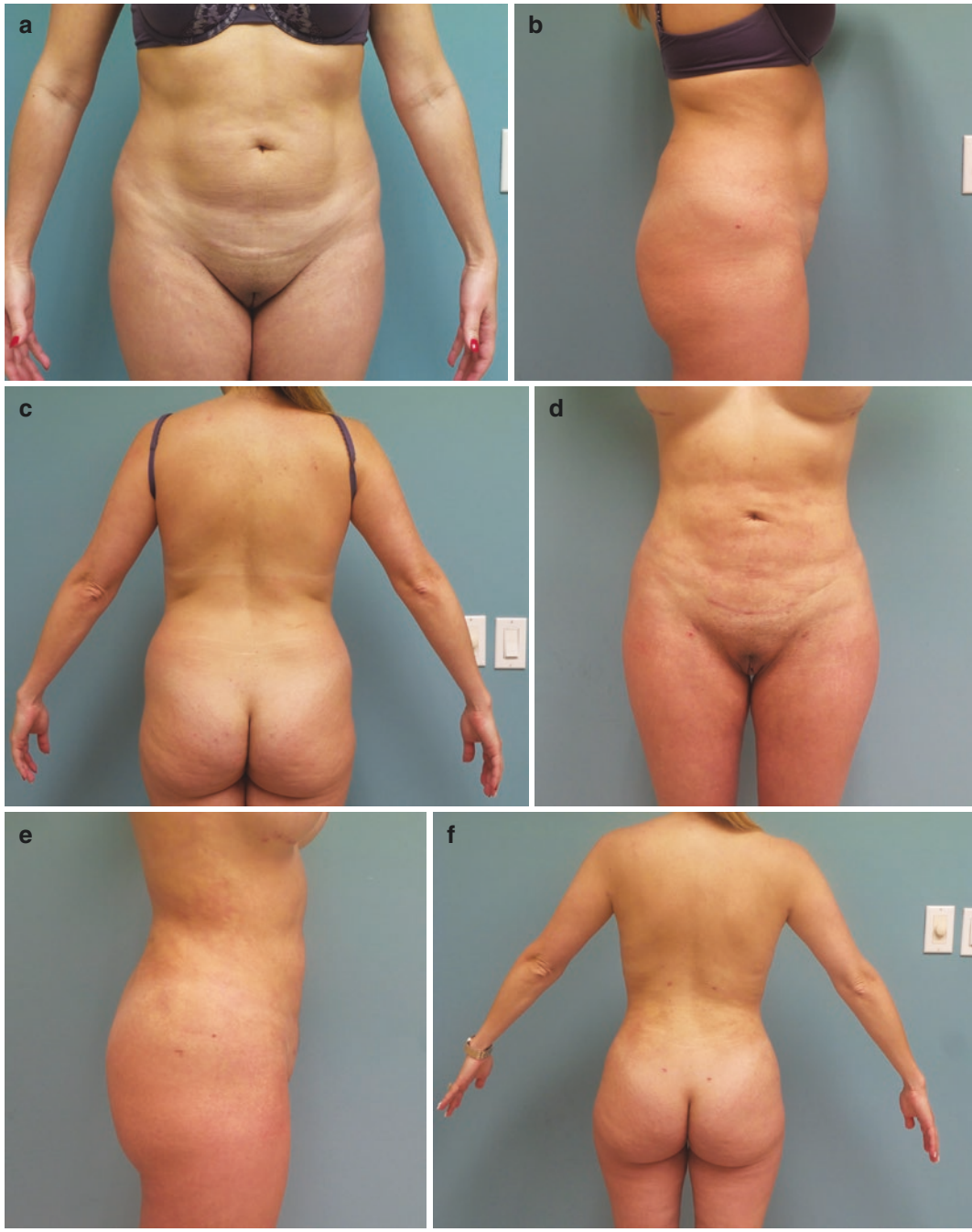

Fig. 10.9 (**a**–**c**) Preoperative appearance before circumferential VASER-assisted liposuction of trunk. (**d**–**f**) Appearance of 1-year postcircumferential VASER-assisted liposuction of trunk

Contouring of the Extremities

In the authors' experience, approximately 40% of liposuction cases involve the extremities, either by themselves or in combination with other anatomical areas. The extremities are three-dimensional, cylindrical structures that exhibit an uneven distribution of compartmentalized fatty deposits, as such this anatomical area presents greater challenges to the body-contouring surgeon. It is generally agreed that circumferential liposuction of the extremities—either with traditional suction-assisted lipectomy (SAL) or with VASER-assisted liposuction (VAL)—yields a better aesthetic result than "spot liposuction."

The efficacy of ultrasound-assisted liposuction (UAL) compared with that of SAL for multiple anatomical sites was assessed by Rohrich, Beran, and Kenkel [33]. The efficacy of UAL was rated as good to excellent for the thighs and arms, fair to good for the calves, and fair to ineffective for the ankles. In the authors' experience, the efficacy of VAL for contouring of the arms and thighs is rated as excellent, while the experience with the calves is mediocre at best. It is suggested that contouring of the calves be restricted to patients with significant lipodystrophy of the area, in order to have enough of a subcutaneous layer to provide a safety margin for the ultrasound probes and for the surgery to provide a significant visual difference for the patient. The overall experience with any type of UAL on the ankles is poor; therefore, it is suggested that UAL not be used in this particular area.

One must pay close attention to the placement of the access incisions during the preoperative marking session, since ultrasonic liposuction surgery requires a greater number of access incisions of a slightly longer length to accommodate the skin protectors. It is imperative that the ultrasound probes have direct lineal access to the treatment areas, since the probes do not bend, and the surgeon should avoid placing torque on the probes.

All the lower extremity liposuctions performed by the authors are in the supine and lateral decubitus positions (Fig. 10.10). The supine-to-right lateral-to-left lateral-to-supine position requires an additional turn and repositioning over the supine-to-prone-to-supine position; however, it is chosen for UAL and VAL cases because it provides direct lineal access to the treatment areas for the ultrasound probes [34]. The supine position provides a direct access to the anterior thighs, medial thighs, and knees. The lateral decubitus position provides access to the upper, lateral thighs, and infragluteal area. When extracting large volumes from the hips and flanks, the lateral decubitus position helps to avoid "end hits" where the tip of the probe or cannula is forced into the deep dermis. Access incisions for UAL or VAL should be of sufficient length to accommodate the skin protectors.

Five zones of adherence have been described in the thighs, and these are areas that should be avoided during liposuction procedures: (1) the lateral gluteal depression, (2) the posterior-distal thigh above the popliteal crease, (3) the gluteal crease, (4) the mid-medial thigh area, and (5) the lower lateral thigh area of the iliotibial tract. Violating these areas with either ultrasonic probes or aspiration cannulas can often lead to contour deformities. Some experienced body-contouring surgeons occasionally make an exception to the zones of adherence in relation to the mid-medial thigh [35]. In patients with significant fat lipodystrophy, the authors often achieve improved aesthetic results by performing judicious fat aspiration in the mid-medial thigh area

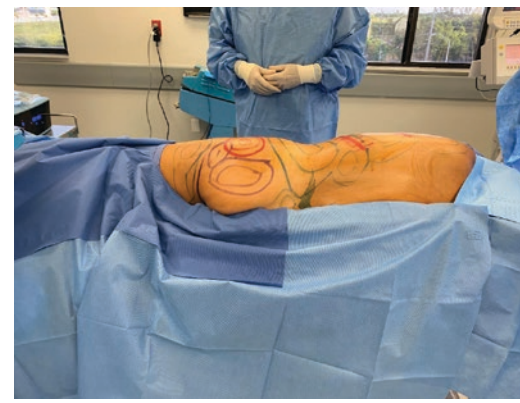

Fig. 10.10 Lateral decubitus position provides an ideal access for VASER contouring of the flanks and back

in order to blend the superior medial thigh with the medial knee area.

The ultrasound energy is delivered to the medial knees and medial thighs by a five-ring, 3.7-mm diameter VASER probe at 70% energy level in VASER (pulsed) mode. Total ultrasound time for medial thighs and knees should be approximately 45 seconds per 100 ml of expected aspirate from these areas. Ultrasound application to the lateral thighs, anterior thighs, hips, and infragluteal areas is delivered with a 3.7-diameter five-ring probe at 80% energy level in VASER (pulsed) mode. Ultrasound times for these areas should not exceed 1 minute per 100 ml of expected aspirate.

Contouring of the calves is not nearly as common as thigh contouring. A relatively high amount of wetting solution is recommended for calve contouring, about a 4:1 ratio of solution to expected aspirate. A 3-mm diameter five-ring probe is used at 60–70% energy level in VASER (pulsed) mode for 45 seconds for every 100 ml of expected aspirate.

Positioning for arm contouring involves placing the patient in the supine position on the operating table, with the elbow flexed 90 degrees and stabilized on a surgically draped mayo stand at the head of the table (Fig. 10.11). The arm is circumferentially prepped to allow free movement. The posterior axillary fold and the radial aspect of the elbow serve as locations for the access incisions. Contouring of the arms with VAL can be efficiently accomplished with a relatively low ultrasound energy delivered to the tissues. Five-ring, 3-mm diameter VASER probes are used with the energy settings at 70% VASER (pulsed) mode for 45 seconds for every 100 ml of expected aspirate.

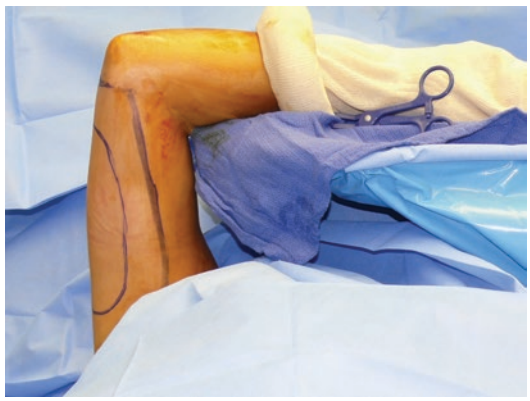

Fig. 10.11 Position for VASER-assisted liposuction of arm

Fat aspiration from the lower extremities is performed with 3-mm and 3.7-mm VentX cannulas, and for the arms the authors employ a 3-mm VentX cannula. The emulsified VASER aspirate easily flows through small-diameter cannulas, which provide a higher level of precision when contouring these areas than the larger-diameter cannulas. It is useful to leave behind about 5–10% of the fragmented fat. This loose, emulsified fat can be manually shifted in the treated area until it is smooth. This process of fat equalization has been described by Wall [36] as part of the separation, aspiration, and fat equalization (SAFELipo) technique. This technical maneuver is easily applied during VAL cases because the fatty emulsion of VAL aspirate is comprised of living fat cells that are suitable for fat grafting when harvested at clinically recommended energy settings [37–39]. The maneuver is helpful for avoiding contour irregularities in areas with thin dermal cover, such as the arm or inner thigh.

The original recommendation for VAL procedures was to deliver the ultrasound energy for 1 minute for every 100 ml of the wetting solution infused. That formula may have been adequate when using a “superwet” technique with a 1:1 ratio of wetting solution to expected aspirate. However, the current recommendation for VAL employs much higher volumes of wetting solution (at least 3:1 ratio of solution to expected aspirate), and the previous formula would deliver a higher dose of ultrasound energy to the tissues than what would be necessary to achieve adequate fat fragmentation [40].

A 31-year-old nulliparous woman was seen in consultation regarding contouring of her abdomen, back, arms, hips, and thighs. She stands 5 feet 7 inches tall and weighs 162 pounds. The patient underwent circumferential VAL of her trunk, arms, and thighs under general anesthesia. The surgery was performed in a hospital environment. Following the high-volume VAL extrac-

tion, appropriate fluid management was performed overnight with intravenous crystalloids and an indwelling Foley catheter to monitor the urine output. The total aspirate volume was 10,500 ml, with 7100 corresponding to the hips and thighs, and 500 ml corresponding to the arms. Approximately 3000 ml of the lower extremity aspirate was supernatant fat.

The surgery was performed under general anesthesia and the positioning was lateral decubitus-to-lateral decubitus-to-supine. A total of 5400 ml of wetting solution consisting of 1 mg of epinephrine per liter of Ringer's lactate solution was infused into the extremities. A 3.7-mm, three-ring VASER probe in pulsed mode was used in the hips and lateral thighs at 80% energy level, and at 70% energy level for the inner thighs. The arms were treated with a 2.9-mm, three-ring probe at 70% energy level in pulsed mode, after infusion of 350 ml of wetting solution per arm. Aspiration was performed with 3.7-mm and 3.0-mm VentX cannulas, and the access incisions closed with buried absorbable sutures. The patient was discharged home the day after surgery after an uneventful recovery. Preoperative appearance and surgical results at 1 year are displayed in Fig. 10.12a–d.

A 38-year-old woman was seen in consultation regarding lipodystrophy of her arms (Fig. 10.13a, b). The upper extremity skin tone

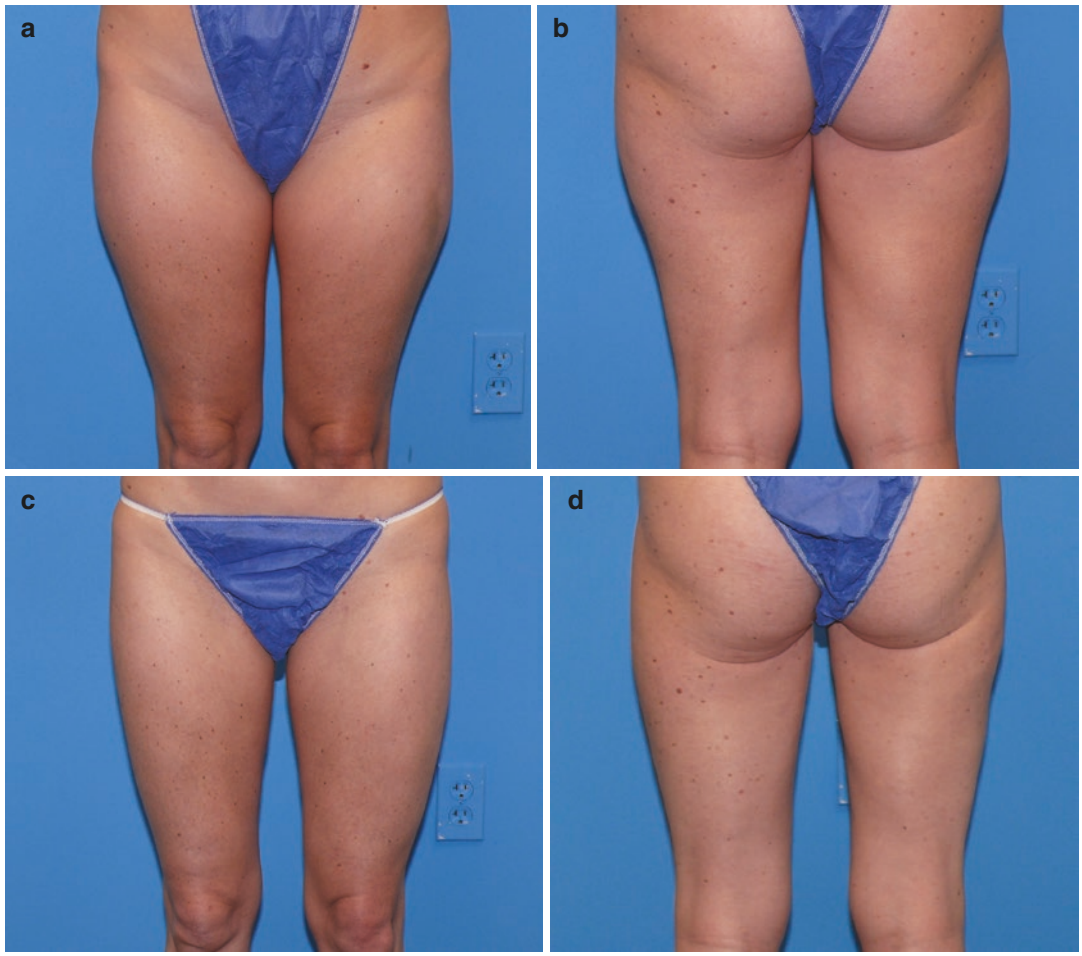

Fig. 10.12 (**a**, **b**) Preoperative appearance before VASER-assisted liposuction of thighs. (**c**, **d**) One-year post-VASER-assisted liposuction of thighs

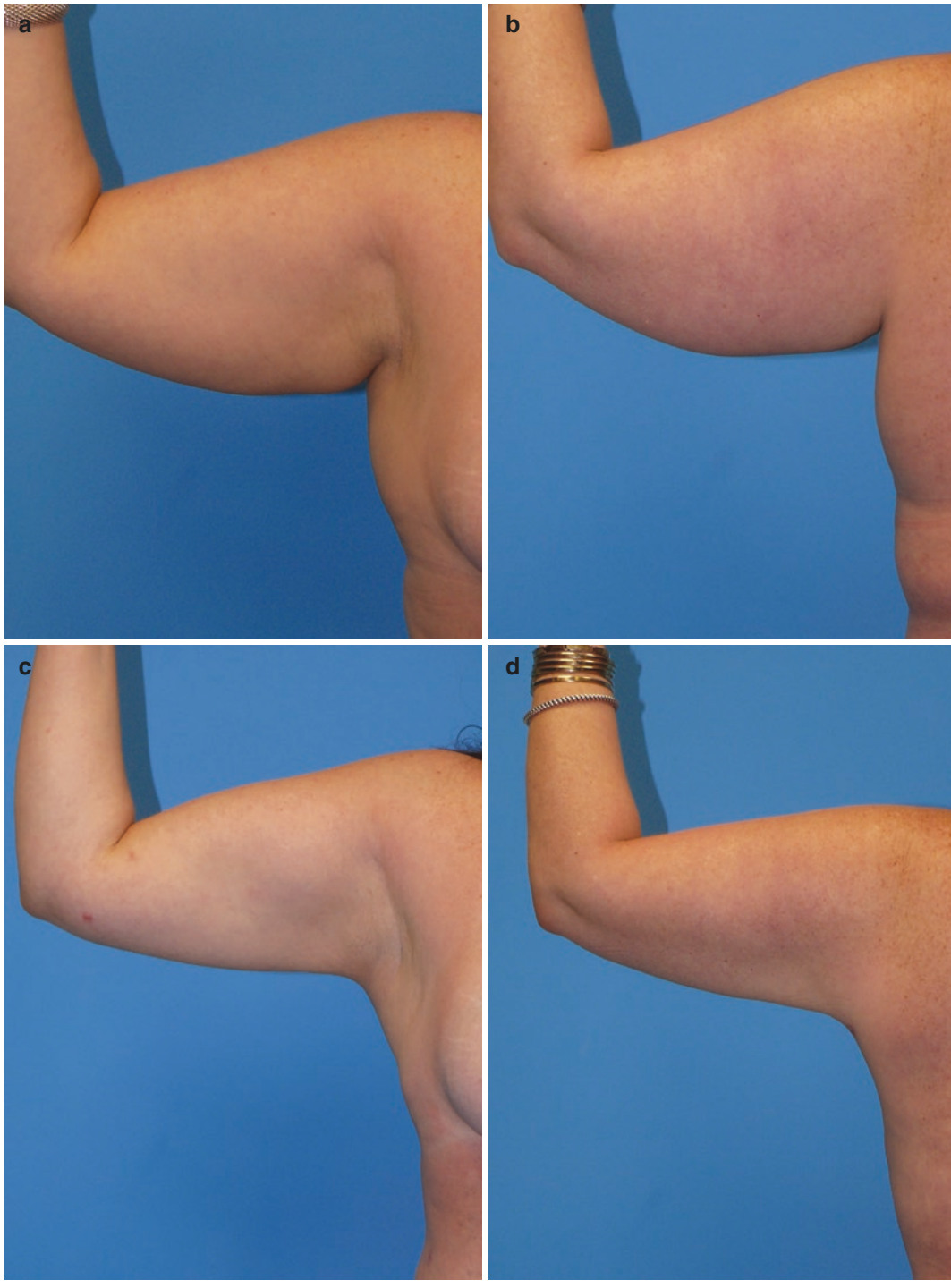

Fig. 10.13 (**a**, **b**) Arm-contouring, preoperative appearance. (**c**, **d**) Six months' post VASER-assisted liposuction of arms

was moderate; however, the patient did not wish to undergo an open brachioplasty procedure and was willing to accept partial fat evacuation with limited improvement. She underwent circumferential VAL of her arms under general anesthesia as an outpatient procedure. A total of 500 ml of the authors' wetting solution was infused into each arm per infusion pump at 250 ml/minute. A 3.7-mm, five-ring probe at 70% energy level in pulsed mode was utilized for 3 minutes per arm. The aspiration was performed with 3.0-mm VentX cannula. The total aspirate removed during the surgery was 560 ml. Approximately 210 ml of supernatant fat was removed from each arm. Surgical results at 6 months are displayed in (Fig. 10.13c, d).

Vaser-Assisted Contouring of Gynecomastia

Gynecomastia is a condition where the glandular tissue of the male breast undergoes benign proliferation, resulting in visible breast enlargement. The majority of the cases are considered idiopathic. However, there are a number of etiologies reported in the literature [41–43]. Most common among them are liver cirrhosis, hypogonadism, testicular tumors, kidney disease, and certain drugs. There is still significant controversy among authors regarding the incidence of the condition, based on the wide margins reported in the literature. A prevalence of 32–65% has been reported in adult males [44, 45] and a range of 4–69% has been reported in adolescents [46, 47].

More than 24,000 cases of surgical correction of gynecomastia were reported by board-certified plastic surgeons in 2018, making it the second most common plastic surgical procedure in men. There are numerous surgical approaches for the correction of gynecomastia reported in the literature. In the past 20 years, several techniques involving liposuction in combination with glandular resection through minimal, well-concealed incisions have become popular due to their consistently good aesthetic outcomes and a lack of postoperative surgical stigmata. Bracaglia [48] published his experience with liposuction followed by a pull-through technique for the gland and reported good, consistent results. Hammond et al. [49] modified the previously reported pull-through techniques using ultrasound-assisted liposuction (UAL), with good results, and Ramon et al. [50] introduced the concept of endoscopic visualization to these techniques in 2005. A few years later, Lista and Ahmad [51] reported on a similar pull-through technique, but this time employing power-assisted liposuction (PAL). Currently, the authors [52] employ a similar technique using VASER-assisted liposuction (VAL) for the fat extraction.

An extensive preoperative hormonal workup is not recommended, unless there is a high index of suspicion about an underlying anomaly, or other contributing factors, such as drugs. Recently, Malhotra et al. [53] reported on a series of 197 patients and concluded that routine endocrinology workups were of little value, and that patients with gynecomastia who persisted beyond 16 years of age should undergo surgery as the primary method of treatment. A detailed history and physical, along with typical presurgical laboratory studies, usually is sufficient preoperative workup in most of these cases. Rohrich et al. [54] reported on the management of gynecomastia and published an algorithm for its evaluation and treatment.

Preoperative markings are performed in the standing position and extend beyond the anatomical boundaries of the breast to include all lipodystrophy areas involving the chest (Fig. 10.14).

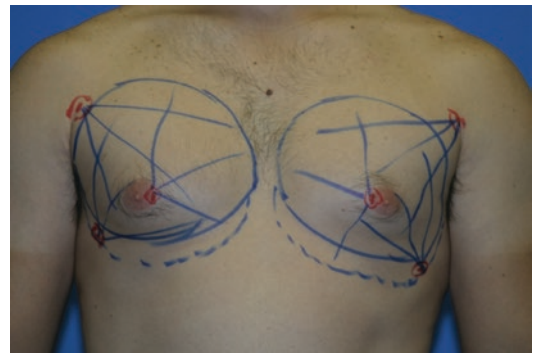

Fig. 10.14 Markings for VASER-assisted liposuction of gynecomastia

It is of paramount importance to also extend inferiorly beyond the inframammary fold into the upper abdomen, and to properly disrupt a well-defined inframammary fold.

A 26-year-old male with persistent idiopathic bilateral gynecomastia was seen in consultation. VASER-assisted liposuction with resection of the subareolar fibroglandular tissue with a pull-through technique was recommended. The surgery was performed under general anesthesia as an outpatient procedure. Wetting solution consisting of 1 ml of epinephrine 1:1000 in a liter of Ringer's lactate solution at room temperature was infused at 300 ml per minute to a total of 750 ml per side. Ultrasound was delivered by means of a 3.7-mm, two-ring, VASER probe at 80% energy level in continuous mode for 3 minutes per breast. Aspiration was performed with a 3.7-mm VentX cannula for the deep tissue and a 3-mm VentX cannula for the superficial, subdermal liposuction. The supernatant fat aspirate volume consisted of 175 ml from each breast. Following the aspiration of the fatty tissues, the fibroglandular component was resected via the pull-through technique. TopiFoam was applied immediately upon completion of the surgery, followed by a compression vest. The subareolar glandular tissue and VASER fat aspirate are depicted in (Fig. 10.15a, b). Preoperative appearance and surgical outcomes at 6 months are depicted in Fig. 10.16a–f.

VASER-assisted liposuction as an adjunct to excision of male breast fibroglandular tissue is a safe and effective treatment for gynecomastia. It is associated with a very low complication rate and typically yields aesthetically pleasing results. The fact that it is currently the second most common aesthetic surgical procedure in men is a testament to the high patient satisfaction rate associated with the procedure. The use of ultrasound energy has made evacuation of the fibrous fatty component easier and less traumatic for the patient. The small access incisions are barely perceptible once healing has taken place, and the ability to contour the whole chest with VAL provides more harmonious results.

VASER-Assisted Contouring of the Buttocks

Gluteal augmentation by means of fat grating is currently the 12th most common aesthetic surgical procedure, with more than 25,000 cases reported in 2018 to the American Society for Aesthetic Plastic Surgery. That figure represents an increase of over 25% from the previous year, making gluteal augmentation the fastest growing aesthetic surgical procedure currently performed in the United States.

Although gluteal fat grafting is sometimes necessary to achieve the ideal buttock contour, it is the fat extraction from surrounding anatomical areas that offers the greatest contribution to the final aesthetic result. Contouring of the posterior trunk, upper lateral thighs, and infragluteal rolls has a profound effect on the shape of the buttocks. When contouring the thighs as a complement to the buttocks, it is important to pay special

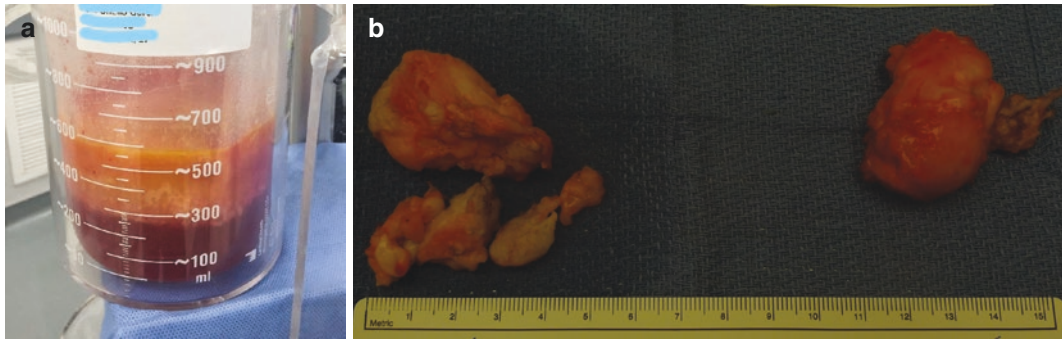

Fig. 10.15 (**a**) VASER fat aspirate. (**b**) Gynecomastia of the glandular tissue

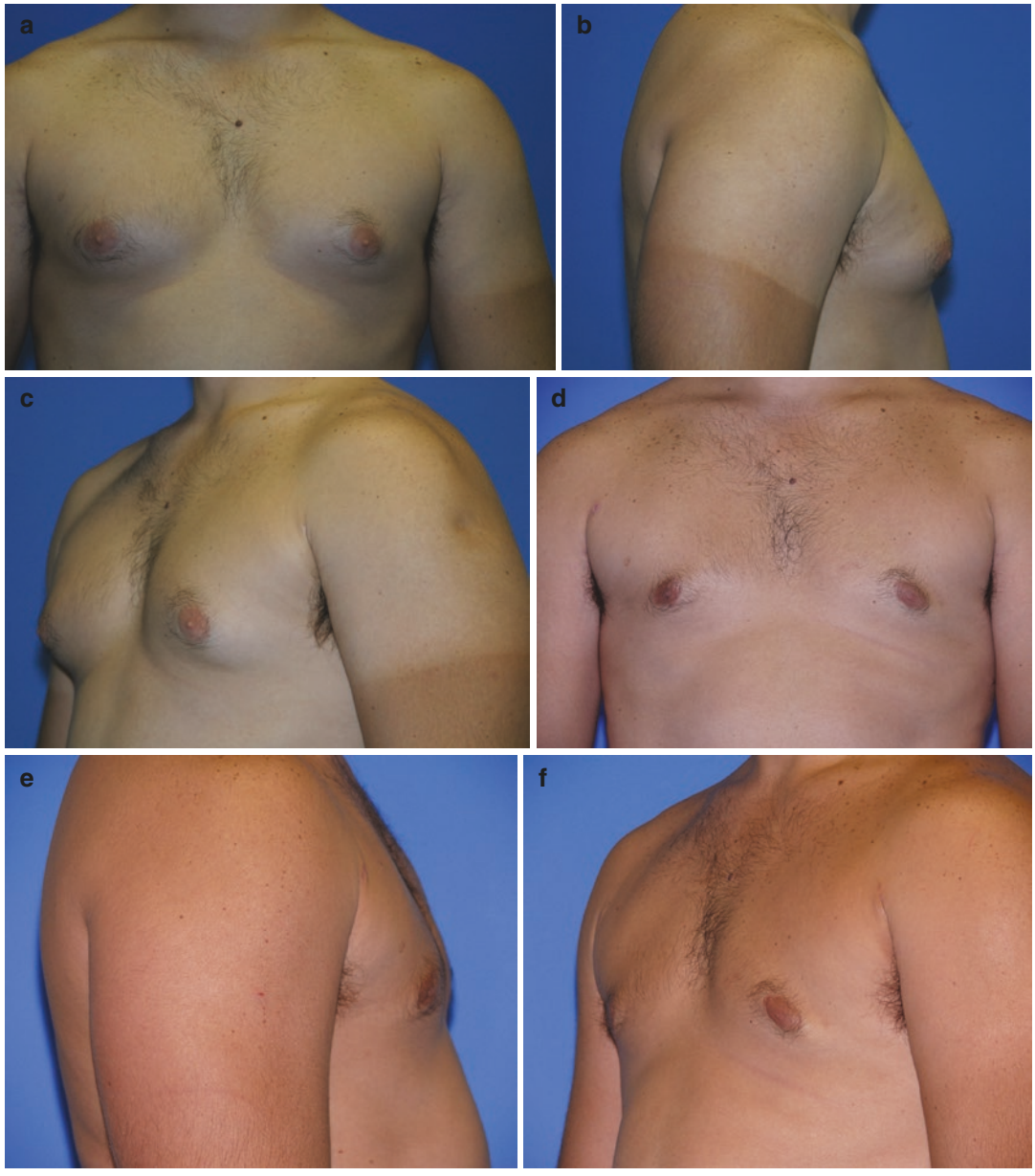

Fig. 10.16 (**a**–**c**) Preoperative appearance of a 26-year-old with persistent, idiopathic gynecomastia. (**d**–**f**) Appearance of 6 months' post-VASER-assisted resection of gynecomastia

attention to the zones of adherence previously described in this chapter.

In regard to gluteal contouring, it is imperative that both the patient and the surgeon are well aligned in respect to the aesthetic goals of the operation. Is the patient seeking a rounder, more athletic buttock shape, or just simply a bigger butt? Sculpting a round, athletic buttock shape typically does not require adding volume. Fat grafting may be required in some cases where the contouring alone is not enough to correct a visual gluteal deficiency, but in the authors' experience with these cases, the grafted volumes are small to moderate, and seldom

exceed 400 ml per buttock injected into the subcutaneous plane.

For safety reasons, gluteal enhancement by means of fat grafting has recently become an operation of the subcutaneous tissues. As plastic surgeons move away from intramuscular grafting, the volumes grafted will need to be adjusted accordingly. Tissue compliance and overall gluteal surface area will play a significant role in determining the fat graft volume limits for a particular patient, in order not to exceed the recipient site capacity. Since subcutaneous grafting has obvious volume limitations, creating the visual of a voluminous buttock will require more aggressive contouring of the surrounding areas.

Preoperative markings for buttock contouring are performed in the standing position. The areas for fat extraction are marked, and in cases of gluteal fat grafting, the recipient areas are also meticulously marked (Fig. 10.17). Gluteal contouring, with or without fat grafting, requires aggressive fat extraction from the posterior flanks. Lipodystrophy of the saddlebags and infragluteal areas also needs to be addressed by the extraction. As opposed to males, where aggressive contouring of the waist provides the desired aesthetic results (small waist/wide back), aggressive sculpting of the waistline on female patients requires extending the contouring into the upper back in order to avoid a masculine appearance postoperatively (small waist/wide back).

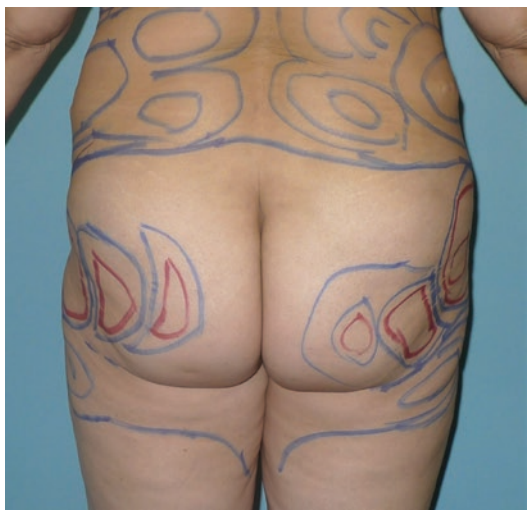

Fig. 10.17 Preoperative markings for gluteal contouring with fat grafting

Positioning is somewhat controversial, since some authors recommend the prone position for contouring the posterior flanks and back, while others prefer the lateral decubitus position. The posterior triangle, an important component of the aesthetic waistline, cannot be adequately addressed from the prone position. In spite of the slightly longer surgical times associated with the lateral decubitus positions, the authors, as well as other experienced body-contouring surgeons, frequently use this position when contouring the waistline [55, 56].

A 22-year-old overweight female is interested in improving the contours of her trunk and the shape of her buttocks. A recommendation was made for circumferential VASER-assisted liposuction of the trunk. The surgery was performed as an outpatient procedure under general anesthesia. Positioning for the surgery consisted of lateral decubitus stabilized on a bean bag surgical positioner and supine. A Foley catheter was inserted as soon as the patient was anesthetized, and a Bair Hugger was used over the nonsurgical areas. The authors' wetting solution formula for general anesthesia cases was infused with a power infusion pump at a rate of 400 ml/minute. A total of 8 liters was employed for the procedure, with 5 liters infused into the posterior trunk. The ultrasound was delivered with a 3.7-mm, two-ring VASER probe at 80% for a total of 8 minutes per side in pulsed mode. Aspiration was performed using 4.6-mm, 3.7-mm, and 3.0-mm VentX cannulas. The total aspirate was 5980 ml, with 4000 ml as the supernatant fat fraction. The posterior trunk yielded 2500 ml of the supernatant fat. Preoperative and surgical results at 8 months are depicted in (Fig. 10.18a, b). Note the improved buttock contour in the posterior view. The aggressive debulking of the posterior flanks gives the appearance of improved buttock projection on the lateral views, even though gluteal volume was not added as part of this procedure.

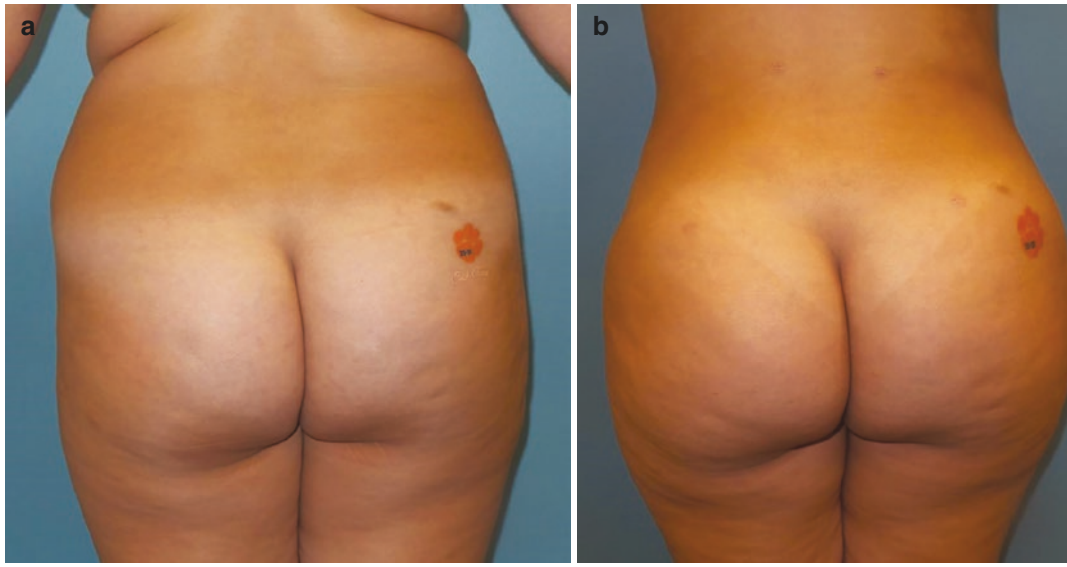

Fig. 10.18 (**a**) Preoperative appearance. (**b**) Eight months' post-VASER-assisted gluteal contouring *without fat grafting*

Brazilian Butt Life

Gluteal augmentation via fat grafting is a powerful body-contouring technique that can create impressive results not obtainable with implants or liposuction alone. This procedure is very technique-dependent and, because of the too frequent fatal complications, it has been recommended that surgeons avoid intramuscular injection and only fat graft in the subcutaneous space above the deep gluteal fascia. The subcutaneous space, however, is a thin curving dome that ranges in thickness from 1 cm at the outer hips to 3–4 cm at the central gluteal dome. This creates a difficult target for gluteal surgeons who do not use intraoperative imaging. Real-time intraoperative ultrasound-guided fat grafting during a Brazilian butt lift (ultraBBL) allows the surgeon to consistently avoid an intramuscular injection and manipulate the two distinct subcutaneous gluteal spaces. With ultrasound, the surgeon can target either the deep or superficial gluteal spaces to precisely control fat graft volume and distribution, create projection, and correct superficial irregularities. The surgeon can also create a ultrasound video of the entire procedure to document that they remained above the deep gluteal fascia at all times, and analyze how their fat graft placement affected their ultimate clinical results. Recent advances in ultrasound technology have made real-time intraoperative ultrasound an affordable tool than can not only make a Brazilian butt lift more accurate and powerful, but safer, as well.

Gluteal contouring and augmentation has proven to be a powerful and extremely popular addition to the body-contouring armamentarium of the plastic surgeon. This has been driven largely by patient demand, as over the last 10–20 years, society's ideals of beauty have continued to expand. Beautiful is now possible at any size and in many shapes. Patients are specifically requesting fuller hips and buttocks, both as standalone procedures and to complement other breast- and body-contouring surgeries [57–60].

It is possible to emphasize gluteal contours with liposuction and fat extraction alone. Mild asymmetries and depressions can also be effectively corrected with fat separation and fat shifting [61–63]. However, true gluteal augmentation can only be done with fat grafting.

Gluteal augmentation with fat grafting has been proven to be effective in the plastic surgery

literature and memorialized by patients and surgeons throughout social media [58, 64]. This is a powerful technique, but it must be performed cautiously.

Over the last 10 years, there have been an excessively high number of complications and patient deaths after gluteal fat grafting. Fat pulmonary embolisms are the most common fatal complications that can occur when fat grafting is performed intramuscularly in the gluteus maximus and the fat graft is inadvertently injected into the gluteal veins [59, 65–67]. The now intravascular fat graft travels to the heart, lungs, and brain with fatal results. Deaths from fat pulmonary emboli have occurred throughout the world, but in the United States, South Florida has been the epicenter of these tragedies. In the last 10 years, in South Florida alone, 17 deaths from fat pulmonary emboli have been identified [68, 69]. The lead author (OG, Jr.) has observed autopsies of these deaths when they were performed by the Medical Examiner of the Miami Dade County. The postmortem results confirmed a two-hit hypothesis for this fatal complication: fat must be injected into the muscle around the deep gluteal veins, and a gluteal vein injury must occur. These events most commonly happen when fat is injected into the gluteus maximus or deeper muscles, and the fat grafting cannula inadvertently injures the gluteal veins, creating an opening for the fat graft to enter the venous system, with fatal results [59, 69].

These autopsy results were reviewed by the Multi-Society Task Force for Safety in Gluteal Fat Grafting [70], as they designed cadaver research to further study this issue. The task force was able to delineate the vascular gluteal danger zone and describe safer cannula angles and lengths to avoid these injuries. The task force issued guidelines for safe gluteal fat injection, which include constant vigilance of the cannula tip during fat grafting, a rigid cannula system, and most importantly, to avoid intramuscular fat injection by staying above the deep gluteal fascia on the superior surface of the gluteus maximus at all times [70].

The operating surgeons of South Florida responsible for the fat pulmonary emboli mortalities used different fat graft volumes, different patient positions, different access incisions, and different cannula styles, but the one factor all of these deaths had in common was that every surgeon insisted that they were subcutaneous and above the deep gluteal fascia at all times. Unfortunately, the autopsies disagreed [69]. The South Florida experience demonstrates that surgeons currently do not have a consistent and reliable way to always know the position of their cannula tip during gluteal fat grafting. Furthermore, surgeons have no way to prove that they only injected fat subcutaneously and to document that they never injected fat into the gluteal muscles, in order to protect themselves for medicolegal reasons.

It is exactly because of the possible dangers with this procedure that plastic surgeons must not abandon gluteal fat grafting. Gluteal fat grafting is a powerful tool that can augment tissue, correct deformities, and create impressive results that cannot be produced any other way. Because of this, high patient demand for this procedure will continue. If board-certified plastic surgeons stop performing this procedure, interested patients will simply go to the nonboard-certified practitioners, who have had the majority of the complications, and even more deaths will occur. As researchers and patient advocates, plastic surgeons must study this technique and determine how gluteal fat grafting can be performed safely and consistently.

Ultrasound can help plastic surgeons achieve these goals and can be used to evaluate the thickness and quality of the subcutaneous envelope preoperatively [71]. In the last 2 years, ultrasound equipment has become portable, wireless, and affordable, opening the door for its use in the sterile field of the operating room (OR). Ultrasound visualization can be used with any cannula style or injection system. Real-time intraoperative ultrasound visualization can help the surgeon perform fat harvesting and accurate fat grafting into the unique spaces of the subcutaneous region. This will not only make for a safer surgeon, but a better surgeon—a surgeon who can manipulate subcutaneous anatomy not appreciable without ultrasound.

Gluteal Anatomy and Ultrasound

The pelvic bony framework, gluteal muscles, gluteal fat, and skin have been well described in our literature [58, 72, 73]. Ultrasound can help us accurately delineate and manipulate the subcutaneous zone. Cadaver dissections have actually identified two gluteal fascias (Fig. 10.19).

The superior surface of the gluteus maximus muscle is covered with a fascial plane (the deep gluteal fascia) that the Multi-Society Task Force for Safety in Gluteal Fat Grafting has recommended surgeons never penetrate [65, 70]. However, there also exists a second fascial layer (the superficial gluteal fascia) within the subcutaneous zone above the deep gluteal fascia and below the dermis. The superficial gluteal fascia is thick, impregnated with fat, and can only be appreciated in an open dissection or with ultrasound visualization.

The superficial gluteal fascia is part of the superficial fascial system and is analogous to Scarpa's fascia in the abdomen, and divides the subcutaneous zone into two subcutaneous spaces: the superficial subcutaneous space (between the dermis and the superficial gluteal fascia) and the deep subcutaneous space (between the superficial gluteal fascia and the deep gluteal fascia), Fig. 10.20 [74].

More important clinically, if the superficial gluteal fascia remains intact, it can retain the fat graft that is specifically injected above or below it, like the casing of a sausage. Fat graft injected into the deep subcutaneous space (above the deep gluteal fascia and below the superficial gluteal fascia) can create excellent volume and central dome projection, similar to a subfascial implant. Fat graft precisely injected into the superficial subcutaneous space (above the superficial gluteal fascia and below the skin) can correct superficial contour deformities and depressions. The consistently accurate injection of fat graft to either the superficial or deep subcutaneous spaces can only be performed with real-time intraoperative ultrasound visualization.

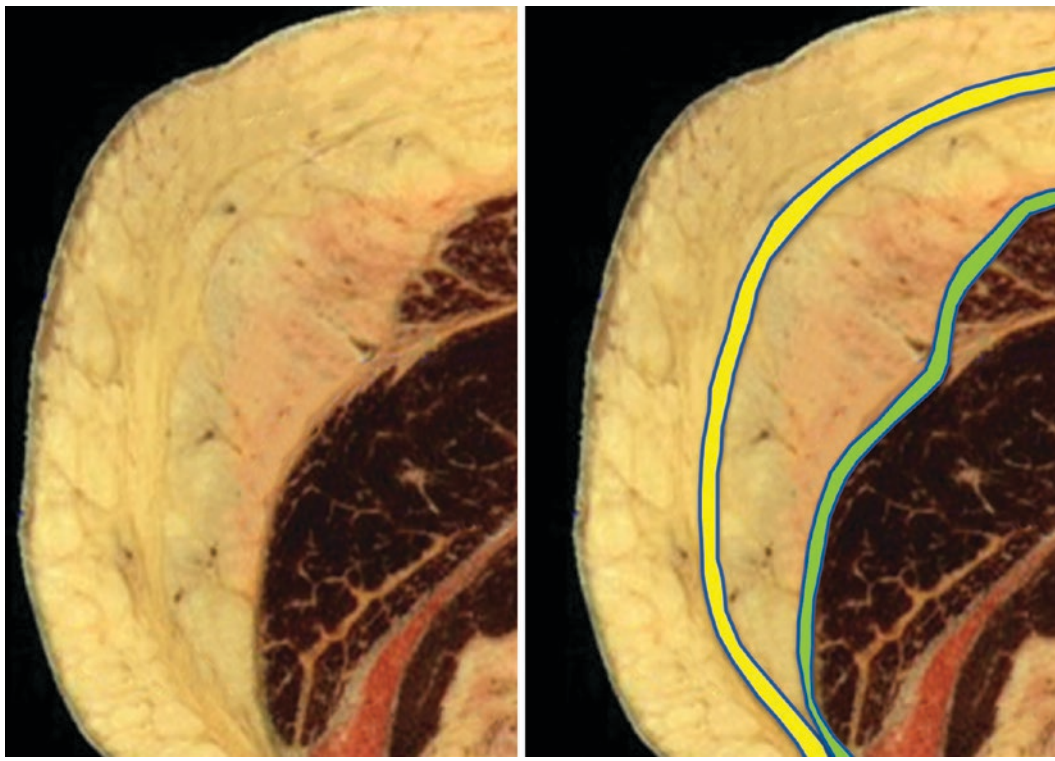

Fig. 10.19 Transverse cross-section of female buttocks. The DEEP gluteal fascia (GREEN) lies on top of the surface of the gluteus maximus muscle. The SUPERFICIAL gluteal fascia (YELLOW) is above the deep gluteal fascia and below the dermis and divides the subcutaneous region into two spaces

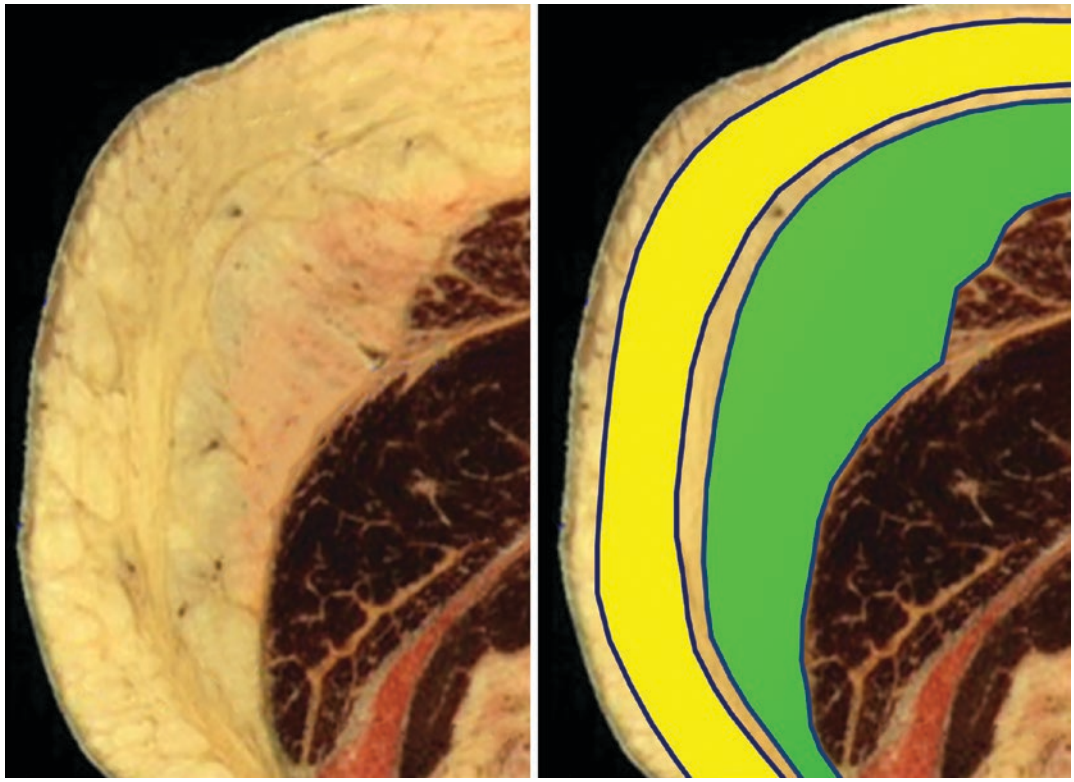

Fig. 10.20 Transverse cross-section of female buttocks. The superficial gluteal fascia divides the subcutaneous region into two spaces. The SUPERFICIAL subcutaneous space (YELLOW) is below the skin and above the superficial gluteal fascia. The DEEP subcutaneous space (GREEN) is below the superficial gluteal fascia and above the deep gluteal fascia. Ultrasound allows the surgeon to accurately enter each space and manipulate it while always remaining above the deep gluteal fascia

It is also important to remember that the entire subcutaneous zone (including both the superficial and deep gluteal spaces) ranges in thickness from 1 cm (outer hips) to 3–4 cm (central gluteal dome). This means that gluteal surgeons must graft in a thin space under a curving dome of varying thickness. This small variable target may account for the inadvertent deep intramuscular injections by well-intentioned surgeons grafting without ultrasound visualization.

A surgeon can use real-time intraoperative ultrasound to not only avoid an intramuscular fat graft injection, but to also accurately target fat graft into the superficial or deep subcutaneous spaces. Neither of these techniques is possible without ultrasound. Real-time intraoperative ultrasound during a Brazilian butt lift (ultraBBL) can not only make fat grafting safer, but much more powerful and accurate as well.

Preoperative Assessment

Like all plastic surgeries, careful preoperative assessment and planning before gluteal contouring and fat grafting is essential. The surgeon should sit with the patient to understand their goals, priorities, and areas of importance. Asymmetries must be identified before surgery and a discussion should be held about the preoperative shape of the patient's waist, hips, buttocks, thighs, and back. The surgeon should ask what kind of shape the patient would like, and understand how the patient would like to specifically change their waist, hips, point of maximum hip projection, buttocks, thighs, and back. Within each anatomic zone, the bony framework, the muscles, fatty layer, and skin should be assessed to determine how each of these components affects the contour. Ultrasound can be used to

determine the thickness of the subcutaneous envelope in each region and to plan the quantity and location of the fat graft in each subcutaneous space, as well as any areas of adhesion that should be released.

Digital imaging is helpful to show the patient the effects of liposuction, fat shifting, and fat grafting. It is even more useful in managing expectations and showing the patient what is not possible. If the patient has requested a very large-volume result, digital imaging can illustrate what is reasonable and safe and open a discussion on staging the procedure. Patients interested in large-volume results—that would be best served with staged procedures—can be shown where fat can be left undisturbed and ready for harvest in a second round of fat harvest and grafting.

Once the final operative plan has been decided, the surgeon should discuss the recovery, expected fat resorption rates, and limitations on postoperative activity.

Surgical Equipment and Setup

Intraoperative Ultrasound Systems

Over the past 7 years, the author (Pazmiño) has used five different ultrasound systems with gluteal fat grafting. Real-time intraoperative ultrasound can actually be used with any cannula or liposuction/fat grafting system. However, when a syringe fat grafting system is used, both of the surgeon's hands are occupied. One hand must hold the syringe while the other hand pushes the plunger to inject the fat. In this scenario, the surgical assistant or scrub tech must control the sterile ultrasound probe, making coordination with the injecting surgeon difficult. To allow the surgeon to control the fat grafting system and the ultrasound probe simultaneously, a power-assisted liposuction system (PAL, MicroAire Charlottesville, VA) is used in conjunction with a peristaltic pump for controlled propulsion of the fat graft. In this manner, the surgeon can inject fat via expansion vibration lipofilling [75] with one hand and control the ultrasound probe with the other hand.

Currently, one of the two ultrasound systems for real-time intraoperative ultrasound is being used: the Clarius Ultrasound (Clarius, $4000) or the Butterfly iQ (Butterfly, $1999 with $420 annual subscription). The Clarius is a 4–13 Mhz high-frequency linear L7 portable, waterproof, wireless ultrasound probe (maximum depth of 7 cm) that can be placed entirely in a sterile probe cover and can stream a high-resolution ultrasound video to Apple iOS or Android tablets (Fig. 10.21). The Butterfly iQ is a wired, porta-

Fig. 10.21 The Clarius ultrasound probe is a 4–13 MHz high-frequency linear L7 portable, waterproof, wireless ultrasound probe (maximum depth of 7 cm) that can be placed entirely in a sterile probe cover and can stream a high-resolution ultrasound video to Apple iOS or Android tablets. (Reprinted by permission from Springer Nature. ultraBBL: Brazilian Butt Lift Using Real-Time Intraoperative Ultrasound Guidance, by Pat Pazmiño. Copyright © 2020)

Fig. 10.22 The Butterfly iQ ultrasound probe is a new generation probe that uses microchips rather than piezoelectric crystals to generate and interpret ultrasound waves. This is a wired portable ultrasound system that is currently compatible with iOS devices. (Reprinted by permission from Springer Nature. ultraBBL: Brazilian Butt Lift Using Real-Time Intraoperative Ultrasound Guidance, by Pat Pazmiño. Copyright © 2020)

ble, waterproof, ultrasound probe (maximum depth of 14 cm). The wired probe is attached to an iOS device (iPhone or iPad) and can be used in the operating field, as well (Fig. 10.22). Both systems will upload their data to the cloud, so that ultrasound still images and video can be accessed on a computer or added to a patient chart.

Surgical Technique

Liposuction of the torso and fat grafting to the gluteal areas and hips is designed to be an outpatient procedure performed under general anesthesia. Specific types of anesthesia do not effectively protect the patient from fatal complications, such as fat pulmonary emboli. What does protect the patient is ensuring that there is no intramuscular fat injection. Ultrasound visualization can continuously confirm the real-time position of the cannula tip and keep the patient safe. The ultraBBL is performed under general anesthesia to facilitate comfortable controlled extraction of deep and superficial fat, and for maintenance of the airway when the patient is in the prone position.

Liposuction and Liposculpture

Surgeons often struggle with identifying the end point in liposuction. Some surgeons record the volume removed from one side and match this to the contralateral side. Other surgeons count the minutes of liposuction or VASER liposuction in one treatment area and match them to the contralateral side. We must keep in mind that ultimately, liposuction is sculpture. A sculptor does not weigh the amount of stone removed from one side and continues to chisel the opposite side, until the same amount of stone has been removed. Like all sculptures, our liposuction surgical end point must be anatomic and symmetric.

The anatomic end point of liposuction should be to achieve a consistent thickness of the skin-fat flap throughout the torso, and to ultimately create the specific anatomic shape the patient requested for. This process begins before surgery, when the skin and fat thickness in all treatment areas are assessed and asymmetries are highlighted. A strategy should be in place to differentially remove fat, until the flap has a consistent thickness.

The incisions used for liposuction and fat grafting of the torso are designed to access all treatment areas and are placed in inconspicuous locations. On the anterior abdomen, one incision is placed inside the belly button at the 12 o'clock position. An incision in each inguinal crease is also made to access the anterior abdomen, lateral abdomen, and waist and thighs. Posteriorly, two supragluteal incisions, two infragluteal incisions, and one intergluteal incision are created (Fig. 10.23).

Once the patient is prepped and draped, three access incisions are made in the anterior abdomen—one inside and at the bottom of the umbilicus, and two inguinal incisions, each just under the bikini line. Skin protectors are placed within each incision to minimize abrasions and skin

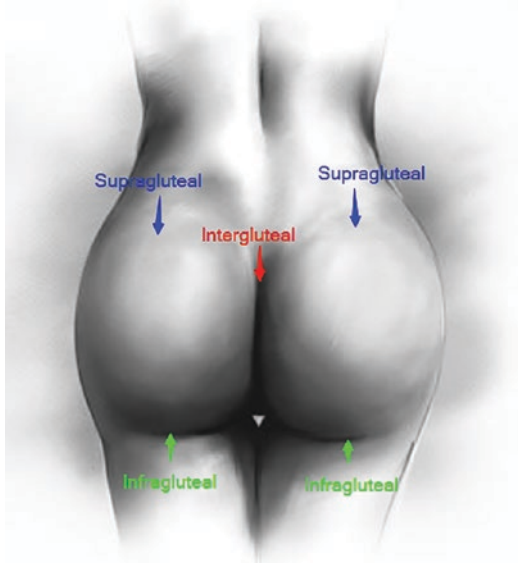

Fig. 10.23 Posterior gluteal access incisions: The supragluteal incisions are used for fat harvest of the back, waist, hips, flanks, and sides, as well as fat grafting to the central dome and superior outer hip. The intergluteal incision is used for fat harvest of the back, along the lower latissimus dorsi, and for contouring the superior buttock as well as fat grafting to the dome and the supragluteal region. The infragluteal incisions are used for fat harvest, fat shifting, and fat grafting to the outer hips and thighs. (Reprinted by permission from Springer Nature. ultraBBL: Brazilian Butt Lift Using Real-Time Intraoperative Ultrasound Guidance, by Pat Pazmiño. Copyright © 2020)

trauma. Tumescent fluid consisting of 1 liter of normal saline and 1 ampoule of epinephrine (final epinephrine concentration of 1:1000,000) is warmed and used in all treatment areas. A typical ultraBBL case uses approximately 4000–5000 cc of tumescent fluid. Tumescent fluid is infiltrated into the treatment areas using the SST (simultaneous separation and tumescence) technique via the MicroAire system using a 3-mm exploded basket cannula. As Del Vecchio and Wall described, this allows for the separation of subcutaneous tissue and a more rapid onset of epinephrine vasoconstriction [75].

More importantly, fat separation is the crucial concept in body contouring [63]. When performing body sculpting, deformities are only created under suction. A deformity cannot occur when fat is displaced or separated without suction. For this reason, it is recommended to separate the fat as much as possible. Fat separation with a 5-mm exploded basket cannula after the infiltration of tumescent fluid and before fat extraction with suction allows the epinephrine to continue working, releases fibers and adhesions, allows for easy subsequent extraction, and creates small fat grafts that can fill and correct small local irregularities. Fat separation continues, until the cannula can move through the treatment area without resistance. No suction has been applied up to this point. Once the separation phase has been completed, fat extraction under suction may begin. Extraction begins deep, at a level just over the fascia, and continues superficially until the desired thickness of the skin-fat flap has been achieved.

Our goal is to extract fat until a 1.5- to 2-cm thickness of the skin-fat flap is achieved throughout all treatment areas. Large cannulas do not cause irregularities and cannula track marks. These deformities occur when fat is torn from the surrounding tissue under suction. A 5-mm exploded basket cannula is used for fat separation and fat harvest. A large exploded basket cannula works very well for fat separation, but any cannula can be used for fat extraction. Although a large cannula can be used for fat extraction, deformities and cannula track marks do not occur because the fat was never torn out with suction—the fat had been separated without suction during the separation phase, and only the loose fat was removed with suction.

To create a uniform thickness of this skin-fat flap circumferentially around the torso, we begin by establishing this thickness first on one side of the patient's waist and flanks and then matching this thickness on the contralateral side, and finally throughout the anterior abdomen and throughout the back. Therefore, every procedure begins with the patient in the lateral decubitus position, as this allows for inferior displacement of the abdominal contents and access to the deep fat of the waist, flanks, lower back, as well as the left costal margin and the left lateral anterior abdomen.

The procedure begins with the patient in the right lateral decubitus (left side up) position. The supragluteal and intergluteal incisions are used to

access the left outer thigh, hips, waist, flank, lower back, costal margin, and lateral anterior abdomen. Once these areas have been tumesced and the subcutaneous tissue has been separated without suction, the fat is then harvested under suction. Once the left side has been completed, the patient is then placed in the left lateral decubitus (right side up) position and the right outer thigh, hip, waist, flank, lower back, right costal margin, and the right lateral anterior abdomen are tumesced, receive fat separation without suction, and finally, the loosened fat is extracted with suction. This continues until the skin-fat flap thickness on this side matches the contralateral side. At this time, the patient is returned to the supine position and the anterior abdomen is treated, until the thickness of the skin-fat flap of the anterior abdomen matches the sides. If the patient requested liposculpture or abdominal etching, it is performed at this time. The inner thighs can be addressed in the supine position, as well. When all fat extraction has been completed, drains are placed through the inguinal incisions, sutured securely, and the patient is placed in the prone position. Once the patient is in the prone position, we check the peak inspiratory pressure and if a marked increase is noted compared to its supine value, chest rolls may be placed longitudinally along the lateral chest. In our experience, this is necessary in less than 1% of cases. The prone position is ideal to treat the bilateral lateral back, lower back, sacral area, and suprагluteal contour. All areas will be tumesced, receive fat separation without suction and loose fat removal under suction, until the skin-fat flap thickness has been reached and our planned anatomic contours have been achieved. The patient is now ready for real-time intraoperative ultrasound-guided fat grafting.

Fat Grafting Using the Microaire System

Ultrasound can make any fat grafting technique safer. For its speed, convenience, low cost, and single-person use, the author (Pazmiño) prefers combining ultrasound with the expansion vibration lipofilling technique using a "candy cane" cannula (Helix Tri-Port III, MicroAire). This cannula's multiple openings prevent the single-hole obstruction of other cannulas, and having all openings on one surface allows for precise unidirectional fat grafting in the subcutaneous space (Fig. 10.24).

Fig. 10.24 A "candy cane" cannula (Helix Tri-Port III, MicroAire) is used for fat grafting because the multiple openings avoid fat graft clogging a single opening; having all openings on only one side of the cannula allows for precise unidirectional fat grafting. (Reprinted by permission from Springer Nature. ultraBBL: Brazilian Butt Lift Using Real-Time Intraoperative Ultrasound Guidance, by Pat Pazmiño. Copyright © 2020)

Fat grafting is performed under real-time intraoperative ultrasound guidance through the intergluteal and suprагluteal access incisions. The infragluteal access incision is only used for addressing the outer thighs and hips.

Real-Time Intraoperative Ultrasound Visualization of Fat Grafting

All gluteal preoperative markings are reinforced, including the horizontal line marking the point of greatest hip projection (at a level bisecting the intergluteal crease), as well as other areas that will require volume, adhesion release, correction of asymmetries, etc.

An Android or iOS tablet is mounted on an intravenous (IV) pole facing the gluteal area and the surgeon. The portable wireless ultrasound probe and a Bluetooth computer mouse are placed into a sterile probe cover (6″ × 48″ Soft Flex Probe Cover REF 20-PC648 Advance Medical Designs, Marietta, GA) and brought onto the field. The ultrasound probe is placed on the skin over the first treatment area (central mound) and the sterile computer mouse is used to adjust the ultrasound probe's depth of field, gain, mode, and contrast. Recording of the ultrasound-guided fat grafting procedure begins.

The surgeon will hold the MicroAire handle and cannula with the dominant hand, the ultrasound probe with the other hand to visualize the cannula tip, and will use the foot pedal to control the propulsion of the aqueous fat graft via the peristaltic pump.

The order of gluteal fat grafting begins centrally to establish projection over the central gluteal dome, then laterally to the hips, and finally into the supragluteal and medial gluteal regions. The cannula is inserted through the supragluteal or intergluteal incisions and advanced into the treatment zone, until it is visualized by the ultrasound. To create significant central dome projection, the cannula tip is placed with ultrasound guidance into the deep subcutaneous space (under the superficial gluteal fascia and above the deep gluteal fascia) and fat graft is precisely injected. The cannula tip is always visualized, and care is taken never to place the cannula tip below the deep gluteal fascia, as this would result in an intramuscular injection. Any adhesions within the deep subcutaneous space can be visualized and released, allowing for even distribution of the fat graft throughout this zone. To correct superficial skin depressions and asymmetries, the superficial subcutaneous space (above the superficial gluteal fascia and below the skin) is specifically addressed. Ultrasound-guided fat separation and release of adhesions is first performed in the superficial subcutaneous space, followed by controlled fat injection. Care is taken to keep the superficial gluteal fascia intact, as this will maintain separate deep and superficial subcutaneous spaces and prevent blowout irregularities. In this manner, the two anatomical subcutaneous spaces can be individually addressed in each anatomical area (Figs. 10.25, 10.26, 10.27, 10.28, 10.29, 10.30, 10.31, 10.32, and 10.33).

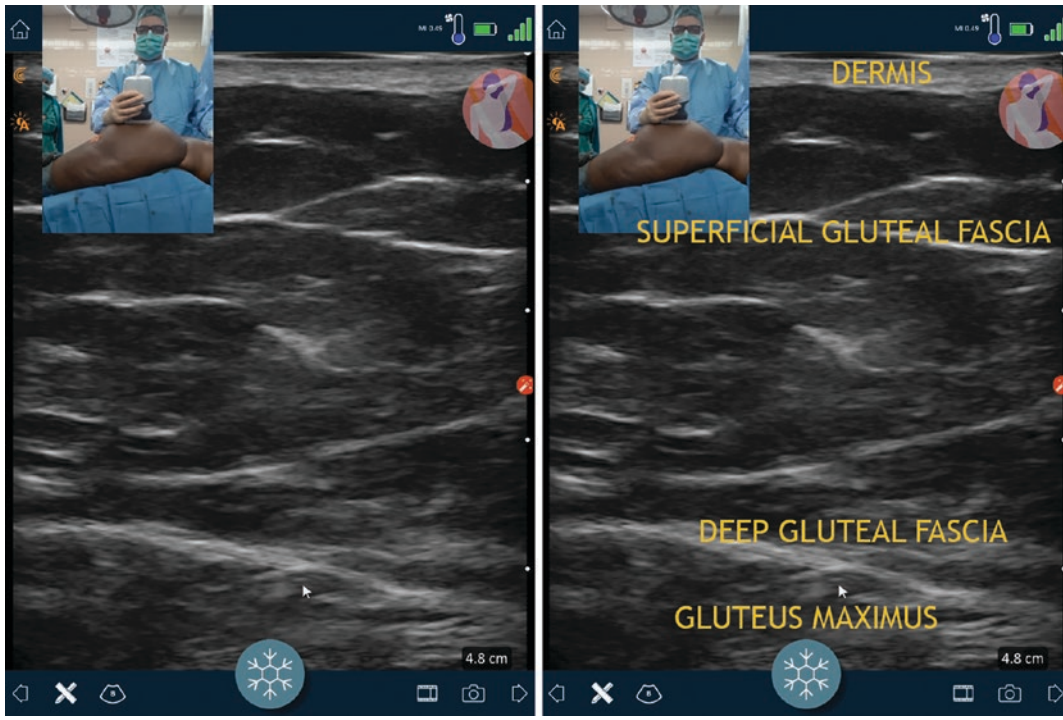

Fig. 10.25 Central dome preinjection: The Clarius portable wireless ultrasound probe is placed over the central dome of the buttock. The probe is transmitting the image to the tablet that is facing the surgeon. The dermis, superficial gluteal fascia, deep gluteal fascia, and gluteus maximus are noted. The superior surface of the gluteus maximus is covered with the deep gluteal fascia and is 4 cm below the skin in this patient. Each white dot along the right side of the image is 1 cm from the surface of the probe. Before injection, the superficial gluteal space (below the skin and above the superficial gluteal fascia) is approximately 1.5 cm thick. The deep gluteal space (below the superficial gluteal fascia and above the deep gluteal fascia) is approximately 2 cm thick before injection

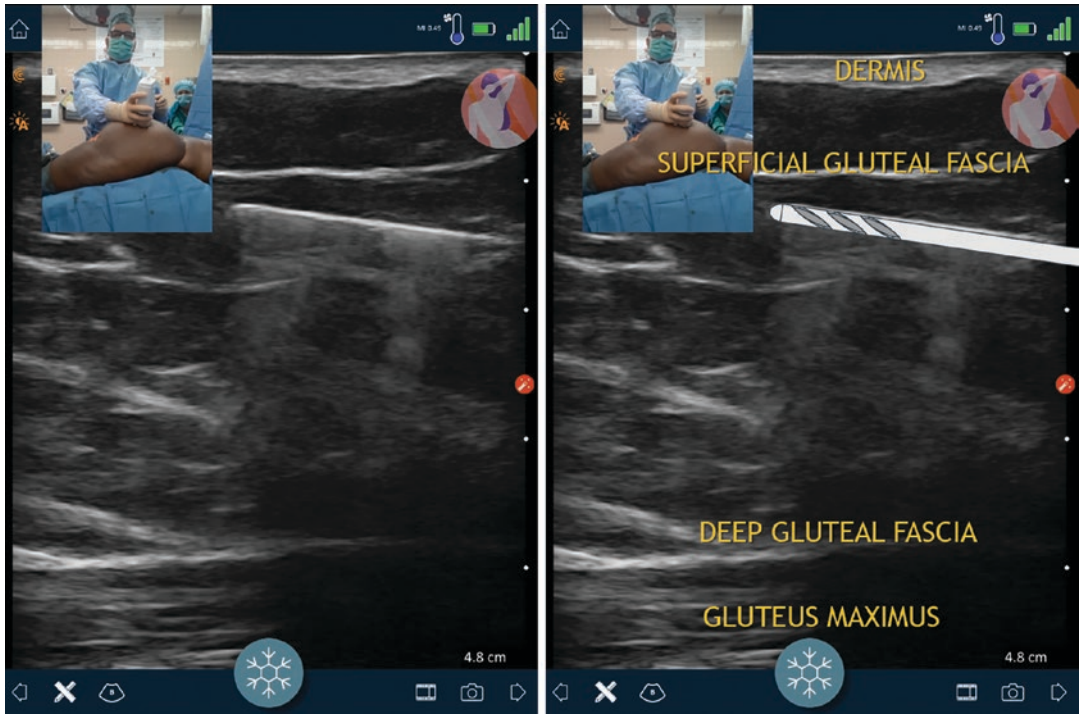

Fig. 10.26 Central dome with fat grafting cannula in deep gluteal space: The "candy cane" fat grafting cannula is directly beneath the superficial gluteal fascia and is facing inferiorly. It is displacing the superficial gluteal fascia superiorly to allow for expansion of the deep gluteal space. The deep gluteal fascia and the gluteus maximus are noted to be 4 cm below the skin surface

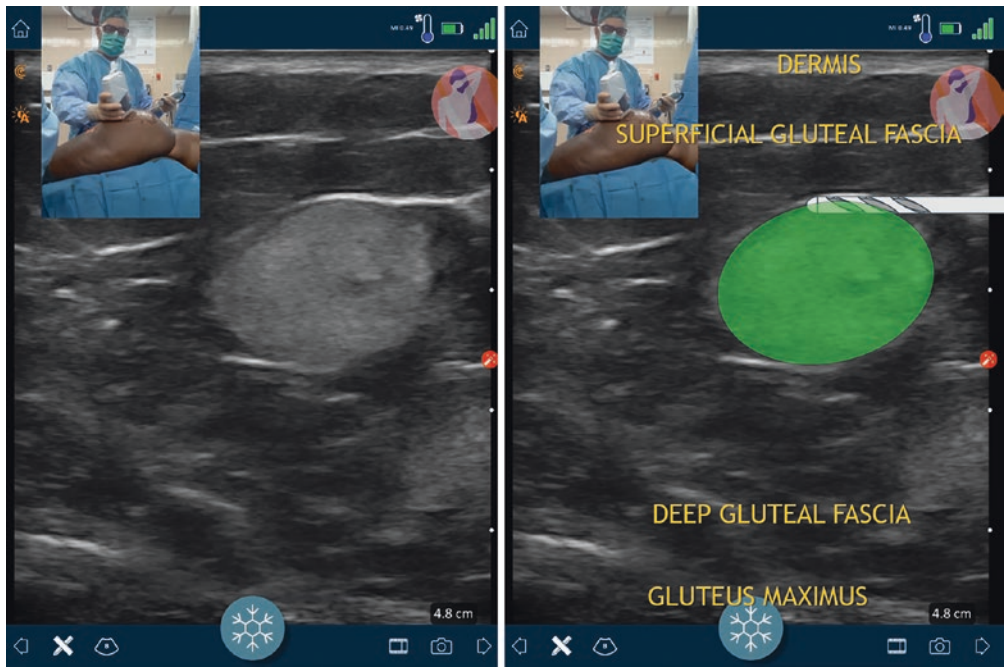

Fig. 10.27 Central dome fat graft exiting the cannula. Fat grafting begins with the aqueous fat graft (light gray hypoechoic bubble) leaving the inferior surface of the "candy cane" cannula under the superficial gluteal fascia and within the deep subcutaneous space

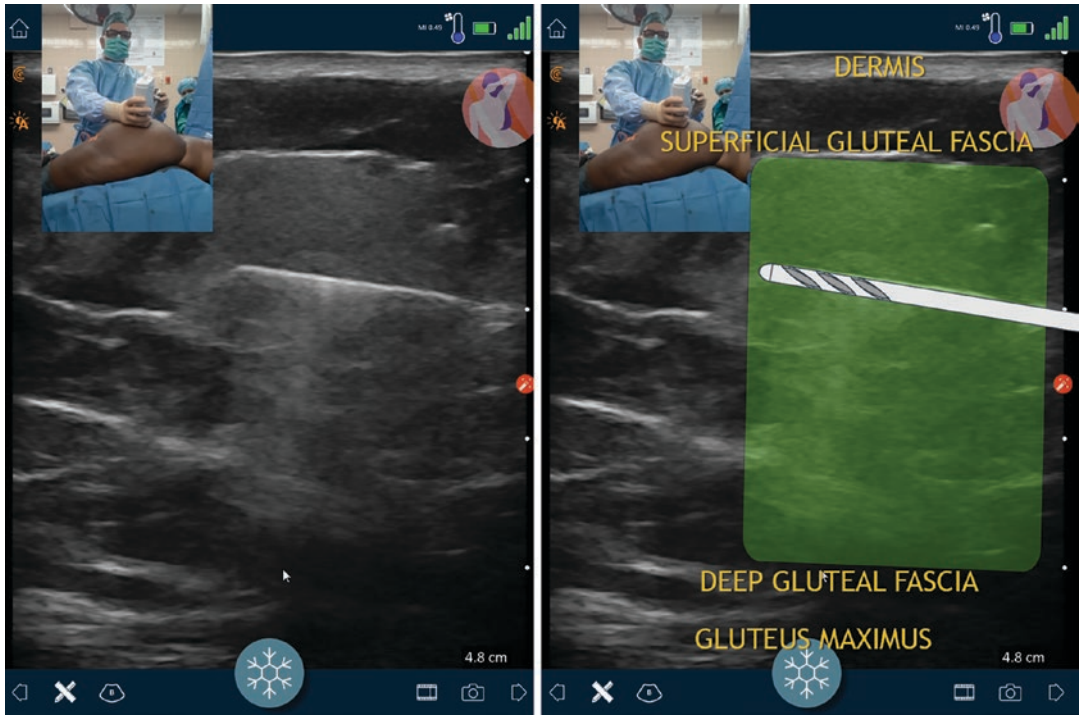

Fig. 10.28 Central dome fat graft expanding the deep subcut space. Fat graft began with the "candy cane" cannula just underneath the superficial gluteal fascia. As the upper part of the deep gluteal space is filled, the cannula is lowered half a centimeter to fill and expand the deep gluteal space

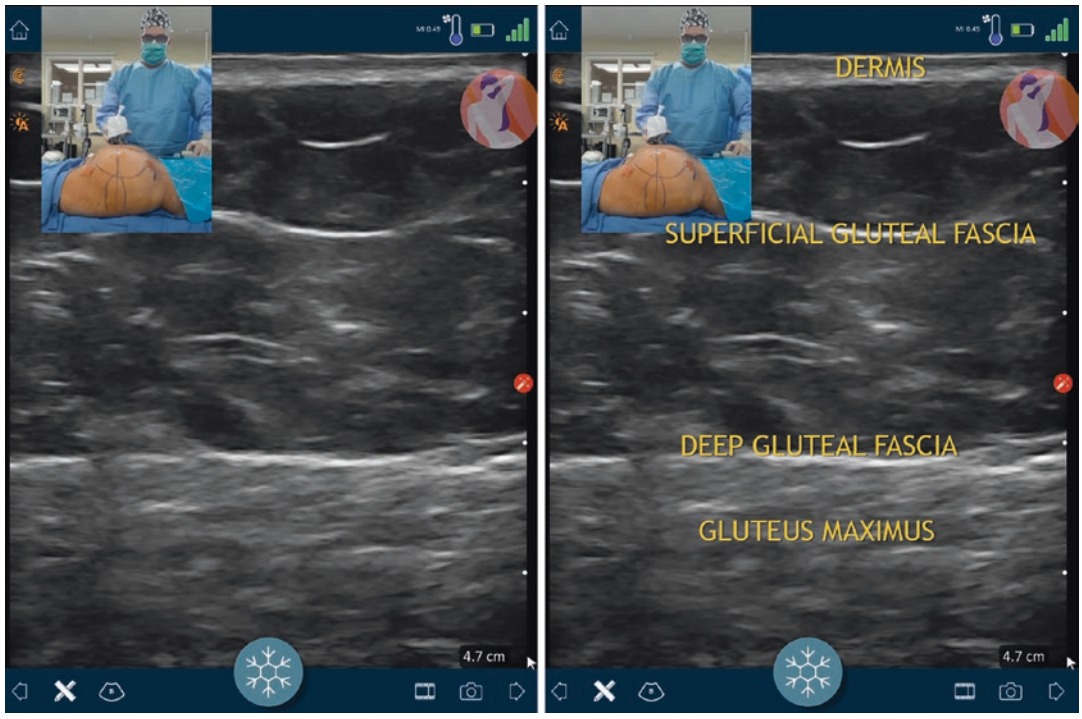

Fig. 10.29 Central dome with cannula under superficial gluteal fascia, example 2. In this different patient, both fascias are visible. Before injection, the superficial subcutaneous space is 1.4 cm thick, the deep subcutaneous space is 1.6 cm thick, and the deep gluteal fascia is 3 cm below the skin

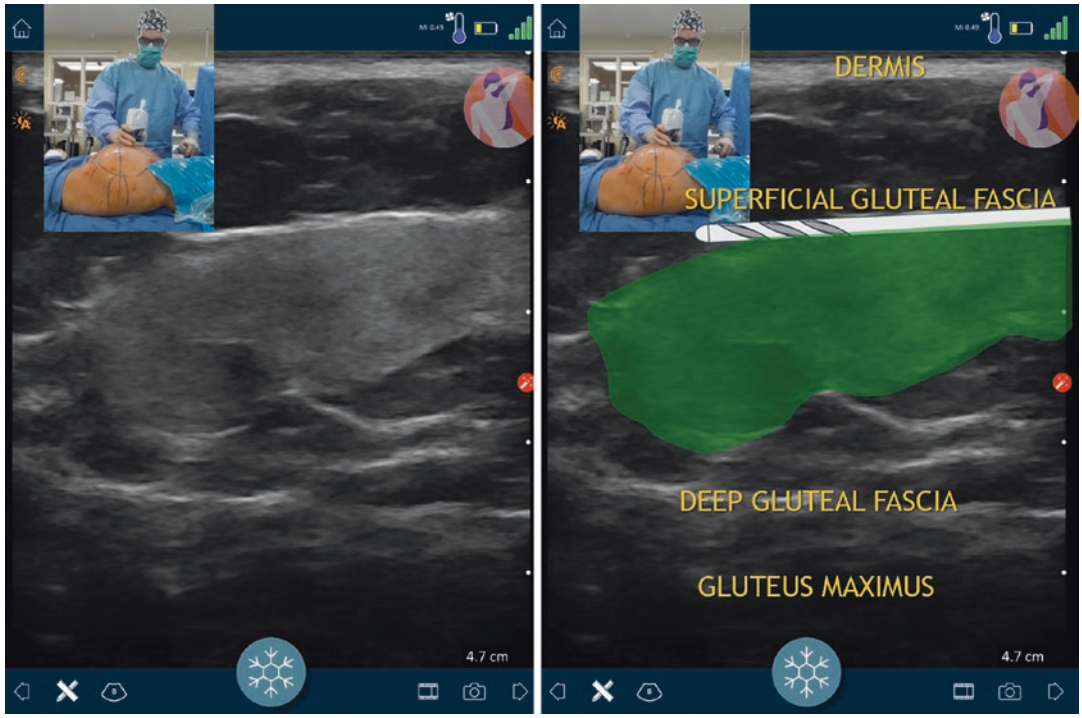

Fig. 10.30 Central dome, example 2. The "candy cane" cannula is inserted just underneath the superficial gluteal fascia and is facing inferiorly. The deep subcutaneous space is filled from the top down. The superficial gluteal fascia remains intact and retains the fat graft beneath it like the casing of a sausage

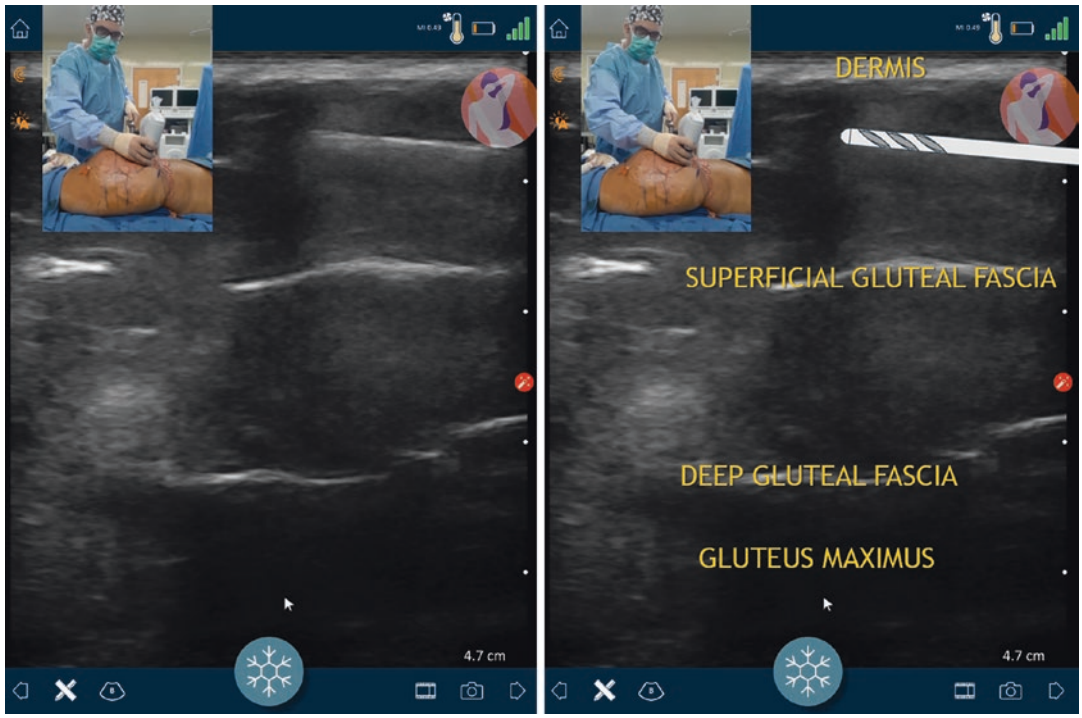

Fig. 10.31 Supragluteal contour, preinjection. The "candy cane" cannula is above the superficial gluteal fascia within the superficial subcutaneous space. Ultrasound guidance allows for precise targeting of thin subcutaneous spaces

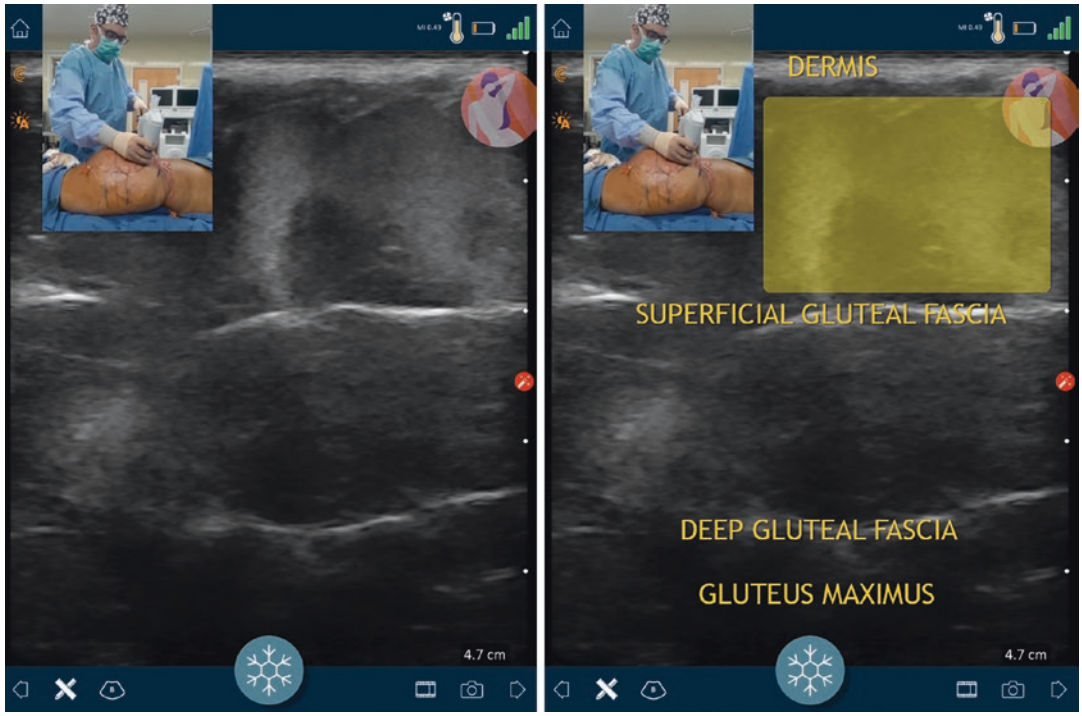

Fig. 10.32 Supragluteal contour, after fat graft. Fat graft has expanded the superficial subcutaneous space from 1.7 to 2 cm. The deep gluteal space remains unchanged

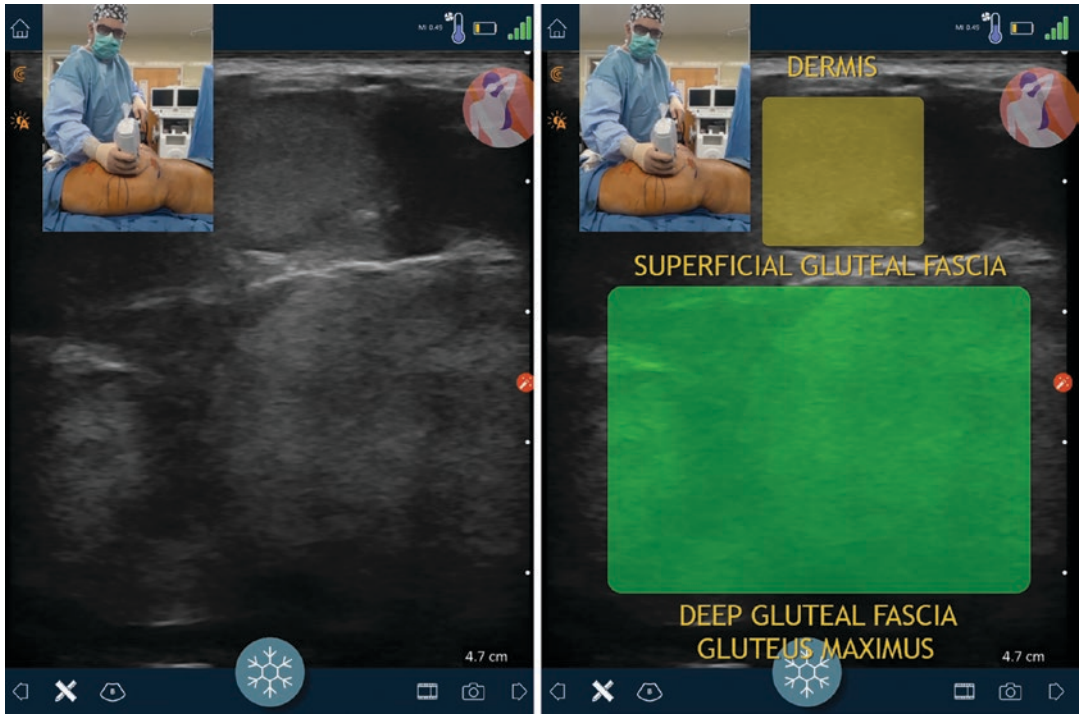

Fig. 10.33 Outer hips, after fat grafting to both spaces. Fat graft has expanded the superficial subcutaneous space and the deep subcutaneous space. This is essential when filling the outer hips

Real-time intraoperative ultrasound-guided fat grafting allows the surgeon to consistently avoid penetrating the deep gluteal fascia and prevents an inadvertent intramuscular fat graft injection. It also lets the surgeon accurately manipulate the structures of the subcutaneous region and to precisely fat graft into the deep or superficial subcutaneous spaces. Ultrasound video of the entire fat grafting process can easily be created to serve as definitive documentation that at no time was there an intramuscular injection. Real-time intraoperative ultrasound allows for precise fat grafting into the subcutaneous spaces, and can keep the patient and the surgeon safe.

Patient Cases

Case One

A 42-year-old G1P1 Hispanic female presents with lipodystrophy of the abdomen, waist, sides, flanks, and thighs; and loss of volume, asymmetry, and ptosis of the gluteal areas and hips, bilaterally. The patient stated that she would like the lipodystrophy of her abdomen and back correct, as well as a rounder and fuller gluteal contour. The patient was evaluated on physical examination and it was noted that she had significant lipodystrophy of the anterior abdomen, waist, flanks, lower back, and sacral area, as well as depressions and volume loss of the outer hips and gluteal ptosis.

Patient's Priorities

The patient stated that she would like to extract as much fat from the anterior abdomen, waist, and flanks as possible. She also stated that she would like a low waist-to-hip ratio (less than 0.6), and would like to fill the lateral gluteal hollows.

Operative Challenges

Fibrous tissue of the back and sacral area may make fat separation and extraction difficult in these important anatomic areas. Outer hip contour after fat grafting will rely on survival of the fat graft, making achievement of the desired waist-to hip ratio with outer hip fat grafting alone difficult.

Surgical Plan

- Fat separation without suction to all areas, followed by fat extraction under suction.
- Deep-space fat grafting to the central domes, supragluteal area, and outer hips at the point of greatest projection.
- Superficial space fat grafting to correct superficial concavities at the outer hips.
- To more reliably achieve the patient's desired waist-to-hip ratio, extract as much fat throughout the waist and flanks as possible, rather than rely on the survival of fat graft in the outer hips (Fig. 10.34).

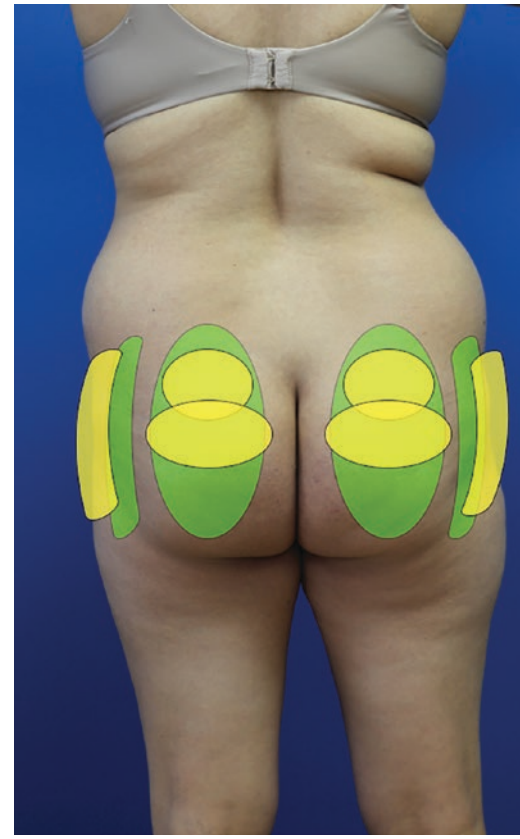

Fig. 10.34 ultraBBL Case 1: Ultrasound-guided fat grafting plan. Gluteal fat grafting was planned to the deep subcutaneous spaces (GREEN) to increase projection and add volume. Fat grafting to the superficial subcutaneous spaces (YELLOW) would supplement the deep volume and correct superficial irregularities

Result

The patient received an ultraBBL (ultrasound-guided Brazilian butt lift) with fat separation and fat extraction of the abdomen, waist, flanks, lower back, and sacral areas. She received 900 cc of ultrasound-guided fat graft per side. Seven hundred cc of fat graft was placed in the deep subcutaneous space (above the deep gluteal fascia and below the superficial gluteal fascia) for the creation of gluteal volume, central dome projection, and outer hip expansion. She then received 200 cc of fat graft to the superficial subcutaneous space (above the superficial gluteal fascia and below the skin) to the outer hips, bilaterally. The patient is shown preoperatively and with a 6-month result; she is satisfied with the result (Figs. 10.35 and 10.36).

Case Two

A 27-year-old G0P0 African American female presents with lipodystrophy of the abdomen, waist, sides, flanks, and thighs; and loss of volume, asymmetry, and ptosis of the gluteal areas and hips, bilaterally. The patient was evaluated on physical examination and it was noted that she had significant lipodystrophy of the anterior abdomen, waist, flanks, lower back, and sacral area, as well as volume loss of the outer hips and gluteal ptosis.

Patient's Priorities

The patient stated she would like to extract as much fat as possible from the abdomen, waist, flanks, and back. She also stated that she would

Fig. 10.35 ultraBBL Case 1. Pre-op, left, and postoperative result at 6 months

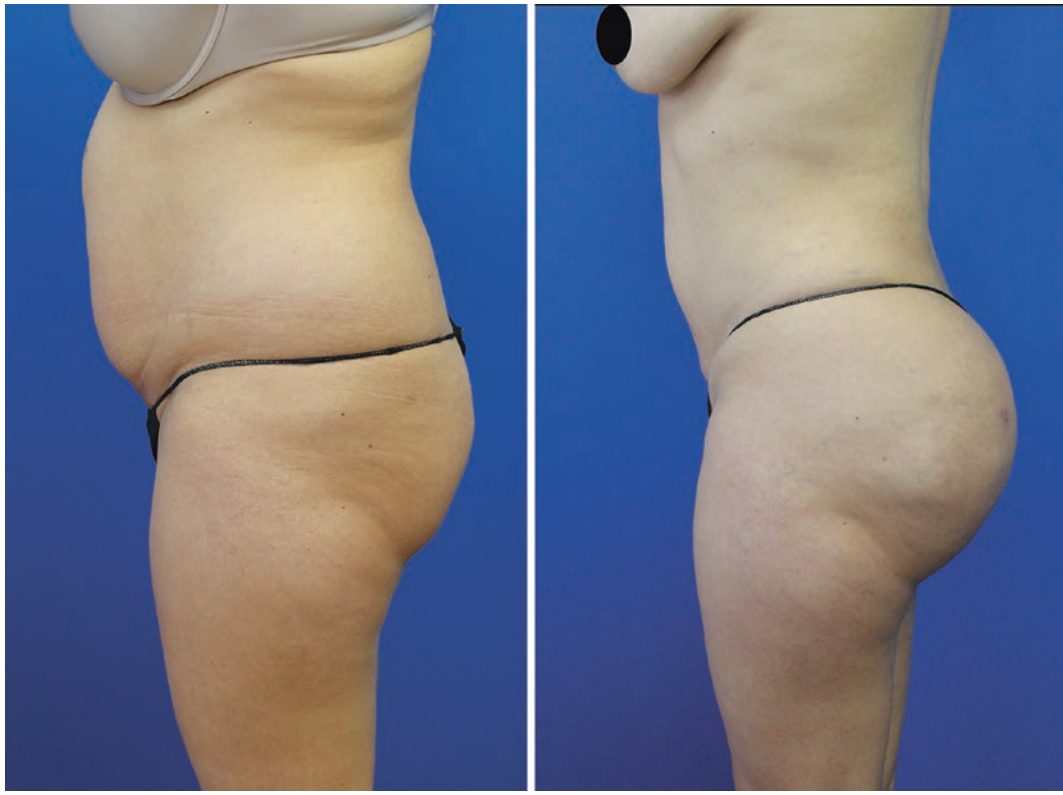

Fig. 10.36 ultraBBL Case 1. Pre-op, left, and postoperative result at 6 months

like to maximize her gluteal volume and create a spherical contour. The patient requested a low hip-to-waist ratio (less than 0.6) and a high point of maximum hip projection (2 cm above the midpoint of the intergluteal cleft).

Operative Challenges

Fibrous tissue of the back and sacral area may make fat separation and extraction difficult in these important anatomic areas. Outer hip contour after fat grafting will rely on survival of the fat graft, making achievement of the desired waist-to-hip ratio with outer hip fat grafting alone difficult. More fibrous tissue superiorly along the outer hip makes a high point of maximal projection difficult.

Surgical Plan

- Fat separation without suction to all areas, followed by fat extraction under suction.
- Deep-space fat grafting to the central domes, supragluteal area, and outer hips at a high point of greatest hip projection.
- Anticipate for additional adhesion release in both spaces along the outer hip before and after fat grafting, for smooth graft distribution.
- Superficial space fat grafting to correct superficial concavities at the outer hips.
- To more reliably achieve the patient's desired waist-to-hip ratio, extract as much fat as possible throughout the waist and flanks, rather than rely on the survival of fat graft in the outer hips. (Fig. 10.37).

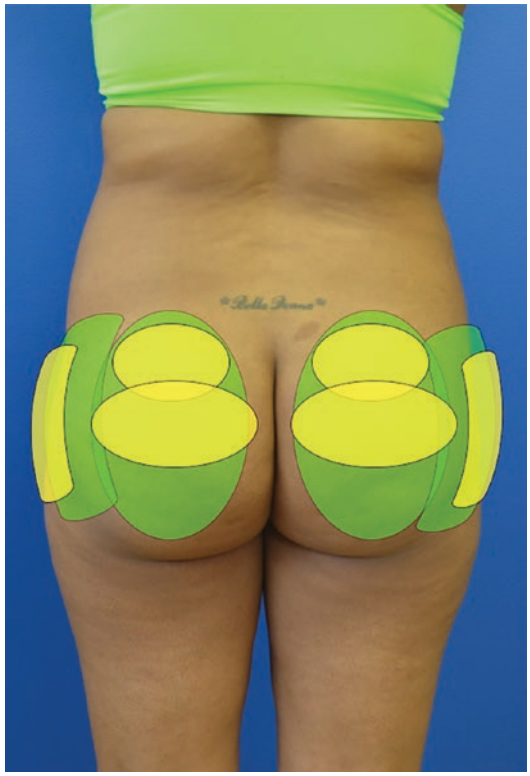

Fig. 10.37 ultraBBL Case 2: ultrasound-guided fat grafting plan. Gluteal fat grafting was planned to the deep subcutaneous spaces (GREEN) to increase projection and add volume. Fat grafting to the superficial subcutaneous spaces (YELLOW) would supplement the deep volume and correct superficial irregularities

Result

The patient received an ultraBBL, a Brazilian butt lift with fat grafting under real-time intraoperative ultrasound visualization. The patient received fat separation without suction and fat extraction under suction of the abdomen, waist, flanks, lower back, and sacral areas. Care was taken to empty the waist and flanks and the suprasacral triangle concavity. She then received 1000 cc of fat graft per side. Seven hundred cc of fat graft was placed in the deep subcutaneous space (above the deep gluteal fascia and below the superficial gluteal fascia) for the creation of gluteal volume, central dome projection, and supragluteal contour. Release of adhesions throughout the deep and superficial gluteal spaces at the outer hips was performed, taking care to leave the superficial gluteal fascia intact. She then received 300 cc of fat graft to the superficial subcutaneous space (above the superficial gluteal fascia and below the skin) at the outer hips, bilaterally. Further adhesion separation was performed after fat grafting to ensure even distribution of the fat graft in both spaces. The patient is shown pre-op and with a 9-month result; she is satisfied with the result (Fig. 10.38).

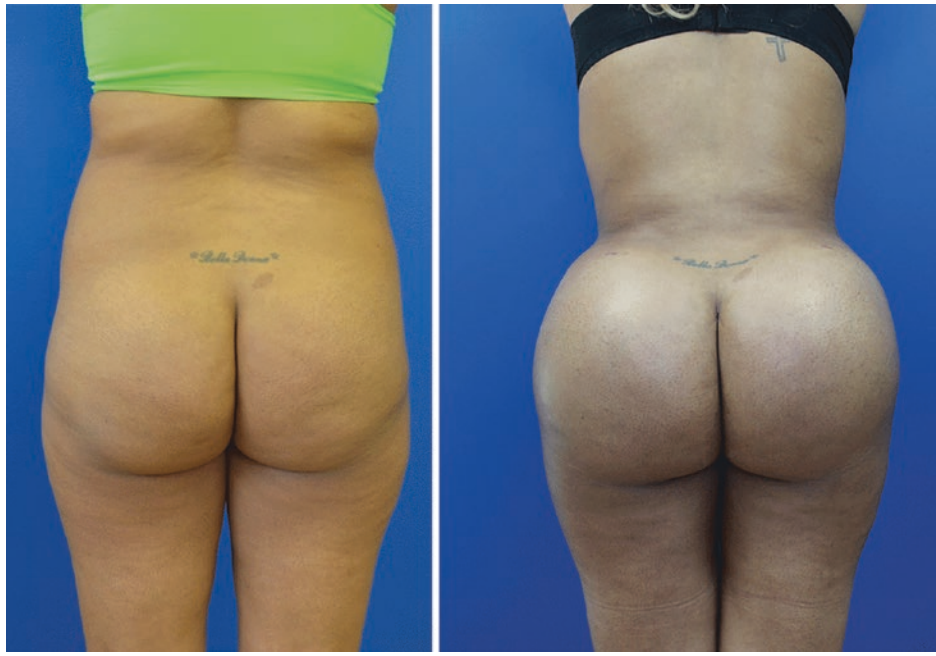

Fig. 10.38 ultraBBL Case 2. Pre-op, left, and postoperative result at 9 months

Conclusion

Gluteal fat grafting is a powerful body-contouring technique that can create impressive results not obtainable with implants or liposuction alone. This procedure is very technique-dependent and because of the too frequent fatal complications, it has been recommended that surgeons avoid intramuscular injection and only fat graft in the subcutaneous space above the deep gluteal fascia. The subcutaneous space, however, is a thin curving dome that ranges in thickness from 1 cm at the outer hips to 3–4 cm at the central gluteal dome. This creates a difficult target for gluteal surgeons who do not use intraoperative imaging. Real-time intraoperative ultrasound-guided fat grafting allows the surgeon to consistently avoid an intramuscular injection and manipulate the subcutaneous spaces above and below the superficial gluteal fascia to precisely control fat graft volume and distribution, create projection, and correct superficial irregularities. The surgeon can also create ultrasound video of the entire procedure to document that they remained above the deep gluteal fascia at all times, and analyze how their fat graft placement affected their ultimate clinical results. None of this is possible without ultrasound. Real-time intraoperative ultrasound is now an affordable tool that can work with any fat grafting system that can not only make a Brazilian butt lift more accurate and powerful, but safer, as well.

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Gynecomastia: Evaluation and Surgical Tips and Tricks

11

Luccie M. Wo, Natalia Vidal-Laureano, Annelise C. Sprau, Seth R. Thaller, and Mary H. McGrath

Introduction

Gynecomastia, a benign enlargement of the male breast, results from variable degrees of ductal proliferation and stromal hyperplasia. It is the most common male breast alteration, commonly developing without a pathologic basis during periods of physiologic change such as infancy, puberty, and old age. The prevalence of gynecomastia in patients 45 years of age or younger has been cited up to 64% [1–3]. Differential diagnosis for gynecomastia is vast. A detailed presurgical workup is essential prior to determining if surgical management is appropriate.

This chapter will discuss surgical management of gynecomastia and highlight several operative techniques that have facilitated the perioperative management of patients with gynecomastia. It is our goal to optimize patient safety, while maintaining operative efficacy and improving aesthetic outcomes.

Etiology of Gynecomastia

Observed in up to 25% of asymptomatic males, physiological gynecomastia is thought to result from an imbalance between testosterone and estrogen in male breast tissue. These physiologic changes explain the bimodal distribution of gynecomastia. In pubertal teens, there is a temporary imbalance between androgens and estrogens, causing the physical appearance of breast growth. Similarly, as men age, the imbalance re-emerges as the aromatase activity increases. This produces a relative increase in estradiol [4]. Increased action of estradiol causes characteristic histological changes, namely, ductal epithelial hyperplasia and an increase in stromal and periductal connective tissue [5]. This ductal proliferation can develop unilaterally or bilaterally. Physiologic gynecomastia is benign and usually is self-limited. Characteristically, it resolves spontaneously within 6 months to 2 years [6].

Other pathologic hormonal etiologies include endocrinopathies, estrogen-secreting tumors, and obesity. Altered hormone homeostasis correlates with the genesis of gynecomastia. Referral to breast clinics for preventative, aesthetic, or therapeutic reasons should begin with a hormonal

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workup [7]. Evaluations including serum testosterone, estrogen ratio, prolactin, thyroid hormone, and growth hormone levels are pivotal to pinpointing and treating endocrine derangements with associated breast growth. Whereas physiologic cases can be managed with reassurance, pathologic causes may require medical treatment and, if unresolved, surgical removal of the excess tissue for correction of the deformity [8].

Preoperative Evaluation

All patients with gynecomastia should be evaluated with a comprehensive history and physical examination of the breasts, genitals, lymph nodes, and thyroid. When examining the breast, it is important to note skin laxity/excess, nipple position and size, position and mobility of the inframammary fold, and degree of breast ptosis. Most commonly, gynecomastia is bilateral, but there may be asymmetry and a history of unequal development of the two sides, with growth that has been sequential or simultaneous. Distribution of breast growth should be noted; gynecomastia typically presents as a subareolar concentric mass, although it can be eccentrically located [9]. Any evidence of nipple retraction, lymphadenopathy, or nipple discharge should raise concern for malignancy [10]. Discussion of a family history of breast and ovarian cancer is appropriate.

Hormonal testing is indicated in prepubertal, pubertal, and adult males, and a thorough pharmacological history is necessary for the evaluation of gynecomastia. Both prescription medications and recreational drugs can induce gynecomastia through a variety of mechanisms [11]. Discontinuation of the offending agent, if possible, or augmenting the treatment with an antiestrogenic agent can halt and often reverse the tissue growth in many cases. Table 11.1 illustrates well-known gynecomastia-inducing drugs and their potential mechanisms.

Recommendations for imaging are based on a clinician's findings and results of the hormone screening. Testicular ultrasound is warranted if the physical exam demonstrates a palpable testicular mass or other symptoms consistent with a testicular malignancy. In adult males with midlife onset of gynecomastia, chest and adrenal imaging as well as liver and renal function testing may be indicated. While mammography is not routinely done, ultrasound or mammography is of value if there are findings on physical exam that are congruent with possible malignancy [12].

After workup, up to 25% of gynecomastia cases are deemed idiopathic. Unresolved gynecomastia can place a substantial social and psychological strain on patients, thus making surgical correction a mainstay of treatment. Surgical management is typically deemed appropriate if the gynecomastia lasts greater than 2 years with no identifiable or reversible cause. After 1 year or more duration, the histologic pattern of the tissue evolves from a florid form to dense fibrosis and hyalinization, which is seldom reversible [13].

Table 11.1 Drugs that induce gynecomastia

Drug type	Drug name	Mechanism of inducing gynecomastia
Antiandrogens	Flutamide and derivatives, finasteride and derivatives	Antiandrogenic effects leave estradiol unopposed
Antifungals	Ketoconazole	Inhibits androgen synthesis
Antipsychotics	Haloperidol, olanzapine, risperidone	Blocks dopamine antagonism on prolactin synthesis
Chemotherapeutic agents	Methotrexate, cyclophosphamide, etoposide, bleomycin, cisplatin	Multiple mechanisms
Exogenous hormones	Estrogens, androgen abuse	Antagonizes testosterone's action
Gastrointestinal agents	H2 receptor antagonists, proton pump inhibitors	Antagonizes testosterone at high levels

Classification of Gynecomastia

During preoperative planning, the planned surgical approach is based on the degree of deformity. For patients with mild to moderate gynecomastia, the surgical objective is excision or liposuction of the excess tissue through small incisions, relying on skin retraction to restore a smooth contour; multiple techniques for this have been described [14]. In the individuals with excessive breast tissue, those with skin redundancy due to ptosis or weight loss, and in the older patients with less skin elasticity, skin excision and consequent scarring is unavoidable. A variety of techniques have been described to keep these scars to a minimal length and to place them where they will be least noticeable, least likely to hypertrophy, and least suggestive of a female breast.

Since a clear description of the deformity is needed for surgical planning, classification is based on the patient's physical appearance, tissue type, imaging, or a combination [15]. Some commonly used classification systems are listed below in Table 11.2. These can guide operative planning, define the cost in scarring, and allow the surgeon to select the necessary procedure in light of patient satisfaction and cosmetic results.

Anatomical Considerations

Surgical anatomy was described by Caridi et al. [16]. It can help to classify the areas of hypertrophy for surgical planning:

- **Zone 0** is the area immediately beneath the nipple areolar complex (NAC). It can give the nipple a "puffy" appearance. In a study of 635 patients treated for gynecomastia, approximately 2% had involvement of Zone 0 alone.
- **Zone 1** is an elliptical shaped area located on the frontal chest, superficial to the pectoralis muscle. It surrounds Zone 0 and it is horizon-

Table 11.2 Classification systems for gynecomastia

Author	Year published	Type of classification	Classification
Webster	1946	Tissue type	Class 1: Periductal connective tissue hypertrophy without adipose tissue change Class 2: Increase in the amount of both connective and adipose tissue Class 3: Adipose tissue hypertrophy alone
Simon	1973	Physical	Grade 1: Small visible breast enlargement, no skin redundancy Grade 2a: Moderate breast enlargement without skin redundancy Grade 2b: Moderate breast enlargement with skin redundancy Grade 3: Marked breast enlargement with marked skin redundancy
Barros	2012	Physical	Grade I: Increased diameter and slight protrusion limited to the areola region Grade II: Moderate hypertrophy of the breast with the NAC above the IMF Grade III: Major hypertrophy of the breast with glandular ptosis and the NAC situated at the same height as or as much as 1 cm below the IMF Grade IV: Major breast hypertrophy with skin redundancy, severe ptosis, and the NAC positioned ≥1 cm below the IMF
Çil	2012	Imaging	Gynecomastic adipose tissue/total gynecomastic tissue, <0.3 Gynecomastic adipose tissue/total gynecomastic tissue, 0.3–0.5 Gynecomastic adipose tissue/total gynecomastic tissue, >0.6

tally oriented with the NAC as its apex. Gynecomastia most commonly presents with involvement of Zone 1. In Caridi's study, approximately 98% of patients had involvement of Zone 1, either alone or in conjunction with other zones.

- **Zone 2** is described as the area lateral to Zone 1, extending caudally to the axilla up to the latissimus muscle. It is involved in 55% of cases of gynecomastia.
- **Zone 3** is located along the upper lateral border of the pectoralis major muscle, adjacent to the axillary crease. It is involved in 51% of patients treated for gynecomastia.
- **Zone 4** is an oblong area caudal to Zone 1 and Zone 2, caudal to the inframammary fold. This area is usually involved in more severe cases. All four zones are involved in gynecomastia; in Caridi's study, this accounted for 16% of all cases.

It is of note that Zone 0 and Zone 1 represent true gynecomastia that leads to a feminine-appearing breast, whereas Zones 2–4 are a result of fatty tissue hypertrophy, and not breast tissue hypertrophy [16].

Besides the tissue hypertrophy, another crucial component of gynecomastia surgery is the nipple areolar complex. Beckstein performed one of the first studies of male nipple position. He analyzed 100 male volunteers and described the nipple position as 20 cm from the sternal notch and 18 cm from the midclavicular line, with a nipple-to-nipple distance of 21 cm [17]. The nipple-areolar complex measured 2.8 cm in diameter, and the shape of the majority of male nipples was oval, with a mean ratio of horizontal: vertical diameter of 27:20 mm [18].

Unfortunately, Beckenstein's descriptions did not take into account variation in patient height, weight, and shape of the chest wall, so subsequent studies looked at the nipple areolar complex (NAC) in relation to additional anatomical landmarks. Using patient height and chest circumference, complex formulas based on these measurements have been created to describe ideal nipple position and size [18, 19]. While relevant in surgical planning, these formulas are cumbersome to use in the operating room.

Nipple position can be determined by anatomical landmarks easily accessible during gynecomastia surgery. The center of the nipple areolar complex is between the fourth (in approximately 75% of males) and fifth (in approximately 25%) intercostal spaces in young Caucasian males [18]. Using the pectoralis major muscle as the point of reference, the NAC is on average 3 cm medial to the lateral border and 2.5 cm above the inferior pectoralis major muscle insertion [20]. Other landmarks could include the mid-humerus point as a vertical reference point; however, this has been considered aesthetically suboptimal [19, 21].

Surgical Markings for Gynecomastia

Preoperative markings should be made with the patient in a standing position. The suprasternal notch, sternal midline, vertical breast meridian, and inframammary fold line are identified and marked. The lateral border of the pectoralis major muscle can be used to help localize the IMF and is identified by asking the patient to flex.

In the case of excess skin laxity and ptosis, the skin to be excised should be demarcated with the patient standing. If a free nipple graft is planned, the proposed new nipple location should be drawn by marking the intersection between the horizontal location of the fourth or fifth rib and the vertical location about 3.0 cm medial to the lateral border of the pectoralis major muscle.

Surgical Approaches to Gynecomastia

The appropriate procedure for each patient is determined by the patient's anatomy and physical examination findings. Patients with minimal skin redundancy, good skin elasticity, and more florid breast tissue or adipose tissue may be treated with liposuction alone, which leaves the least scarring. Males with denser, more fibrous breast tissue but mild skin redundancy and good skin

elasticity may be treated with ultrasound-assisted liposuction or a combination of liposuction and direct excision of the breast tissue through incisions made in or around the nipple areolar complex. The patient presenting with breast ptosis or excessive skin requires skin and breast tissue excision with nipple transposition. In those with more extreme enlargement or a pendulous breast, mastectomy and free grafting of the nipple areolar complex may be required.

Liposuction

Liposuction is used as a primary tool or as an adjunct to excision in most operations for gynecomastia [22]. Often liposuction alone will treat Simon grade 1 or 2a deformities. The breast is infiltrated with a tumescent solution containing epinephrine for hemostasis, and the infiltration should extend from the clavicle to below the IMF so liposuction can be done at the margins of the glandular resection for better contouring of the chest. Generally, the entire chest can be reached with two small incisions: one at the lateral chest at the level of the inframammary fold and the other around the areola. Traditional types of cannulas can be used for gynecomastia excision, but special cannulas have also been developed with features that help break down fibrous connective tissue in the breast. Modifications to the cannula include cutting cannulas with sharp openings, barbed openings, or reserved cutting edge tips [23, 24].

During liposuction, the inframammary fold can be disrupted to help ensure a smoother contouring over the pectoralis major muscle. This facilitates the repositioning of undermined skin after the breast tissue resection. In addition, the lateral border of the pectoralis muscle can be sculpted with liposuction to give the patient a more masculine-appearing chest [25].

Regardless of technique, liposuction may be insufficient to break down dense fibrous breast tissue around and posterior to the nipple-areolar complex. A semicircular intra-areolar or peri-areolar incision can be made for access to the tissue under the NAC. When doing this, it is important to preserve a wafer of tissue, approximately 1–1.5 cm in thickness, on the deep surface of the areola to prevent loss of projection and inversion of the nipple [26].

The persistent fibrous breast tissue resistant to liposuction can be removed with a pull-through method. Using a Kocher or Allys clamp, the dense tissue is mobilized through the incision and excised [27]. Liposuction is then helpful to "feather" or smooth the margins of the tissue excision to produce a smooth contour. There is some degree of skin laxity after surgery, so use of a postoperative compression garment provides support while the skin excess is shrinking to conform to the chest wall contour. Surgeons should wait at least six to 12 months prior to proceeding with skin resection to minimize the amount of skin resected and the length of incision needed [26].

Ultrasound-Assisted Liposuction

Ultrasound-assisted liposuction was introduced to assist in the breakdown of the fibroconnective tissue of the male breast [27]. At higher energy settings, it can even remove the dense parenchymal tissue [22, 28].

These higher energy settings are used in targeted areas of dense fibrous; for example, in the Mentor system, a 90% energy level can be used in the subareolar areas [22]. When performing ultrasound-assisted liposuction, care should be taken to minimize suctioning outside the target zone and avoiding the adherent zones in the upper outer quadrant [22].

An additional advantage of ultrasound-assisted liposuction is the potential for skin tightening. Treating at the subdermal level can cause skin retraction postoperatively, a good trick for treating gynecomastia with mild skin laxity or excess [22, 28]. Both suction-assisted liposuction and excision may be used with the ultrasound-assisted device to optimize results. Skin excision should be done with caution at the time of initial treatment, as there often is skin retraction following ultrasound-assisted liposuction, especially in younger patients [22].

Arthroscopic Shaver

Use of an arthroscopic shaver to "scoop" out the dense fibrous tissue under the NAC may eliminate the need for a periareolar incision. The shaver functions by pulling in breast tissue at its tip and resecting the tissue. Petty described this method in 2010 using the Stryker TPS arthroscopic shaver with the "Aggressive Plus" cutting tip [2]. After completion of liposuction, the arthroscopic shaver is passed through the same liposuction incision. The surgeon then picks up the breast skin and pulls it away from the underlying muscle fascia using his or her nondominant hand. The cutting tip of the shaver is then moved through the remaining fibrous breast tissue. It is important to pass the shaver slowly over the tissue, with minimal pressure, through the remaining breast tissue [2].

Open Excision

Prior to the introduction of liposuction, gynecomastia was treated solely with excision. For minimal to moderate gynecomastia, an intra-areolar or peri-areolar incision gives access to the breast tissue centrally. Variations on the incision have included horizontal orientation and an inverted omega incision to increase exposure to the undersurface of the areola [22].

To avoid scars on the chest, some authors have described a transaxillary approach [29]. Disadvantages of this method are its tedious dissection, length of incision in the axilla, and risk of damage to vital structures in inexperienced hands.

Instruments have been developed to keep incisions size small. A lighted retractor for gynecomastia is especially helpful. This is a specialized retractor that fits into the periareolar incision and is designed with a narrower neck and a wider blade than other lighted retractors [30]. With this, the direct pull-through method can more easily resect glandular tissue without extending the incision [27]. Meticulous hemostasis is necessary to prevent hematoma formation, and fiberoptic lighting can give better intraoperative visualization of the wound.

With moderate to large breasts, there is excess skin, and techniques to address this with tissue reduction, limited skin excision, and transposition of the nipple or reduction of the size of the nipple have been described [22]. With these approaches, the advantage of a suture line confined to the areola is lost, but nipple transposition on a local flap can correct both skin excess and downward displacement of the ptotic nipple [13].

In cases of massive gynecomastia with high-grade ptosis and a large amount of skin excess, resection of the redundant skin is necessary. In these extreme cases, lesser techniques for correction are inadequate, since they rely on elasticity of the skin to compensate for reduced volume [13]. Using an inframammary or transverse breast incision, the skin and breast tissue are resected, and the nipple-areolar complex is removed as a full-thickness graft and placed on a dermal bed prepared at the apex of the newly contoured breast [13]. In such incidences, it is important to create smooth, symmetrical, well-contoured skin flaps that are consistent with the patient's overall body habitus.

Postoperative Care for Gynecomastia

Compression garments or dressings are applied and kept in place for 3 weeks postoperatively and longer in overweight patients or patients who had a large resection. The compression dressings assist in minimizing edema and help stabilize the soft tissues against the chest wall to better conform to the chest contour. Dressings are evaluated and changed or removed at postoperative follow-up visits, depending on the patient's progress [31].

Use of postoperative drains remains a debated topic in the literature, and decisions about their use are best determined by the magnitude of the gynecomastia procedure. Flat channel drains or Jackson Pratt drains are used to limit the substantial dead space after extensive soft tissue dissection [32]. These closed-suction drains have recognized adverse effects, including patient discomfort, bacterial colonization, and their addi-

tional clinical care requirements. Studies about drain usage in gynecomastia surgery have found the rates of hematoma are comparable in cohorts in which a drain is or is not utilized, and the volume of fluid collected is similar in patients with and without drains [33]. However, seromas requiring aspiration have been shown to occur more frequently in patients without drains [33]. In our practice, we do not typically place postoperative drains unless the patient had extensive dissection to achieve an adequate chest contour. Due to the remaining uncertainty about the efficacy of drains, at this time usage remains a matter of institutional and surgeon preference. If drains are placed, ideally they are removed at an early postoperative visit, generally within a week of the operation [34].

Common surgical complications include seroma, hematoma, abscess, reoperation for persistent deformity, and patient dissatisfaction [35]. The most common complication is hematoma, with occurrence rates ranging from 11% to 16% [36]. The most common postoperative deformities include concavity in the central breast area, retraction of the nipple areolar complex, irregularities of the wider chest contour, and breast asymmetry [13, 15, 35]. Careful selection of operative approach, tailored to the individual patient, and attention to intraoperative technique can aid in decreasing the frequency of complications and improving overall patient satisfaction.

Conclusion

Gynecomastia is a common condition for which the etiology remains unknown in many cases. In our experience, after adequately evaluating these patients for medically treatable causes, surgical management is desirable for patients with end-stage fibrosis, and it is well tolerated, with excellent results. Most patients with mild to moderate gynecomastia can be treated with combined liposuction and tissue excision through a periareolar incision to improve the contour of their chest. It is important to address the inframammary fold, to have adequate retraction and exposure for the breast tissue excision, and to leave an adequate cuff of tissue in the retroareolar space to support the nipple and avoid retraction. Patients should be informed that a second stage of surgery may be required if sufficient skin retraction does not occur and that postoperative compression is of utmost importance.

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Labiaplasty and Aesthetic Vulvovaginal Surgery

12

Adam J. Oppenheimer

> Some call surgery a science, others an art; but in my opinion, it may claim either appellation. – Lorenz Heister, 1683–1758

Introduction

The purview of the young surgeon is to challenge—ever so tactfully—the views of one's mentors. I had always contended that surgery was art, while my chairman Dr. Kuzon saw it from the vantage of a tradesman. In the case of aesthetic vulvovaginal surgery, however, I believe we are both right. Labiaplasty is an artistic venture, yet one that requires a technician's skill.

I have suggested to Drs. Thaller and Panthaki that the title *Labiaplasty & Aesthetic Vulvovaginal Surgery* is best-suited to describe this chapter. Approximately one-fourth of my practice is dedicated to the procedure I describe as *labiaplasty* with clitoral hood reduction, which is by far the most commonly requested aesthetic procedure of the female urogenital region. In fact, among all vulvovaginal procedures I perform, labiaplasty with clitoral hood reduction comprises the vast majority of my work. Therefore, in lieu of a comprehensive chapter on procedures that are seldom requested (and in some cases ill advised), I have chosen instead to focus on the procedure of greatest clinical importance.

Every procedure has a learning curve, and while it is not a particularly steep one in the case of labiaplasty, the demands of aesthetic patients are high. The late Dr. Paul Kalanathi noted that "You can't ever reach perfection, but you can believe in an asymptote toward which you are ceaselessly striving." This has been my approach with plastic surgery in general, and specifically my experience with labiaplasty in my current series of 214 patients. The reader will be fortunate to have a text that I lacked: a basic guide to the surgery itself, complete with step-by-step photographs and surgical video footage. I have included previous techniques, once used and now abandoned, as well as the key articles I have referenced—and written—at various timepoints, along my own learning curve. It is my hope that this text will serve as an actual guide to performing the edge labiaplasty with clitoral hood reduction (herein sometimes referenced simply as "labiaplasty"). It will be heavy on surgical techniques and light on academics, reflecting my experience in private practice.

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_12) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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Developmental Considerations

When boys go through puberty, they likely hope for no breasts and full genitalia; when girls go through puberty, it may well be the opposite. For young women, the sudden appearance of long, dark, and hanging labia can add to the intrinsic embarrassment of puberty. "Locker room" antics and layperson misconceptions perpetuate the idea that large labia are related to intercourse and promiscuity. In truth, enlargement of the labia minora is the simple result of hormones: circulating estrogens at pubescence yield the development of secondary sex characteristics in women.

This next fact cannot be overemphasized—there is no "normal" vaginal appearance, just as there is no standard shape, size, and appearance of the male penis. When making a decision to reduce the labia minora in women, this latter point must be reiterated. Figures that display a wide range of vulvar phenotypes can help normalize a patient's concerns (Fig. 12.1).

Nonetheless, labia minora enlargement is in some ways synonymous with gynecomastia development in young men. Both are met with the disdain and ire commonly felt with the physical changes of pubescence, but with an added element of not belonging to the standard sex characteristics of one's given gender. In the best of cases, a mature and educated young woman does her own research and comes to a decision whether or not to seek out consultation for reduction of the labia minora.

The recent rise in labiaplasty procedures has been met with some controversy from the lay press and professional societies alike. The American College of Obstetricians and Gynecologists, for example, discouraged labiaplasty for young women in a 2016 position piece, favoring education and the use of supportive garments and emollients [1]. Of course it is for these reasons—discomfort in certain clothing and personal hygiene issues—that many patients seek treatment [2]. Additionally, comparisons between labiaplasty and female genital mutilation (FGM) have been made—also in the gynecology literature—discouraging the procedure [3]. It is the author's opinion that if a breast reduction can be performed for symptomatic macromastia, a labiaplasty can be performed for symptomatic labia minora hypertrophy. Labiaplasty is no more a mutilation than a reduction mammoplasty; so, too, can an otoplasty be performed for prominent ears. As always, patient selection and education are paramount.

Others have attributed the rise in labiaplasty procedures to widespread availability of pornography [4] and changes in female grooming patterns. Conversely, dissenting evidence suggests that pornographic consumption has no correlation with women seeking out labiaplasty procedures [5]. Instead, it is likely that as women have come to control their own narrative, they also have come to control their own bodies. The most proximate cause is female empowerment.

Pearl: Labia minora enlargement occurs at puberty

Pitfall: Hypertrophy of the labia minora is not abnormal

Clinical Evaluation and Consultation

As a rule, plastic surgery consultations should begin with a patient fully clothed and not in an examination chair. Nowhere is this more true than in a labiaplasty consultation. Also of critical importance—particularly with male clinicians—is to be accompanied by a female chaperone. Plastic surgery consultations by definition can engender an element of apprehension about one's body; every effort should be made to help the patient feel at ease.

While the goal is to treat patients at the age of informed consent (18 years of age and older), exceptions can and should be made for mature young women accompanied by a consenting adult. The patient's mother is a frequent accompaniment in the majority of all cases (including

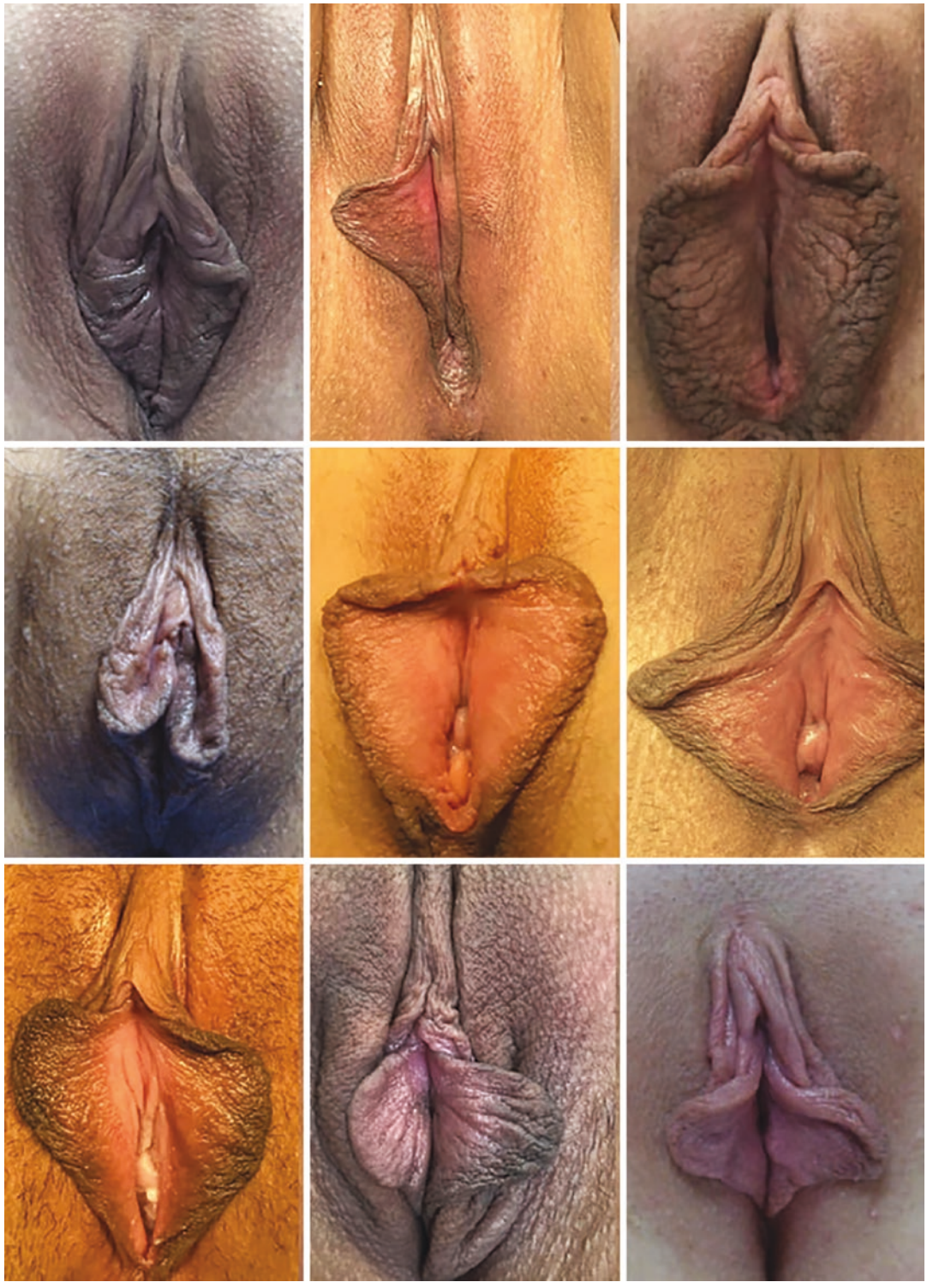


Fig. 12.1 A wide range of "normal" phenotypic variation is seen in patients presenting for labiaplasty

with consenting young adults) and is a sign of a thoughtful exchange and good support system.

The first aspects of the consultation fall on the responsibility of the physician to normalize the patient's concerns and provide reassurance on the process, while also acknowledging that the process of evaluation is intrinsically awkward and that feelings of awkwardness are commonplace in this setting. A second, concomitant task is to specifically outline the pertinent female anatomy, using specific anatomical designations wherever possible and avoiding slang terms at any cost. By using the words "labia minora, clitoral hood, and clitoris," the therapeutic relationship is established and professionalism clarified, however simple it may be. While open-ended and patient-directed dialogue is preferred, this is not so at the outset of a labiaplasty consultation; the examiner should take the helm and initiate a monologue that reviews pertinent anatomy and common symptomatology.

In this vein, a woman most often presents for labiaplasty consultation with one simple complaint: dissatisfaction with the appearance of prominent labia minora. Indeed, up to one-third of patients present with purely aesthetic complaints [6].

Other complaints range from the physical to the psychosocial. Psychosocial discomfort—self-consciousness—is more commonplace. Physical discomfort can be variable and not always present. Physical symptoms from hypertrophic labia minora can include the following:

- Pinching or pulling with exercise or intercourse (dyspareunia).
- Undesirable friction and chafing with daily activities.
- Challenges with tight clothing, ranging from visibility to discomfort requiring frequent adjustment.
- Hygiene challenges from excess rugae (folds) including, most commonly, toilet paper.
- Urinary and/or yeast infections [7], also related to the foregoing.

Psychosocial discomfort is far less straightforward to define. When reviewing this second element of discomfort, it is incumbent on the physician to reiterate that there is no baseline normal anatomy and that vulvar appearances vary widely.

The reasons for psychosocial discomfort are more complex. The essences of maleness and femaleness are hardwired into our psyche and are deeply seated in our anthropology. Ergo, while we may not be able to truly understand the biological underpinnings, we can accept the psychosocial discomfort that may exist for specific characteristics, specifically: large breasts are undesirable in a man because they are perceived as feminine; large genitalia are undesirable in women because they are perceived as masculine. It is with this in mind that the labiaplasty consultation is approached.

One final and critical element of psychosocial complexity must be known to the provider: sexual assault of any kind can precipitate feelings of revulsion on the behalf of the patient with regard to their own genitalia. A sense of shame that accompanies a woman's own genitalia after sexual trauma is quite different than feelings of embarrassment about one's appearance. While difficult to glean, this critical omission in patient history could lead to a surgical intervention that would only worsen the emotional toll of the trauma. Tearfulness and patient reports of strong words like "disgust" should alert the mindful clinician of such a history. Notably, a history of sexual trauma is no more common in consulting patients when compared to the general population [8]. Nonetheless, labiaplasty should be undertaken with great caution in these patients, and psychological consultation is recommended prior to surgery.

Providing reassurance is the sine qua non of any elective aesthetic plastic surgical consultation, and two specific elements are required here. One, as previously discussed, communicating that variations in anatomy are normal, and the wide range in morphologies should be normalized to the patient. Two, changes in sensation after labiaplasty are not encountered with current techniques [9]. With careful technique, labiaplasty with clitoral hood reduction can be performed without adverse sensory sequelae and may even improve the sexual response [10].

The final aspect of consultation is a discussion of anesthesia. Both local anesthesia and intravenous sedation may be employed, based on patient and surgeon preference. Using the detailed approaches outlined below (see section "Technical Considerations"), a local anesthesia labiaplasty can be quite comfortable for the patient. Intravenous sedation with the assistance of an anesthesiologist should be employed in younger patients and in patients with more notable anxiety surrounding the procedure.

Pearl: Review common presenting symptoms prior to eliciting patient history

Pitfall: Missing elements of sexual trauma

External Anatomy

The general anatomy of the vulva may be easily reviewed in a variety of resources [11, 12] and does not merit rote review here. With specific regard to labiaplasty, there are several nuanced elements to consider that cannot be found in anatomy texts.

From a clinical perspective, the primary anatomical concern is the amount of labia minora "show" beyond the labia majora (Fig. 12.2). Because most women desire "hidden" labia minora, a simple binary classification of labia minora visibility is reiterated: whether or not the labia minora protrude beyond the labia majora [13]. This consideration is the primary aesthetic goal of the patient and therefore the surgeon. The amount of labia minora "show" and classification schemes to define this—and the length of the labia minora for that matter—are irrelevant [14]. This is a *relative* measure of labia minora hypertrophy; women with elongation of the labia *majora*, for example, may more readily tolerate longer labia minora because they remain hidden. Conversely, women with deflated and atrophic labia majora may experience labia minora show at shorter inner labia lengths and may seek consultation thusly.

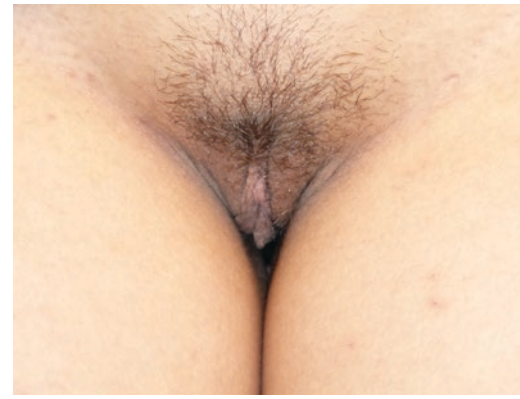


Fig. 12.2 Labia minora "show" when standing is a common presenting complaint

Another anatomic concern is the degree of labia minora pigmentation (Fig. 12.3). Not only do the labia minora become larger with puberty, but dark pigmentation can frequently develop at the labia minora edge. This can also be a source of distress among young women who may desire a more pink appearance to the genitalia. Pigmentation concerns are more pronounced in women with darker skin tones, but hyperpigmentation of the labia minora is seen across all races and ethnicities in response to circulating estrogens.

The clitoral hood, or prepuce, may be prominent at the top of the vaginal cleft and should be identified (Fig. 12.4) in order to guide surgical planning of the clitoral hood reduction. Failure to do so—performing a labiaplasty without clitoral hood reduction—leads to an unbalanced appearance. Indeed, this result has been described by women seeking surgical revisions as having "a small penis" [15]. A simple rule: the larger the labia, the larger the hood. Much in the way that macromastia always displays concomitant enlargement of the nipple-areola complex, so too does clitoral hood excess accompany hypertrophy of the labia minora.

Asymmetry is another common presenting concern (Fig. 12.5). A mirror image of the human body does not exist, and the labia are no exception. Elongation of one labia alone as the central

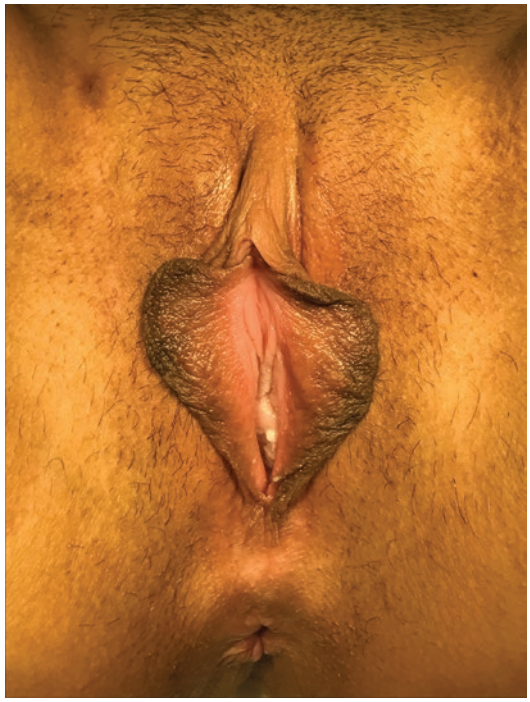


Fig. 12.3 Hyperpigmentation of the labia minora edge, in addition to hypertrophy, is an additional patient concern

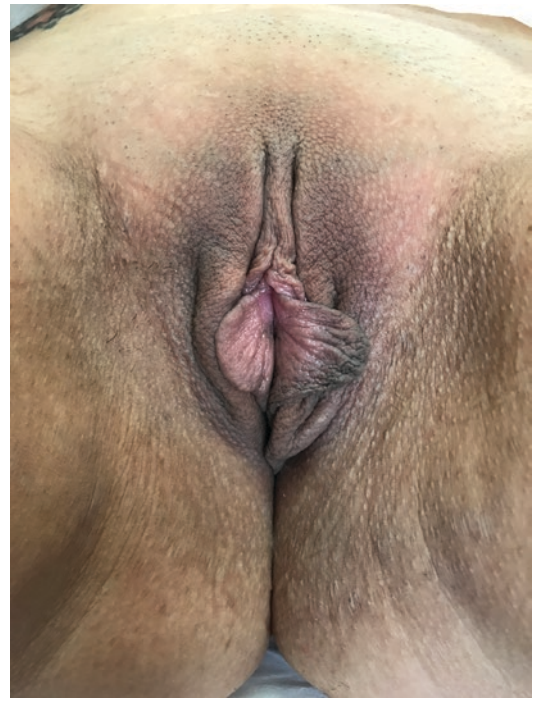


Fig. 12.5 Labia minora asymmetry is an additional patient complaint; the patient's left labia minora is larger and displays hyperpigmentation, which is also seen throughout the vulva

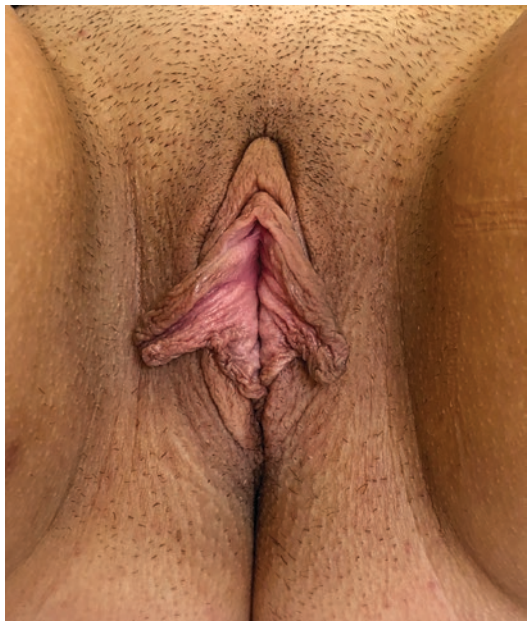


Fig. 12.4 A prominent clitoral hood (prepuce) is often an additional finding to labia minora hypertrophy

concern may present, as may fullness of only one side of the clitoral hood (Fig. 12.6a). A unilateral procedure, while uncommon, should be considered (Fig. 12.6b). This also applies to the clitoral hood folds, also known as labia minora reduplication folds. For example, a unilateral labiaplasty *could* be performed in isolation, as could a bilateral labiaplasty with a unilateral hood reduction. These differences, when present, should be noted. Every effort should be made to achieve the patient's desired goals for symmetry with the least amount of possible surgery.

Another overlooked anatomical variant is the clitoral length. While most physicians, and laypersons alike, view the clitoris as a single ball of tissue (the glans), the reality is that the anatomy of the clitoris is far more complex. The clitoris not only has a glans, but it has a body or shaft, which determines clitoral length. Also present are the crus and bulb of the clitoris, the corpus cavernosum homologues (albeit less critical for surgi-

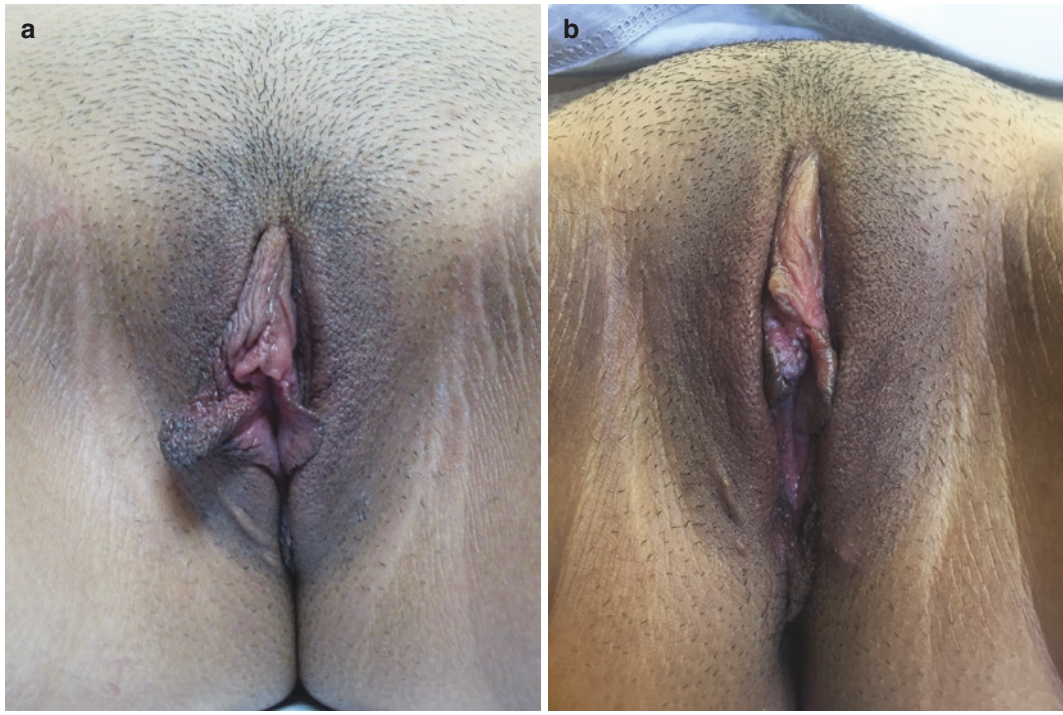


Fig. 12.6 (**a**) A patient with right labia minora hypertrophy and ipsilateral associated clitoral hood enlargement. (**b**) 3 weeks after reduction of the right-side only reduction of the labia minora and clitoral hood

cal planning). A long clitoral shaft, however, has surgical implications: despite the goal of removing excess hood tissue, an overly aggressive hood reduction can leave the clitoris exposed, particularly when the clitoris is low, owing to a long clitoral body. In these cases, patient hypersensitivity can result from over-exposure, and a modest hood reduction is advised. Clitoropexy procedures, whereby the clitoral glans is detached and advanced cephalad, securing to the pubic bone, are unadvisable in this author's opinion and should be reserved for the reconstruction of female genital mutilation (FGM). Nonetheless, clitoropexy procedures have been described [16].

Clitoromegaly is another clitoral variant that can lead to patients presenting for labiaplasty. Most, if not all, cases reveal a history of androgen use for fitness or bodybuilding. The absence of such history should prompt the clinician to order a hormone panel to check androgen levels and initiate referral to an endocrinologist. Clitoral reduction procedures are again ill-advised and may hold too great a risk of nerve injury and resultant sexual dysfunction.

More subtle: The labia minora will each have a different angle of takeoff at the clitoral frenulum, the wishbone-like structural bands that branch out from the glans clitoris (Fig. 12.7). As the male testes sit at different levels, the clitoral frenulum also have different positions from right to left. Frequently this leads to one labium protruding more anteriorly than the other, despite a roughly equal labia minora length. Patients should be advised of these anatomic variances.

The labia majora cleft width is also pertinent to surgical planning and patient expectations. Cleft diameter may be viewed as analogous to breast cleavage. When planning breast augmentation, a patient's intermammary distance may preclude close cleavage despite the surgeon's best efforts. Similarly, a wide gap between the labia majora may eliminate the possibility of a closed cleft. Even with reduction of the inner labia and hood, some visibility of these tissues will remain

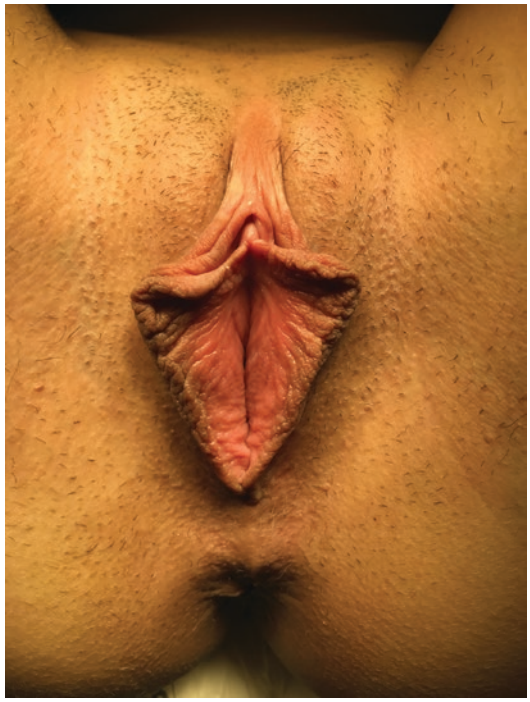


Fig. 12.7 The clitoral frenulae are the "wishbone"-like bands extending from the glans clitoris; they may have a different takeoff angle and therefore protrude differently. Here, the left frenulum has a 90-degree takeoff and projects anterio-laterally, while the right frenulum has an obtuse angle and inferior projection. This has implications for planning the excision for the edge labiaplasty

if the outer labia are widely spaced (Fig. 12.8a and b).

Pearl: Attend to excesses in the clitoral hood as well as the labia minora

Pitfall: Failure to recognize a clitoromegaly and/or long clitoral body

Photography

Presurgical photography is beneficial not only for documentation, but also for discussing the plan of care. Two photographic views are recommended (Fig. 12.9a and b). A standing anterior photograph (with inferior flash directed superiorly to avoid shadowing) is helpful in defining the amount of labia minora "show" and provides information on the width of the vaginal cleft. A lithotomy view allows a much more close-up view of the anatomy, revealing details like clitoral body length and clitoral frenulum takeoff angles, as well as asymmetry and size concerns. These photographs facilitate a discussion of each patient's unique anatomy. With the magnification and detail of photographs, even now on smartphones, a nuanced conversation can be had that promotes realistic expectations.

Photographic storage can be maintained in a HIPAA-compliant online database, or on a locked and password-protected local hard drive. When storing these photographs, it is recommended that patient names not be used. Instead, abbreviations or internal alphanumeric codes can further protect patient identity in case of security breach. Needless to say, genital photographs are more inherently private than other items in the patient chart.

Pearl: Set the flash below the subject when taking a standing photograph

Pitfall: Failure to directly review unique anatomical variants with each patient

Surgery should be a merciful art; the cleaner and gentler the act of operating, the less the patient suffers. – Berkeley Moynihan, 1865–1936

Technical Considerations

A variety of technical approaches have been discussed, ranging from de-epithelialization to more complex patterns [17]. Indeed, the author's own approach has varied from a wedge labiaplasty as first described by Alter [18] to a horseshoe [19] approach, to the current edge labiaplasty with clitoral hood reduction, the latter of which has been

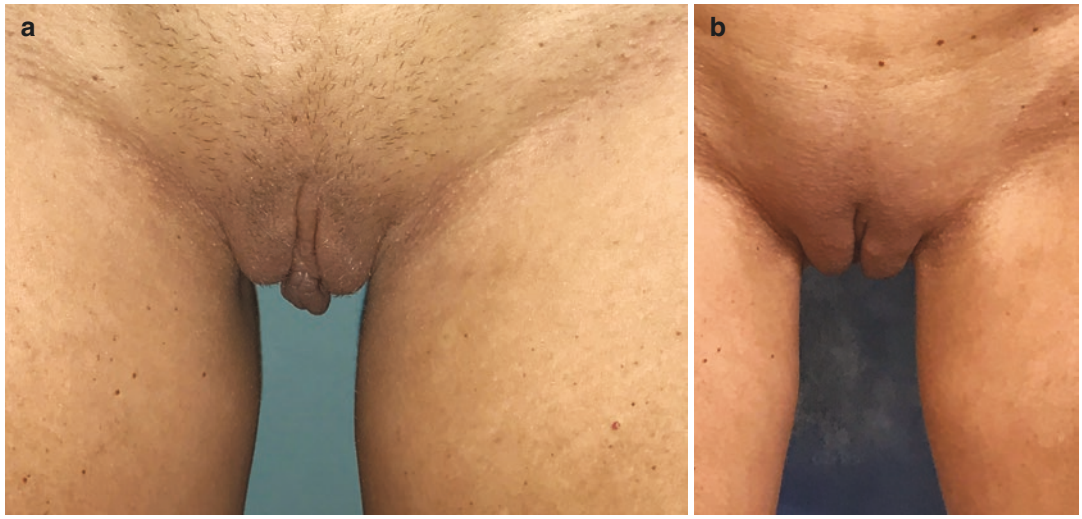


Fig. 12.8 In patients with a wide vaginal cleft (**a**), a central band of hood and labia minora tissues will still be visible after labiaplasty (**b**)

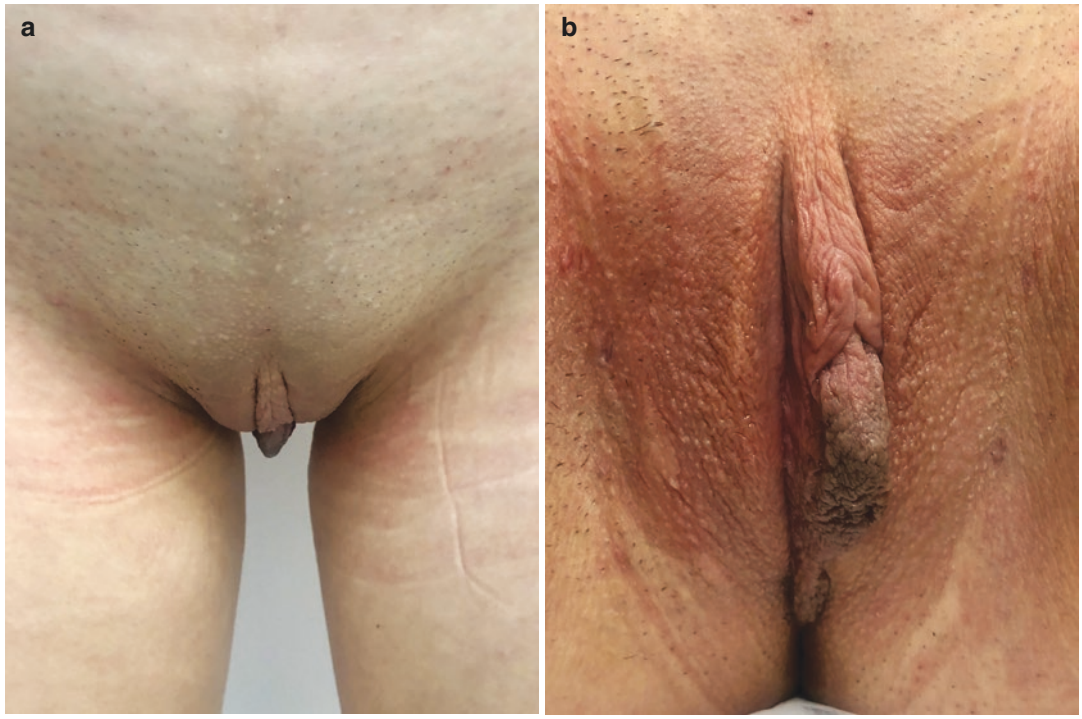


Fig. 12.9 Standard AP (**a**) and Lithotomy (**b**) photographic views are recommended

employed for the more recent 189 cases. While different approaches can be espoused for different anatomical variants—as described by Hunter [20] —the edge labiaplasty with clitoral hood reduction is the most versatile, can be implemented with variations to meet the unique anatomical constraints of each patient's anatomy, and has the least likelihood of dehiscence and the lowest incidence of operative revision [21].

The techniques below will closely follow the author's own experience and shifting techniques, beginning with brief discussions of the wedge and horseshoe approaches, then focusing on the current and favored approach of the edge labiaplasty with clitoral hood reduction.

Wedge Labiaplasty

The wedge labiaplasty, where a central triangle is excised from the most prominent portion of the labia minora, is technically easy to execute. Healing issues with this approach, namely dehiscence, can result in wedge separation. The labia minora can heal in a taffy-like manner, and if outright dehiscence is not encountered, a slow separation can result. The dehiscence rate for this approach has been underreported in the literature [21].

In addition, the natural rough edge—the rugae—of the labia minora is preserved, along with segments of hyperpigmentation. While proponents of this result claim a natural appearance, it is often seen as "too natural" by some patients. In some cases, a delineated pigment transition is visible. In addition, the labia are not able to be aggressively reduced with this technique: the only option to remove more tissue is a wider wedge, which by definition puts more stress on the already delicate closure. Heavier suture and everted wound edges—as a means to reduce tension—only result in suture track marks and channels. Longer lasting suture (e.g., PDS), in addition, creates discomfort, with painful knots that can take months to dissolve.

Lastly, because the hood is not able to be fully addressed with the wedge approach, redundant folds of the clitoral hood can remain visible, leading to an imbalanced look and prominence of the hood region.

Horseshoe Labiaplasty

The horseshoe labiaplasty, or wedge labiaplasty with a contiguous horizontal hood excision, was devised in order to reduce fullness at the clitoral hood. This allowed for tissue to be removed from a redundant hood and large labia simultaneously in a single incision. The resulting removed tissue has a horseshoe shape [19]. Unfortunately, disruption of lymphatic drainage pathways from the horizontal hood incision resulted in significant postoperative edema and a protracted convalescence. The technique was therefore abandoned in favor of the edge labiaplasty with clitoral hood reduction.

> Gentleness, not speed, is the cardinal surgical virtue. – Henry Buchwald, 1932–

Edge Labiaplasty with Clitoral Hood Reduction

Occam's razor suggests that the simplest solution is most likely the correct one [22]. From a surgical standpoint, the edge labiaplasty with clitoral hood reduction satisfies this requirement. Often thought of as an oversimplification, the dictum "everything in plastic surgery is an ellipse" indeed applies in this procedure. The following approach is a detailed review of the author's preferred method for the labiaplasty procedure, as shown in the Fig. 12.10. Regardless of the specific technical steps, gentleness to tissues is paramount. Clamping, grasping, and cauterizing should be minimized wherever possible.

Anesthesia

Based on preoperative consultation, three options exist to ensure patient comfort prior to labiaplasty. In addition to local anesthesia:

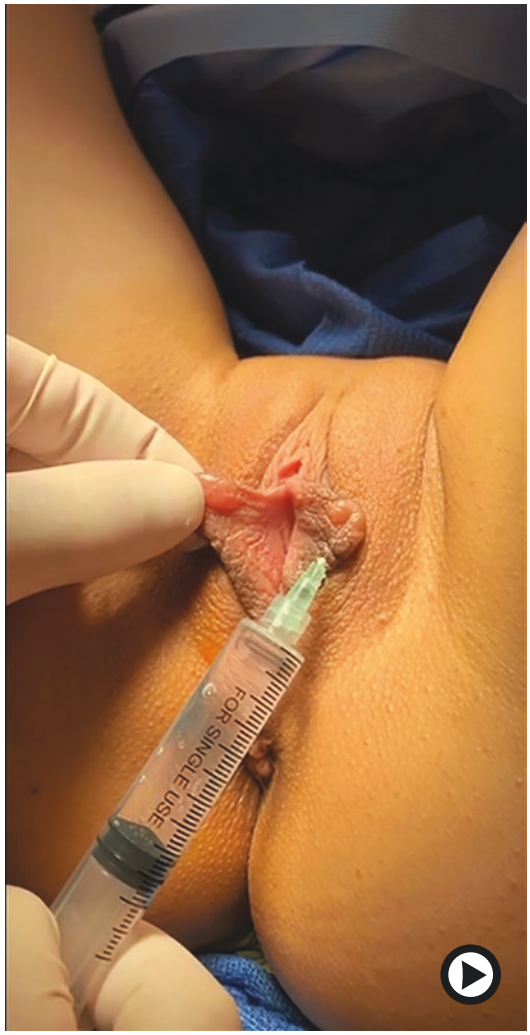


Fig. 12.10 Video: The labiaplasty procedure (▶ https://doi.org/10.1007/000-3tm)

1. The patient is induced into intravenous sedation (most commonly using Midazolam and Propofol) by the anesthesiologist.
2. The patient is given oral sedation (Diazepam) with topical anesthetic gel placed over the vulva.
3. The patient is provided with anesthetic gel alone (benzocaine 20%, lidocaine 8%, tetracaine 4%, BLT ointment).

In the first two cases, the patient requires an adult chaperone for transportation purposes. In the latter case, the patients may drive themselves to and from the clinic.

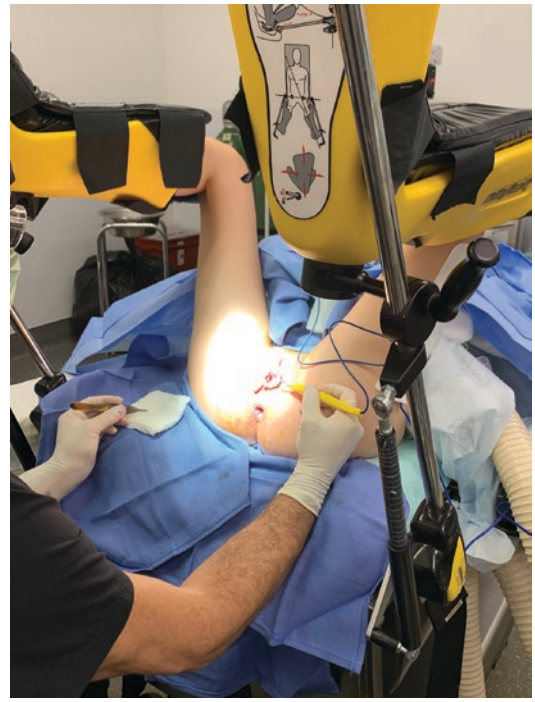


Fig. 12.11 Preoperative positioning of the patient and surgeon for labiaplasty. Note that extensive draping and gowning is not necessary for this clean-contaminated procedure. Loupes are used to enhance visual acuity

After satisfactory provision of the desired anesthesia, the patient is positioned into lithotomy, and the field is prepped and draped (Fig. 12.11). Warmed Betadine or baby shampoo can be applied to the vulva (Fig. 12.12), cleansing away any residual BLT ointment. Because the labiaplasty procedure is classified as *clean-contaminated*, extensive draping and the use of gowns is at the discretion of the surgeon. A small field thus unencumbered can be readily navigated. Loupe magnification is strongly advised.

Preoperative antibiotics can be limited to a single oral or IV dose, at the discretion of the operating surgeon and depending on the patient's level of sedation. In patients with a strong recurrent history of yeast infections, these should be avoided. Notably, the Betadine prep alone can precipitate candida overgrowth in some patients.

Particularly in the case of the awake patient, there are several subtle maneuvers that aid in patient comfort. First, a liquid nitrogen spray can be used by the assistant in the precise location and

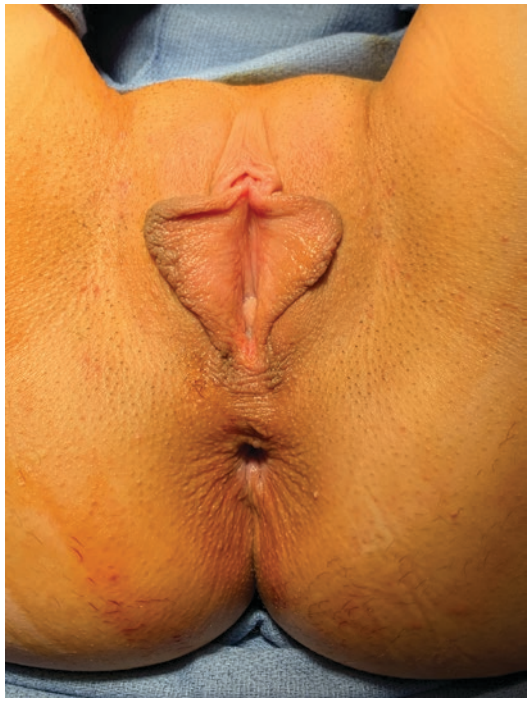


Fig. 12.12 Surgeon's perspective of the operative field after Betadine (or baby shampoo) application

timing of anesthetic infiltration, namely the most distal and protruding portion of the labia minora. This area is the most readily accessible and the least sensitive. The smallest possible needle is used for infiltration (e.g., 32 gauge) and the anesthetic of choice can be mixed with bicarbonate solution to increase pH. Once a small wheal of anesthetic is delivered, the anesthetic can be infiltrated into the remaining field with a larger caliber and longer needle. Many of the subtle injection techniques described for wide-awake hand surgery per Lalonde should be implemented [23].

Initial Markings

Patients are not marked in the recovery room. Because the vulva is an intertriginous area, the least amount of surgical marking is recommended, so as to avoid ink spreading throughout the vulva and confusing excision patterns.

After infiltration of the initial wheal of anesthesia as above, the surgeon should mark the two lateral clitoral hood ellipses for excision (Fig. 12.10). A 1 cm bridge should be maintained across the central element of the clitoral hood to preserve lymphatic drainage. These are the medial boundaries of each hood ellipse. The lateral boundaries are the interlabial sulci (the crease between the majora and minora). The proximal point of the ellipse is made at the origin of the sulcus cephalad, and the distal point made at the very tip of the labia minora. When the labia is gently retracted, the excess fold of labia reduplication can easily be visualized. It is this fold that is to be excised (Fig. 12.10).

Step-by-Step Techniques

Once the clitoral hood ellipses have been marked and infiltrated, a 15 blade is used to gently incise along the markings, retracting the tissue for counter-tension using the nondominant hand. The clitoral hood excisions should be thought of as a full-thickness skin graft harvest, only removing the dermis (Fig. 12.10). The dissection plane proceeds nicely at this level. The clitoral hood mucosa is reflected from the superior point of the ellipse caudally to the labia minora margin. A Colorado needle can be used to facilitate this step.

Once the hood tissue has been excised bilaterally, hemostasis is ensured. A single stitch of 5–0 monocryl on a tapered RB-1 needle (Ethicon, Somerville, NJ) is placed at the midpoint of the ellipse to bisect the closure evenly. The tapered needle is preferred to a cutting needle so as to readily pass through the delicate submucosa in intradermal fashion. Care must be taken here so that the central hood tissue is not pulled cephalad; the glans clitoris should remain covered at this point in the operation. Further, if hood retraction seems imminent based on the excision pattern or a long clitoral body length, the central tissues can be advanced caudally as a remedy.

After partial closure of the hood defects, two smooth convex curves for the proposed labia minora excision are marked (Fig. 12.13). The apex of this excision should be made at the very end of the clitoral frenulum, taking care to avoid any incisions at the glans clitoris, but beveling

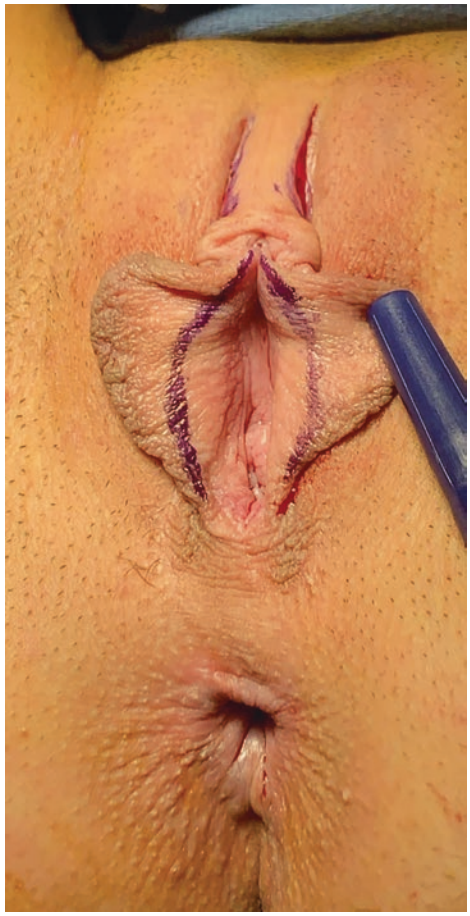


Fig. 12.13 Appearance after clitoral hood reduction and subsequent curvilinear markings of the labia minora. Note the preserved central band across clitoral hood to preserve lymphatic drainage pathways

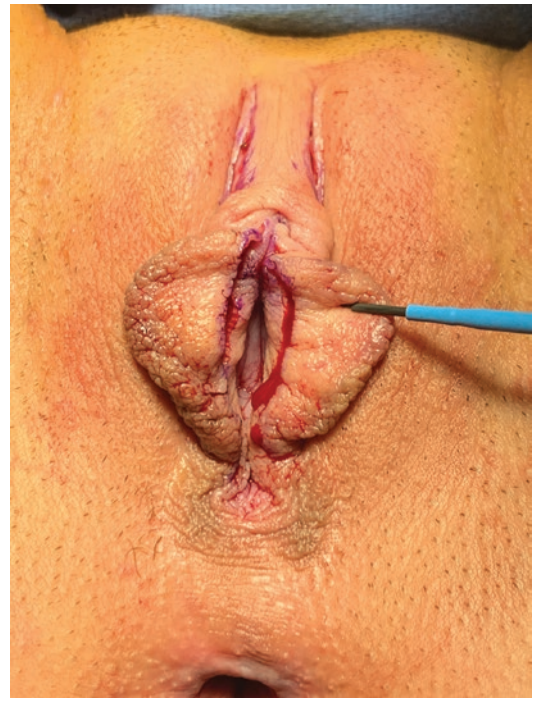


Fig. 12.14 Labia minora incised partial thickness along previous markings

onto the frenulum as needed to reduce prominence, particularly when an acute takeoff angle is present. These markings are then infiltrated. Because the initial local anesthesia has already been injected, subsequent injections are not painful and may proceed with alacrity.

The 15 blade is again used to incise on the medial, mucosal surface of the labia (Fig. 12.14). The most critical aspect of the operation occurs at the clitoral frenulum. If the incision here proceeds too close to the glans clitoris, or if the cut is at a right angle to the frenulum (instead of along a tapered curve), a neuroma-type protrusion can occur in this location. Once the mucosal incision has been made, the Colorado needle is used to cauterize the submucosal layer, proceeding outward to the "back wall" of the lateral mucosal surface. In this plane, the posterior labial artery and small branches of the perineal artery (itself emerging from the internal pudendal artery at Alcock's canal) must be identified and cauterized (Fig. 12.15). Bleeding from these visible branches, and not oozing from the submucosal edge, is a potential source of postoperative hematoma.

Once hemostasis has been ensured, the back wall—the lateral surface of the labia minora—is assessed for excision. Greenberg PAR scissors, or similar serrated-edge fine-tissue scissors, can be used to sharply excise this surface. Using the tips of the scissors as a stylus, an aliquot of blood from the field can be used to mark the tissue (Fig. 12.16). This surface should be aligned with the medial mucosal surface and clitoral hood reduction to ensure that adequate tissue remains (Fig. 12.17).

With the labia minora and hood excess thus removed (Fig. 12.18), the resection patterns can

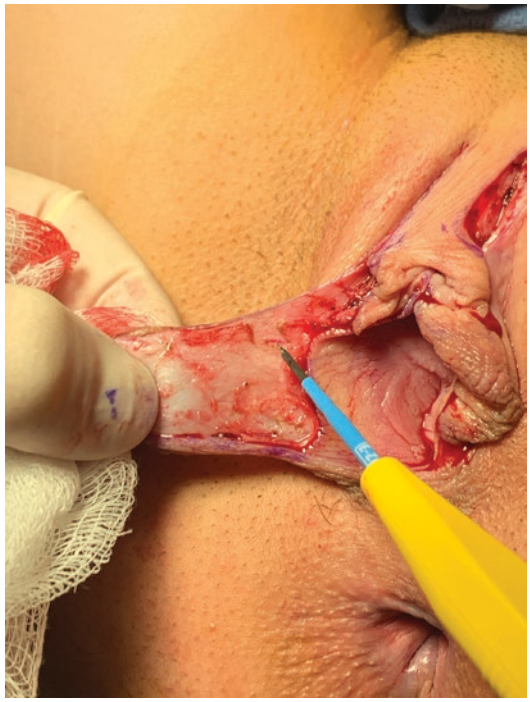


Fig. 12.15 Branches of the posterior labial artery are seen and cauterized within the submucosa

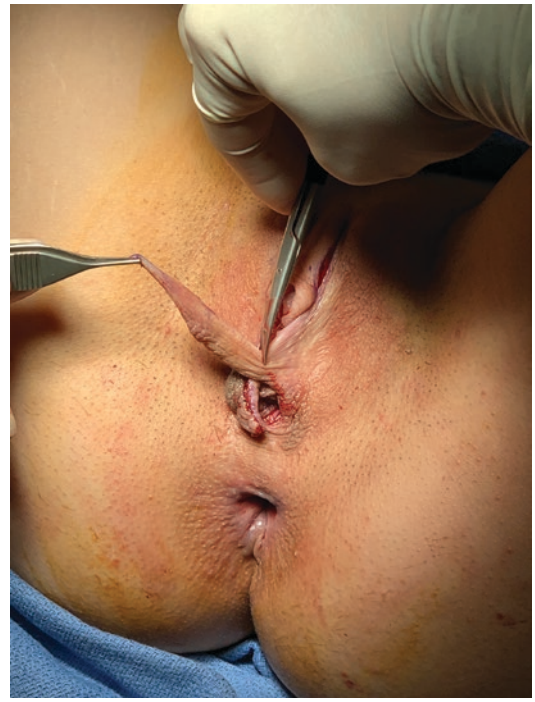


Fig. 12.17 The lateral mucosal surface is sharply excised

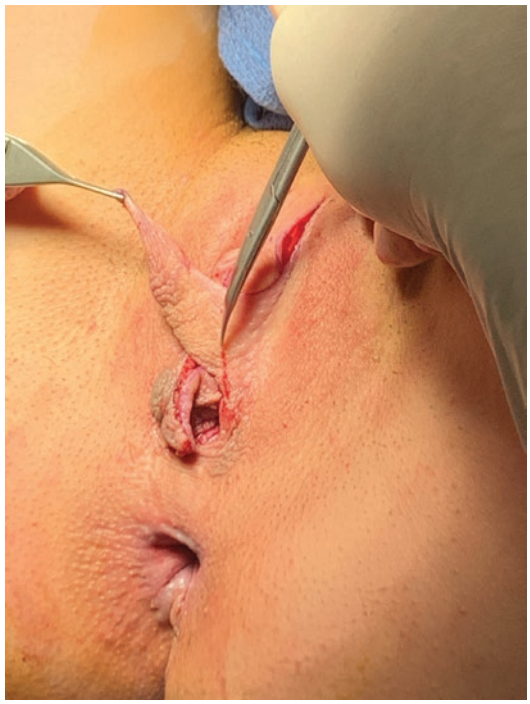


Fig. 12.16 Greenberg PAR scissors are used as a stylus to mark the "back wall" of the mucosa, leaving approximately 1 cm of tissue at the sulcus

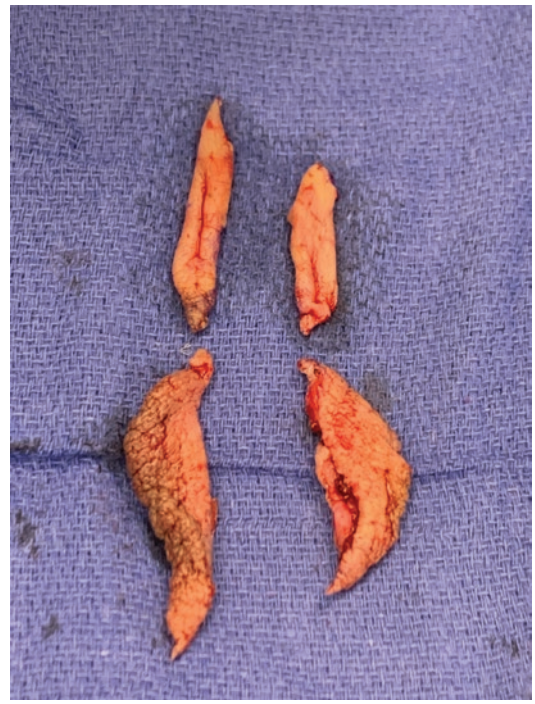


Fig. 12.18 Typical hood and labia minora specimens be seen to resemble an offset "Y." A three-point

location exists at the junction of these two ellipses, with the short segment of the "Y" laying over the frenulum excision, and the two long segments extending cranially over the hood excision and caudally toward the perineum. In certain cases, the perineal tissue is also redundant and may require a continuous excision around to the opposite side. The determining factor in this is the degree of decussation of the perneal raphe. In some patients, the labia minora terminate laterally onto the majora, while in others, the termini are together closely in the midline with redundant tissue present. This is distinguished from a perineoplasty, which is discussed below (see section "Perineoplasty and Vaginoplasty").

Key buried submucosal sutures are placed at the center of the minora, with additional stay sutures placed at the offset "Y" junction and at the inferior most part of the closure. These stay sutures provide intermediate and final anchoring points for the running subcuticular 5–0 monocryl suture (Figs. 12.19, 12.20, and 12.21). Olsen-Hegar needle drivers allow the operating surgeon a facile cutting ability while sewing (Fig. 12.22). When the labia minora swells after surgery, a simple running suture results in intermittent strangulation points. These, in turn, result in ridging along the edge (which ideally should be smooth) as well as channels, sinuses, and tunnels into the tissue. A subcuticular suture technique is therefore preferred in all cases.

At the end of the case (Fig. 12.23), ointment is liberally applied, along with Xeroform gauze, an ABD pad, and an ice pack. Photographs are taken for patient records (Figs. 12.24 and 12.25). Mesh undergarments provide a simple and readily disposable cover for these early postoperative dressings.

Pearl: A smooth, convex curve marking of the labia minora will lead to an even excision pattern

Pitfall: Simple running sutures will result in trackmarks, sinuses, and channels

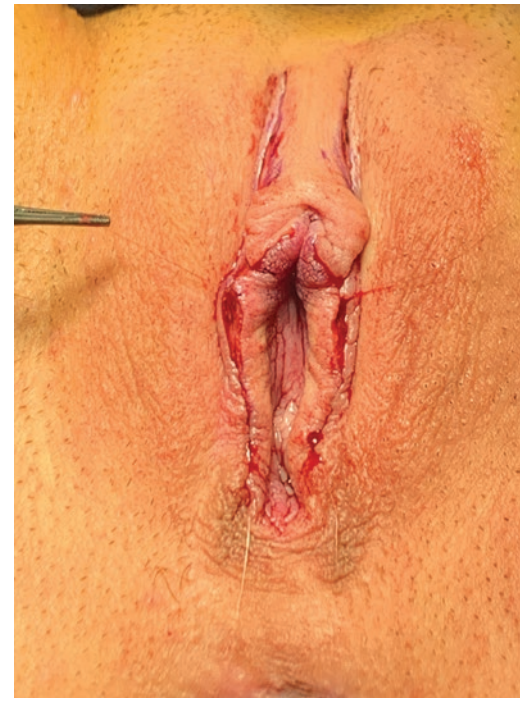


Fig. 12.19 The offset "Y" appearance of the vulva after tissue excision. Note key stay sutures placed at the junction of hood and labia excisions, as well as at the completion of the proposed subcuticular suture, used for knot closures at each location

Postoperative Management and Recovery Protocols

Ice is the single most important postoperative activity and is recommended 30 minutes on and off for the first 24 hours as possible, continuing for the first 3 days. Pain is greatest on the first evening after resolution of local anesthetic effects; ice implementation is of greatest importance at this time, owing to improvements in pain control as well as edema prevention. Patients are recommended to remain supine and recumbent for this time period, with standing and walking kept to a minimum. Loose-fitting clothing is advised.

There is a tendency for women to overclean the area, so instructions are made to the contrary. A small spray bottle is to be filled with warm water and to be implemented after urination and bowel movements. Bacitracin ointment is recom-

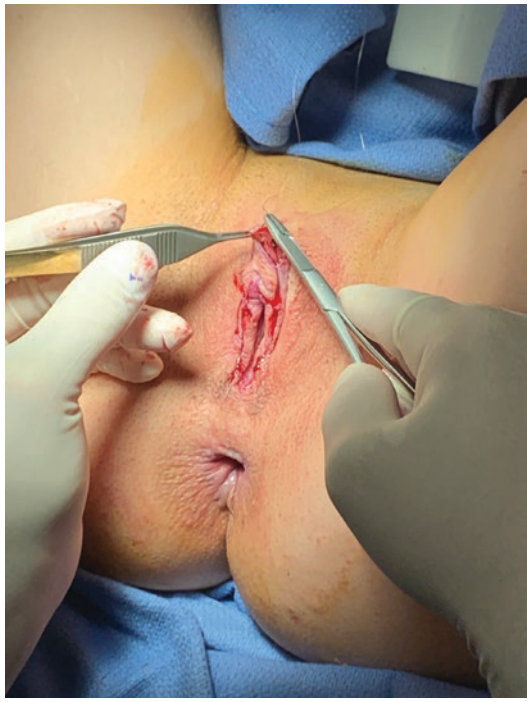


Fig. 12.20 Initiating the subcuticular suture with 5-0 monocryl

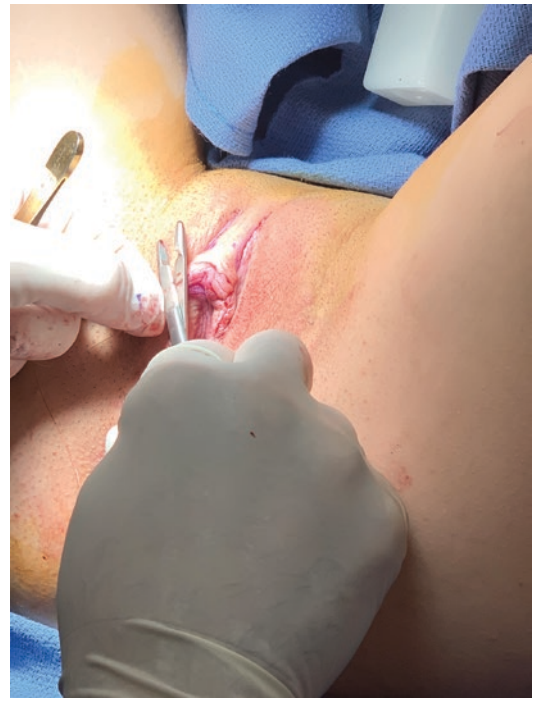


Fig. 12.22 Cutting needle drivers (Olsen-Hegar) allow facile trimming of suture tails by the operative surgeon. No assistant is necessary

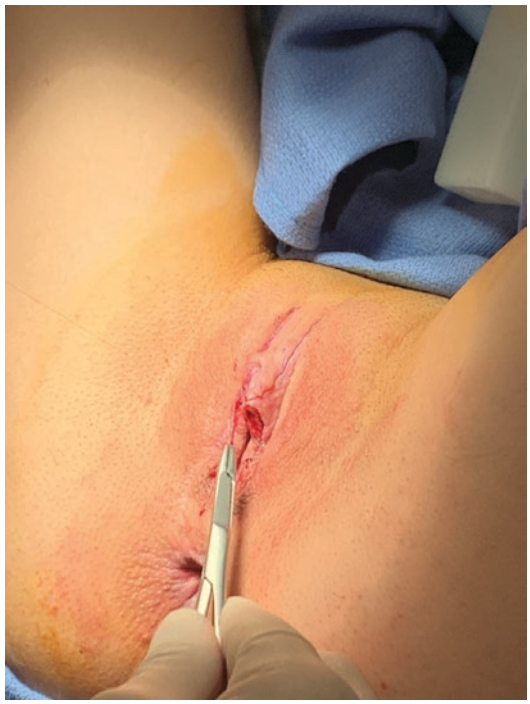


Fig. 12.21 Appearance of hood reduction with subcuticular suture. The midpoint knot is currently being secured and continuation of the subcuticular suture from this critical junction will ensue

mended twice a day for the first 2 weeks, which is then transitioned to a silicone scar gel of choice. Showering is permitted at the patient's convenience.

Spotting may occur for the first 1–2 days after surgery, and ABD pads or maxi-pads should be sufficient management. Frank bleeding accompanied by swelling, particularly when unilateral, should be a harbinger of hematoma (see section "Complications").

At 3 weeks postoperatively, tampon use is permitted, as well as light exercise and bathing. Intercourse is prohibited for 6 weeks after surgery and then permitted with caution and care. The ideal silicone scar gel can also double as a lubricant. To ensure compliance, patients are provided with all necessary items in recovery kit.

Prescribed medications are kept to a minimum, in favor of simple over-the-counter medications. Tylenol is sufficient for pain control and Colace is advised for stool softening to avoid constipation. For breakthrough pain, several tabs of Tramadol are prescribed, particularly for peace

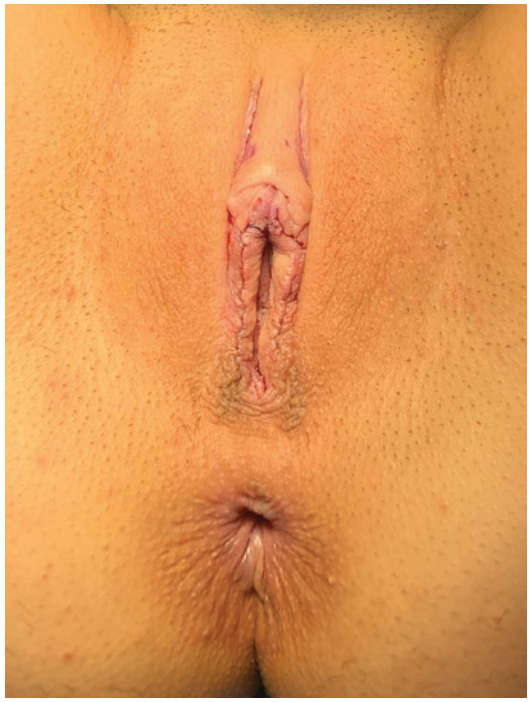


Fig. 12.23 Final appearance of labiaplasty with hood reduction on the operating room table

of mind on behalf of surgeon and patient alike. Diflucan is also routinely provided, and patients are instructed to initiate antifungal treatment at the earliest signs and symptoms of yeast infection.

Pearl: Ice provides dual benefits of analgesia and edema management

Pitfall: Perioperative antibiotics can precipitate yeast infection

Complications

Owing to its rich blood supply, the labia minora can swell significantly after labiaplasty. The astute clinician must be able to differentiate swelling from hematoma, the latter of which requires emergent reoperation. Uniform swelling is more likely to be postoperative edema, while unilateral swelling accompanied by ecchymosis is more likely a hematoma. Bleeding at the incision line, the presence of clots, and pain that *worsens* beyond the first 24 hours point toward bleeding as the culprit. Anesthesia beyond simple local infiltration may be required in these cases, as the pain is often more pronounced than in the original procedure itself. Surgical bleeding and hematoma is the result of inadequate cauterization of the posterior labial artery branches. Re-exploration and control of these small vessels is advised, as simple watchful waiting can result in severe ongoing pain and immobility.

Clitoritis—inflammation and infection of the clitoral body—while exceedingly rare, can result from bacterial overgrowth. Isolated swelling and erythema in the prepuce that begins 5–7 days postoperatively is a certain sign. Purulent drainage and exudate from the incisions are an accompaniment. A brief course of oral antibiotics is advised.

Late complications are less frequent. Neuromas at the clitoral frenulum are the result of improper edge technique, namely, not tapering the ellipse over the frenulum and instead cutting at a right angle. The remedy is re-excision of the tissue prominence, which can be performed under local anesthesia. A sharp angle of frenulum takeoff (as discussed in section "External Anatomy" above) will predispose to this phenomenon. Patients whose labia appears to protrude at a right angle from the body should be advised that some prominence of the minora in this location will remain after surgery. This is preferred to an over-aggressive removal of the frenulum, which otherwise would require the excision to abut too closely the glans clitoris. A tapered excision is ideal.

Dehiscence of the wedge, as discussed, has clinical implications for repair and revision. On the contrary, dehiscence of the edge repair does not require intervention and tends to heal secondarily with no obvious sequela.

Under- and/or over-resection are the result of poor technical execution in most cases, although certain patients may desire the smallest possible labia minora. It is always prudent, of course, for

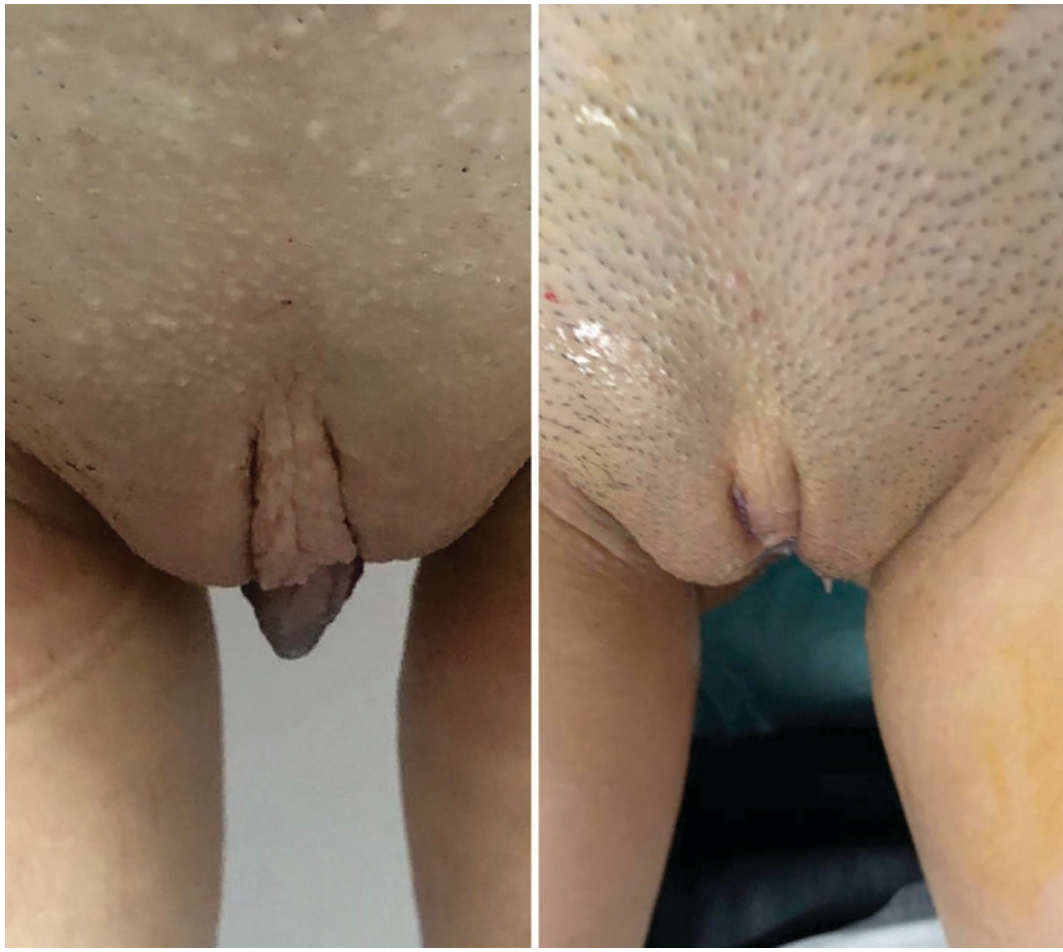


Fig. 12.24 Standing views before and immediately after surgery

the surgeon to leave slightly more tissue than to be overly aggressive. The former can be treated with surgical revision, while the latter—in some cases—cannot be easily rectified.

Pearl: Identify and cauterize the posterior labial artery branches during primary labiaplasty

Pitfall: Right-angle resections at the clitoral frenulum can result in painful neuromas

Revisions

Clitoral hood reductions are the most commonly required revision procedures. Because the clitoral hood is most often ignored, some revisions may proceed with the standard lateral ellipses, ending in each interlabial sulcus, as described above.

Scalloping, or central deficiency of the labia minora, can also result from retraction of the labia minora with subsequent scissors amputation (Fig. 12.26). This leaves superior and inferior excess, with central deficiency. In most cases, the superior and inferior labia minora excess can simply be reduced to the level of the least prominence. A hood reduction is almost always required in revision cases (Fig. 12.27).

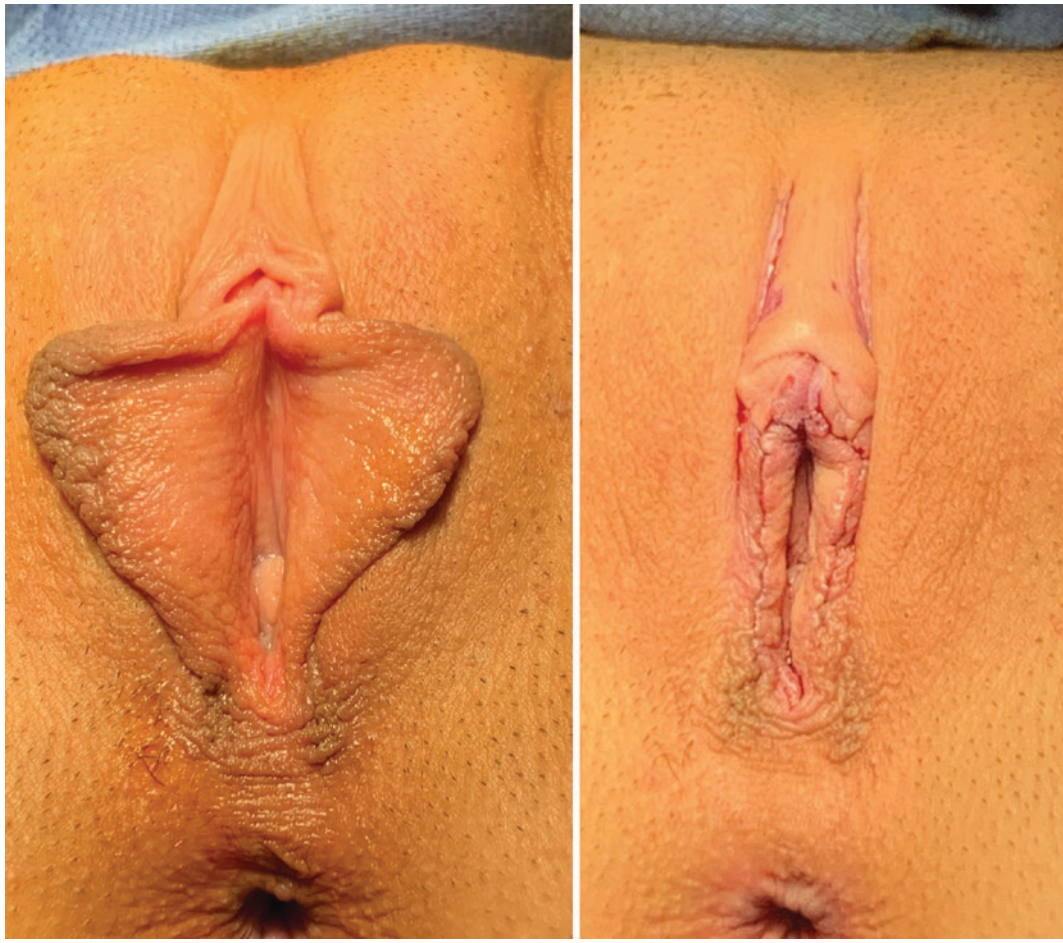


Fig. 12.25 Lithotomy views before and immediately after surgery

In cases where under-resection of the clitoral hood and over-resection of the labia minora are encountered simultaneously, a parsimonious approach to tissue utilization is the implementation of clitoral hood flaps. This concomitantly reduces the clitoral hood while restoring volume to the labia minora. The flap is based inferiorly and elevation proceeds in similar fashion to a clitoral hood reduction: from superior to inferior. The flap is then rotated into a freshened defect of labia minora where tissue restoration is desired [24].

Wedge revisions are often required, and as such, the wedge procedure is no longer employed by the author. Simple re-excision of the wedge is accompanied by layered closure using 5–0 monocryl. The same issues remain, even with revisions, and recurrent dehiscence can be expected in some cases. At other times, the wedge can be converted to an edge resection. This may leave a central deficiency, but does not display the same risks of healing.

Another adage of plastic surgery—"It is not what you take but what you leave"—has additional applicability here. When in doubt, retaining a 1 cm fold of labia minora is a good heuristic when performing the edge labiaplasty.

Pearl: The revision labiaplasty patient may only require reduction of the clitoral hood excess

Pitfall: Correcting the wedge with a wedge may result in recurrent dehiscence; pulling the labia minora while performing an amputation cut will lead to a scalloped labia minora with central deficiency

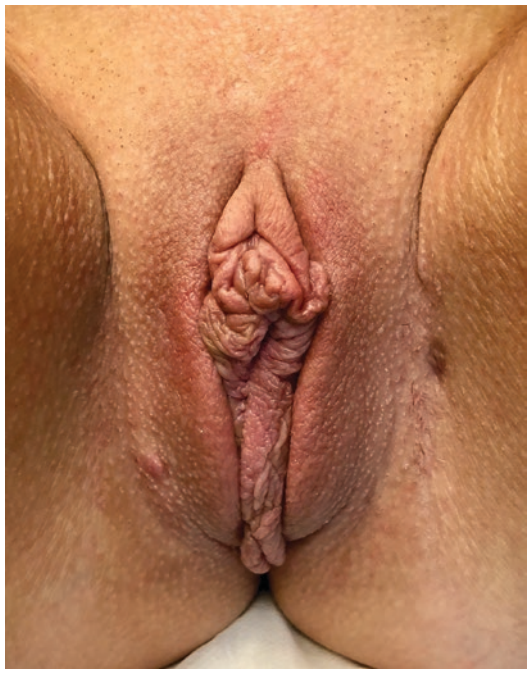


Fig. 12.26 An outside surgeon's results from amputation labiaplasty. Note the scalloped appearance of the labia, with central deficiency. Excess labia minora is noted above and below the amputation. No hood reduction was performed, and fullness at the superior portion of the vulva is obvious

Follow-Up

Unlike with most surgical procedures, follow-ups can be kept to a minimum and may be limited to the early postoperative period. A nurse visit is recommended within 5–7 days after surgery. While it may seem prudent to evaluate the patient within 24 hours to determine if a hematoma is present, most often the efforts of patient transit—from bedrest to the clinic—outweigh the peace of mind; the only person treated here

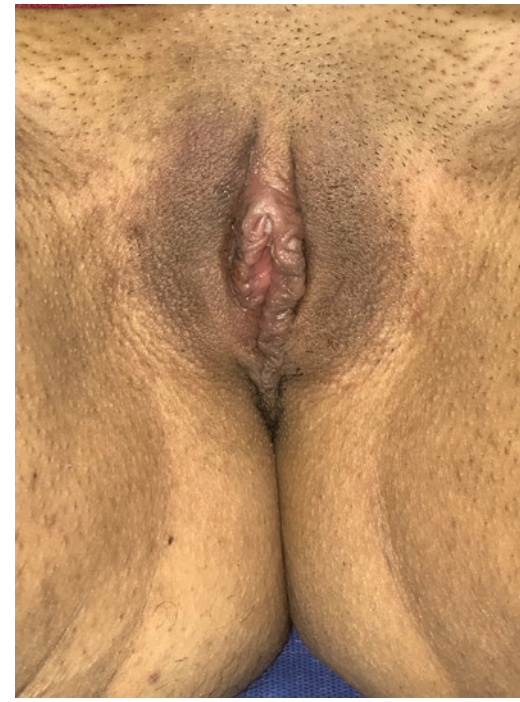


Fig. 12.27 Three weeks following revision edge labiaplasty with hood reduction

is the doctor. If a fastidious nurse is under employ, photographic follow-up via HIPAA-compliant means can assuage any patient concerns. It should be reiterated that swelling and edema are the norm and can be significant (Fig. 12.28).

A single visit with the surgeon at 3–4 weeks affords maximum modesty to the patient and allows for a visit where edema will be resolved. The results viewed here are close to the final appearance. Asymmetry may still be present here, and if there are patient concerns, subsequent appointments can be made. At this time point, the surgeon can liberalize restrictions to enable a full return to activity. Silicone scar massage can continue more aggressively here, but scars are virtually invisible, owing to the mucosal healing process involved.

Standard photographs are taken here, and before and after photographs are compared (Fig. 12.29a, b). The helpfulness of photographic documentation here in direct patient communication cannot be overemphasized.

Fig. 12.28 Clockwise from *top left*: labiaplasty with hood reduction before, at 24 hours postoperatively, at 1 week postoperatively, and *bottom left*, at 3 weeks postoperatively

Patient satisfaction has been consistently demonstrated to be high following labiaplasty [25]. Studies have shown not only improved self-confidence after the procedure, but also benefits in sexual health [5]. Unlike the male sexual response, the female one is more complex and has underpinnings beyond the physiological. While some authors have contended that greater exposure of the clitoris allows more facile sexual stimulation, the benefit is more likely the result of relief from self-consciousness and resultant sexual liberation.

Pearl: Review photographic before-and-after results with the patient

Pitfall: Follow-up visits on postoperative day one treat only the surgeon

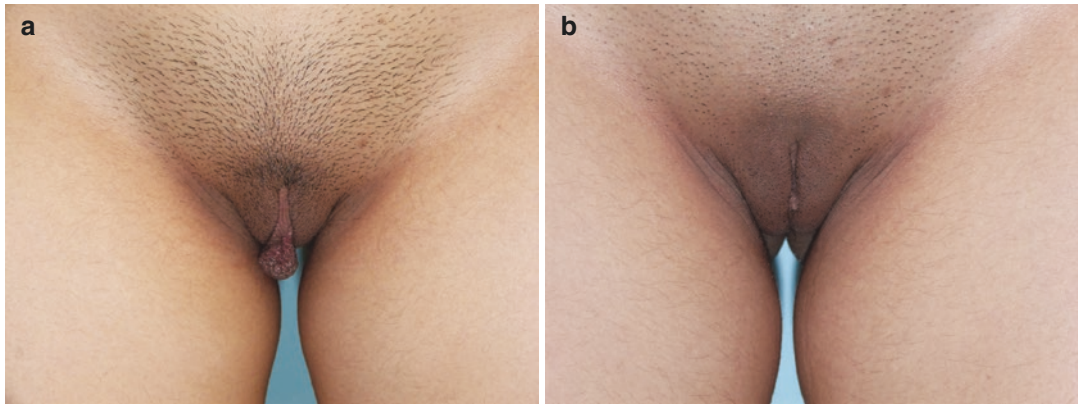


Fig. 12.29 Standing views (**a**) before and (**b**) 3 months after edge labiaplasty with hood reduction. Note reductions in labia minora show and hood prominence

Additional Aesthetic Procedures

While labiaplasty with clitoral hood reduction is the quintessential aesthetic vulvovaginal procedure, there are other procedures worthy of mention. In order of frequency, these are:

- Internal laser vaginal rejuvenation
- Perineoplasty with or without vaginoplasty (posterior repair)
- Labia majora augmentation
- Labia majora reduction
- Hymenorrhaphy and hymenoplasty
- Pubic lift procedures

Internal Laser Vaginal Rejuvenation

Laser vaginal resurfacing, often referred to globally as laser vaginal rejuvenation, involves the circumferential internal application of ablative laser energy. Atrophic changes to the vaginal mucosa—atrophic vaginitis—result from low estrogen circulation that accompanies menopause. Iatrogenic causes of hormone dysfunction include aromatase inhibitors and oophorectomy, which may be encountered in breast cancer patients.

These women most commonly present with complaints of vaginal dryness and dyspareunia. Immediate results are not always evident, and a series of three to four treatments, spaced monthly to annually, is the norm.

Histological sections of the vaginal mucosa [26] have demonstrated remodeling consistent with improvements in atrophic changes [27], namely thickening of the extra-cellular matrix, active fibroblasts, and neovascularization—similar to findings seen with cutaneous laser applications [28]. These findings were also accompanied by improvements in sexual well-being, primarily related to improvements in natural lubrication [29].

Perineoplasty With or Without Vaginoplasty

Perineoplasty and vaginoplasty are related procedures that reduce the caliber of the vaginal opening. These vaginal tightening procedures are performed most commonly after childbirth via vaginal delivery to treat subjective feelings of vaginal looseness. These symptoms can be reported by the patient as feelings of emptiness with intercourse, or the inability to feel one's partner properly during sex.

The changes that occur to perineal body musculature can be likened to those of the abdominal wall after pregnancy. Perineal body laxity—separation of the superficial perineal, the bulbospongiosus, and levator ani muscles (Fig. 12.30)—are akin to rectus diastasis.

While the perineoplasty procedure involves an external only repair, a vaginoplasty extends

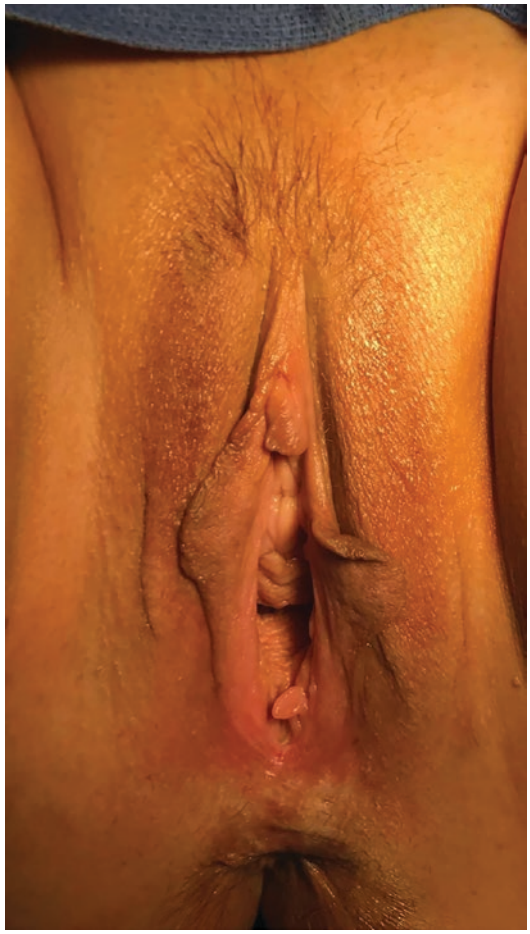


Fig. 12.30 Vaginal laxity following perineal lacerations after multiple deliveries. Note an additional tear at the left labia minora frenulum and hymen tag at the posterior fourchette

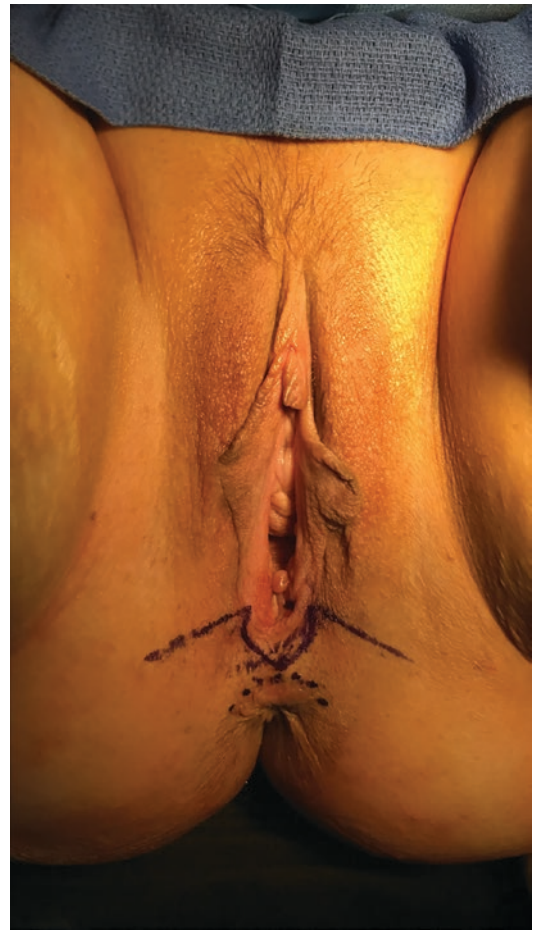


Fig. 12.31 Markings for the perineoplasty portion of the posterior repair (every vaginoplasty includes a perineal repair). The *dashed line* represents the anal sphincter while the central *triangle* indicates the perineal tissue to be removed. Lateral *horizontal lines* are used to guide tissue re-approximation

the repair inward (Fig. 12.31). Such posterior repairs (Fig. 12.32), as they are known in the gynecology literature, require layered closure and care to avoid iatrogenic rectovaginal fistulae. Rectoceles may be encountered and are often accompanied by varying degrees of scarring from perineal lacerations during childbirth. As such, only the experienced surgeon, with sound knowledge of the relevant clinical anatomy, should embark on the reconstruction of obstetric trauma and related vaginal tightening procedures (Figs. 12.33 and 12.34). A detailed review of these techniques is partially reconstructive in nature, and a full description falls outside of the scope of this work.

Labia Majora Augmentation

Deflation of the labia majora can be seen most commonly postpartum, following the resolution of edema and weight fluctuations. Aging processes involving fat atrophy and involution are additional culprits. Wrinkling and folding of the outer labia belie the youthful and full appearance of the ideal labia majora. As such, the restoration of volume to the outer labia can restore this appearance (Figs. 12.35 and 12.36).

There are two primary methods through which labia majora augmentation can be performed:

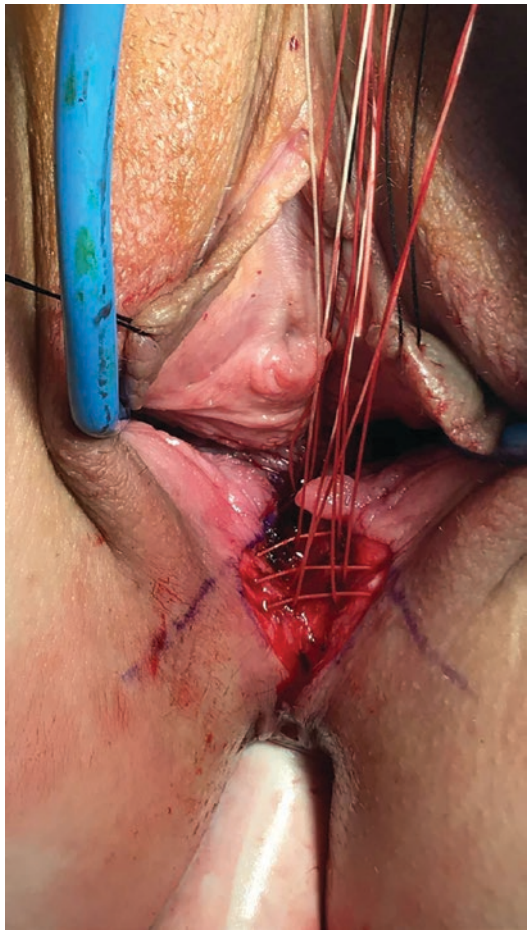


Fig. 12.32 Layered repair of the posterior vaginal wall. An insulated lateral vaginal wall retractor is in place (*blue*), and 0 vicryl sutures are visible in parachute fashion. The nondominant hand is used transrectally to avoid injury of the mucosa during the repair

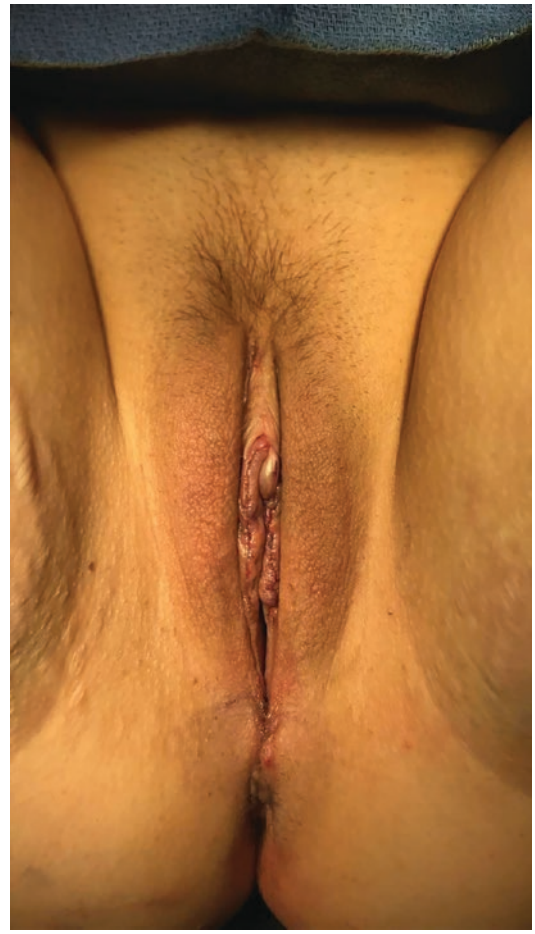


Fig. 12.33 At completion of the reconstructive efforts. The posterior repair is visible, as is the repaired laceration of the left frenulum. A contralateral edge labiaplasty was performed with bilateral hood reductions. The hymenal tag was also removed

with autologous fat transfer or with soft tissue fillers. By definition, autologous fat transfer requires coincident liposuction be performed for fat harvesting. A logical location for harvest is the mons pubis, with a secondary location being the inner thighs, both of which are in the surgical field. When injecting fat into the labia majora, a high labia majora or interlabial sulcus access point is suggested. Disposable cannulas—both for liposuction and for fat transfer—are advisable. In the author's experience, a 3 mm Mercedes tip Microaire harvesting cannula (Microaire Surgical Instruments, Charlottesville, VA) can be implemented to obtain the graft material, while a 14 gauge SoftFil blunt-tipped side-hole cannula (Soft Medical Aesthetics, Paris, France) can be used for injection. Multiple pretunneling passes should be performed to allow for uniform spread of the grafts, and the smallest amount of fat should be injected with each pass; the goal is 0.5–1 cc per pass, and no more than 6–8 cc transferred per side. Slight overcorrection should yield fullness of the labia majora in an oval pattern, beginning with the slight concavity of the mons

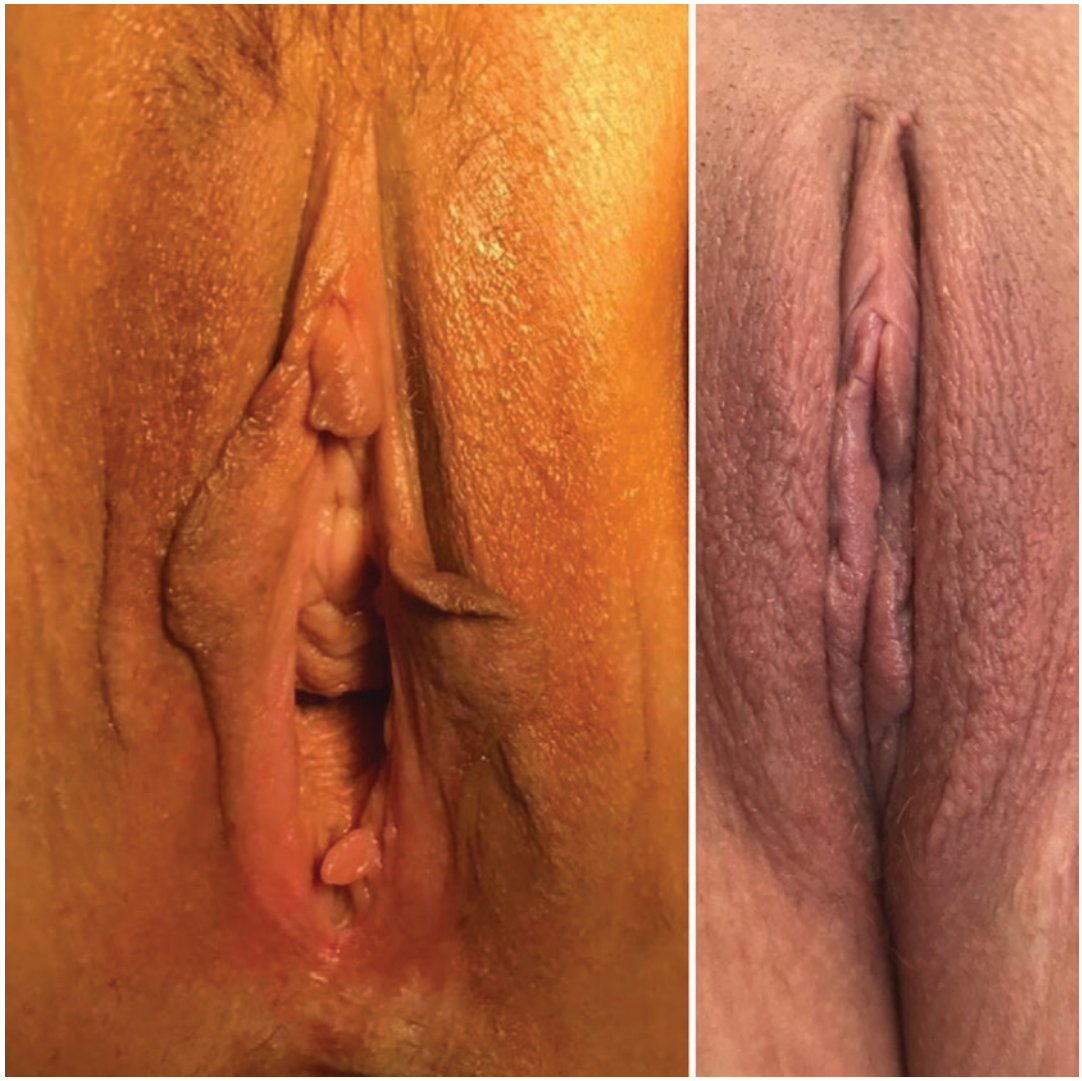


Fig. 12.34 Before-and-after appearance of above patient at 3 months postoperatively

pubis, and extending downward, tapering in volume at the perineum (Fig. 12.37).

When soft tissue fillers are used, a similar technique should be implemented. Sculptra has the benefit of allowing for the longest lasting augmentation, but carries several distinct downsides. Most notable among these are firm granulomatous areas and the need for multiple treatment sessions. In comparison, hyaluronic acid fillers can be used, which yield immediate benefits, but are less longer lasting and can be more easily contaminated with biofilm, resulting in the presence of nodules; hyaluronidase can be used as needed.

Labia Majora Reduction

Labia majora reduction involves the direct elliptical excision of redundant and elongated labia majora tissue. Long outer labia can be the result of genetic variation, but is commonly seen after massive weight loss and in the aging patient. Deflation of the labia majora after pregnancy and

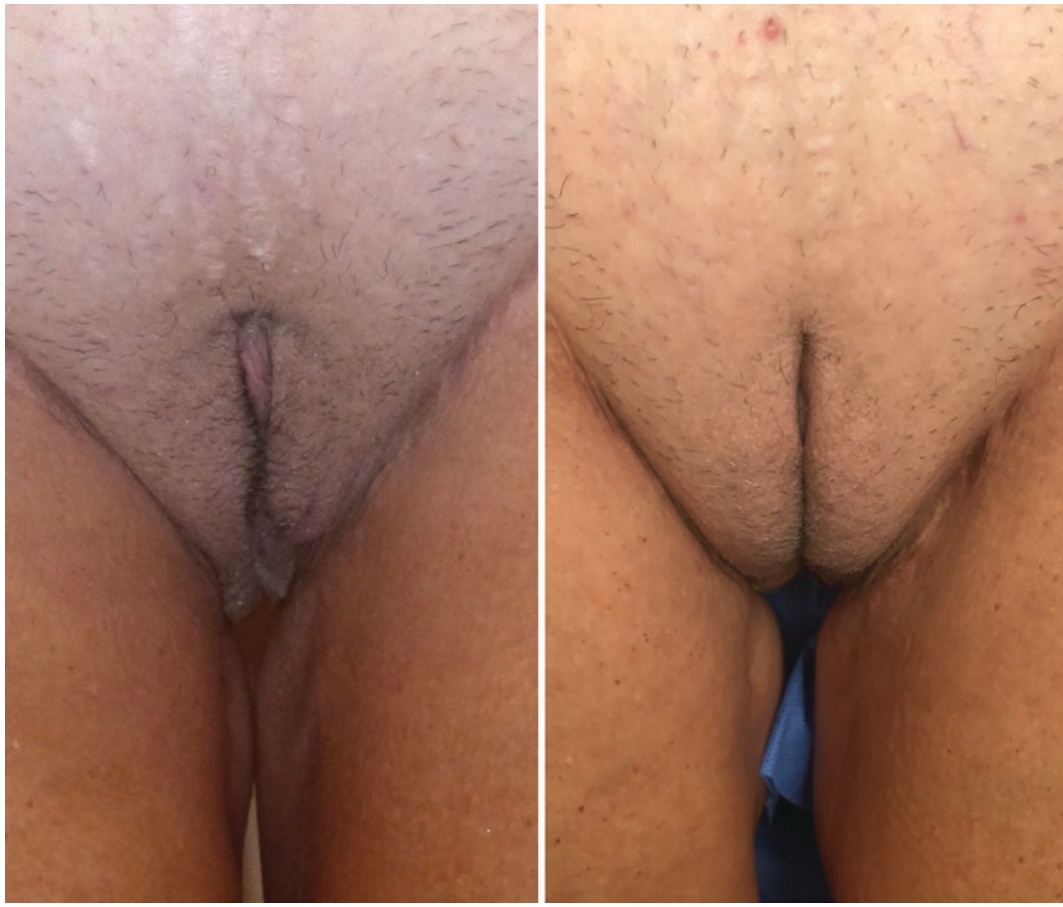


Fig. 12.35 Standing views before and after fat transfer to the labia majora. A tummy tuck was performed, having the added benefit of a pubic lift. A labiaplasty with hood reduction was also performed on this patient

childbirth—as noted above—may also result in long outer labia.

Labia Majora reduction should be approached with caution for three reasons: First, the labia majora is hair-bearing. An elliptical excision along the outer labia will draw hair-bearing skin inward, leading to the potential for chronic irritation of the mucosa, and similar challenges with intercourse.

Second, the scars are visible and unable to be hidden. Unlike the labia minora, which heal virtually scarless owing to their mucosal surface, the majora may heal with visible scars on the outside of the vulva.

Third, the relationship between the outer and inner labia is a key aesthetic one. When the outer labia are reduced, the inner labia can become more prominent, leading to labia minora show. This can lead to an undesired effect and the need to potentially perform a labiaplasty with hood reduction when one was not initially foretold.

Hymenorrhaphy and Hymenoplasty

Protruding remnants of the hymen can become pronounced, becoming unsightly for some women (Fig. 12.30). A simple hymen tag excision is an expedient procedure that can be performed under local anesthesia and with cautery alone.

Restoration of the hymen, in contradistinction, is sought out by women who desire a return of their anatomy to a virginal state. While sur-

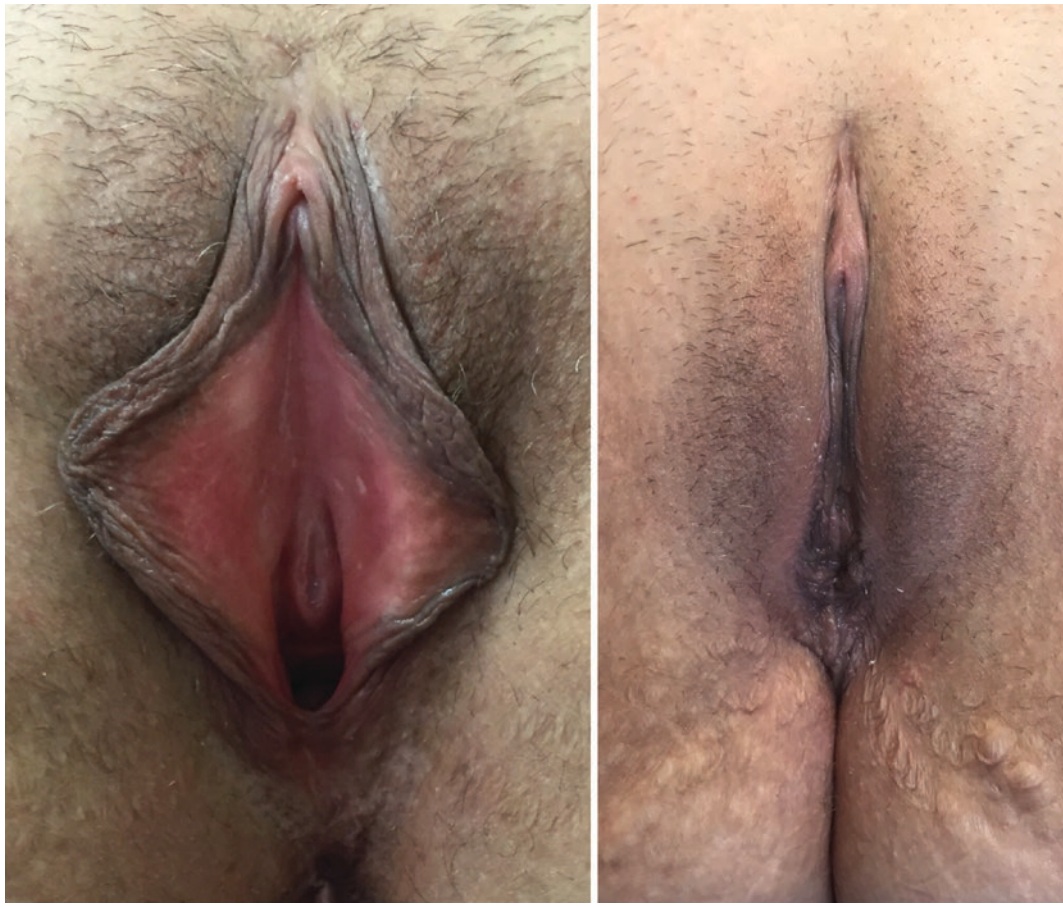


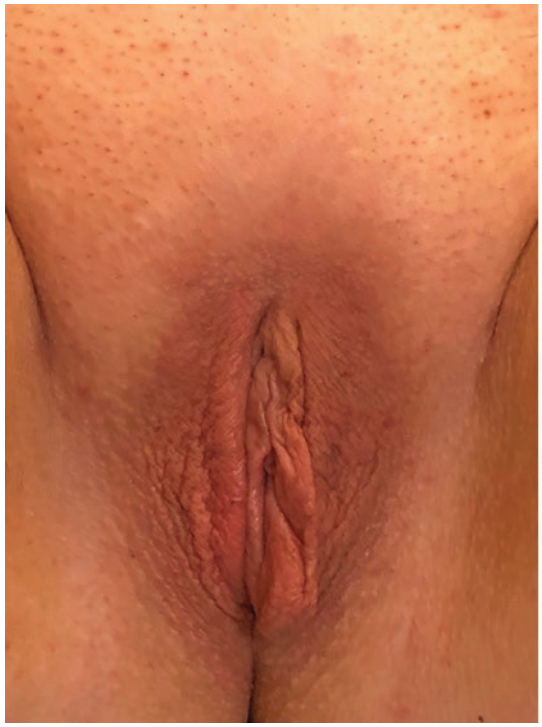
Fig. 12.36 Lithotomy views of the above patient demonstrating a more aesthetic appearance to the vulva: fuller labia majora and less prominent minora and hood

geons may view themselves simply as the technician, the decision to undertake the hymenoplasty procedure is fraught with ethical considerations and dilemmas [30]. In many cultures, primarily in the Middle East, a woman's virginity signifies honor. Postcoital bleeding is desired by patients seeking hymen repair.

Several methods have been described, from circlage patterns, to z-plasty techniques that re-approximate hymenal remnants. Regardless of the approaches utilized, philosophical complexities abound. An intact hymen, for example, could protect the welfare of a patient whose well-being is predicated on her sexual state. Conversely, some societies, particularly in Iran, have heaped repercussions on surgeons who perform these procedures as acting dishonestly in the greater community. Others still propose that hymenoplasty is inherently inegalitarian, subverting women and requiring conformity to gender norms [31].

Pubic Lift Procedures and Mons Pubis Liposuction

Pubic lift procedures are generally not performed in isolation, but rather are viewed as a component of sound aesthetic abdominoplasty surgery (Figs. 12.35 and 12.36). Nonetheless, reduction in the mons pubis with direct excision and or liposuction can be performed in isolation. In either case, incisions should be transverse, aligned with previous cesarean section or



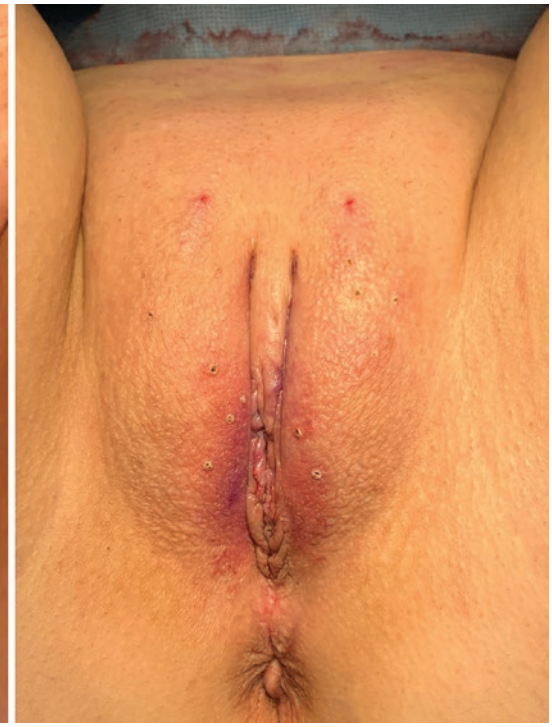


Fig. 12.37 A variety of aesthetic techniques can be implemented simultaneously. Here, an edge labiaplasty with clitoral hood reduction was accompanied by mons liposuction and labia majora augmentation with fat grafting. Small hemangiomas were also cauterized. Note the access points for blunt cannula insertion at the apex of the final oval-shaped labia majora

Pfannenstiel approaches when present, and should be hidden within undergarment lines. If required, the mons lipoaspirate can be used to augment the labia majora (Fig. 12.37).

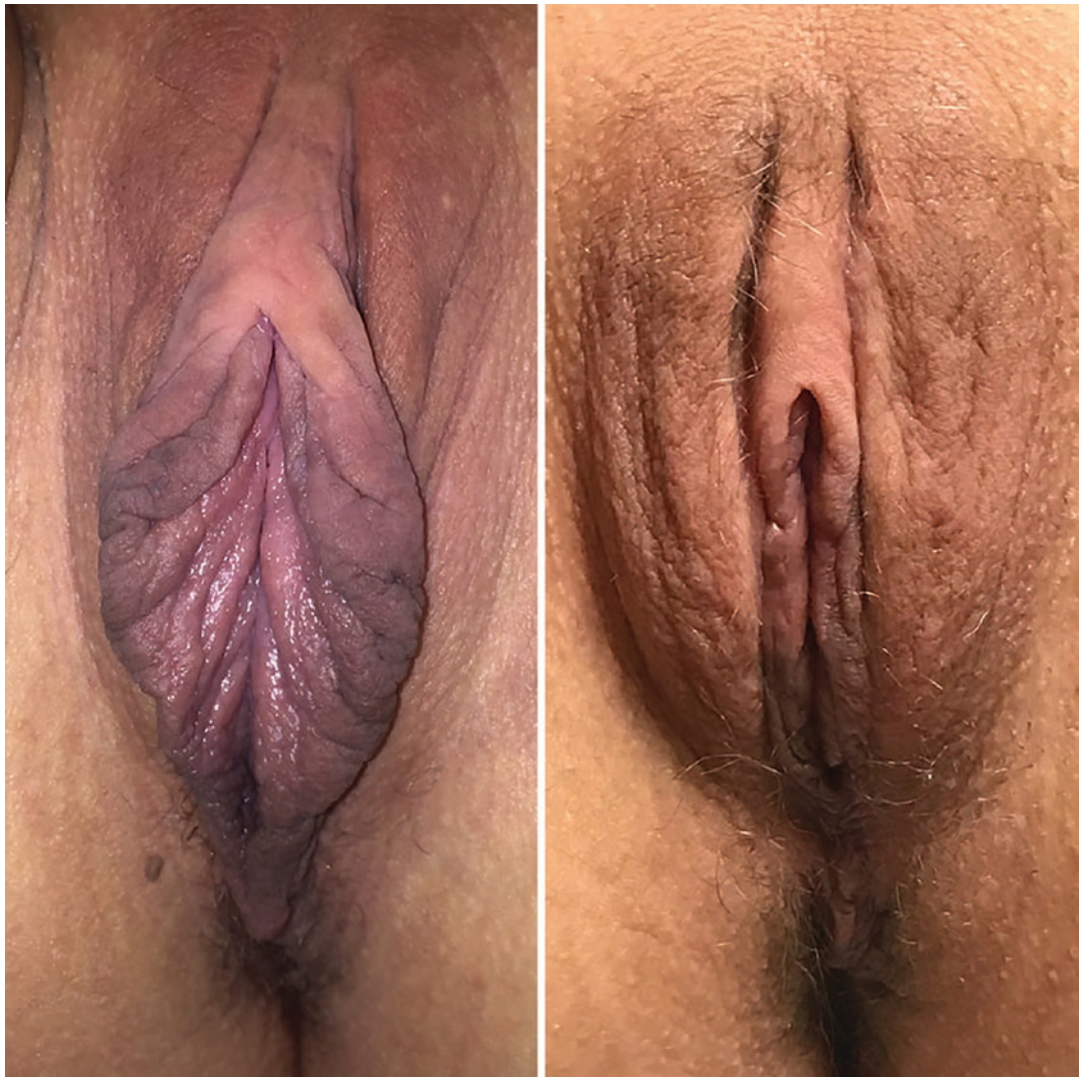
Pearl: Laser vaginal rejuvenation can provide a safe clinical adjunct to ameliorate the postmenopausal symptoms of vaginal dryness

Pitfall: Aesthetic procedures beyond labiaplasty are complex, infrequently encountered, and may be best avoided

Conclusion

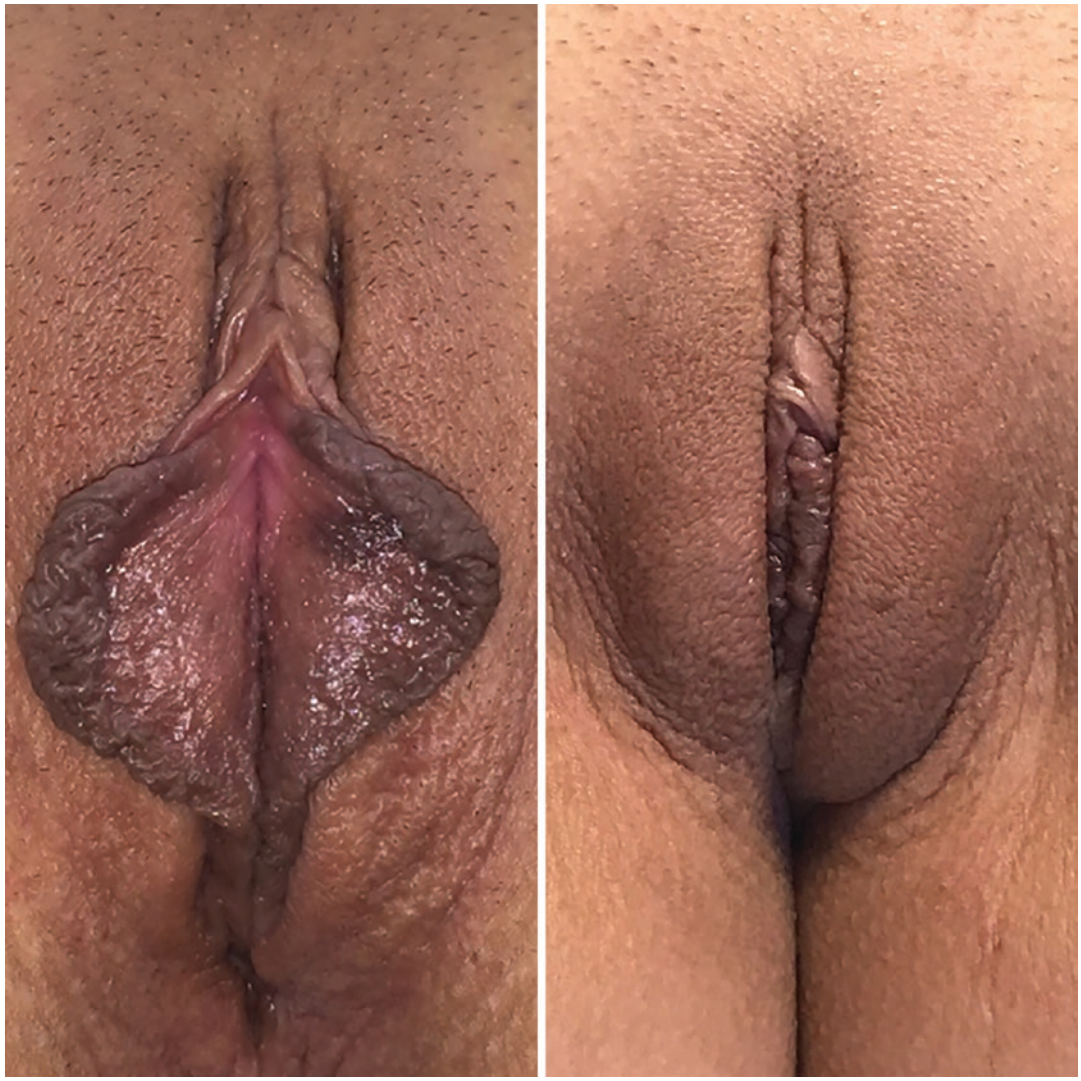
As the aphorism goes: "Everything in plastic surgery is an ellipse." This is true in labiaplasty, with each side of a labiaplasty with hood reduction comprising a pair of ellipses. If a breast reduction is a combination of a vertical and horizontal ellipse, a labiaplasty with hood reduction is an offset "Y." By distilling the procedure down to its simplest patterns, the surgeon is able to take complex three-dimensional anatomy and simplify it into two dimensional constructs. Thusly, symmetry and balance in both lithotomy (Figs. 12.38, 12.39, 12.40, 12.41, and 12.42) and standing positions (Figs. 12.43, 12.44 and 12.45) is reached.

Gentle handling of tissues is a paradigm of surgery set forth by Halstead [32] that has tre-

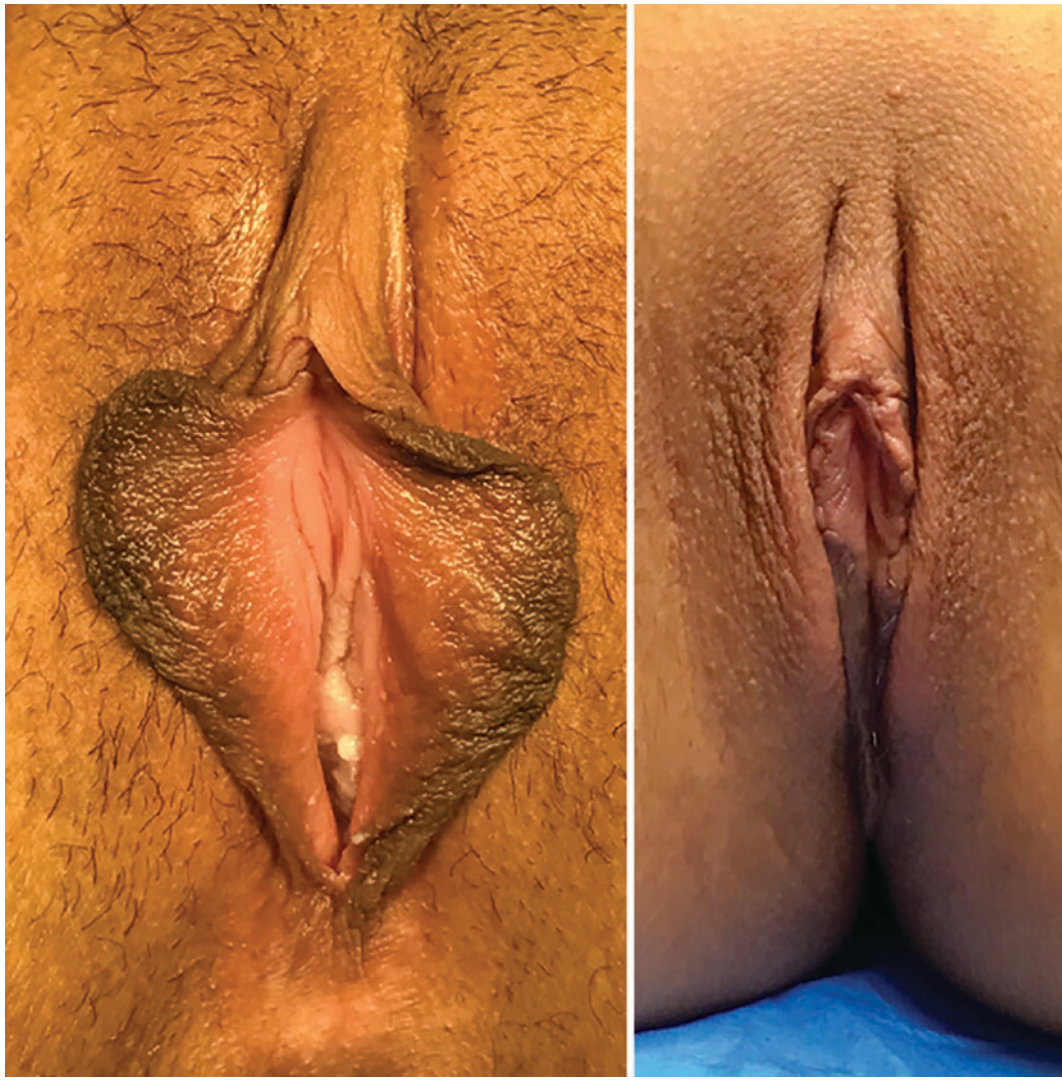


Figs. 12.38, 12.39, 12.40, 12.41, and 12.42 Before-and-after results from the edge labiaplasty with clitoral hood reduction in lithotomy

mendous applicability in labiaplasty. The technical artistry of labiaplasty requires a special gentleness, not only with surgical technique, but also with interpersonal disposition. If the surgeon approaches with kindness the labiaplasty patient and procedure alike, excellence will follow.



Figs. 12.38, 12.39, 12.40, 12.41, and 12.42 (continued)



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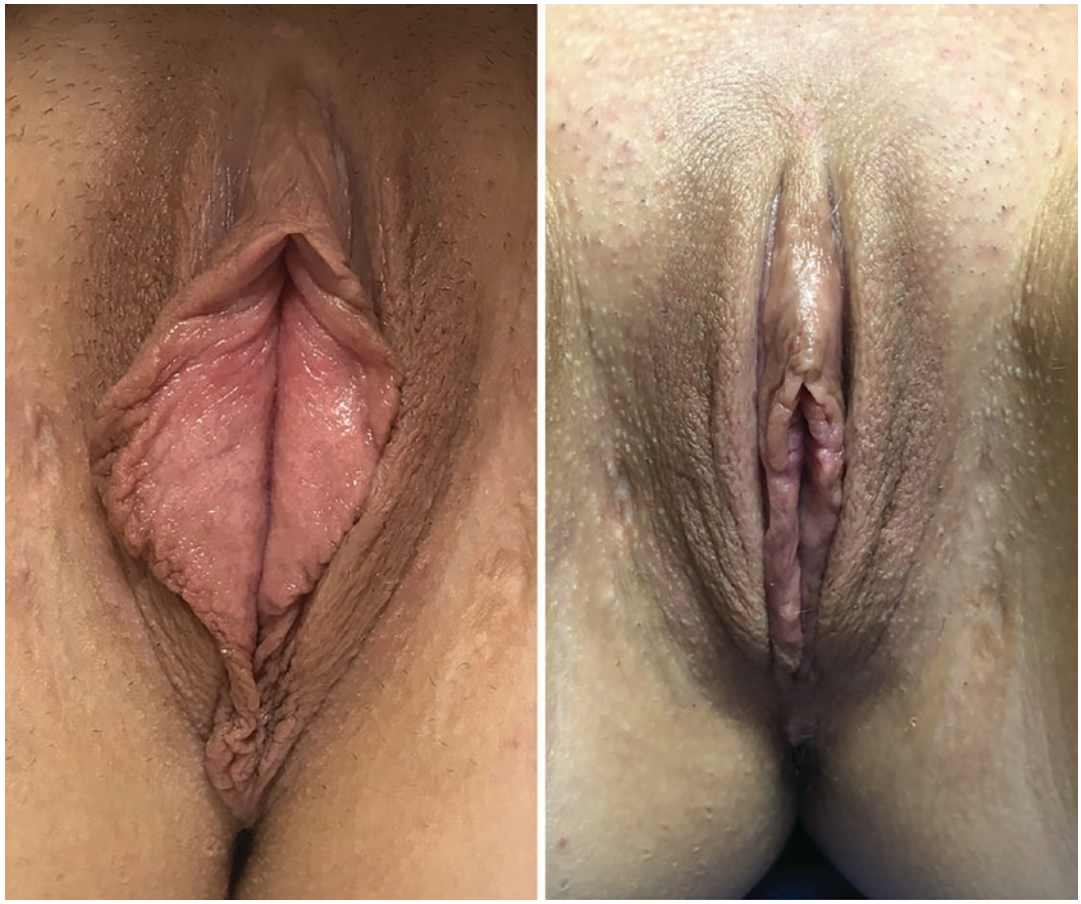

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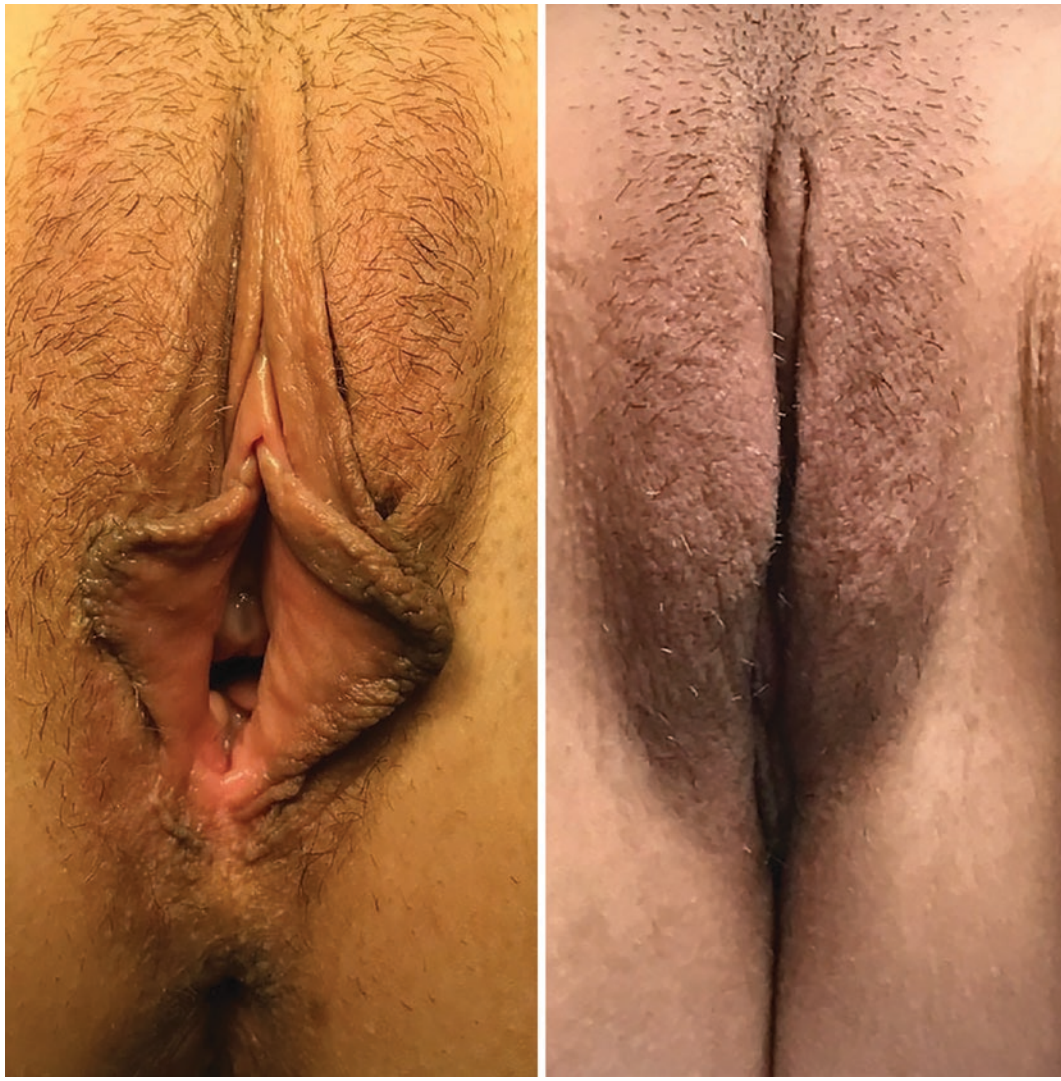

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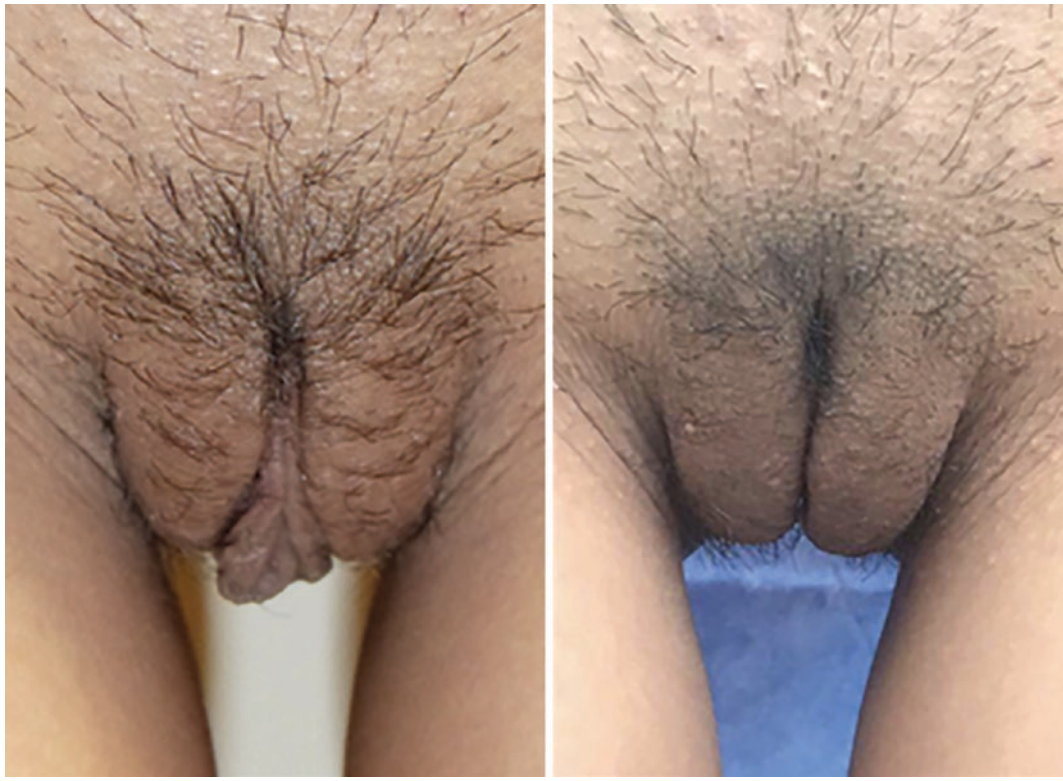
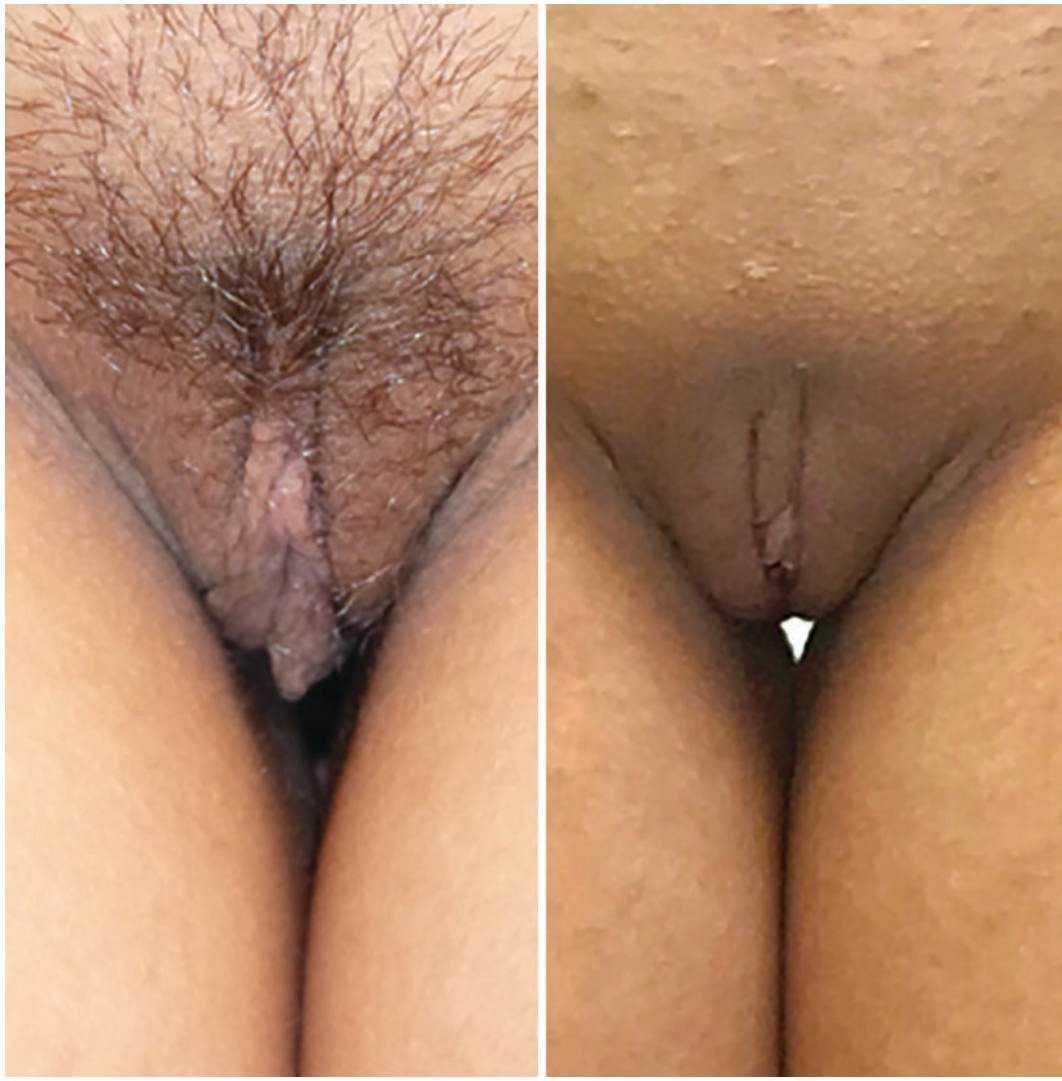
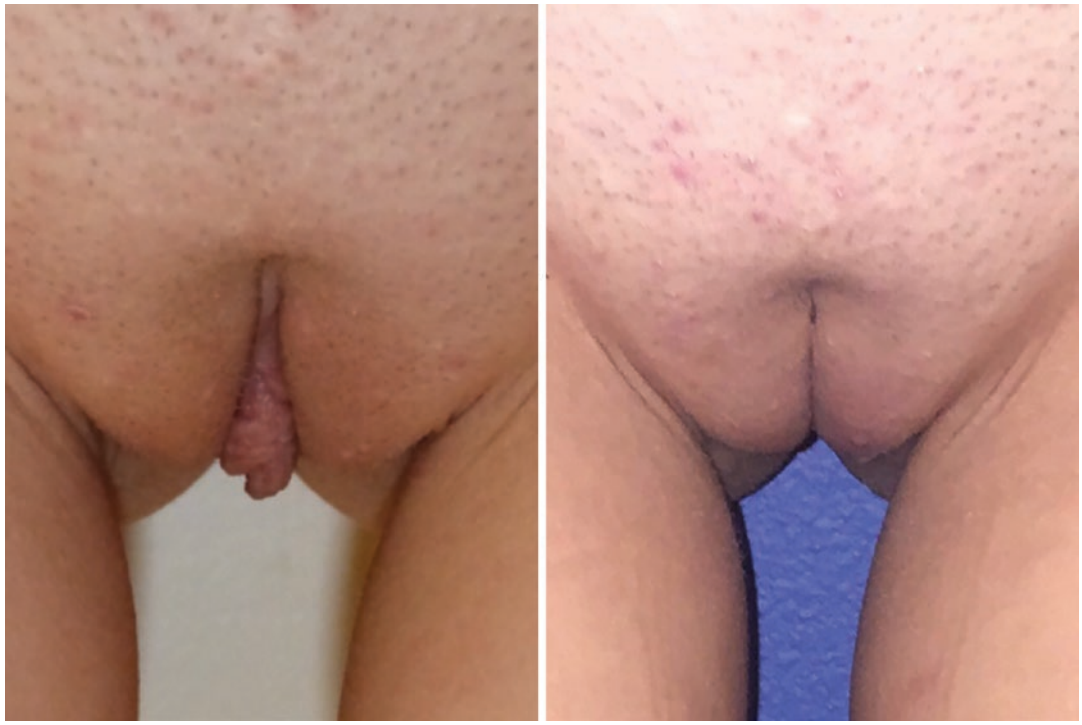


Figs. 12.43, 12.44, and 12.45 Before-and-after results from the edge labiaplasty with clitoral hood reduction in standing positions



Figs. 12.43, 12.44, and 12.45 (continued)



Figs. 12.43, 12.44, and 12.45 (continued)

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Part II

Reconstructive Procedures

13

Post-Oncologic Breast Reconstruction: Autologous and Alloplastic Approaches

Geoffrey M. Kozak, Joshua Fosnot, and Joseph M. Serletti

Introduction

Breast cancer is a devastating malady affecting one out of every eight women in their lifetime, often times at a young age. According to the American Cancer Society, approximately 330,000 women were diagnosed with breast cancer in 2018. Globally, there were over two million new cases in 2018 [1]. Although common, the disease is often curable; thus, most women live many years following treatment for their breast cancer. Despite many advances in the detection and treatment of breast cancer, mastectomy continues to play a significant role in the management of this disease. Of the women diagnosed, approximately 40% will subsequently receive breast reconstruction, of which approximately 25–30% will receive autologous breast reconstruction, utilizing the patient's own tissue for reconstruction [2]. In addition to autologous methods, there are options using alloplastic materials, such as an expander or implant. Expander/implant reconstruction, in fact, by far remains the most common method for reconstruction. We aim to explore the various methods of both autologous and alloplastic reconstructions and discuss the relative risks and benefits of each in an effort to present the breadth of options to restore a woman's sense of self following treatment for breast cancer.

Autologous Reconstruction

A breast cancer patient seeking reconstruction via a plastic surgeon presents at varying stages of the treatment of their disease, often with varying levels of understanding of the types of reconstruction available. It is important to take the time with each and every patient to describe the options fully, listen to the patient's wishes and expectations, and formulate a plan for moving forward. Breast reconstruction is not a simple procedure and can result in complications, making an open dialogue paramount to avoiding inconvenient outcomes and disappointment with the final result.

Autologous reconstruction offers the unique ability to replace "like with like," which may lead to improved overall and long-term patient satisfaction in many patients. It may be particularly beneficial in unilateral reconstruction in order to create lasting symmetry. Over time, an

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implant-based reconstruction tends to behave differently than the normal contralateral breast, resulting in positional and volumetric differences—this may be ameliorated by autologous tissue reconstruction, which behaves more similarly to native tissue. Additionally, it also does not suffer from the long-term complications such as device failure and capsular contracture. Once reconstructed, patients need not worry about having to have implant exchanges, which on average occur every 10–15 years.

Preoperative Assessment and Patient Selection

Patient comorbidities play a critical role in the likelihood of complications postoperatively and should be recognized prior to undertaking any operation. While smoking and obesity have repetitively been implicated as independent risk factors for complications, such as wound infection, mastectomy flap necrosis, abdominal flap necrosis and fat necrosis, these are not considered absolute contraindications to free flap breast reconstruction [3]. Conversely, many have shown free flap reconstruction to be safe in the obese, comorbidly diseased, or advanced aged populations [4, 5].

While not necessarily an absolute contraindication, a hypercoagulable state does place a patient at higher risk for thrombosis during free flap reconstruction. Patients should be asked specifically about a history of deep venous thrombosis (DVT), multiple miscarriages, pulmonary embolism, family history of DVT, pulmonary emboli (PE), stroke, or genetic diseases such as Factor V Leiden. Although no studies definitively support the practice, if patients are willing to accept an increased risk of flap failure and wish to proceed, more aggressive anticoagulation should be considered postoperatively. While our success rate in these patients is 80%, one cautionary point is that when these flaps thrombose, there is essentially a 0% salvage rate [6, 7]. In our practice, we offer free flap reconstruction if the patient accepts the higher risk, but rarely offer attempts at heroic salvage in the event of a postoperative thrombosis.

Previous history of radiation should be known. Radiation has been shown to lead to a higher rate of intraoperative vascular complications requiring anastomotic revision and the use of intraoperative anticoagulation [8]. This appears to be limited to an intraoperative phenomenon, and in our experience, does not connote a higher incidence of postoperative thrombosis or flap loss. We do not specifically change our approach knowing that radiation was received; however, radiated vessels may be less ideal for teaching purposes, and one should have a low threshold for redoing an anastomosis if it does not look perfect [8].

Prior surgical history is important and may help guide flap choice to ensure pedicle and perforator patency. For instance, a previous inguinal hernia or paramedian incision may have transected the inferior vessels, making a deep inferior epigastric perforator (DIEP) based on the pedicle on that side impossible. A prior abdominoplasty is generally considered an absolute contraindication of a DIEP, given the previous transection of all central perforators. A prior coronary artery bypass graft (CABG) may make the internal mammary vessels unavailable or undesirable for recipients of a free flap. CT angiography or magnetic resonance angiogram (MRA) have been shown to play a role in assessing pedicle and perforator anatomy, especially those with prior abdominal surgeries [9, 10].

MSFTRAM Flap

When considering all methods, most surgeons agree that the lower abdominal tissue is unmatched for its ability to create a soft, pliable, and natural breast mound, with excellent potential for symmetry to an intact opposite breast. Two common techniques involve the muscle-sparing free transverse rectus abdominis myocutaneous (MSFTRAM) flap and the pedicled TRAM flap. Anatomically, the rectus abdominis muscle originates on the pubic symphysis and crest and inserts on the fifth, sixth, and seventh costal cartilages. This muscle is an integral component of the abdominal wall and flexes the ver-

tebral column. The innervation to this muscle is the lower six or seven segmental intercostal nerves, and it has a dual blood supply. The superior muscle is supplied by the superior epigastric vessels, which are terminal branches of the internal mammary vessels. The inferior muscle is supplied by the inferior epigastric vessels, which originate from the external iliacs. These two systems anastomose with each other through choke vessels within the center of the muscle.

The MSFTRAM flap is based on the inferior epigastric vessels. The skin island of the MSFTRAM flap is positioned over the lower portion of the rectus muscle, thus it is actually closer to the inferior epigastric blood supply. As a result, the MSFTRAM skin island is now in the primary angiosome, based on the inferior epigastric vasculature. This flap design provides a more direct and improved blood supply to the MSFTRAM skin island [11].

Prior to surgery, the patient is marked in the standing position. The MSFTRAM skin island and the inframammary fold are marked bilaterally. The upper edge of the MSFTRAM skin island is incised, and an upper-abdominal flap is raised to the xiphoid and the costal margins. This upper skin flap can be draped over the MSFTRAM skin island to ensure an acceptable abdominal closure. The lower portion of the skin island is then incised. A decision as to whether to use an ipsilateral or contralateral free flap has usually been made preoperatively, based on the shape of the contralateral breast. In general, a narrow pendulous breast is reconstructed with an ipsilateral flap, and a less ptotic but wide breast is reconstructed with a contralateral free flap. The lateral portion of the skin island closest to the selected muscle is elevated to the first row of lateral perforators. The opposite side of the skin island is elevated to the medial perforators exiting from the selected muscle. The flap includes only as many perforators as the surgeon feels is necessary. The fascia is incised medially and laterally to include the desired perforators. In many cases, no fascia is included in a MSFTRAM. A muscle-splitting dissection is performed medially and laterally to the perforators of the flap, and the inferior epigastric vessels are identified and dissected to the external iliac vessels. There is usually a single inferior epigastric vein at this level, or a large vein with a smaller counterpart entering the external iliac vein. The flap is now ready for division and transfer (Fig. 13.1a, b). The vascular anastomosis and inset of the flap is discussed later in this chapter. After the tissue is harvested, the abdomen is typically repaired by primary closure and either onlay or inlay mesh. The abdominal donor site is closed in a manner similar to that of an aesthetic abdominoplasty.

The improved blood supply and more limited donor site defect achieved with the MSFTRAM flap technique, as opposed to the pedicled TRAM,

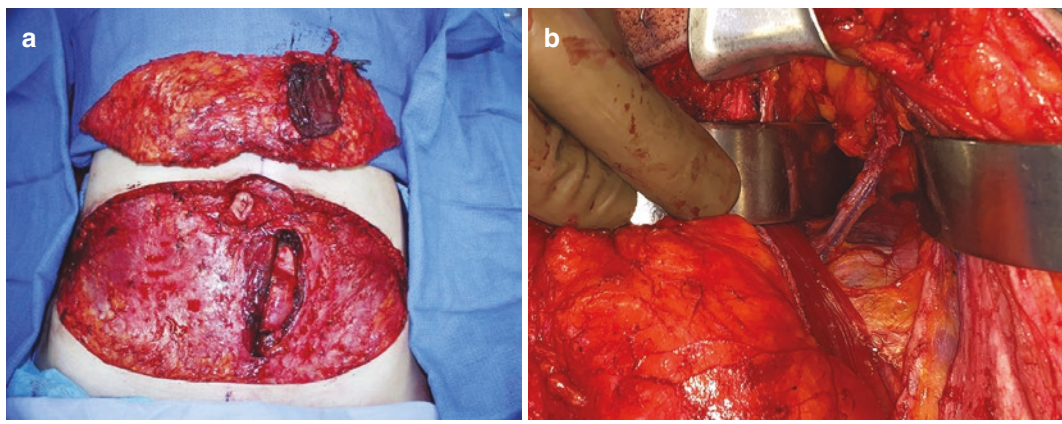

Fig. 13.1 (**a, b**) In the muscle-sparing free TRAM flap, only the central portion of the muscle is dissected and harvested. The inferior epigastric vessels are dissected to the external iliacs; this provides for sufficient pedicle length

has allowed MSFTRAM flap breast reconstruction in higher risk patients to have acceptable complication rates [12–14]. Insetting of the MSFTRAM flap is easier and less restrictive as compared to the pedicled TRAM flap. An advantage of the MSFTRAM flap over other choices for free flap breast reconstruction, such as the gluteal, thigh, or Ruben's flaps, is the quality of the soft tissue. The adipose tissue and skin in the MSFTRAM flap more closely mimics breast skin and fat, generally producing the most natural reconstructive results. As a result of these benefits, the MSFTRAM flap technique is now one of the most common and safe methods of free flap breast reconstruction.

Deep Inferior Epigastric Perforator (DIEP) Flap

Criticisms of both pedicled and MSFTRAM flaps have mostly centered on the abdominal wall donor site [15]. Initially, the entire lower portion of the rectus muscle was harvested with the free flap. This was followed by the muscle-sparing approach as described above, in which both a lateral and a medial strip of muscle and anterior rectus fascia are preserved. The DIEP flap uses the same skin island as described above, but preserves all of the rectus muscles and anterior rectus fascia. The skin island in the DIEP flap is based on one or more of the perforating vessels and their connection to the inferior epigastric vasculature.

Prior to surgery, the major perforators on each side of the skin island can be identified with a handheld Doppler instrument [16]. The sensitivity of CT angiography for preoperative evaluation of the perforator blood supply has been demonstrated; however, there is little evidence that routine use is warranted [17]. Upon selecting the right or left side, the lateral edge of the ipsilateral part of the skin island is elevated off of the fascia. Using loupe magnification and atraumatic technique, the surgeon identifies an acceptably large perforator (or perforators). The anterior rectus fascia is incised above the perforator for a short distance, and below it to just above the inguinal region. The fascia is reflected off of the muscle in a lateral direction. The muscle is splayed for a short distance around the perforator, identifying its connection to the inferior epigastric system. The lateral edge of the muscle is elevated off of the posterior rectus sheath for further identification and dissection of the inferior epigastric vessels. Care is taken to maintain all of the intercostal motor nerve supply to the rectus muscle. After completion of the flap dissection, the inferior epigastric vessels are divided proximally and passed through the opening in the muscle at the level of the perforator. The flap is separated from its remaining attachments to the abdominal wall and passed to the chest for anastomosis and inset. The incision in the anterior rectus fascia is closed directly, without the need for mesh, and the entire muscle with its nerve supply has been preserved (Fig. 13.2a–c). Proponents of this technique suggest that it results in less postoperative pain, a shorter hospitalization, and a more prompt recovery with little or no functional deficit in the abdominal donor site [18]. Because this flap relies on one or two perforators, it has been recommended that this technique be avoided in smokers and in obese patients [19].

Recipient Site

The axilla is fairly well exposed during a modified radical mastectomy, making the thorocodorsal (TD) system useful as a recipient site; however, in most circumstances, the internal mammary (IM) vessels have become the primary recipient site for free flap breast reconstruction. Outcomes between the two recipient sites have proven to be similar, and the IM site allows for more medial positioning of the flap, leading to improved symmetry and aesthetics [20]. In addition, using the IM avoids having to access the axilla in a simple mastectomy, and avoids the risk of injury in cases where reoperating in the axilla for further nodal resection is possible at a later date. The IM system also requires less pedicle length compared to the TD, which is particularly helpful in short pedicles, such as those found in

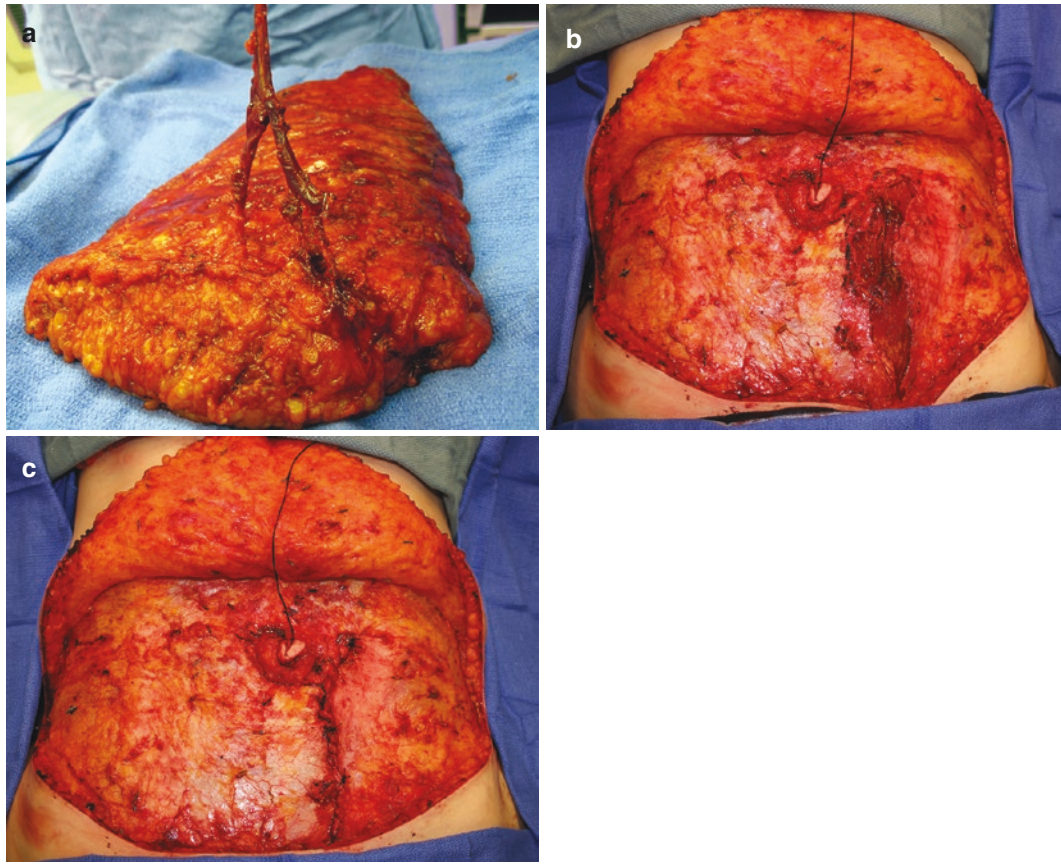

Fig. 13.2 (**a**) In performing a DIEP flap, a large perforator is identified and dissected with a long inferior epigastric pedicle. (**b**) The flap consists of skin, subcutaneous tissue, the perforator, and the attached inferior epigastric vessels. There is no muscle and no fascia within this flap. (**c**) The fascial incision is closed directly without the need for mesh

other free autologous methods such as transverse upper gracilis, superior, or inferior gluteal flaps.

The internal mammary vessels are first approached by separating the fibers of the pectoralis muscle overlying the third costal cartilage. The perichondrium is incised along the mid-anterior surface from the junction of the sternum to 1–2 cm medial to the costochondral junction. The perichondrium is separated off of the cartilage, although complete separation of the posterior perichondrium can be difficult and is unnecessary. Next, a rongeur is used to remove the cartilage. The posterior perichondrium is incised lateral to the internal mammary vessel and reflected lateral to medial. Care must be taken to avoid transection of the small intercostal vessel branches coming off of the internal mammary system. Once the vessels are identified and separated from the internal mammary lymphatics, the length of dissection is increased by dividing the intercostal muscle adjacent to the rib removed; this is done by staying lateral to the internal mammary vessels. The second costal cartilage can be removed in order to reach a larger diameter vein if needed. Compared with most other recipient vessels throughout the body, the internal mammary artery is more susceptible to injury and thrombosis during its dissection. Minimal use of vascular forceps is recommended. The internal mammary vein tends to be larger on the right side than on the left side. Once fully dissected, the internal mammary artery and vein are

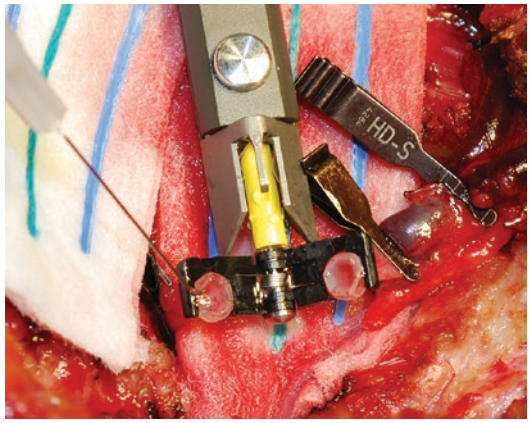

Fig. 13.3 For venous anastomoses, the coupler device offers a fast and reliable alternative to hand-sewing the vein. The coupler can be sized and used on veins of various calibers. We have not had reliable success with coupling arterial anastomoses. This is likely due to the thicker arterial wall and more dynamic nature of the artery compared to the vein

divided at the level of the third rib. The free flap is temporarily positioned to allow easy performance of the anastomoses. The artery is typically hand sewn with 8 or 9-O nylon. The vein is usually amenable to use of the coupler device (Fig. 13.3).

Other Free Flap Options

Superficial Inferior Epigastric Artery (SIEA) Flap

In addition to the deep inferior epigastric system, a superficial inferior epigastric artery (SIEA) and vein exist which feed into the same island of tissue used for the free TRAM. The difference lies in the fact that these vessels are entirely extrafascial. In the majority of patients, these vessels are not large enough to support a free flap; however, when present, this less invasive technique offers another option for autologous reconstruction.

The patient is marked and the case started in the same fashion as the free TRAM or DIEP. The superficial vessels, if present, are encountered via the inferior flap incision at the midpoint between the anterior superior iliac spine and pubic tubercle in the subcutaneous tissue (Fig. 13.4a–g). If it appears that these vessels will be large enough, the dissection is carried inferiorly to their origin at the superficial femoral vessels roughly 2–3 cm below the inguinal ligament. If sufficient, the flap dissection is then carried out by harvesting the typical lower abdominal ellipse of tissue. The difference in the SIEA is that this flap is entirely superficial to the abdominal wall musculature and anterior rectus fascia. The vessel origins are then taken and the flap is ready for insetting. The resultant donor site defect is closed similar to the free TRAM or DIEP, but without the need to close fascia.

The major drawbacks to the SIEA include a relatively short vascular pedicle in comparison to the free TRAM or DIEP, as well as smaller vessel caliber. In addition, because the vascular pedicle comes off inferiorly rather than deep to the flap, insetting can be sometimes more problematic. The SIEA is not present in 10–35% of patients [21, 22]. In addition, the angiosome distribution of the SIEA appears to be highly variable, such that simple inspection of the caliber of the vessel may be inadequate to reliably predict a dependable outcome [23]. Reports have indicated that the abdominal wall morbidity of SIEAs is lower; however, this benefit is balanced by an increased risk of flap complications due to compromised blood supply [18, 24].

Transverse Upper Gracilis (TUG) Flap

The TUG flap is another excellent option for autologous breast reconstruction in patients who are not candidates for transverse lower abdominal-based flaps. In these cases, the upper inner thigh flap is based upon the medial femoral circumflex vessels, and is oriented transversely, with the widest portion directly over the gracilis muscle. The patient is placed in the supine position with legs abducted and knees slightly bent. The anterior portion of the flap is dissected first, superficial to the fascia of the thigh muscles. Upon reaching the adductor longus, the fascia is incised, allowing for exposure of the gracilis pedicle under the adductor longus muscle. At this point, the posterior end of the flap can be elevated and the gracilis can be divided proximally and distally. The vascular pedicle can be further dissected if needed for length. The pedicle is gen-

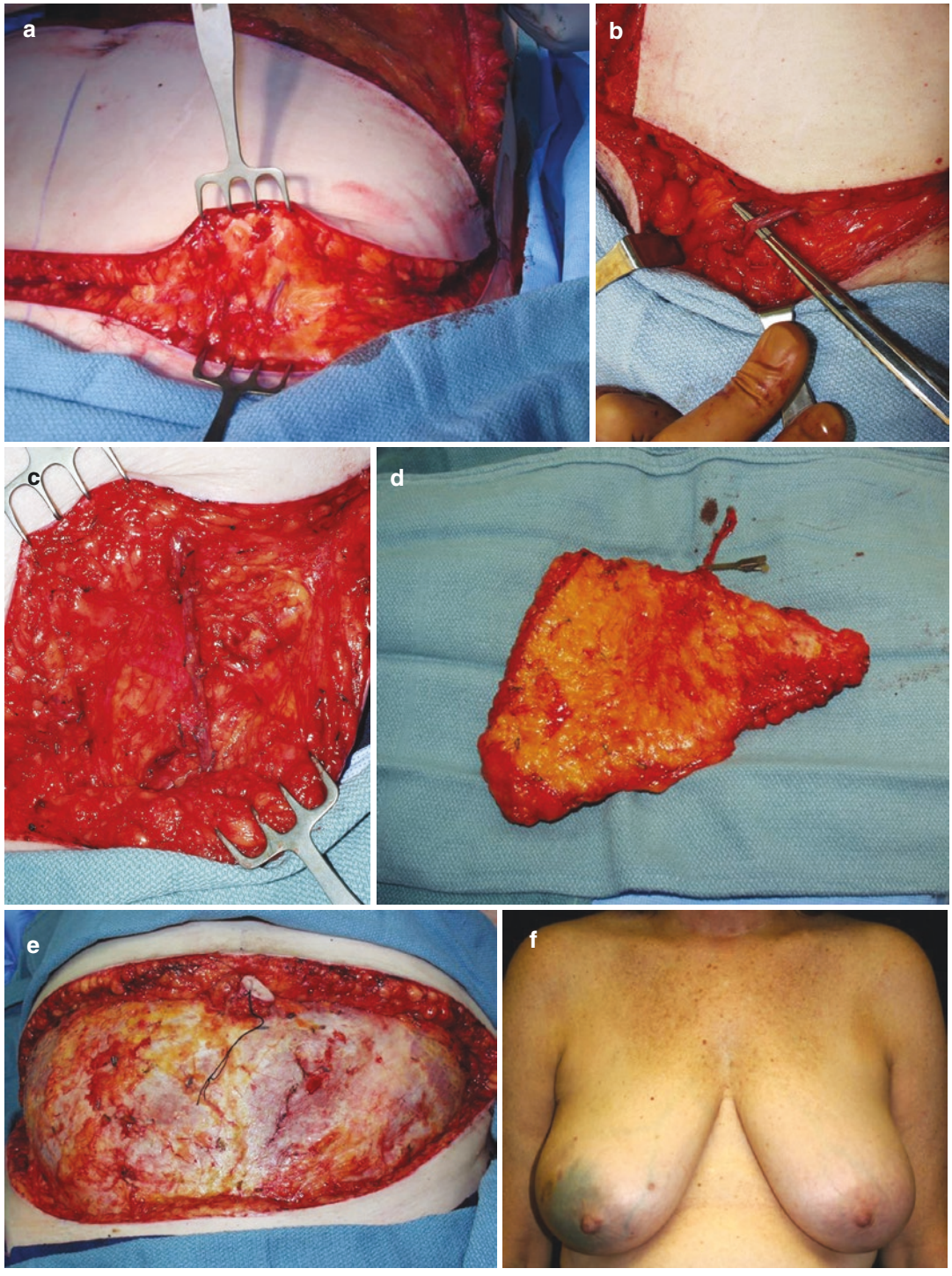

Fig. 13.4 (**a**) Dissection of the typical lower abdominal transverse flap; however, in this case, an adequate SIE artery and vein are encountered. (**b** and **c**) The SIEA is dissected out in its entirety to ensure adequate pedicle length. (**d**) The SIEA flap after removal from the abdomen, prior to inset. (**e**) The abdominal wall following removal of the flap. Note that the fascia is intact and is not in need of any closure. (**f**) Preoperative photo of a patient with a right breast cancer. (**g**) Postoperative photo of the same patient following a right SIEA with concomitant left reduction for symmetry

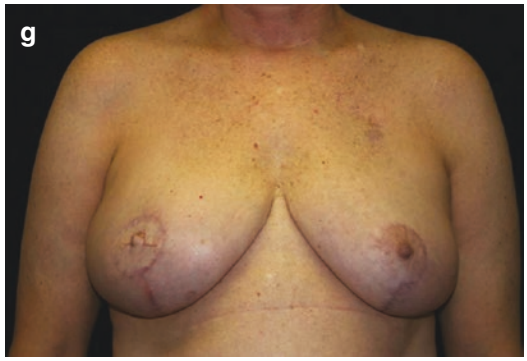

Fig. 13.4 (continued)

erally 5–6 cm, and insetting of the flap provides excellent contour due to the crescent shape of the flap. In addition, this flap offers a simultaneous cosmetic procedure with an inner thigh lift as the donor site is closed.

Profunda Artery Perforator (PAP) Flap

In addition to the flaps mentioned above, another good option is the PAP flap when abdominal-based reconstruction is contraindicated. In these patients, the flap is harvested medially and posteriorly using the groin crease and gluteal fold as landmarks. The patient is placed in lithotomy position. The anterior portion of the flap is dissected first, superficial to the fascia of the thigh muscles. The dominant perforator is about 2–3 cm posterior to the gracilis as it transverses the adductor magnus. The pedicle is dissected out to allow adequate length for anastomosis, requiring no more than 7 cm in length.

Alloplastic Reconstruction

Alloplastic techniques remain the most common form of reconstruction performed in the United States, with 70–75% of women undergoing this form of reconstruction [2]. Many women have the predisposed notion that they do not want implants, stemming from concerns about foreign bodies and fear of implants being associated with cancer, although the risks are very low [25]. These patients should be counseled on the safety and benefits of expander/implant reconstruction regardless of their initial plan, as often a patient's initial understanding is inadequate to make an educated decision. As previously mentioned, achieving breast symmetry is more difficult with unilateral implant reconstruction than for autologous reconstruction, which is especially true for ptotic and large breasts. A prerequisite for successful implant placement is healthy mastectomy skin that provides adequate coverage to avoid prosthesis exposure and to minimize complications. A collegial relationship with your breast surgeon is paramount to achieving consistent results with alloplastic reconstruction. Advantages to alloplastic reconstruction include lower initial cost, technical ease, decreased operative time, and no donor site morbidity [26].

However, there are several disadvantages like long-term outcomes, the need for additional revisions, capsular contracture, implant rupture, and infection requiring implant removal. The two-stage submuscular approach is often used, but the direct-to-implant (DTI) and prepectoral reconstructive techniques have gained momentum more recently [27–31]. We will describe all three options.

Submuscular Two-Stage Reconstruction

The two-stage approach is the most common form of implant-based breast reconstruction. Proponents of this technique argue that it minimizes tension and stress on the skin flaps at

the time of mastectomy and allows for more flexibility in choosing final breast size and volume. Additionally, it offers a second surgery in which revisions can be made, if necessary.

After mastectomy, the surgeon must take a moment to assess the mastectomy pocket. In order to maximize long-term aesthetic results, the first stage must include refinement of the pocket and flaps, and this may require additional work by the plastic surgeon. These issues include making sure the skins flaps are not only well perfused, but even in thickness. If skin is poorly perfused, it should be removed. If there are large medial or lateral dog ears, these should be removed at this stage, as excess skin can be unpredictable during the expansion process and can leave areas of edematous and wrinkled skin than cannot be easily corrected at later stages. Care should be taken to make sure that the Inframammary Fold (IMF) is well defined in its native position, and any implant or pocket position mimics the IMF to one's best ability.

After the pocket has been defined, the inferolateral border of the pectoralis major is identified. A submuscular pocket is dissected from the lateral to medial direction, up to the medial footprint of the breast and along the IMF. For inferolateral coverage, a serratus muscle flap is lifted from a medial to lateral direction. Only dissect as far lateral as is necessary to avoid lateral fallout of the implant pocket.

An alternative placement is partial submuscular, where the upper pole of the tissue expander is covered by the pectoralis muscle and the lower pole is covered by biologic mesh. In this case, the entire lower insertion of the pectoralis muscle is divided off of the chest. The biologic mesh is sewn into place as a lower and lateral sling over the implant, along the lower border of the pectoralis and down to the chest wall. It is important to note the biologic mesh, while commonly used in breast reconstruction, is not FDA-approved for this use. Many studies have shown a reasonable safety profile, but some have shown an increased rate of seroma and infection. The main benefit of using mesh is less discomfort and tightness by the serratus dissection, and in some cases, it provides for better ptosis in the final result [32].

Expander choice is paramount to a consistent result. We typically use a moderate height expander to preferentially expand the lower pole; however, some surgeons prefer a full height expander. The most important variable to consider is the base width of the device. This should match the general width of the patient's native breast or desired outcome, as correcting width in the next stage is more difficult. Device technology continues to evolve, the latest trends being smooth expanders and dual port devices that allow for seroma evacuation in a safer technique.

The tissue expander can be filled at the time of surgery, but care should be taken to assess muscle tension and skin tension. An added benefit of filling more aggressively is the reduced risk of hematoma and seroma, but this must be done without increasing the rate of mastectomy flap failure [33, 34]. The first expansion postoperatively occurs anywhere from 10 to 21 days postop. This is done typically by injecting about 60 cc every week or biweekly while paying close attention to the quality of the mastectomy flaps and patient tolerance. Fluid can be removed if necessary for wound healing or discomfort, if needed. The pace of expansion is also based on the desired timing of final implant. Final fill volume is dictated by either tissue tolerance or patient aesthetic desire. The expander should sit at its final fill volume for at least a month prior to exchange.

Expander Exchange for Implant

Implant choice was once more complicated than perhaps it is now. We used to use round or shaped cohesive silicone devices; however, with the increasing volume of literature showing increased risk of anaplastic large cell lymphoma (ALCL) with textured devices, we typically are only using round smooth devices at this time [35–38]. Surgeons should familiarize themselves with the many implant options on the market. Overfilled and/or cohesive round implants may have the additional benefit of resisting rippling. We do not recommend saline implants for breast reconstruction, due to a more noticeable device and more unnatural feel. We recommend at least a

high-profile device or more for projection, unless performing a very small reconstruction where the added width of a lower profile device may be of benefit. Implant size is typically dictated by expander volume. When using a medium height expander, one can expect to place a gel implant that is approximately 100 cc larger, which accounts for the pocket expansion and expander device volume itself. That being said, the patient should not be led to believe that the increase in volume will make the reconstruction larger, as sometimes patients feel the actual implant looks smaller than a fully expanded expander.

The exchange surgery is typically fairly straightforward. The pocket is accessed via the original mastectomy scar. The expander is removed and capsulotomies are performed to further refine the pocket position. Commonly, the upper pole requires release, and medialization of the pocket is commonly desired as well. The IMF can be adjusted, but the best results are achieved when the IMF position was correctly established at the first stage with expander placement. The pockets are copiously irrigated with antibiotic solution prior to placement of the final implant. We recommend at least re-prep of the chest, if not, use no-touch technique with a funnel to minimize the risk of infection.

Direct-to-Implant Reconstruction

In recent times, nipple preservation has become more common during mastectomy. In addition, there is an increasing population of young patients undergoing prophylactic procedures [39, 40]. In the right circumstances, some mastectomy patients may be candidates for a one-stage procedure with placement of a gel implant at the time of mastectomy. In our practice, the main criteria needed for success with this approach include grade 1 ptosis; smaller breasts, but similar to the patient's goal final volume; nonsmoker; and the right breast surgeon. The breast surgeon plays an incredibly key role in the success of this operation, and this should not be overlooked. The main obvious advantage of direct-to-implant (DTI) reconstruction is that it only involves one surgery as opposed to two, offering the patient a complete reconstruction at the time of mastectomy. The majority of women actually prefer a one-staged surgery, providing established psychosocial benefits [41, 42]. Several disadvantages include limited size of reconstruction, less input into final size, higher mastectomy flap necrosis, and higher incidence of shape or volume asymmetry [26]. There is a higher revision rate associated with DTI surgery, and this must be communicated clearly with the patient.

The first step is assessing the quality of the mastectomy skin flaps and nipple-areolar perfusion. The implant can either be placed in a dual plane position, or a prepectoral position. In the dual plane approach, a subpectoralis dissection is followed by disinsertion of the IMF insertion of the muscle. A biologic mesh sling is then sewn into place, similar to that described in a two-stage approach described earlier. This sling serves for inferolateral coverage and support. A series of sizers to assess for implant choice is very helpful to choose an implant that fills out the pocket without placing untoward tension on the closure. Implant choice is very similar to that described above.

In a prepectoral DTI procedure, we typically use medium-thickness acellular dermal matrices (ADM) sewn with Vicryl suture for anterior coverage only and to hold the implant in place. There is no need for posterior coverage. Further research is needed to determine if cheaper solutions than ADM exist to provide coverage and support, as this is typically a large and expensive piece of ADM [43, 44] Drains are placed into the inferolateral gutters, brought out laterally, and secured into place. Drains in prepectoral reconstruction are left in place longer than most indications to account for the seromagenic quality of ADM. Our typical cutoff is less than 20 cc/day for 3 days in a row.

Prepectoral Reconstruction

Similar to direct-to-implant reconstruction, prepectoral reconstruction has gained traction in recent years with the advancements of ADM, fat grafting, and optimally filled prosthetic devices

[45–47]. Prepectoral reconstruction can be performed in two stages or direct-to-implant. The two-stage technique is important because it gives the patient the ability to choose her own volume, and it can reduce the risk of nipple loss or necrosis in nipple-sparing mastectomies [48]. The skin and subcutaneous tissue have a tendency to recoil, so the delayed approach is often favored. For nipple-sparing mastectomies through an IMF incision, we recommend reconstruction through an ex vivo ADM-prosthetic construct, as we described in our DTI section. In addition, the significant benefits of prepectoral surgery is less pain and tightness, quicker recovery, and complete avoidance of motion deformity (Fig. 13.5a–d). The downside of prepectoral approaches are the limitation of the thinner soft tissue envelope, which can make contour irregularities and rippling more noticeable. Staged fat grafting plays an incredibly important role in this approach, to blend the contour and build up the soft tissue envelope. The patient must be made aware of the likelihood of needing at

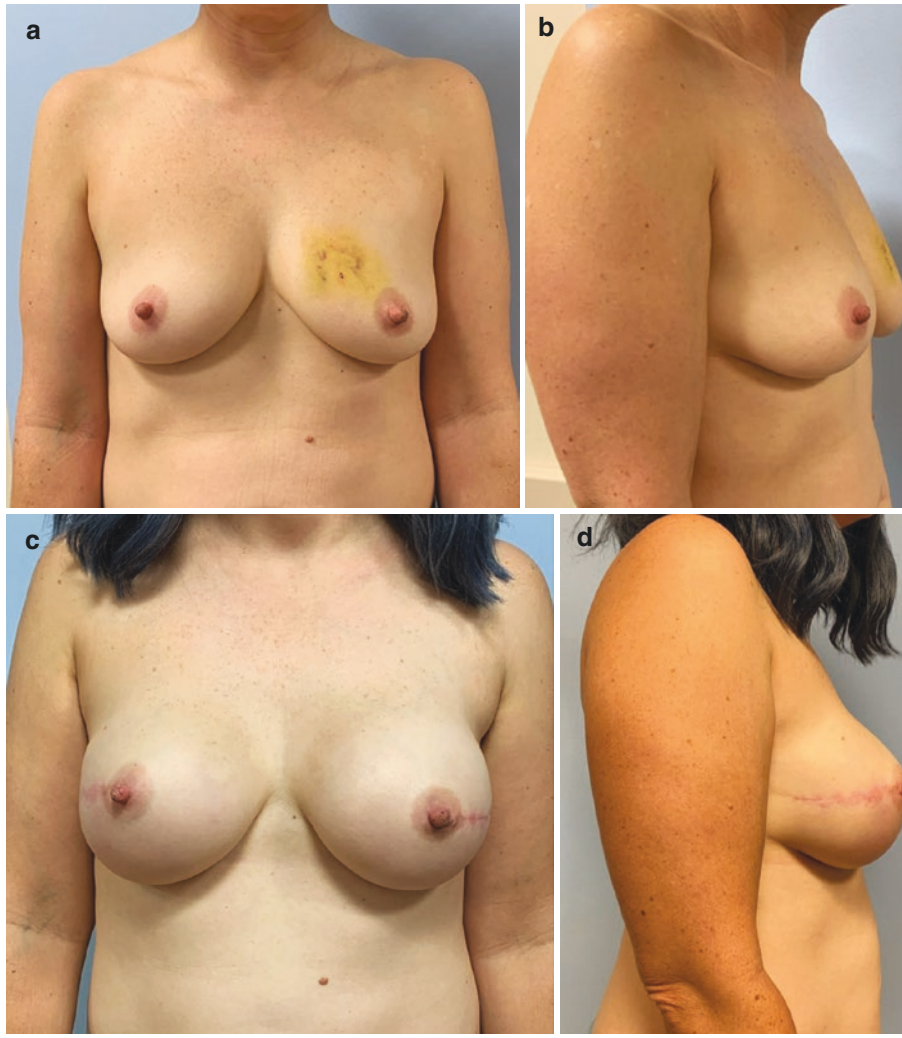

Fig. 13.5 (**a**, **b**) Preoperative patient with breast cancer undergoing bilateral nipple-sparing mastectomies. (**c**, **d**) Postoperative patient following one-stage prepectoral placement of round silicone implants with Alloderm. The patient will benefit from superior fat grafting if desired, but already benefits from a quick recovery and natural ptotic result with zero-motion deformity

least one, if not more, revision surgeries. In addition, without muscular coverage, delayed wound healing or superficial infection may make implant loss more likely [49].

Conclusion

Autologous breast reconstruction can be performed using a wide variety of flaps, which all offer the ability to reliably recreate a breast mound following mastectomy. This has the unique ability to replace "like with like," and although it is not free of complications, can be performed in a variety of settings with the expectation of excellent patient satisfaction. Alloplastic reconstruction is far more common, with many surgeons taking advantage of its initial lower cost, technical ease, and decreased operative time, and no donor site morbidity. Either type can be utilized and should be in the plastic surgeons' armamentarium for breast reconstruction.

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Eyelid Reconstruction

14

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Introduction

The eyelids are complex structures with intricate functional and aesthetic properties. Plans for surgical reconstruction must achieve three goals while restoring normal anatomy: (1) Protect the globe. (2) Restore eyelid function (a complete blink, allow for an opening to allow light through the pupil, and drain the tears). (3) Create a cosmetically acceptable appearance (upper and lower lid height and contour, appropriate position of medial and lateral canthal tendons, and match eyelid skin color, texture, and thickness).

The need for periocular reconstruction may occur in the setting of trauma, surgical excision of neoplasms, and repair of congenital defects. Various etiologies for periocular soft tissue defects involve unique pathophysiologic considerations and present distinct challenges to surgical reconstruction. Trauma is often associated with crush injury to the involved tissues; tumor removal with margin control can significantly enlarge the defect associated with a seemingly small lesion; and congenital defects can present with lack of normal bony development and associated connective tissue support.

Proper reconstruction of the eyelids involves providing a posterior mucosal surface to maintain the integrity of the corneal epithelium, establishing structural support to the eyelid by repairing or replacing tarsal defects, achieving adequate tensile strength of the lid margin to prevent ectropion or entropion, avoiding vertical tension on the anterior lamella to prevent lagophthalmos or retraction, and matching the eyelid's thin skin and delicate texture when using local flaps or skin grafts in order to achieve optimal cosmesis. The close proximity of the eyelids to other delicate structures such as the lacrimal puncta, canaliculi, and lacrimal sac further complicates reconstruction, as these structures must be identified, preserved, and meticulously repaired in the event of concurrent injury.

Reconstruction of the lower eyelid must meet the basic demand of providing coverage for the globe with a smooth mucosal surface. This is done by minimizing retraction or ectropion and avoiding entropion or trichiasis. Reconstruction of the upper eyelid involves additional demands, as functional considerations are more complex and aesthetic considerations are more apparent [1, 2]. In addition to the basic demands, successful upper eyelid reconstruction must provide adequate motility to allow opening and closing of

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the eyelid. Furthermore, a complete posterior mucosal lining (more important in the upper eyelid than the lower eyelid) is critical to ensure that the posterior surface of the upper eyelid glides across the cornea without scratching it. Additionally, aesthetic qualities such as eyelid height and contour, tarsal show, and eyelid crease are more important in upper eyelid reconstructions [1]. Even an upper eyelid asymmetry of as little as 1–2 mm may be deemed unacceptable by the patient.

Although cosmesis is important, the primary goal of any eyelid reconstruction is to provide protection to the globe. Failure to meet the functional demands of the eyelid with reconstruction can lead to corneal exposure, ulceration, and even globe rupture leading to permanent vision loss. Particularly with larger defects, a staged approach may be necessary, where secondary reconstructive efforts to address malposition or cosmesis are deferred to a later date. As with any complex surgical procedure, emphasis is placed on engaging in a thorough preoperative discussion with the patient that highlights the treatment plan, expected result, possible complications, and the potential need for subsequent revision procedures.

Pertinent Anatomy

A thorough knowledge of eyelid anatomy is the basis for surgical planning (Fig. 14.1). Starting from the eyelid margin, the first 10–12 mm of the upper eyelid and the first 4 mm of the lower eyelid have similar anatomic layers: the skin, orbicularis oculi muscle, tarsal plate, and conjunctiva. These layers comprise two reconstructive units, the anterior lamella (skin and orbicularis oculi muscle) and the posterior lamella (tarsal plate and conjunctiva). The puncta are located medially along the upper and lower eyelid margins and are responsible for draining the tears through the nasolacrimal system. Above the superior tarsal border of the upper eyelid, the anterior lamella remains the same, but additional structures are present deep to this layer. The orbital septum, also known as the middle lamella, lies deep to the orbicularis. The orbital septum is a dense layer of connective tissue that separates the eyelid anteriorly from the orbital structures posteriorly. Posterior to the orbital septum of the upper eyelid lie the preaponeurotic fat, levator aponeurosis, Muller's muscle, and the conjunctiva, in that order. Inferior to the tarsal plate of the lower eyelid, analogous structures exist: the orbital septum lies deep to the anterior lamella of skin and orbicularis oculi muscle and runs from the tarsal plate to the inferior orbital rim. Deep to the orbital septum of the lower eyelid lie the lower eyelid fat pads, capsulopalpebral fascia (the lower eyelid retractor; an equivalent structure to the levator palpebrae aponeurosis of the upper eyelid), and conjunctiva.

The medial and lateral canthal tendons anchor the tarsal plate to the bony orbit. The medial canthal tendon is an extension of the pretarsal and preseptal orbicularis oculi muscle and has two insertions: one anteriorly at the anterior lacrimal crest and one posteriorly at the posterior lacrimal crest. While the anterior limb of the medial canthal tendon can be disinserted without causing canthal malposition, the posterior attachment is critical in maintaining good eyelid-globe apposition. The lateral canthal tendon inserts at Whitnall's tubercle, a bony prominence 2 mm posterior to the lateral orbital rim. Preserving or reconstructing the attachment of the lateral canthal tendon to the lateral orbital wall, deep to the rim, is essential to maintain adequate tension of the eyelid and prevent malposition or poor apposition between the lid and globe. Stretching or disinsertion of the lateral canthal tendon can narrow the eyelid fissure and cause rounding of the lateral canthal angle.

In the lower eyelid, the weight of the midface, transmitted to the eyelids through the facial ligaments, asserts a downward pull on the lower eyelid. This force vector is negated by a firm adherence of the periosteum to the inferior orbital rim and by the horizontal anchoring of the canthal tendons. Additional vertical support is provided by attachment of the levator aponeurosis of the upper eyelid or capsulopalpebral fascia of the lower eyelid to the tarsal plate. Vertical support provided by the upper and lower eyelid retractors requires that

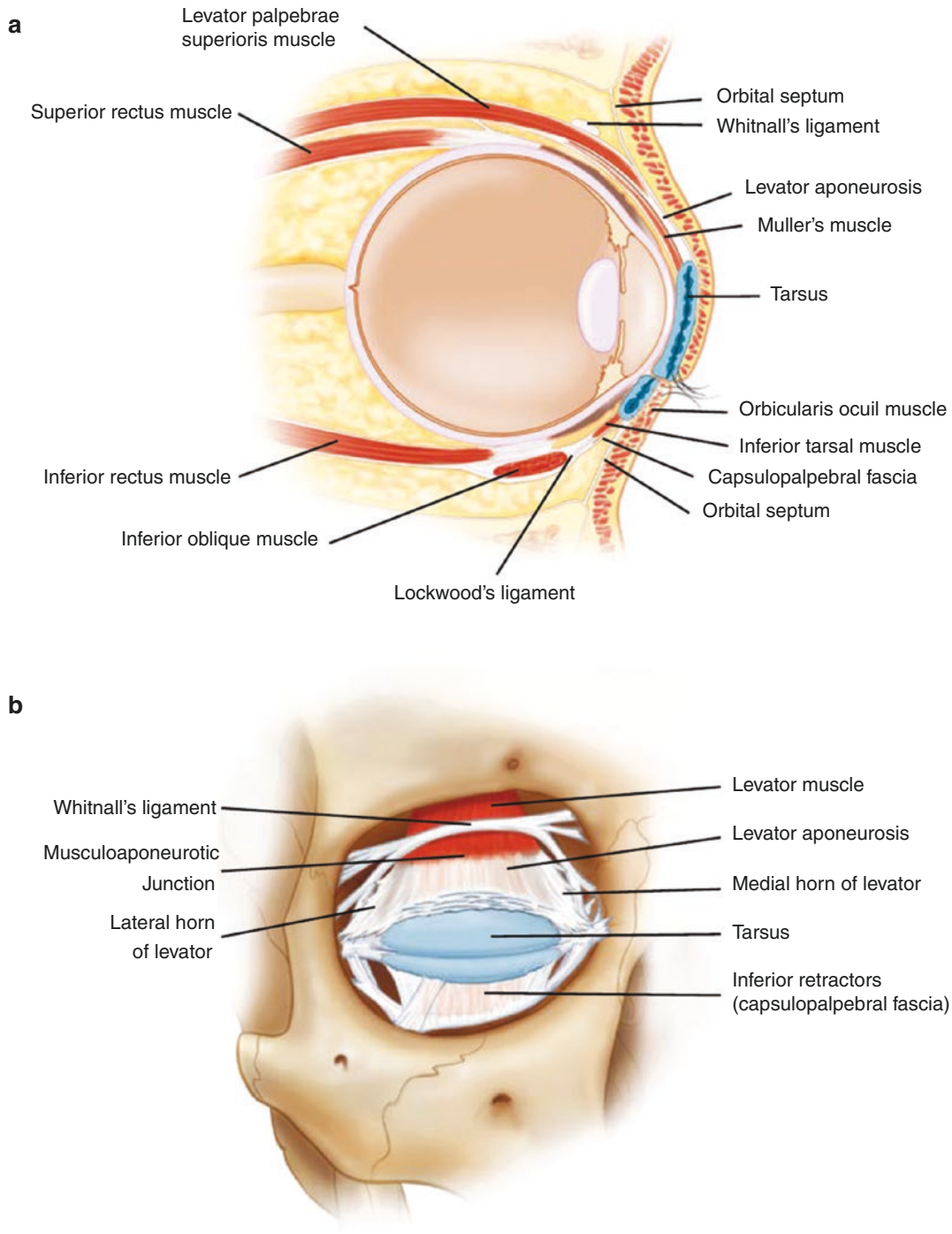

Fig. 14.1 Eyelid anatomy: (**a**) sagittal view; (**b**) tendinous attachments. (Reproduced with permission from Codner and McCord [3])

their insertions to the tarsal plate be maintained. Disinsertion of the levator aponeurosis gives rise to upper eyelid ptosis, and disinsertion of the capsulopalpebral fascia to lower eyelid malposition. Dehiscence of the capsulopalpebral fascia from the lower border of the tarsal plate can sometimes be visualized as a thin white line deep to the conjunctiva within the inferior fornix.

Principles of Eyelid Reconstruction

Eyelid reconstruction shares the same basic principles of plastic and reconstructive surgery applied to other anatomical locations, as described throughout this book. In sum, the tenets of the "reconstructive ladder" should be followed, opting for the simplest reconstructive procedure. Direct closure takes preference over local flaps, which in turn are favorable compared to distant grafts. Tissues should be restored in a "like-for-like" fashion, respecting the lamellar structure of the eyelids. Graft viability is maximized by ensuring that the graft is placed in a well-vascularized tissue bed, avoiding placement of a graft over a second graft or a full-thickness skin graft (FTSG) directly over bone, due to the lack of a secure blood supply [4]. Owing to the unique anatomy of the eyelid, this general principle can occasionally be circumvented by using an orbicularis muscle flap as a "sandwich flap," thereby allowing the use of both anterior and posterior grafts concomitantly [5].

Approach to Eyelid Reconstruction

The reconstructive approach in any particular scenario will depend on the anatomical characteristics of the defect. Nonetheless, some general guidelines for repair of eyelid defects are as follows:

- *Identify which lamellae are involved*: Isolated anterior lamellar defects usually do not require additional structural support. Posterior lamellar defects require tarsal repair or substitution and a mucosal surface.
- *Find suitable anchoring points:* Long-term, excellent functional results depend on stable anchoring of the eyelid structures to the bony orbit. Adequate structural support is key to maintaining appropriate eyelid position and, subsequently, protection of the globe. A canthal stump or the periosteum of the orbital rim can serve as an anchoring point in extensive or deep defects. When these anatomic anchoring points are not available, more complex anchoring solutions, such as titanium screws or trans-nasal wiring, can be used.
- *Consider facial aesthetic units:* When tissue is needed to fill a defect, attempt to recruit tissue from the same facial aesthetic unit, or that of the contralateral side, as this tissue often provides the best match in terms of thickness, texture, and pigmentation.
- *Avoid vascular complications:* Typically, the eyelids have excellent wound-healing qualities due to a robust blood supply rich with vascular anastomoses; however, special circumstances require additional consideration. Patients who have previously undergone radiation, diabetic patients, and patients who have undergone multiple periocular surgeries are more prone to graft and flap failure due to compromised blood supply. These patients may be better treated with axial flaps rather than random flaps or grafts.

Preoperative Assessment

General Considerations

When an eyelid defect results from the resection of a cutaneous neoplasm, the surgeon should verify prior to reconstruction that all tumor was removed. Margin-controlled excision, via Mohs micrographic surgical technique or frozen section, are advised. When deep margins cannot be verified, attempt should be made to avoid violation of adjacent bone, as this creates a potential pathway of spread into adjacent anatomical compartments. All pertinent available imaging should be reviewed, and the surgeon should be aware of any facial fractures or other bony or soft tissue abnormalities that might influence the reconstructive plan. Operative reports of prior

periocular surgical procedures should be obtained and reviewed prior to surgery.

The surgeon should review the patient's medical history to identify risk factors for intraoperative and postoperative complications, such as bleeding and poor wound healing. The use of antiplatelet or anticoagulant agents should be documented and, if cleared by the prescribing physician, suspended prior to surgery.

Assessing the Defect

The surgeon must determine whether the defect is limited to the anterior lamella or is a full thickness defect involving both anterior and posterior lamellae. Deeper defects require reconstruction of both anatomical layers. Any defect medial to the punctum should raise suspicion for a laceration of the lacrimal apparatus, and the lacrimal system should be probed to assess for injury requiring repair.

Next, the integrity of the medial and lateral canthal tendons should be evaluated to determine if repair or resuspension is required. Assess the laxity of the eyelid margin to determine if direct closure is possible. Assess the availability of surrounding tissues, paying careful attention to any scars that may indicate prior violation of the tissues or disruption of normal anatomy.

If a defect requires the use of a graft, carefully examine the planned donor site for texture, laxity, and presence or absence of hair follicles. Carefully inspect the site to confirm the absence of lesions that could be neoplasms or preneoplastic.

As with any defects involving other anatomical locations, the defect to be repaired should be well documented and, ideally, preoperative photographs should be included in the medical record.

Anterior Lamella Reconstruction Techniques

Direct Closure

Small-to-medium defects of the anterior lamella can be directly closed after undermining the adjacent skin. Adjacent tissue should be advanced from the medial and lateral aspects of the wounds, creating a wound closure that is oriented perpendicular to the eyelid margin. Effort should be made to ensure that any forces of tension on the wound have horizontal rather than vertical vectors, to minimize the risk of eyelid retraction, lagophthalmos, or malposition of the eyelid. For defects located further from the eyelid margin, vertical tension on the closure is more tolerable. Consequently, wound closure distal to the eyelid may be planned in an effort to place the scar along resting skin tension lines, thus minimizing scar visibility.

Very small anterior lamellar defects (≤3 mm) granulate nicely and do not necessitate closure. Small anterior lamellar defects of the upper or lower eyelid (≤33% eyelid length) located lateral to the lateral canthus are particularly tolerant of direct closure because of the support provided by the lateral canthal tendon (Fig. 14.2a). In the lower eyelid, these defects can often be closed with a sub-ciliary incision and advancement of a skin muscle flap into the defect. For such defects temporal to the lateral canthus, recruitment of skin lateral to the defect is preferred (Fig. 14.2b). This area allows for relatively large skin advancement and cosmesis is excellent, as the scar can be disguised within the smile lines.

Local Myocutaneous Flaps

Local flaps are considered when direct closure is not possible. Mobilization of adjacent tissue usually results in a like-for-like replacement, with good matching of skin color and texture. Importantly, flaps mobilized from the forehead and glabella area can introduce thicker skin to the eyelid area and may require a second procedure for debulking.

Periocluar flaps rely on the area's rich blood supply. The commonly suggested length: width ratio of 3:1 should be respected at all times. Many local flaps have been described for periocular reconstruction; following are our tips for flaps we commonly use:

- *O-Z Flap:* Small round defects can be reconstructed with a variety of advancement, rotation, or transposition flaps. A V-Y, O-Z, O-S,

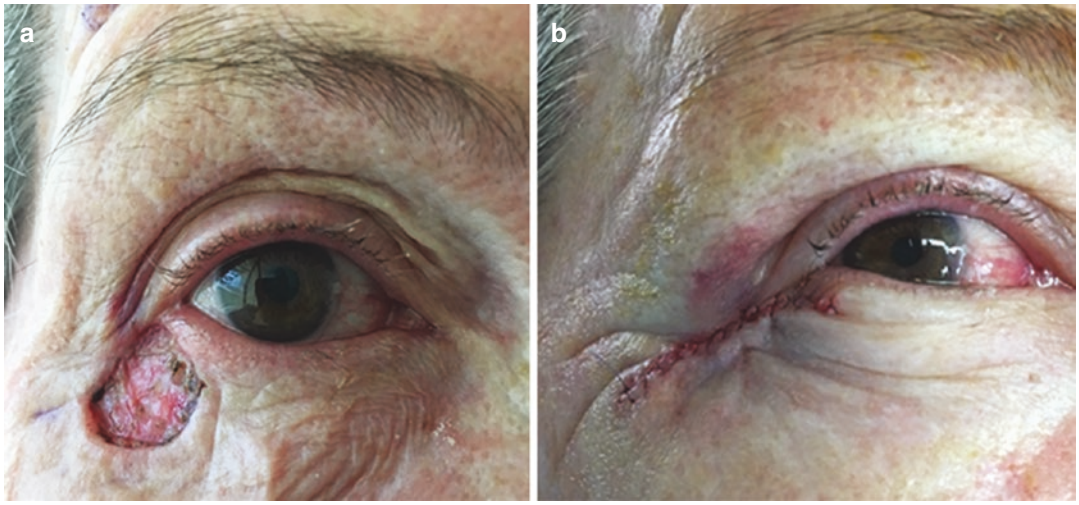

Fig. 14.2 (**a**) A lower lid defect next to the lateral canthus involving only the anterior lamella. (**b**) Primary closure using a small temporal relaxing incision. Sufficient laxity allows parallel rather than vertical pretarsal scar alignment. Notice how the scar is positioned within the laugh lines

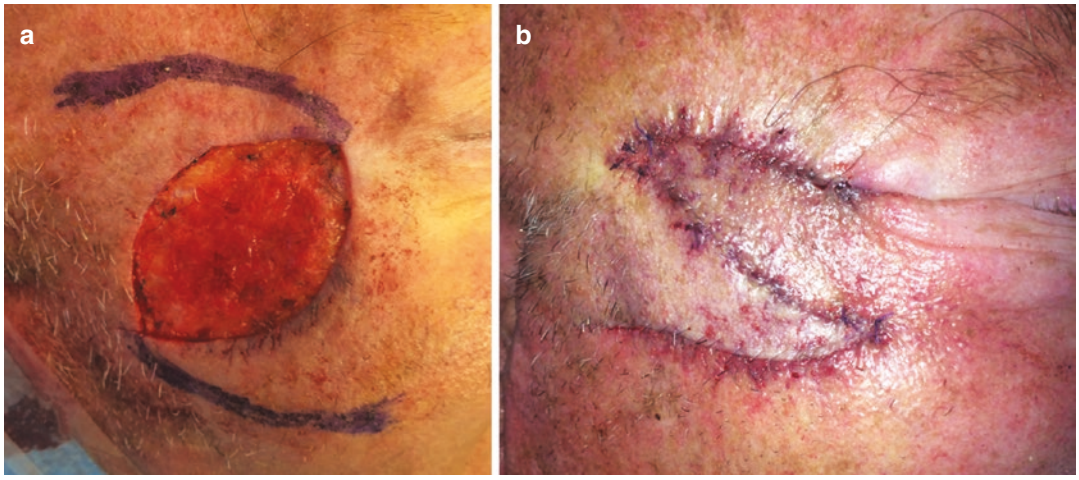

Fig. 14.3 (**a**) A large superficial temporal defect with the flaps marked. (**b**) Flaps sutured into place, notice the gentle up-curve of the superior flap

A-T, or Z-plasty flaps have all been described with good results. We commonly use the O-Z flap (Fig. 14.3a), which maintains favorable wound tension vectors. Note that the vector force of the inferior pedicle is horizontal and slightly superior, a critical direction to avoid ectropion and lower lid retraction (Fig. 14.3b). Again, care is taken to avoid damage to the branches of the facial nerve along the zygoma as dissection is carried out in a subcutaneous plane. The distal tips of these larger flaps, demonstrated in the figure, are at risk of necrosis; however, they granulate nicely and rarely need surgical management.

- *Tripier flap:* For large lower eyelid defects, we prefer using a bipedicle flap from the upper eyelid (Tripier flap, or "bucket-handle" flap). This myocutaneous flap is fantastic for broad and narrow (<1 cm in vertical height) lower lid defects. The approach to

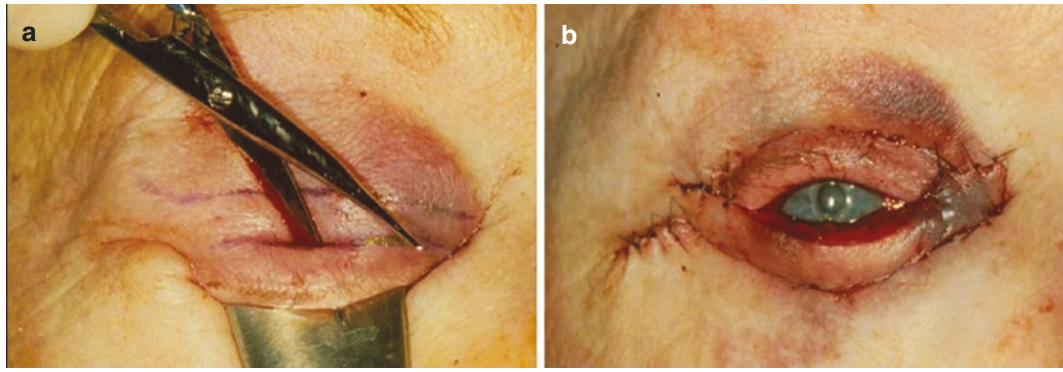

Fig. 14.4 Tripier flap: (**a**) A horizontal flap is fashioned from the upper eyelid. Notice flaring of the lateral border of the planned flap. (**b**) The Tripier flap is repositioned over the lower lid defect. (Photos courtesy of Dr. David Tse)

this flap should be similar to an upper lid blepharoplasty. It is important not to take away too much skin, which will come at the expense of anterior lamellar shortening and incomplete eyelid closure. Marking this flap is extremely helpful, and should start by delineating the upper eyelid crease. The markings are extended to just beyond the medial and lateral canthus. Excess skin is then clamped and marked. As the superior markings extend medially and laterally, the incisions should flare superiorly, at approximately creating a 135- to 150-degree angle (Fig. 14.4a and b). This allows for the flap pedicle to be oriented inferiorly, and helps to prevent webbing along the medial canthus. For defects less than 66% of the eyelid's length, we convert the flap into a unipedicle flap hinged laterally (Fig. 14.5).

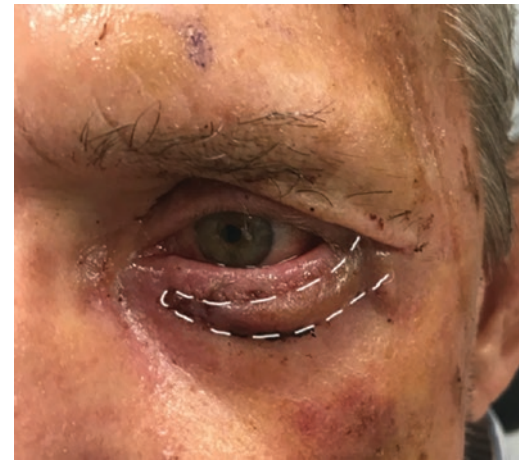

Fig. 14.5 Postoperative picture for a patient who underwent correction of cicatricial ectropion. Lower eyelid anterior lamella shortage was addressed through a unipedicle flap from the ipsilateral upper eyelid

- *Fricke Flap:* This rotational axial flap, ideally based on the superficial temporal artery, recruits skin superior to the brow into the defect (Fig. 14.6a and b). Patients with large anterior lamellar defects who lack available upper eyelid skin are ideal candidates for this technique (e.g., postblepharoplasty patients) [6]. We find the skin match to be better than expected, especially when compared to the FTSG alternative. It is important to remember that use of the Fricke flap will raise the brow on the operated side, and can cause significant brow asymmetry (Fig. 14.6c).
- *Rhomboid/Bi-lobe flap:* We use this rotational flap for small-to-medium defects (3–7 mm) in the medial canthus because when performed correctly with the appropriately oriented pedicle, they do not create medial canthal webs (Fig. 14.7a and b). It is important to notice if the defect is confined to the medial canthus area or if it is extending into the eyelid skin, as these techniques recruit thick glabellar skin, which can cause significant retraction if attached to the delicate eyelid skin. For medial canthal defects that extend to the upper eyelid, we prefer a combined approach, using a rhomboid/bi-lobe flap to reconstruct the medial

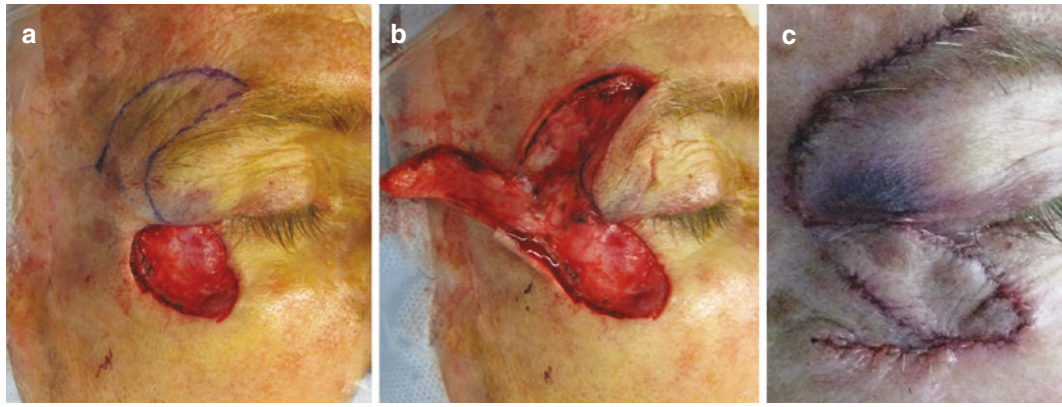

Fig. 14.6 (**a**) Fricke flap marked. Notice lack of upper eyelid skin redundancy. (**b**) Flap dissected and reflected. (**c**) Flap in place

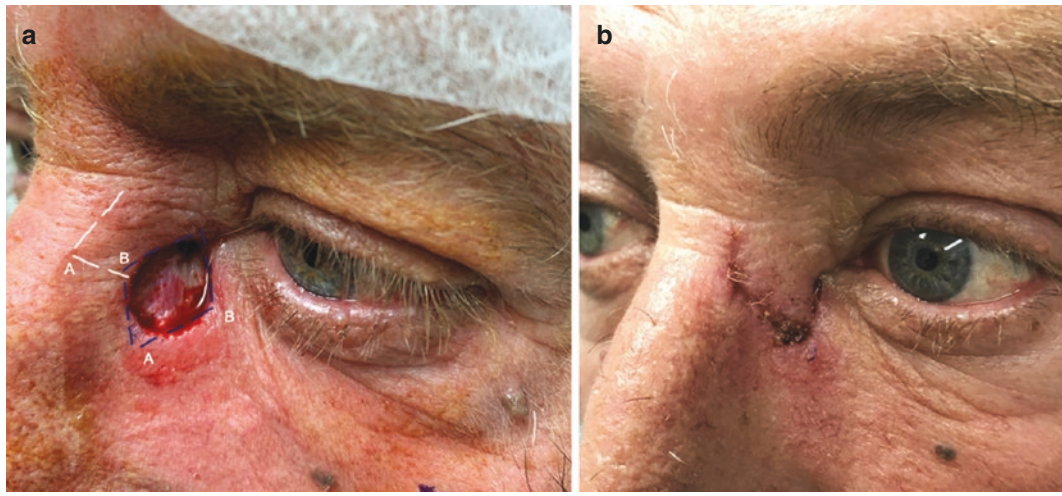

Fig. 14.7 Rhomboid flap: (**a**) Flap marked with planned rotation. (**b**) Postoperative result with no webbing

portion of the defect, and V-Y advancement or FTSG from the contralateral upper eyelid for the temporal portion of the defect.

- *Glabellar/Midline flap:* Used for larger medial canthal defects, the glabellar flap is a modification of a V- to Y rotation flap. Thicker skin from the glabella area is recruited into the medial canthus, and a second debulking surgery may be necessary. An inverted V is drawn, and the flap outlined and dissected. Special attention is given to ensure that the supratrochlear artery is not damaged in the process. Much like a Fricke flap, this flap can cause brow asymmetry, drawing the brows closer together.
- *Mustarde cheek rotation flap:* We reserve this rotational flap for very large defects of the lower eyelid that extend to the cheek, (Fig.14.8a) as the size of the flap needed is three to four times bigger than the defect. The design should be directed superiorly and posteriorly from the lateral canthal angle to the ear, in an effort to negate lower vertical tension post-rotation. The approach to this flap mirrors the approach to the flaps that follow. The dissection plane in this flap is above the

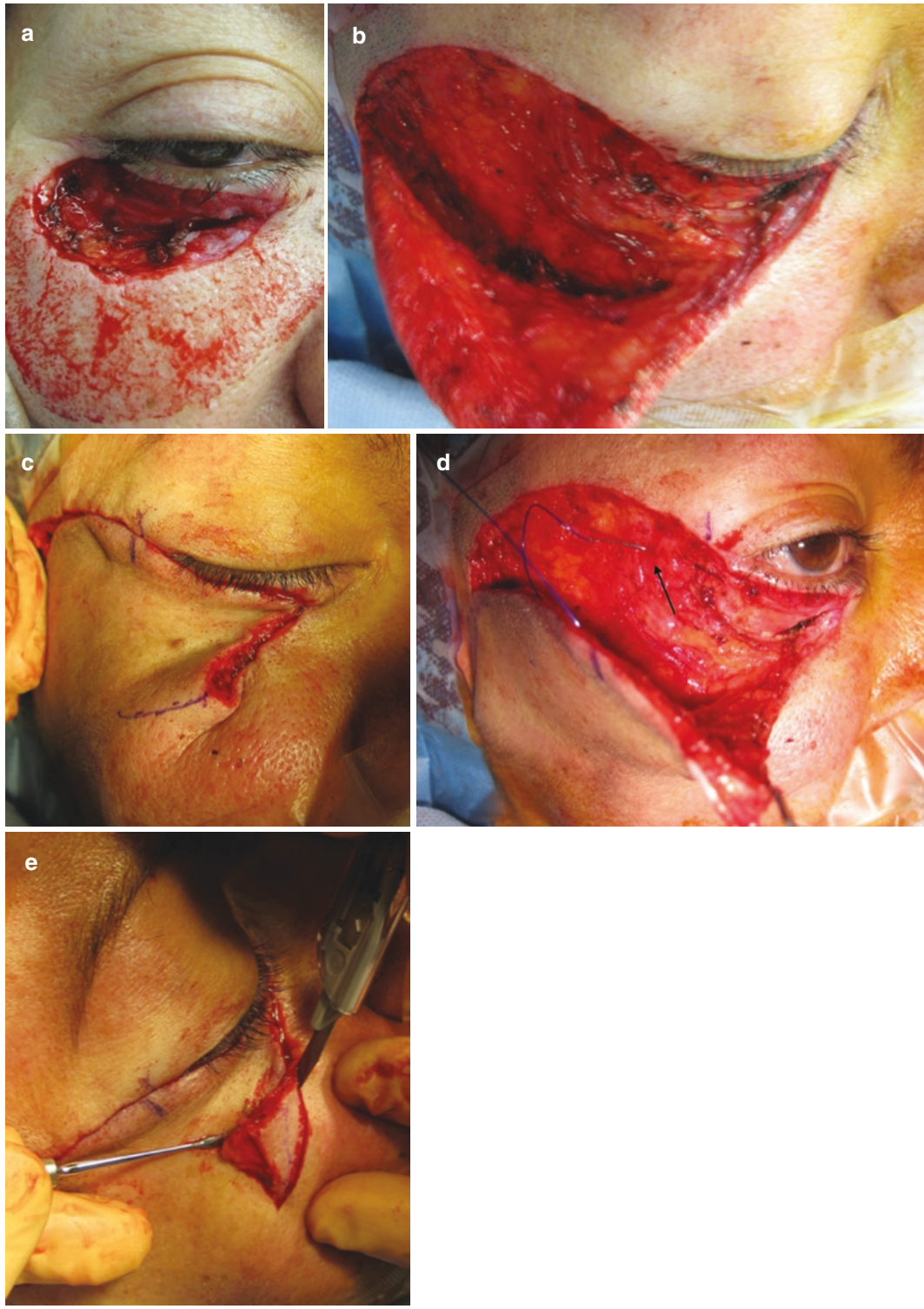

Fig. 14.8 Mustarde cheek rotation flap. (**a**) A large lower eyelid defect extending to the cheek. (**b**) The dissection plane aims to leave fat on both sides of the flap. (**c**) Rotating the flap into place allows identification of appropriate anchoring points and areas of excess skin. (**d**) A Prolene suture is used to anchor the flap to the zygomatic arch periosteum. (**e**) Excess skin is excised and trimmed for perfect positioning of the flap

most superficial muscles of the face so as to avoid damage to the facial nerve (which courses directly over the zygoma). As the dissection extends beyond the orbital rim, the surgeon should look to create a "fat sandwich" such that fat is visible within the flap and the fatty plane is still visible along the host (Fig. 14.8b). Flap thickness should be monitored throughout, as too superficial a dissection is prone to flap necrosis, and dissecting too deep can damage vessels and prevent vascularization of the flap. Dissection of this flap is carried out to the level of the tragus and extended inferiorly until enough tissue release is obtained. These patients are at risk for developing lower lid retraction and/or ectropion given the weight of the flap. If there is horizontal laxity, it is advisable to perform a lateral tarsal strip procedure or lateral canthopexy procedure to better support the lid and prevent postoperative malposition. Additionally, it is important to support this flap by securing it to the periosteum of the inferior orbital rim. Placement of the flap in its desired final position allows for an opportunity to mark the anchoring points along the orbital rim and excess skin and ensures that dissection is sufficient (Fig. 14.8c) Two anchoring points using 3-0 or 4-0 Prolene suture corresponding to these areas provide adequate support (Fig. 14.8d). Redundant tissue can be excised to allow for perfect in-set of the flap (Fig. 14.8e). Upon layered (deep and superficial) closure of the wound, the lower eyelid can further be supported by placement of a Frost suture and a pressure dressing. These can both be removed the following week.

- *Paramedian forehead flap:* Conserved for larger and deeper medial canthal defects, this two-step procedure recruits forehead skin and mobilizes it to the medial canthal area either directly or through a tissue tunnel [7]. We mainly use this flap in high-risk patients, with a high risk of flap/graft failure, as is the case in patients with recurrent disease after prior reconstruction or radiation treatment. Preoperative marking of the supratrochlear artery is essential. Dissection of the flap in a supra-periosteal plane allows for rapid, straightforward dissection. Basing the flap on the contralateral supratrochlear artery allows for easier flap rotation.

Skin Grafts

Skin grafts can be used alone or in combination with other reconstructive efforts. While autologous skin grafts are most commonly used, new bioengineered dermal substitutes are also available when local tissues are unavailable.

Autologous Grafts

Full thickness skin grafts (FTSG) are preferable to split-thickness grafts, because they provide better color match, undergo less contraction, and result in a more uniform scar. We prefer using FTSG harvested from either the ipsi- or contralateral upper eyelid. When insufficient eyelid skin is available, our second best option is postauricular skin. When larger amounts of skin are necessary, we opt to harvest from the supraclavicular space.

We learned that these help maximize the results of FTSG:

- *Edge trimming:* The edges of the defect should be "freshened" and be clean and sharp.
- *Delicate hemostasis:* There is a fine balance between attaining sufficient hemostasis (minimizing egress of blood between the vascular bed and the skin graft) and maintaining a robust vascular supply to oxygenate the graft. Generally speaking, a charred tissue bed is to be avoided.
- *FTSG sizing and preparation:* A template 10–20% bigger than the defect size is preferable, to account for graft contracture. We thin the graft significantly by resecting all subcutaneous tissue, until the dermis and rete pegs are easily identified. Creating two or three full-thickness perforations also allows blood or serous from accumulating between the interface of the graft and the wound bed.

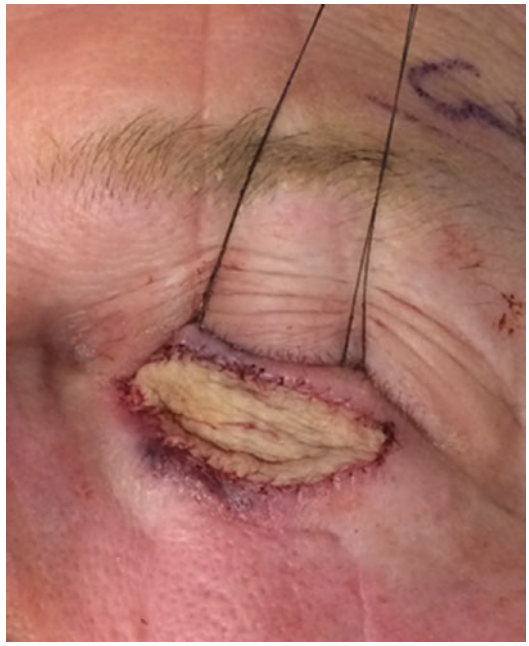

Fig. 14.9 Frost suture. A traction suture used to counteract the vertical cicatricial forces during the initial stages of the graft's healing

- *Placing the wound on tension:* A Frost suture is helpful to place the eyelid (particularly the lower eyelid) on stretch to counteract the cicatricial forces that cause the skin graft to contract, and thus place the lid at risk of ectropion (Fig. 14.9). The medial eyelid is at particular risk of lid malposition, given its minimal support at the level of the medial canthal tendon.
- *Pressure dressing:* Application of a pressure dressing on the wound (author's preference) or bolsters, or both, can further aid in optimizing contact of the skin graft with the vascular bed below.

Allograft Substitutes

Allografts are available as anterior lamella replacement in the periocular region. Integra® (Integra LifeSciences, Plainsboro, NJ), a dermal regeneration template, is a bi-layered substitute made of bovine collagen cross-linked with glycosaminoglycans, and serves as scaffold for vascular and dermal regeneration. The allograft is designed to promote healing that integrates the substitute into the surrounding native tissue. Integra® has shown good results in the periocular region, with a favorable contraction profile compared to FTSG alone, especially in young patients and in patients suffering extensive defects [8]. We have had incredible success using this dermal substitute without secondary skin grafting, leading to amazing results as it pertains to color and texture match (Fig. 14.10a–c).

Secondary Intention Healing ("Laissez Faire")

Specific anterior lamella defects can be left to heal by secondary intention healing. This approach can be employed in fragile patients who may not be fit for general anesthesia or prolonged surgical procedures, and in patients who are vulnerable for the development of recurrent neoplasms or lack healthy tissue for reconstruction, such as patients suffering from xeroderma pigmentosa or Gorlin syndrome. Factors discouraging the use of this approach include a relatively long healing time and some unpredictability of results. Wound contracture can be unpredictable and create webbing and eyelid malpositions [9–11]. In such situations, we suggest consideration of placement of a dermal matrix with or without placement of a second-stage skin graft.

Full-Thickness Eyelid Defects

Direct Closure

Defects of up to one-third of the eyelid can usually be directly closed. In older patients with preexisting eyelid laxity, defects of up to 50% of the eyelid can be directly closed, avoiding more complex surgical procedures. It is important to note that in such upper eyelid reconstructions, the eyelid can be initially ptotic; however, eyelid expansion ensues and cosmesis and function are ultimately preserved [12].

Before starting this eyelid repair, it is paramount to have clean and straight edges. Incomplete, uneven, or partially crushed tarsal

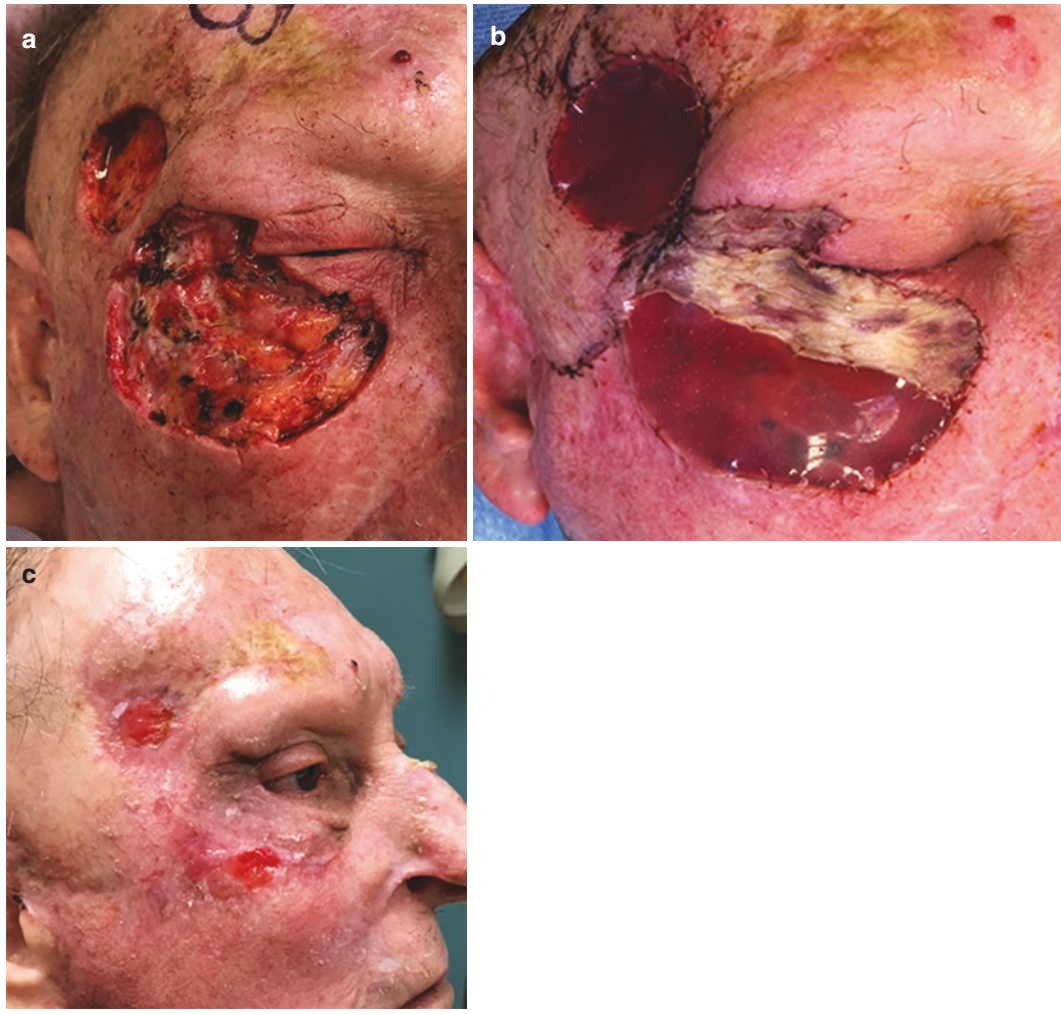

Fig. 14.10 (**a**) A very large anterior lamellar defect. (**b**) The defect was reconstructed with a full-thickness skin graft and with Integra® mesh. (**c**) Postoperative result showing small areas of granulation tissue, but otherwise excellent tone and texture match, with minimal cicatrization

defects should be revised and made sharp and parallel. Orienting the defect perpendicular to the eyelid margin permits proper re-alignment. Next the surgeon should attempt to manually bring the two edges of the wound together. If the wound does not re-approximate, then direct closure is not possible and a different approach will need to be considered. When direct closure is not possible, a simple technique to gain a few millimeters is cantholysis of the relevant canthal tendon near its lateral attachment.

The most critical portion of the direct closure approach is proper placement of the vertical mattress pass along the eyelid margin. This is performed using a 4-0 or 5-0 silk suture, and using the Meibomian glands within the tarsal plate as an alignment guide. We do not tie this suture initially because it makes re-approximation of the remainder of the tarsal plate challenging. We do simulate tightening this suture in an effort to ensure that the alignment is perfect (Fig. 14.11a). Horizontal lamellar passes through the tarsal plate are then performed using a 5-0 vicryl suture on a spatulated needle. This needle makes it easier to achieve a partial thickness pass through the tarsal plate. A full-thickness pass through the tar-

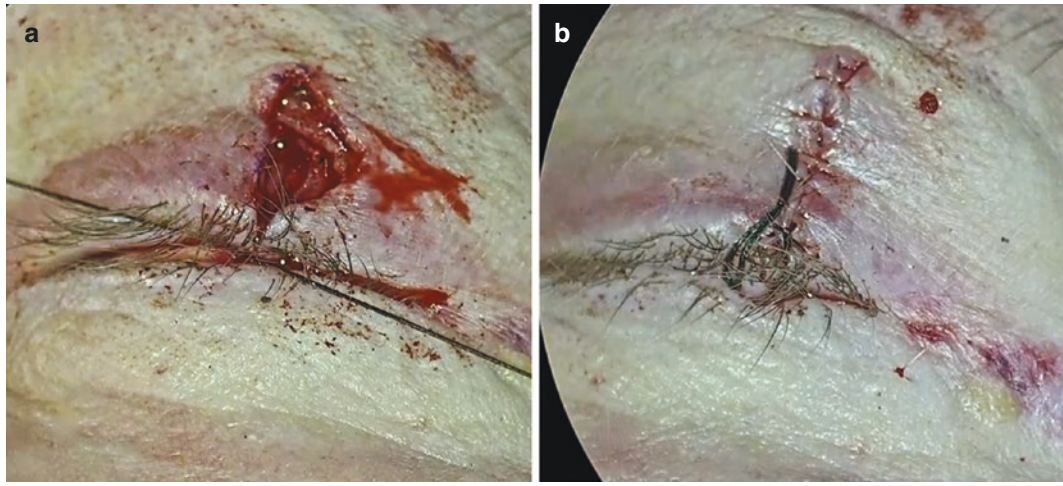

Fig. 14.11 (**a**) A silk suture is passed in a vertical mattress fashion through Meibomian glands. The suture is temporarily tied to assess alignment. (**b**) The silk suture ends are incorporated into the skin sutures to avoid corneal irritation

sal plate will lead to chronic irritation of the cornea with each blink. Everting the lid after each pass is important to verify that each pass is lamellar. Once this step is completed, the silk vertical mattress suture can be tied. It should be tied such that the two ends of the margin are well approximated and the wound edges are tented up in anticipation of scar formation. This ensures that a notch along the lid margin does not develop. The suture is left long so it can be incorporated into the skin passes and thus avoiding postoperative irritation from the suture. The horizontal lamellar bites are then tied, followed by skin closure. We also advocate for placing an extra suture along the lash line using the 5-0 vicryl suture. This additional support also ensures that the lash line is well aligned. This suture is also kept long and incorporated into the sutures used for skin closure to avoid ocular surface irritation. The skin can be closed with an absorbable 6-0 or 7-0 suture (Fig. 14.11b). The silk suture is kept in for approximately 2 weeks to allow for wound healing in a tension-bearing area, and to prevent wound dehiscence.

We use a simpler technique for tarsus repair in simple, clean defects without tension: An oblique, partial-thickness tarsal suture exiting at the corner of the tarsus closest to the eyelid margin, combined with a second tarsal suture and overlying skin closure without eyelid margin closure sutures. This technique is less cumbersome than the classic approach, avoiding the need to incorporate eyelid margin suture ends into the skin sutures, but it requires extra attention when placing the cardinal tarsal suture, as it serves as a singular fulcrum for tarsal re-orientation. We do not use such techniques in larger tarsal defects [13].

Full-Thickness Reconstruction Using Local Myocutaneous Flaps

Lower Eyelid—Medium-Sized Defects

Tenzel Flap

This is an extension of the direct closure with canthotomy/cantholysis that includes a lateral semicircular advancement flap allowing for "sliding" intact lateral eyelid medially toward the defect. Defects of up to 66% of the lid can be repaired in this manner. Useful tips include (a) adequate release of the inferior crus of the lateral canthal tendon (which can be strummed with a blunt instrument if still intact); (b) dissecting in a subcutaneous plane when extending beyond the orbital rim to avoid damaging branches of the facial nerve which runs deep along the zygoma; (c) providing support to the flap by anchoring it high on the orbital rim to counteract downward gravitational and cicatricial vectors (similar to

the method described for the Mustarde flap above); and (d) re-creating a sharp lateral canthal angle with buried canthopexy sutures.

Hughes Tarsoconjunctival Flap

This eyelid-sharing flap takes posterior lamella of the upper lid, connected to its upper lid forniceal conjunctiva, to reconstruct the posterior lamella of the lower lid. Creation of the tarsoconjunctival flap requires that the surgeon adequately measures the length of the horizontal defect of the lower lid so as to fashion the appropriately sized flap from the upper eyelid. Local anesthesia is critical to making the patient comfortable during flap creation.

A subcutaneous and subconjunctival injection of 1–2% lidocaine with 1:100,000 epinephrine into the upper lid allows for that. A traction suture is placed on the eyelid using a 4-0 silk suture. This allows for retraction of the eyelid when the flap is being dissected. A wide chalazion clamp is applied to the eyelid, which stabilizes the lid, allows for easy eversion of the eyelid, and helps with hemostasis. Upon everting the eyelid, a horizontal marking is made along the tarsal plate approximately 4 mm above the lid margin. Cutting a flap closer to the margin will compromise the stability of the upper eyelid and may subject the eyelid to eyelash ptosis or even entropion from overriding anterior lamella. The dissection of the tarsal plate off the orbicularis muscle is fairly easy, as the plane is clear; however, above the tarsal plate, it is important to identify the plane between the Muller's muscle and the conjunctiva. At this point, removing the chalazion clamp allows for access to the conjunctiva and Muller's muscle in the fornix. The previously placed traction suture becomes quite helpful, and in combination with a Desmarres retractor, the eyelid can be easily everted.

When dissecting the Muller's muscle off the conjunctiva, it is important to avoid overcauterization. This step tends to be bloody, as the Muller's muscle is vascular. It is also important to avoid creating buttonholes in the conjunctiva. The authors advocate for using a blunt Westcott scissors oriented parallel to the flap. Cuts are made along the superior border of the tarsal plate until vertical fibers are no longer visible, and only conjunctiva is exposed (Fig. 14.12a). As the dissection proceeds superiorly, you will find that a cotton-tipped applicator can be used to gently complete the dissection. If you are not in the correct plane, then this trick will not work. Once an adequate amount of the flap has been dissected, the medial and lateral borders can be relaxed, allowing for the flap to be brought down. We like to secure the medial and lateral aspect of the flap to the adjacent tarsal plate using 5-0 vicryl sutures on a spatulated needle in a horizontal lamellar fashion (Fig. 14.12b). We also like to secure the lower lid retractors and conjunctiva to the inferior border of the flap using a 6-0 gut suture or a 7-0 vicryl suture in a running fashion. Anterior lamel-

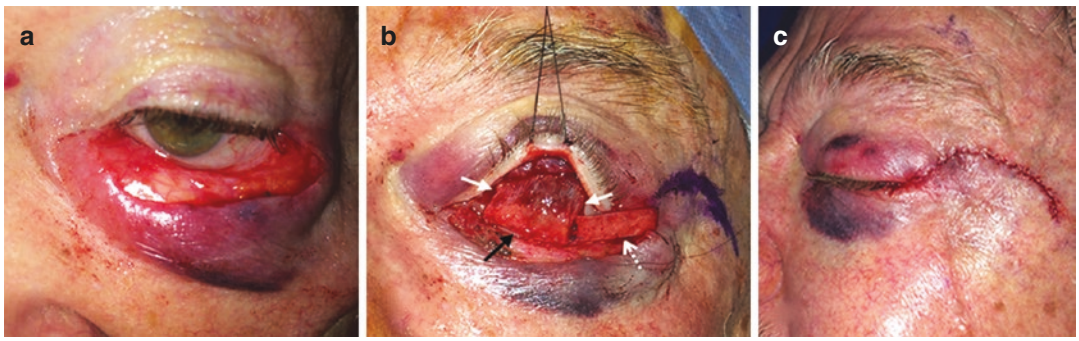

Fig. 14.12 Hughes tarsoconjunctival flap. (**a**) A total lower eyelid defect. (**b**) Hughes tarsoconjunctival flap in place. Upper eyelid tarsus (*black arrow*) attached to the inferior retractors by a conjunctival bridge (between *white arrows*). Additional hard palate graft was placed laterally (*dashed white arrow*). (**c**) The anterior lamella was reconstructed with a Tenzel rotational flap

lar reconstruction is achieved by either local advancement flaps or FTSG (Fig. 14.12c). If FTSG is used, the blood supply from the conjunctival flap may not be adequate to support it. The authors advocate for bringing down a conjunctival and Muller's muscle flap in such cases, as the Muller's muscle will provide the extra vascular support.

The Hughes flap is performed in two stages. The second stage is performed approximately 6–8 weeks after the first stage. This allows for vascularization of the overlying tissue (especially if a skin graft was used). Severing this flap can be performed in the clinic chair. This should be done carefully, given that the contour of the lower lid can be affected if an improper cut is made. We advocate for making the cut slightly above the lid margin, with a slight bevel out to allow conjunctivalization of the posterior aspect of the eyelid margin (Fig. 14.13a). Placing the blunt end of a small Freer periosteal elevator or similar instrument under the eyelid is advisable to prevent inadvertent damage to the globe (not pictured). Hand-held cautery can be effective to promote hemostasis, but can also be used to promote epithelialization of the most superior and anterior portion of the lid margin (Fig. 14.13b).

One of the more common findings after releasing this flap is upper eyelid retraction. This occurs if there Muller's muscle (or part of the muscle) was not completely dissected off the conjunctival flap during the first stage of surgery. Another finding is that the flap can be seen to be bulky as it retracts into the upper eyelid fornix. In these cases, we do not hesitate to trim the flap so as to allow the upper eyelid to directly contact the globe.

Upper Eyelid Defects

Many upper eyelid reconstruction techniques are modifications of procedures that were originally designed for lower eyelid reconstruction (e.g., Inverse Tenzel flap).

Sliding Tarsoconjunctival Flap

In defects of ~50%, advancing a tarsus-conjunctiva flap of partial height either laterally or medially is a relatively simple technique with a low rate of complications. When considering creation of a sliding flap, it is important to make sure that the harvest starts at least 4 mm or more above the upper lid margin, as described earlier in the Hughes flap. The anterior lamella can be reconstructed with any of the techniques mentioned.

Cutler-Beard Flap

This eyelid-sharing technique to repair the anterior lamella of total upper eyelid defects advances a full-thickness lower eyelid skin-muscle flap into an upper eyelid defect under a "bridge" of remaining lower eyelid margin tis-

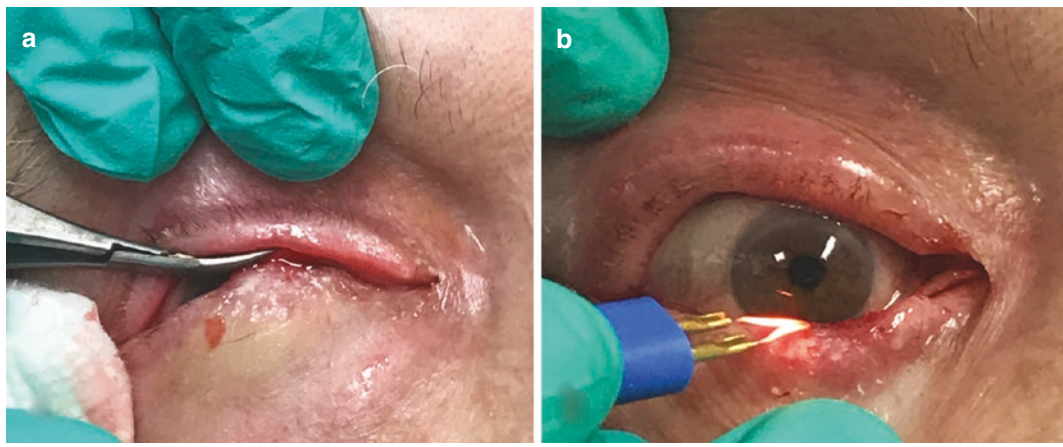

Fig. 14.13 Division of a Hughes flap. (**a**) The flap is dissected open using Wescott scissors. Notice slight beveling out of the cut. (**b**) Cauterization of the superior and anterior edges of the reconstructed eyelid promotes epithelization

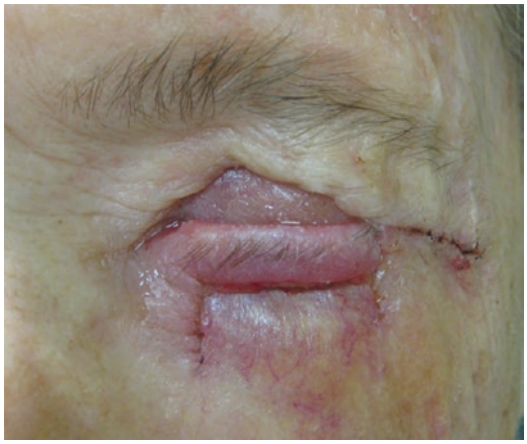

Fig. 14.14 A Cutler Beard flap. The lower eyelid advancement flap is tunneled under the lower eyelid margin and provides the globe with conjunctival protection while the flap heals

sue (Fig. 14.14) [14]. It is important to ensure that the lower lid flap is at least 4 mm or more below the lid margin, so as to preserve blood supply to the bridge. In full-thickness defects, a tarsal substitute should be used. This will help prevent skin overriding the upper eyelid margin that will be created during the second stage of the procedure. It will also allow for attachment of the levator aponeurosis, a critical element that allows for eyelid opening. A second procedure to sever the reconstructed flap is necessary. The second stage creates the new upper eyelid margin while performing an inset of the severed flap below the lower lid bridge.

Posterior Lamellar Grafts

When local flaps are unavailable, the posterior lamella can be reconstructed by autografts, allografts, and xenografts.

- Free tarsoconjunctival grafts: These can be harvested from either the ipsi- or contralateral eyelid. The anterior lamella is dissected off the tarsoconjunctival wedge, leaving the eyelid margin with its lashes intact. A local flap repairs the anterior lamella in such cases. Several free grafts can be used adjacent to one another to close bigger defects. The lashes are an important feature of the upper eyelid, and such reconstruction gives superior cosmetic results.
- Hard palate grafts: Large posterior lamella substitutes can be harvested from the hard palate. These provide adequate mucosal lining and carry little donor site morbidity. It is important to avoid the central raphe when harvesting the graft. We routinely use a mouth guard postoperatively to aid in healing. Only minimal shrinkage is expected with such grafts. Some patients can have postoperative whitish secretions from the graft, which usually can be wiped off and require no further intervention. When considering reconstruction of total upper eyelid defects, we sometimes combine a hard palate graft with a free tarsal graft from the contralateral eyelid. This technique creates a gentle curve to the graft, which confers better to the globe (Fig. 14.15a, b).

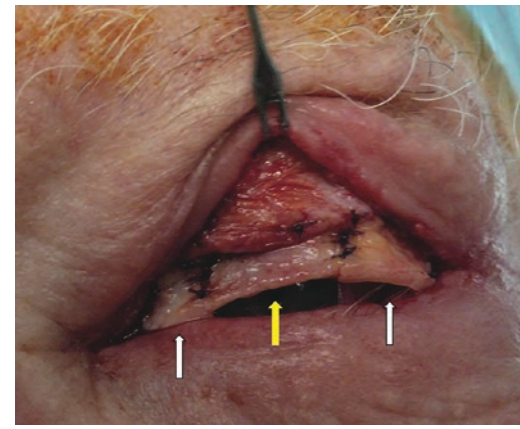

Fig. 14.15 A composite posterior lamella substitute made of a central free tarsal graft from the contralateral eyelid (*yellow arrow*) and flanking hard palate grafts (*white arrows*). The anterior lamella was reconstructed with an advancement upper eyelid flap (not shown). (Photo courtesy of Dr. Wendy Lee)

Special Considerations

Lateral Canthal Defects

The lateral canthus has an important functional significance as an eyelid fixation point, ensuring proper eyelid movement, and also significant aesthetic qualities, creating a sharp lateral corner to the eye. Adding canthal forming (or reinforcing) sutures at the time of initial reconstruction are worth the extra operative time.

A periosteal flap helps to reconstitute posterior lamella while also reforming the upper and/or lower lid lateral canthus (Fig. 14.16). Originating the flap slightly superior to the intended lateral canthus position aids in avoiding postoperative sagging. When periosteum is not available, a hole drilled in the area of Whitnall's tubercle can serve as an anchoring point.

Canalicular Reconstruction

Eyelid defects medial to the puncta often involve the lacrimal system. Such insult carries a significant risk for epiphora if the canaliculi is not reconstructed. Identification of the cut ends of the canaliculi can be a daunting task, especially in complex traumatic laceration and in patients presenting late after the injury. Irrigating the punctum of the lacerated canaliculus helps locate the proximal end of the canaliculus, and irrigation of the opposing canaliculus can help identify the distal cut end. When both cut ends are located, a canalicular stent is threaded through both ends using a mini-monoka® (FCI ophthalmics, Pembroke, MI, USA). The canaliculus is then further re-approximated using an interrupted 7-0 vicryl suture on each of the superior, inferior, and anterior walls. Common practice advocates for repairing canalicular lacerations within 6–12 hours after injury; however, our experience shows excellent results in canalicular reconstructions done up to 48 hours after injury.

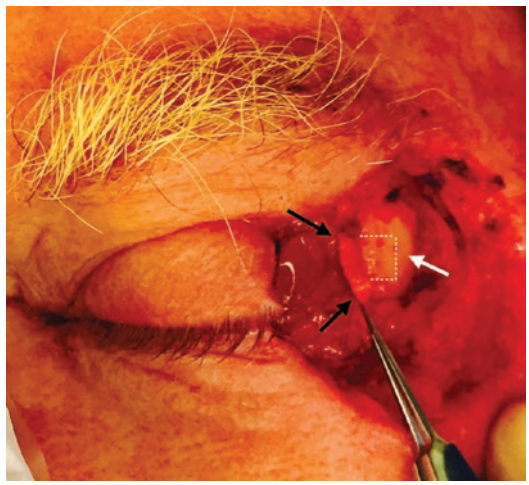

Fig. 14.16 A periosteal flap is cut (*dashed lines*) and reflected off (*black arrows*) the lateral orbital rim (*white arrow*) to elongate the posterior lamella

Complications of Eyelid Reconstruction

Scar Formation

Scars in the periocular region have important aesthetic and functional consequences. Their vector force can pull tissues in undesired directions, creating eyelid ectropion, entropion, eyelid retraction leading to lagophthalmos or canthal webbing. The natural history of a scar spans approximately 6 months and involves three phases: inflammation, proliferation, and remodeling. Eyelid skin rarely heals with a pronounced scar, likely due to the fact that it is the thinnest skin in the body. Patients prone to developing keloids and those undergoing skin grafting, however, will often face sequelae of scar formation. Intraoperative tips to counteract anticipated skin graft cicatrization have been discussed earlier in this chapter.

The authors typically engage in wound closure for reconstructive efforts using absorbable suture (e.g., vicryl or gut sutures) to promote a mild amount of inflammation at the wound interface that better stabilizes the wound; however, a less inflammatory suture (e.g., nylon or prolene sutures) may be a better option in a patient with a history of keloid formation.

Conservative measures can be applied for all patients in the perioperative period, as most scars can be observed over the course of 6 months. Daily massage to the area can be recommended starting approximately 2 weeks after surgery. Topical agents are difficult to recommend, as the active molecules are too large to penetrate the epidermis. Agents containing silicone gels (polysiloxane) have been found to have an effect on scar proliferation [15].

Disfiguring hypertrophic scars can be managed through intralesional injections of steroid (triamcinolone), 5-Fluorouracil, or a combination of the two. The mechanism of action of both agents include fibroblast inhibition. The authors recommend using both in combination using the following formula: 0.1 ml of 40 mg/cc triamcinolone with 0.9 ml of 50 mg/cc of 5-Fluorouracil with plan to inject approximately 0.5 cc/cm^2 [16]. Some will inject in weekly intervals; however, the authors have found much success with monthly injections beginning as soon as 3–4 weeks after surgery. Injection technique is critical around the eye for two reasons: (1) Triamcinolone has crystals that are large enough to block small arterioles (including the central retinal artery) and (2) the eyelid has quite a robust blood supply. Cannulating a periocular eyelid artery and applying too much pressure while injecting can lead to retrograde flow of triamcinolone crystals back to the level of the ophthalmic artery, followed by anterograde flow into the central retinal artery, leading to a central retinal artery occlusion or branch retinal artery occlusion, a catastrophic outcome that leads to irreversible vision loss.

Laser scar manipulation using CO2, Er:YAG, and YSGG lasers also improves scar thickness, pliability, and texture. Multiple treatments are sometimes necessary. Care should be taken with patient selection. Those who are prone to postinflammatory hyperpigmentation (Fitzpatrick skin Type IV–VI) are not ideal candidates for ablative laser. Ablative laser precautions including antiviral prophylaxis should always be employed to prevent laser-related complications.

Use of a combination of fractionated laser along with topical +/− subcutaneous Triamcinolone/5 Fluorouracil has been used with much success. The fractionated ablative laser creates multiple columns of tissue loss, clearing damaged collagen to the level of the superficial dermis. The microthermal zones created in the process stimulate the keratinocytes and fibroblasts to create a more organized scar. The epithelial defects are so small that they heal quickly (on the level of days). In the short time (minutes) after these columns are created, a negative pressure differential exists within them, which makes it an ideal opportunity for resorption of topical agents that can now reach into the dermis where they are needed.

Surgical scar management can be quite helpful (e.g., Z-plasty with scar revision, flaps from uninvolved tissue, etc.) and the authors feel that a combination of surgery, lasers, and antifibrotic agents can yield excellent results (Fig. 14.17a–c).

Eyelid Margin Notching

Eyelid margin notching is often aesthetically displeasing. This is usually the result of improper alignment of the eyelid margin at the time of reconstruction or from postoperative wound dehiscence and subsequent granulation. Treatment involves pentagonal removal of the eyelid deformity and direct closure with proper alignment. It is important to ensure that there is not too much tension on the wound, as it will only dehisce again. In these cases, waiting for the eyelid to stretch and/or performing a lateral canthotomy and cantholysis will allow for some horizontal mobility of the eyelid and ease tension on the wound.

Flap and Graft Necrosis

Flap necrosis in the periocular region is particularly uncommon, given the fantastic blood supply in the region; however, distal tip necrosis can be seen in patients where the 3:1 ratio of length to width of the flap is not respected. Skin graft necrosis can be seen with more frequency and occurs most often in the patient with poor protoplasm (vasculopathy, tobacco user, etc.), thus patient selection is key when determining which type of approach (flap vs graft) is used. Anytime flap/graft necrosis is suspected, infection should be considered on the differential diagnosis.

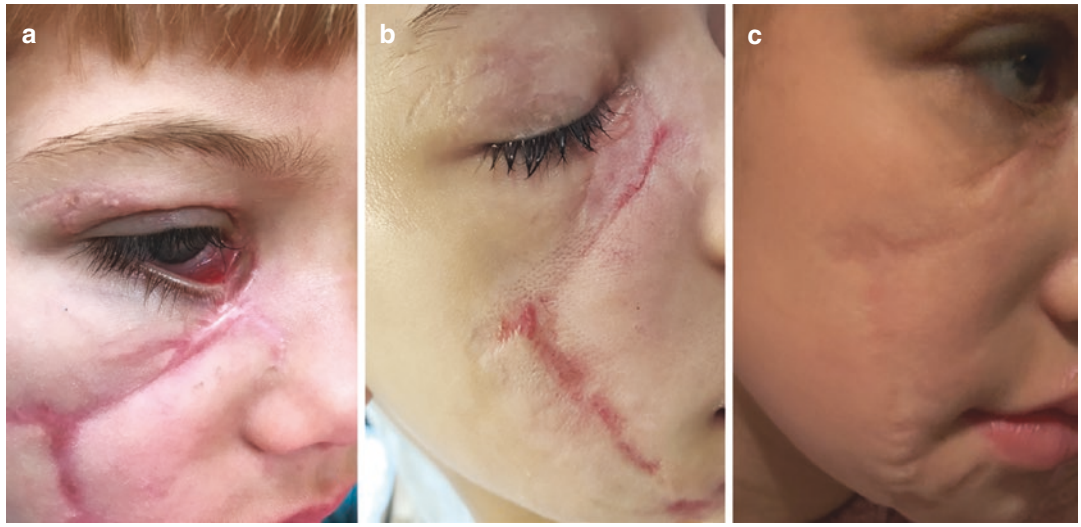

Fig. 14.17 (**a**) A young girl presents several months after a pitbull injury. She underwent lower lid scar release and skin graft to right lower eyelid, along with medial canthal fixation shortly thereafter. (**b**) One month after her second treatment with laser-assisted drug delivery of 5 FU/triamcinolone (topical and subcutaneous) using one pass of 2790 ErYSGG confluent laser followed by two passes of 2790 Fractional ErYSGG). (**c**) After Z-plasty to scar, along with CO_2 laser therapy (by outside physician)

Prompt culture of any visible discharge and empiric coverage for gram-positive organisms should be started. If there is suspicion on postoperative week one that a skin graft is failing (e.g., a violaceous hue is noted), fenestration of the graft (if not done intraoperatively) along with placement of topical antibiotic ointment and a pressure dressing is performed to maximize contact of the graft with the vascular bed. The authors do not favor debridement of an uninfected necrotic graft/flap in the periocular region. This eventually falls off, giving rise to healthy-appearing granulation tissue beneath. Some advocate for the use of hyperbaric oxygen; however, this is not a resource that is readily available, and as such is not used often by the authors.

Eyelid Retraction

It is important to determine the etiology of eyelid retraction before addressing it. Upper eyelid retraction can be seen after a second-stage Hughes procedure, due to the presence of Muller's muscle within the released conjunctival flap. This can be addressed by performing a levator recession or a blepharotomy.

Upper eyelid and lower eyelid retraction can also be seen in the setting of cicatrization of the anterior lamella or inadequate anterior lamellar height. Patients exhibiting lagophthalmos need careful monitoring by an ophthalmologist. A priority in this scenario is to ensure that the ocular surface is well lubricated, so as to minimize corneal exposure and prevent corneal melt. The anterior lamella can be addressed through measures mentioned above for scar (intralesional agent, laser, or both). Surgical management often involves full scar release, placement of a full-thickness skin graft, or if possible, advancement of a local myocutaneous flap.

Ptosis

Ptosis can be appreciated postoperatively; however, it is important to understand the impact of swelling and horizontal tightening on the position of the upper eyelid. The authors recommend waiting and observing for at least 6 months after surgery before addressing this. Some of the cases of ptosis will resolve as swelling resolves, and as the lid becomes more lax. Additionally, ptosis repair in such cases may prove to be surgically

challenging, as anatomy may be distorted. A thorough and candid preoperative discussion about what can be achieved by surgery is essential.

Retrobulbar Hemorrhage

Though extremely rare and devastating, retrobulbar hemorrhage can be blinding. An expanding hematoma within the bony-confined orbital space creates an orbital compartment syndrome. Early clinical signs include pain, restricted motility, eyelid ecchymosis, elevated intraocular pressure, and decreased vision. Emergent treatment is a must, as the window for treatment is narrow. Urgent canthotomy and cantholysis is needed, and can be performed at bedside. Definitive treatment is evacuation of the hematoma and cautery of the bleeding vessel. Again, prevention is key, and includes suspension of antiplatelet and anticoagulant agents prior to surgery, meticulous intraoperative hemostasis, and patient instruction to avoid strenuous physical activity postoperatively.

Conclusion

This chapter describes the procedures the authors use most frequently to repair eyelid defects. Often eyelid defects pose a considerable challenge to the surgeon who is trying to choose the appropriate procedure for the specific patient. Intimate knowledge of eyelid anatomy and function, mastering of the principals of eyelid reconstruction, and continued creativity are all essential in achieving great results for patients.

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Nose Reconstruction

15

Petros Konofaos and Robert D. Wallace

Introduction

Although the first written report of nasal reconstruction is found in Sushruta Samita, which was written during the Vedic period (600–1000 BC) [1], it was not until World War I when the use of free cartilage grafts and pedicled flaps were included in the reconstructive armamentarium. A significant turning point in the thinking process of reconstruction was the subunit principle by Burget et al. [2] who divided the nose into nine subunits (the dorsum, tip, columella, two lateral side walls, two alae, and two soft triangles), and proposed that if greater than 50% of a subunit was lost, it would be better to excise the remaining subunit and reconstruct it as a whole.

Nasal reconstruction can be challenging, depending on the size of the defect and if the defect is partial or through-and-through involving all the three layers of the nose. On top of that, nowadays, patients hope for an aesthetic outcome that becomes inconspicuous to the general public and a functional result that is normal which, in some instances, are expectations that are difficult to meet.

Today, reconstructive options range from skin grafts to complex free-tissue transfer [3–9]. The purpose of this book chapter is to analyze principles and planning of reconstruction, and offer a simplified approach for nasal reconstruction.

Preoperative Evaluation

A detailed evaluation of the nasal defect, along with patient's medical and surgical history, is the backbones of a successful reconstruction. Moreover, the patient should actively participate in the decision-making, particularly if it involves undertaking a complex multistage procedure. Thus, the consulting surgeon should educate the patient regarding the necessary steps that will be required to repair the defect. The goal of reconstruction should always be a solution with no or minimal physical and emotional morbidity to the patient.

During the patient's history taking, the following information should be included in the questionnaire: (1) the etiology of the nasal defect, (2) smoking history, (3) previous local (nose) and/or

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regional surgeries (midface/forehead areas), (4) history of radiation therapy and/or chemotherapy, (5) general health status, (6) patient's ethnicity, and (7) active drug use [10].

A systematic defect analysis includes evaluation of (1) wound dimensions, shape, and location, (2) identification of nasal and/or facial subunits involved, (3) the presence of infection, constrictions, and other deformities, and (4) nasal tissues involved [11]. Moreover, the presence of difficulty breathing should be documented, along with the presence of constrictions, lateral nasal wall collapse, and/or external nasal valve collapse.

Nasal defects are categorized as small or large, and as superficial or deep. Defects are classified as small or large if the width is $\leq$1.5 cm or $>$1.5 cm, respectively. Superficial defects include skin and a portion of underlying subcutaneous fat, whereas deep defects are those in which the underlying supportive framework or lining is also missing.

The role of imaging studies in nasal reconstruction is limited. In cases with high risk of tumor, recurrence or extensive bony and soft-tissue injury of the midface region, facial X-rays, computed tomography (CT) scans, or magnetic resonance imaging (MRI) are usually employed. On the other hand, it is essential to document preoperatively the nasal defect, and also the reconstruction outcome, with use of photographs and videos in order to review the outcome and identify the need for additional procedures.

Surgical Planning

Several factors should be taken under consideration when planning reconstruction of a nasal defect. Among them, the defect's size, along with its depth, the percentage of the subunit(s) involved in the defect, if the nasal framework (cartilage/bone) and/or lining need to be reconstructed, are the most important.

Nasal defects with width $\leq$0.5 cm can be closed primarily. Primary repair is less likely in ala and tip of the nose, where the skin is thick, because it leads to landmark distortion and wide depressed scars. Defects with width up to 1.5 cm with an intact cartilaginous framework can be closed with local flap and/or full-thickness skin grafts (FTSG). Recruitment of skin and subcutaneous tissues from the nose itself, or from closely adjacent tissues, provides an excellent color and texture match. Reconstruction of defects with width $>$1.5 cm often requires the use of interpolated flaps and/or FTSG, and in rare occasions, the use of free flaps [12].

The subunit principle is a useful tool in nasal reconstruction because it helps to camouflage scars within natural creases, or at borders of two subunits. However, this is not universally applicable, as enlarging small defects may increase the amount of donor tissue needed (and the morbidity) for defects where smaller local flaps may suffice [13].

When the defect involves the cartilaginous and/or bony framework of the nose as well, then both the soft tissue and structural defects should be repaired. The goal of reconstruction is to mold cartilage and/or bone into a subsurface framework in order to support the nasal soft tissue. Autologous cartilage or bone, or a combination of the two, are considered the gold standard of framework reconstruction. Cartilage can be harvested from the ear, septum (if a septoplasty is planned), and/or costal pleura. The iliac crest and the outer table of the calvarium are the most common sources of bone grafts. Alloplastic materials and, more specifically, porous polyethylene nasal implants have been used in cases with limited availability of either cartilage and/or bone grafts.

Surgical Techniques

General endotracheal anesthesia is utilized in most cases of nasal reconstruction, except in cases where primary closure is indicated where sedation and/or local anesthesia can be used. Templates, based on the contralateral normal, are especially helpful to determine the dimension, outline, and contour required to restore the defect. Using the foil of a suture pack, a template of the contralateral normal side can be created with the silver side exposed. Templates are very useful,

especially for defects with width >1.0 cm. Once the markings have been placed, local anesthetic (lidocaine 1% with epinephrine 1:100,000 concentration) is injected around the planned incision lines for hemostasis. A prophylactic anti-staphylococcal antibiotic of the surgeon's choice is administered intravenously. An algorithm for nasal defects reconstruction is provided in Table 15.1.

Primary Closure

Primary closure is used for nasal defects less than or equal to 0.5 cm. The only exceptions are defects located on the tip of the nose and at the ala, where due to limited skin laxity, the use of a bilobed flap can provide a better aesthetic outcome.

Table 15.1 Algorithm for nasal reconstruction

Anatomic location		Size	Preferred reconstruction
Ala		≤0.5 mm ≤1.5 cm, intact alar rim >1.5 cm	Direct closure Bilobed flap, FTSG Nasolabial flap ± cartilage
Dorsum	*Proximal half*	≤0.5 mm ≤2.0 cm >2.0 cm	Direct closure Glabellar flap, FTSG FTSG, forehead flap
	Lower half	≤0.5 mm ≤1.5 cm >1.5 cm	Direct closure Bilobed flap FTSG, forehead flap
Sidewalls		≤0.5 mm ≤1.5 cm >1.5 cm	Direct closure Bilobed flap FTSG, nasolabial flap, forehead flap ± cartilage
Tip		≤0.5 mm ≤2.0 cm >2.0 cm	Direct closure FTSG, bilobed flap (for lateral tip, supratip) Forehead flap ± cartilage
Internal lining			FTSG, nasolabial flap, mucosal flaps

FTSG full-thickness skin graft

Bilobed Flap (Modified by Zitelli) (Fig. 15.1a and b)

This flap is used for defects located between 0.5 and 1.5 cm of the distal and lateral aspect of the nose, particularly defects involving the ala with intact alar rim, the lateral tip, supratip, or tissue near the tip, that range up to 1.5 cm in size. The flap design involves two lobes, each rotating a maximum of 45–50° for a total arc of rotation of 90–100°. A Burow's triangle, which serves as the pivot point of the flap, immediately inferior to the advancing edge of the first lobe, is always removed in order to efface the "dog-ear" deformity which is created by the transposition of the first lobe.

When the bilobed flap is used for a lateral nasal tip defect (Fig. 15.2), the following are important:

- To design the pivot point of the flap in lateral alar crease.
- That the angle of rotation of the first and second lobes is reduced.
- That the lobes of the bilobed flap be designed slightly larger to account for the difficulty rotating thicker skin to nasal tip.

In cases with missing cartilage, the bilobed flap is used in combination with a cartilage graft, in order to avoid nasal valve collapse. Moreover, the flap should be designed away from the alar crease, and/or the alar margin, in order to avoid distortion of these important landmarks.

Nasolabial Flap (Fig. 15.3)

This flap is utilized as a two-stage procedure for partial and full-thickness alar defects with widths ranging between 1.5 and 2.0 cm. It has been suggested that as both random flap receiving its blood supply from the subdermal plexus [14] as well as axial flap supplied by branches of the angular and facial arteries [15].

The flap should be designed at least 1–2 mm larger in all dimensions to allow for postoperative contraction. The flap is raised in a distal-to-proximal

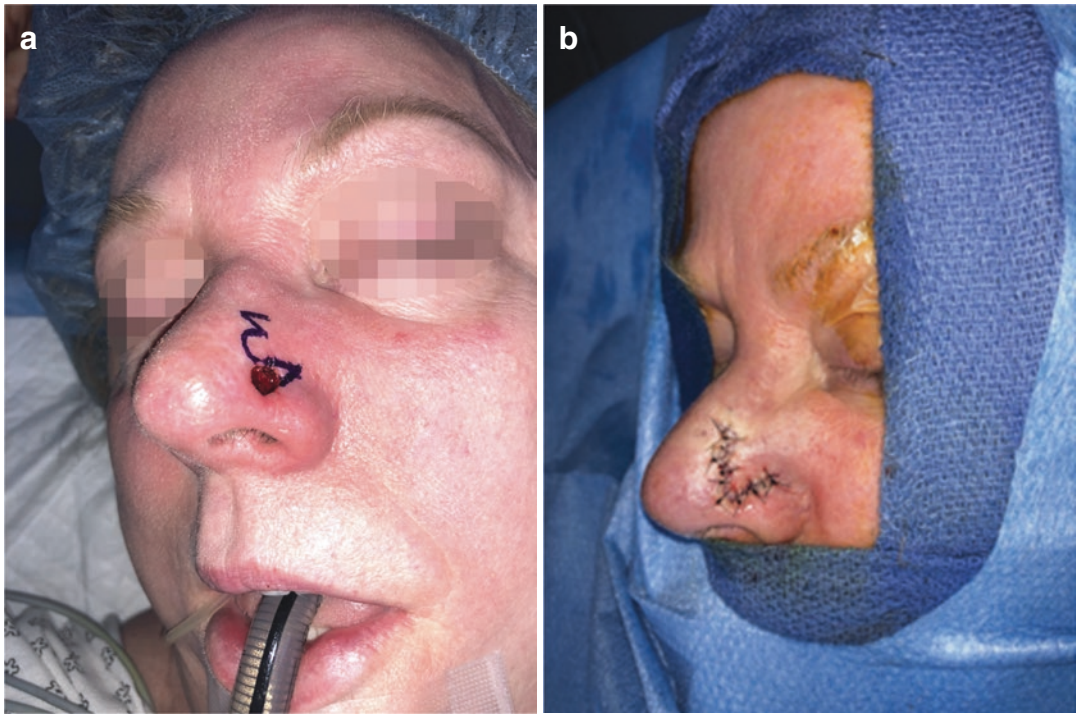

Fig. 15.1 Mohs defect of the nasal ala. The size of the defect was 0.9 × 0.9 cm. (**a**) Design of the bilobed flap. (**b**) Inset of the bilobe flap into the defect

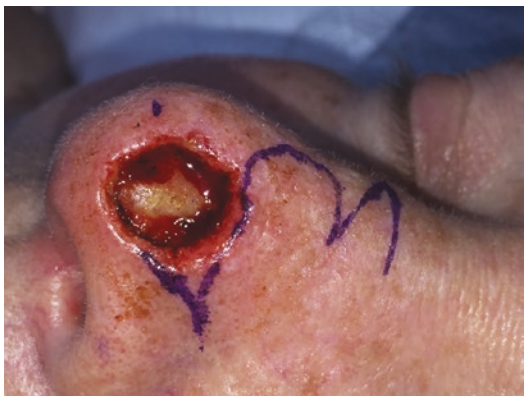

Fig. 15.2 Lateral nasal tip defect with modified bilobe flap design

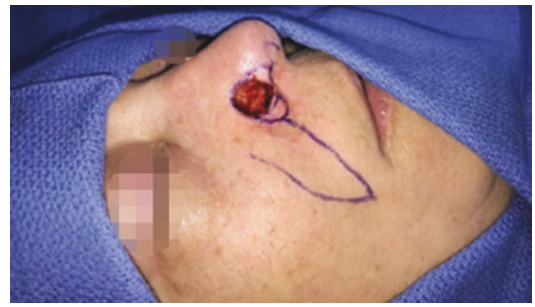

Fig. 15.3 Lateral ala defect 1.5 cm. Design of the nasolabial flap. The alar subunit was marked. The remaining portions of the subunit were excised before inset of the nasolabial flap

fashion, taking care to avoid injury to the underlying subdermal plexus. The flap can be rotated nearly up to 150°, if required. The donor site is closed primarily, although, based on the flap width, undermining and advancing the adjacent cheek tissue may be occasionally required. When the flap is used as a two-stage procedure, the pedicle is divided 3 weeks after the first stage.

Although the nasolabial flap is one of the commonly used flaps in nasal reconstruction, its use is not without disadvantages. The donor site may be pronounced, especially in young patients or in patients with flat nasolabial folds. Moreover,

the flap can occasionally have a bulbous or "biscuit" appearance with healing and contracture, especially when the flap is used for defects of the nasal tip or side wall.

Forehead Flap (Figs. 15.4a and 14.4b, 15.5, 15.6, and 15.7)

Along with the nasolabial flap, this is the most commonly used flap in nasal reconstruction. This is due to its excellent color match, its robust blood supply, and its close vicinity to the nose. Among the various types of forehead flaps, the paramedian forehead flap, based on the supratrochlear vessels—which utilizes the central forehead tissue on a unilateral vertical axial blood supply—is the most commonly used.

The flap is indicated for nasal defects >2.0 cm in width and, more specifically, for defects involving the tip and the ala or large nasal defects. The flap can be performed in two stages when used for small defects which do not require contour recreation, complex support grafts, or lining replacement. For subtotal or total nasal defects, a three-stage forehead flap is used, along with septal or ear support grafts as needed.

Lengthening of the flap can be achieved by extending the design into the hairline or inferiorly across the eyebrow toward the medial canthus. Elevation of the flap is straightforward and proceeds in the subfascial plane, above periosteum, from superior to inferior fashion. Following flap elevation, donor site closure is accomplished in layers after undermining, in the subgaleal plane, of the skin borders up to 1 cm.

The flap, once dissected, is then rotated and can reach as far as the columella. Thinning of the distal portion of the flap, through removal of the muscle and most of the subcutaneous fat, is necessary in order to conform to the nasal framework

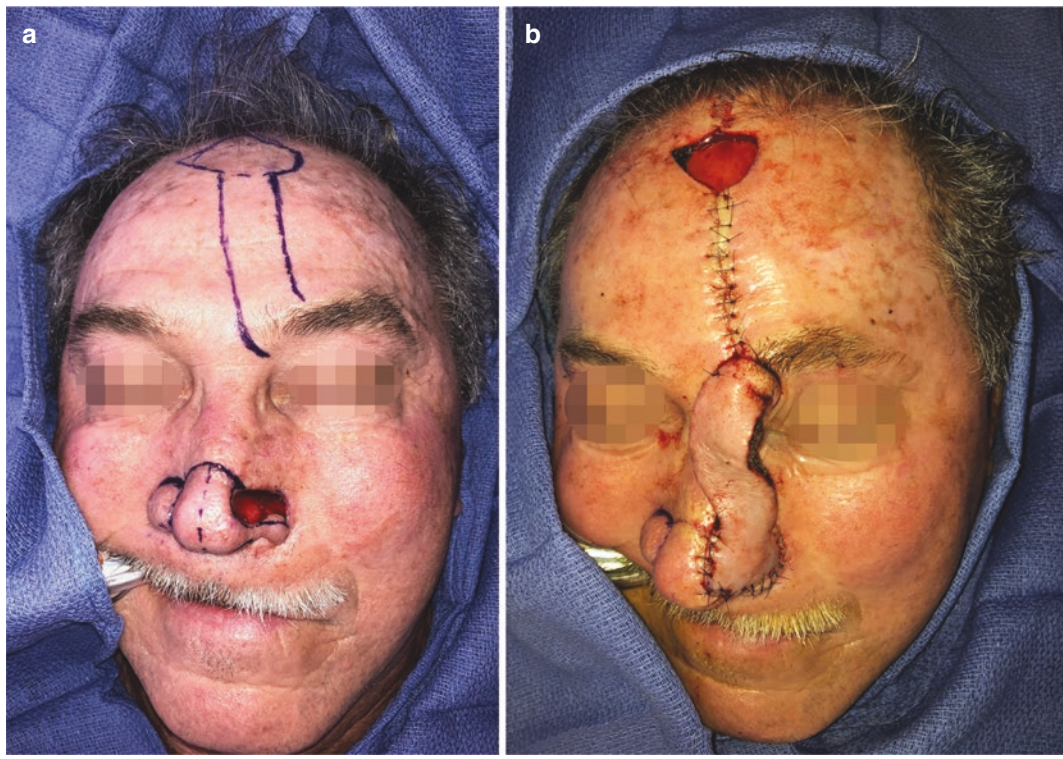

Fig. 15.4 A forehead flap for a nasal ala defect. (**a**) Design of the forehead flap. The alar subunit was marked. The remaining portions of the subunit were excised before inset of the forehead flap. (**b**) Inset of the forehead flap into the defect and partial closure of the donor site

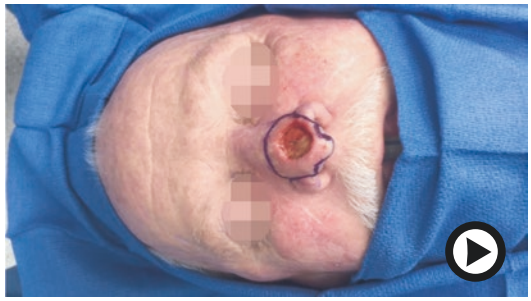

Fig. 15.5 Design the template for a nasal tip subunit reconstruction (▶ https://doi.org/10.1007/000-3tp)

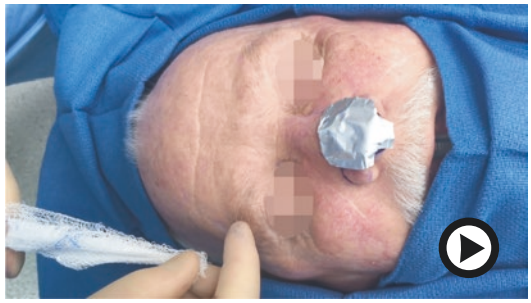

Fig. 15.6 Transposition of the template design to the forehead (▶ https://doi.org/10.1007/000-3tn)

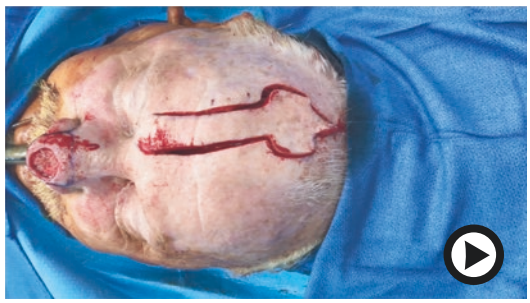

Fig. 15.7 Flap elevation and inset (▶ https://doi.org/10.1007/000-3tq)

and manifest its contour. Further thinning of the flap can be performed during the second and third stage of reconstruction.

If there is a need for internal lining reconstruction, this is repaired prior to inset of the flap. The most commonly used options, if the defect cannot be closed primarily, are either the ipsilateral septal mucosal flap [16] or a folded forehead flap. If the latter is used, no primary cartilage support is placed within the folded flap at this stage. Following lining reconstruction, the missing framework is substituted by means of cartilage grafts. For ala cartilage grafting, the senior author's preference is the use of ear concha cartilage.

Three to four weeks after the flap transfer into the nasal defect, sculpture of the nasal repair is performed. The flap is elevated at its distal portion, and additional thinning of the flap is performed in order to eliminate the excess flap between the cover and lining. Moreover, in cases where the folded forehead flap is used, placement of cartilage grafts also takes place at this stage.

Three to four weeks later which 6-8 weeks after initial flap transfer, the pedicle is divided at the superior margin of the nasal defect in order to improve nasal contour, through thinning and proper trimming and inset of the flap. The remnant of the pedicle is completely excised in a fusiform shape, and the defect is closed along the line of the donor site closure, and thus, returning the brow to its anatomic position.

Glabellar Flap described as a V-Y advancement or rotational flap based on a random blood supply. It is best suited for defects of the two upper thirds of the nose, with width $\leq$2.0 cm. The flap can be used as a rotation or advancement flap. The glabellar skin is transferred into the defect by rotation/advancement, and the donor site defect in the glabella is closed primarily.

Preoperatively, an inverted V is marked on the glabellar region (with less than 60° angle) from the midpoint of the glabella just above the brow. It is important to emphasize that the longer dimension of the flap should join the lateral aspect of the defect. Raising of the flap is performed in the subcutaneous plane using blunt dissection. Once the flap is raised, it is then rotated into the defect, with its apex placed at the lateral edge and the tip of the inverted V at the inferior tip of the defect. The tip of the flap is trimmed to fit the defect, and the flap is secured in the defect with interrupted stitches.

The most important advantages of glabellar flap are the ease of raising, even with local anesthesia, the similar texture, consistency, and color of the flap to that of the defect. Moreover, the

donor site can usually be closed primarily and the scars are generally well camouflaged. On the other hand, closing of the donor site can lead to narrowing of the interbrow distance, especially when the glabellar flap is used for nasal defects with width larger than 2.0 cm.

FTSGs

Full-thickness skin grafts (FTSGs) are mainly indicated for small defects (width up to 1.5 cm) of the nose or for large defects (width >2.0 cm) of the upper two-thirds of the nose in high-risk patients who cannot tolerate complex procedures, and for those in high risk for malignancy recurrence. When the FTSGs are used for large defects, the subunit principle is not applied. For defects of the lower third of the nose, FTSGs are used for defects with width smaller than 1.0 cm, and for partial-thickness defects (without involvement of underlying dermis, subcutaneous tissue, or perichondrium).

The characteristics of skin graft donor sites should be considered, and appropriate FTSG should be selected based on texture, thickness, color, and tendency toward hyperpigmentation or hypopigmentation in order to avoid patchwork appearance. The preferred donor site is the supraclavicular area, because it has minimal morbidity from harvesting and a good color match.

The aesthetic results of FTSGs are unpredictable, due to the fact that graft loss is always a concern, and the healing period involves color and texture changes in an unpredictable manner.

Free Flaps

Free flaps are used for reconstruction of total nasal defects, and facial defects involving the nose, along with the upper lip and/or the cheek. Although several options for free flap nose reconstruction have been described, the free radial forearm flap is currently considered the gold standard due to its skin quality and tissue thickness, which resemble those of the nose and its long and large-diameter pedicle, which allow the vascular anastomosis to be performed at the neck where vessels are of high flow and larger diameter.

In such cases, regional flaps, and especially forehead flap, may be used to resurface the nose and the facial regions because skin from other anatomical regions does not usually match facial skin in quality and thickness. The free flap is usually used for lining reconstruction.

In cases in which regional flaps are not available, the selected free flap is used for both resurface and lining of the nose. Virtual surgical planning in such cases is utilized in order to produce a 3D model of the upcoming reconstruction, which is based on the normal/optimal nasal dimensions. The model is then used as the basis for the design of the selected free flap which, when it is assembled, will duplicate the desired dimensions of the missing nasal lining elements.

Internal Lining

Unrecognized or inadequately reconstructed lining is a common cause of failure in nasal reconstruction [17] because it can result in distortion of the nasal framework, or in exposure of overlying structural grafts, and make them susceptible to infection. Lining reconstruction involves the use of thin vascular tissue that will sustain cartilage grafts placed for support, and maintain a patent airway. Numerous techniques have been described for lining reconstruction including skin grafts, internal nasal and nasal septal flaps, local/regional flaps, and free flaps [18–24].

Currently, septal mucoperichondrium flap with or without septal cartilage (thus the flap provides both lining and support for nasal reconstruction) is the most commonly used technique for lining reconstruction, and can be designed as axial or random flap. It is mainly indicated for small-to-medium-sized mucosal defects of the nasal vestibule, alar rim, and lateral sidewall. Bilateral septal mucoperichondrium flaps can be used to line the middle and upper nasal vaults. Relative contraindications include large defects, prior radiation therapy (RT), cocaine use, or other intrinsic disorders affecting the vascularity of the nasal septal mucoperichondrial lining.

FTSGs are mainly used for restoring small lining vestibular defects or the undersurface of the external cover flap (e.g., paramedian forehead flap) [20]. In such cases, the cartilage graft, if needed, for nasal framework reconstruction is performed at a later stage, because a skin graft cannot survive on an avascular cartilage graft. Sometimes, the reconstructed nose may be less defined and bulkier at the alar margin if the FTSG is used to reconstruct the entire lining defect to the alar rim [20].

Regional flaps can also be used for lining reconstruction. Among them, the forehead flap can supply both cover and lining in nasal reconstruction. The distal end of the forehead flap can be folded inward to line the nostril rim or the columellar and both alar margins, simultaneously. Disadvantages of this technique include a very thick nostril margin and poor support of the rim, nostrils, and other parts of the nose.

Nasal Framework

Reconstruction of the nasal framework is essential in indicated cases, and aims to ensure respiratory patency and to act as a scaffold for the outer nasal covering. Reconstruction can involve the cartilaginous and/or bony elements of the framework, although in most cases, the cartilaginous framework is involved.

Park [25] suggested that cartilage grafts in nasal reconstruction aim to provide rigidity to the sidewall and resist lateral collapse during inspiration, to prevent cephalic retraction of the alar margin, and to establish nasal contour and projection. Furthermore, cartilage grafts may be necessary for nasal defects which do not normally contain cartilage in order to appropriately support and shape the nasal wall.

Various sources of cartilage include auricular, septal, and costal cartilage. For ala cartilage grafting, the senior author's preference is for the use of ear concha cartilage through an anterior incision. The reasons include the form and structural properties of concha cartilage, which resembles that of the ala. The incision lies within the antihelix, which makes it barely visible, and provides adequate exposure. In most cases, the entire concha is removed. The incision is closed with interrupted 5–0 Vicryl rapide sutures. Quilting sutures approximate the anterior and posterior auricular skin.

Septal cartilage is a very good substitute for the cartilaginous scaffolding of the tip of the nose and the columella. Disadvantages of its use include limited availability and the need for molding in order to resemble the natural curvature of the missing framework. On the other hand, rib cartilage is used as graft material in nasal reconstruction because of the quality and volume of graft available for restoring the alar cartilages, columella, and nasal tip.

The main indications for bone grafts are cases of total or subtotal nasal reconstruction, although its rigidity and risk of resorption deteriorate its use. The iliac crest and the outer table of the calvarium are the most common sources of bone grafts. However, calvarial bone grafts are the most commonly used bone grafts due to their durability and resistance to resorption and the hidden donor site. It is important to emphasize that bone-to-bone contact increases the resistance to resorption and eventually the bony union. An alternative to autologous tissue, if unavailable or insufficient or the patient refuses a second surgical incision, are nasal porous polyethylene implants (see Chap. 4: Facial Implants).

Revisions

Ancillary procedures are used, as needed, for enhancement of functional and aesthetic outcomes and can be classified as minor (inadequate landmark definition) and major (failure to restore symmetry, contour, and function). Indications include contour deformities, the necessity for recreation of facial and nasal landmarks, breathing problems, scars, poor skin quality, and the sequela of complications.

In reconstructed cases with volume and/or contour deformities, the utilization of a new flap and/or debulking of a previously placed flap are the most commonly performed procedures. Furthermore, scar revision and/or dermabrasion

can be employed for improving the skin quality and the aesthetic outcome.

Cases with collapse of either the external and/or internal nasal valve with secondary breathing difficulty represent a challenging entity. In these cases, cartilage grafts and/or FTSGs can provide the indicated support for preventing collapse of the reconstructed nose.

Postoperative Management

Postoperative care consists of application of antibiotic ointment twice daily for 3 days and then cleaning the suture lines with soap and normal saline. Sutures are removed on the 7th–tenth postoperative day on both the recipient and donor side.

The patient is advised to avoid excessive sunlight exposure to the face region for 6 months to prevent post-inflammatory hyperpigmentation of the scars. Moreover, extremes of heat or cold may cause temporary color changes in the flap skin at the recipient site, and thus, it is better to be avoided for several months.

Pitfalls and Pearls

- Analysis of a nasal defect begins with classification by location, size, and depth.
- When more than 50% of a subunit is missing, the entire subunit should be reconstructed for ideal camouflage.
- Subcutaneous thinning and meticulous approximation of flap edges are essential to restore optimal cosmesis.
- Internal lining reconstruction should be thin and supple to preserve the physiologic integrity of the nasal passage.
- Lining and structural support need to be addressed for complex nasal defects at the initial stage of nasal reconstruction.
- Consider strategic placement of cartilage in a nonanatomic fashion at the alar margin and sidewall to avoid nasal collapse.
- Superficial defects on the dorsum and sidewall up to 1.5 cm can be reconstructed with full-thickness skin grafts or the bilobed flap.
- Defects of the ala up to 2.0 cm can be reconstructed using a two-stage nasolabial flap.
- The forehead flap remains the workhorse for resurfacing large (larger than 2.0 cm) nasal cutaneous defects.

Conclusion

Nasal reconstruction continues to evolve to a higher level of finesse that allows the surgeon to restore near-normal form and function to the majority of nasal defects. These advances are based on the concepts of subunit principle, replacing missing tissue with like tissue, and recent developments in soft tissue and structural framework reconstruction techniques. Defect analysis and the patient's need are the backbones for a successful and aesthetically acceptable reconstruction. However, the reconstructive surgeon should always keep in mind that a successful nasal reconstruction can be achieved by means of a less-invasive technique, such as full-thickness skin graft.

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Lip and Cheek Reconstruction

16

W. Kelsey Snapp and Paul Liu

Introduction

Together, the lips and cheek comprise almost half the total surface area of the face. Although the cheek is the largest subunit of the face, it primarily functions as a background for the more prominent subunits of the face such as the lips, nose, and eyes [1]. Unsightly scars and asymmetries can draw the eye away from the central features and disrupt facial harmony. The lips are the significant feature of the lower third of the face and critical to both the appearance of the face and the proper function of the mouth. Aesthetically, the lips contribute to the femininity and youthfulness of the face, as well as play a critical role in facial expressions such as smile and scowl [2]. Functionally, the lips are critical in maintaining oral competence. Loss of domain can lead to problems such as microstomia, difficulty with articulation, and uncontrollable drooling [3].

Lip and cheek defects requiring reconstruction most commonly stem from resection of cutaneous malignancies or posttraumatic defects. Frequently, patients are referred for reconstruction after Mohs surgery, and the exact size and location of the defect may not be known until the day of surgery. Traumatic defects may exist acutely, or more commonly, after scar revision and release. Given the multitude of reconstructive options in the cheek and lips, and the variable nature of the defect, it is important that plastic surgeons be able to employ a broad toolbox of reconstructive techniques and modify their reconstructive plan accordingly.

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Cheek Reconstruction

Anatomy

- The cheek is bound by the zygomatic arch and lower eyelid superiorly, the preauricular sulcus laterally, the lower border of the mandible inferiorly, and the nasolabial fold medially [4].
- It is often divided into three or four overlapping anatomic subunits; however, the exact boundaries of these subunits are less important than the neighboring structures of the lower eyelid, helical root, tragus, nasolabial fold, alar crease, and lateral commissure (Fig. 16.1a, b) [5].
- The layers of the cheek include the epidermis, dermis, subcutaneous fat, and superficial musculoaponeurotic system (SMAS). The SMAS is continuous with the platysma inferiorly and temporoparietal fascia superiorly. The muscles of facial expression, the parotid gland, and the facial nerve all lie deep to the SMAS.

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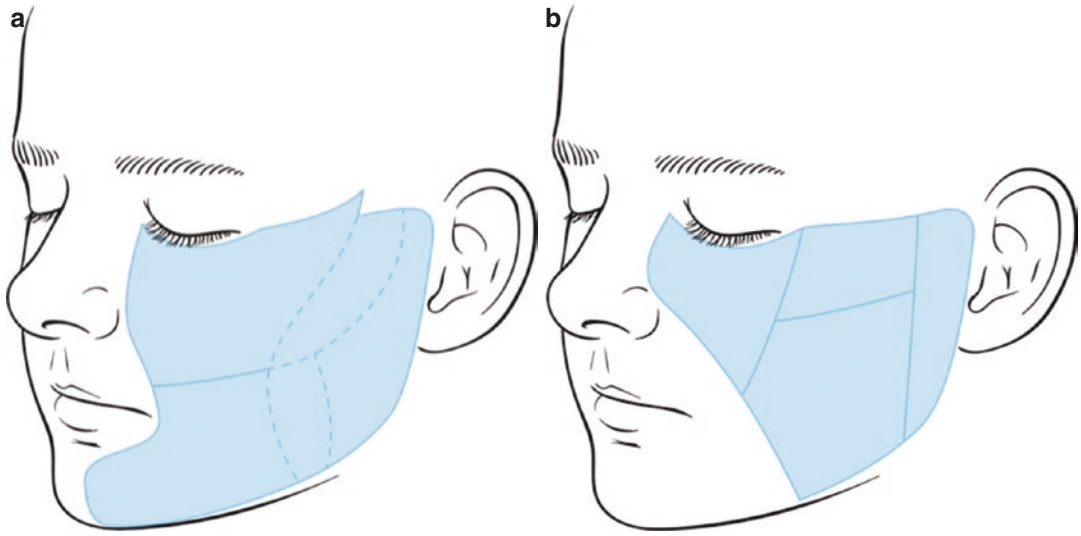

Fig. 16.1 Cheek subunits: (**a**) three aesthetic subunits; (**b**) four aesthetic subunits. (Illustrations by Julia Lerner)

- The skin of the cheek is less mobile laterally than medially, due to the presence of zygomatic and masseteric retaining ligaments.
- The blood supply of the cheek is multifaceted and robust, primarily derived from various branches of the facial artery.

General Considerations

- Although there has long been an emphasis on placing any planned incisions on the face along the relaxed skin tension lines (RSTLs), greater emphasis should be placed on designing incisions along preexisting rhytids or natural subunit borders when possible. Ultimately, this leads to improved camouflage of the scars [4].
- Regardless of scar placement or technique, it is paramount that the surrounding landmarks and structures (the lower lid, oral commissure, nasal ala, etc.) are not deformed by the final reconstruction. An invisible scar that comes at the expense of a lower lid ectropion is far more disfiguring than a slightly more noticeable scar without any change to the lower lid.
- Flaps in the periorbital region should be anchored to underlying periosteum to prevent downward displacement of the lower lid during scar contracture.

Primary Closure

- Given the natural laxity of the cheek, primary closure is an excellent option for closure of many defects. Attention should be paid to the relaxed skin tension lines (RSTLs) of the face (Fig. 16.2).
- Tailor-tacking of the wound with a temporary suture in a far-near near-far vertical mattress fashion allows you to test the ultimate tension on the closure, as well as ensure that no surrounding structures are deformed by the closure.
- Wide local undermining of the surrounding tissue can be utilized to facilitate tension-free closure; however, undermining further than 4 cm from edge of the defect has limited utility on reducing the final tension on the closure [6].
- Dog-ears should be aggressively excised when present. Even small contour deformities create noticeable scars.
- For medial defects, the wound closure should be oriented so that the final scar falls within the nasolabial fold.

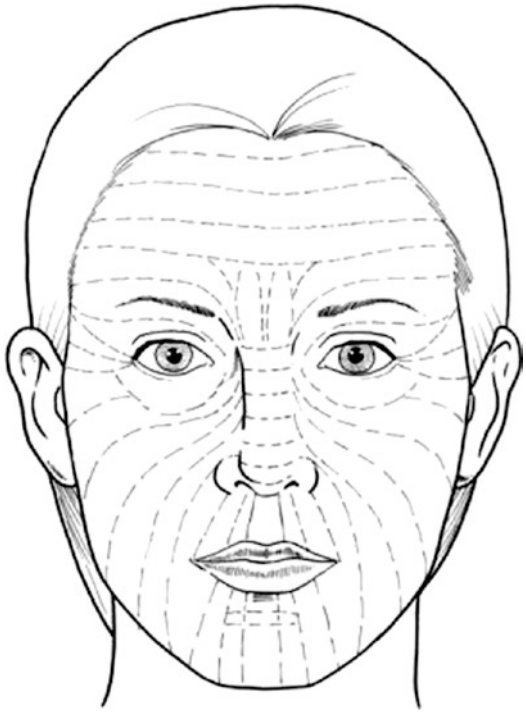

Fig. 16.2 Random skin tension lines of the face. (Reprinted by permission from: Springer Nature. Facial Units and Subunits by Ilankovan V, Ethunandan M, Seah TE. © 2015)

- Small wounds (<1 cm) on concave surfaces can be closed with a combination of a purse string suture and healing by secondary intention. This minimizes the ultimate size of the scar and can lead to an excellent cosmetic result [6, 7].

Transposition Flap

- Various transposition flaps, such as the rhombic, note, and bilobed, have long been described to reconstruct both medial and lateral cheek defects. However, given the laxity of the cheek and natural geometry of its borders, medium- to large-size defects are often better managed with local rotation-advancement flaps or cervicofacial flaps. These are simpler to design and allow for easier camouflage of the incisions along subunit borders and linear rhytids.
- Transposition flaps are still utilized when there are multiple defects that cannot be closed primarily, or there are prior scars preventing the use of rotation-advancement flaps.
- When performing a rhombic flap, the primary author prefers to modify the traditional Limberg flap by designing a pointed flap that is slightly smaller than the defect rather than a rhombus. Given that most defects on the cheek are round, this avoids wasting any of the native skin by converting the defect to a rhombus.

V-to-Y Advancement Flap

- V-to-Y advancement flaps may be used for lateral or medial cheek defects. This is particularly useful in medium-sized defects of the lateral cheek that involve the hair-bearing sideburns. This allows the surgeon to restore the continuity of the sideburns with a vertically oriented advancement (Fig. 16.3).
- To allow adequate advancement of the flap, the SMAS should be circumferentially released; however, the flap should be minimally undermined to preserve the perforator-based blood supply to the flap.

Cervicofacial Flap

- For defects larger than 3–4 cm that cannot be closed primarily, a cervicofacial rotation advancement flap is often the primary author's technique of choice.
- Incisions are hidden along the aesthetic borders of the cheek. Depending on the location of the defect, a superior incision is made at the lid–cheek junction and carried posteriorly and then just superior to the level of the lateral canthus. It then follows the hairline inferiorly into the preauricular sulcus. The incision is continued inferiorly to the lobule, and then curved posteriorly in the postauricular area and hidden at the mastoid hairline when possible (Fig. 16.4).
- Generally, the flap dissection is carried out in the subcutaneous plane just superficial to the SMAS, to allow the greatest degree of mobil-

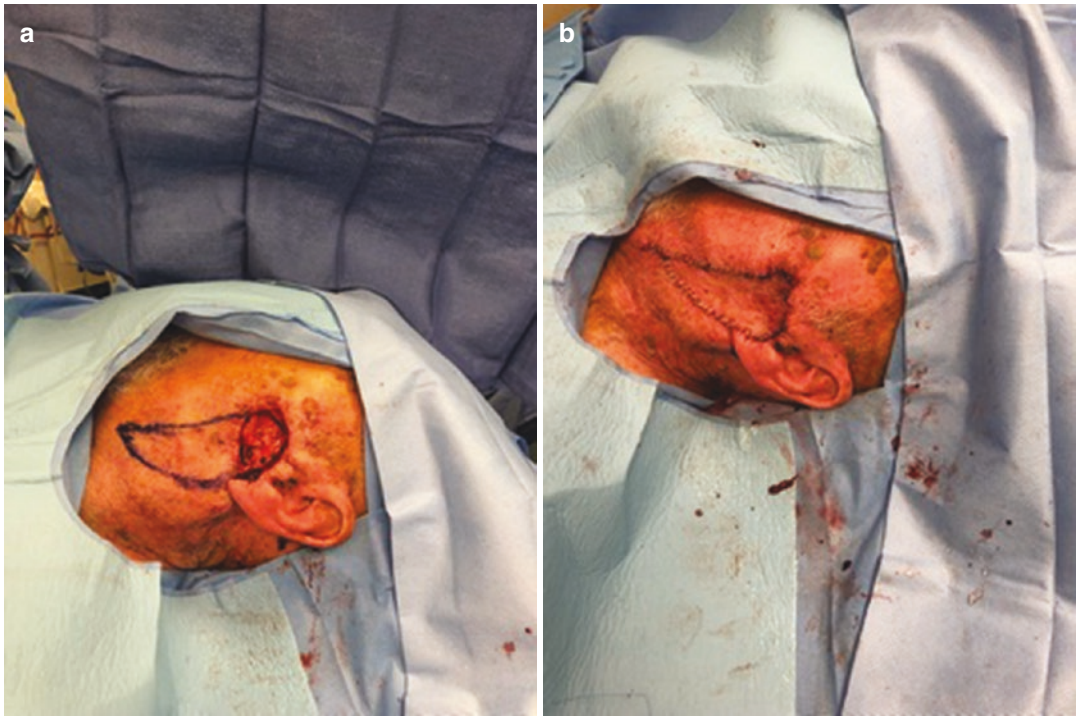

Fig. 16.3 V-to-Y cheek flap. (**a**) Flap design. The flap is tapered caudally to allow primary closure of the most caudal aspect of the donor site. (**b**) Flap inset. The flap is undermined conservatively to preserve the perforators to the skin paddle. The donor site is closed in a V-to-Y fashion

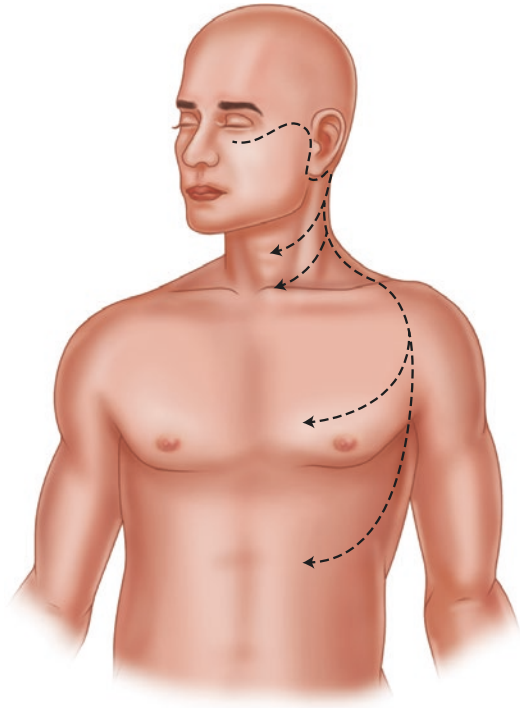

Fig. 16.4 Cervicofacial flap

ity. However, in patients requiring large flaps or who are at a high risk for distal flap necrosis, the dissection is carried deep to the SMAS along the lateral aspect [8]. To prevent an iatrogenic injury to the facial nerve, this deep dissection should not be performed medial to the zygomaticus major muscle. Similarly, when large cervicofacial flaps require dissection inferiorly into the neck, the dissection is made deep to the platysma muscle only once inferior to the marginal mandibular branch of the facial nerve.

- For medial defects in patients without significant skin laxity, it may be necessary to carry the cervical incision anteriorly rather than follow the occipital hairline. This allows greater flap advancement at the expense of a more visible scar (Fig. 16.5) [9].
- After rotation-advancement of the flap, the flap is anchored superiorly above the level of the lateral canthus to minimize the risk of postoperative ectropion.

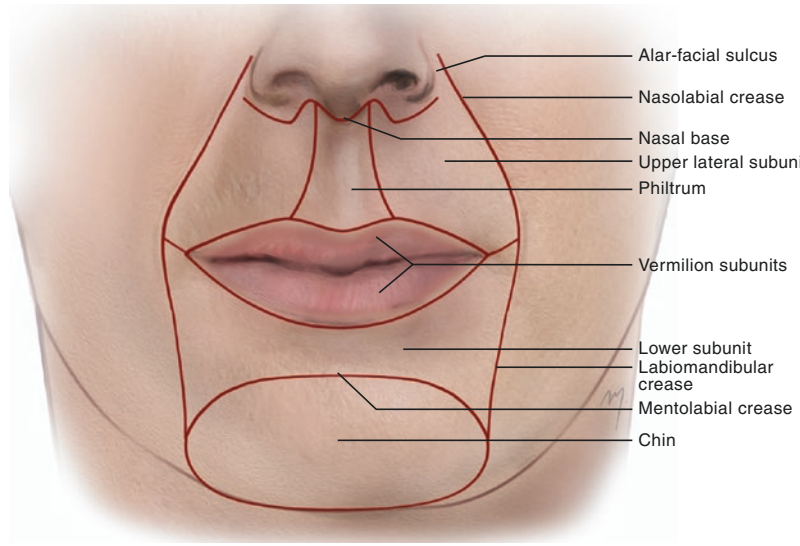

Fig. 16.5 Lip anatomy and subunits. (Reprinted by permission from: Springer Nature. Lips and chin by Vasilios K. Thomaidis. © 2014)

- For medial defects, there is excess tissue bunching inferior to the defect. This tissue is excised and closed, hiding the incision in the nasolabial fold.
- Excision of a dog-ear at the most inferior portion of the lateral incision is necessary. Care must be taken to avoid further narrowing the flap base when performing the dog-ear excision.
- For large defects, the flap can be extended to the supraclavicular and thoracic region by following the hairline to the edge of the trapezius muscle, and then inferiorly along the border. Medial dissection of the flap in the thoracic region should be performed conservatively to allow preservation of the internal mammary perforators.
- A small-caliber Blake drain is left in place to minimize the risk of hematoma and seroma formation. This drain is often removed at the patient's initial postoperative visit.

Full-Thickness Skin Graft

- Although full-thickness skin grafts are rarely favored for reconstructing cheek defects, due to their patchy appearance and unpredictable wound contracture, there are particular instances when they offer the best option for reconstruction:
  - After excision of malignant lesions with a high risk of local recurrence, full-thickness skin grafts offer a "safe" option for reconstruction without sacrificing any local flaps.
  - Full-thickness skin grafts are a simple coverage option for large cheek defects in elderly patients with significant medical comorbidities that preclude more advanced reconstruction.
- Elderly patients have thinner skin in the cheek, allowing for a better color and texture match for skin grafts harvested from the neck and postauricular area. However, their skin often has greater degrees of solar damage, which must be considered when choosing a donor site.
- The donor site should be selected to find the best color and texture match. Common donor sites include the pre- and postauricular neck and supraclavicular regions.
- The primary author (PL) prefers to use a bolster dressing in the face to minimize the risk of hematoma or shearing forces associated with graft loss. This is done by securing the skin graft edges with 3-0 silk sutures, then leaving one tail from each suture long as a tie-over suture. These tie-over sutures are used to

secure a xeroform-wrapped cotton bolster over the underlying graft and recipient site.
- In the setting of questionable margins or high risk of local recurrence, the author prefers to use the Integra dermal regeneration template as a temporizing form of reconstruction.

Tissue Expansion

- Although it takes significant time and patient compliance, tissue expansion offers an excellent option to reconstruct large areas of the cheek with like tissue. Tissue expansion can be particularly effective to replace mismatched skin after reconstruction of a large defect with a free flap or skin graft, particularly in younger patients [10].
- In cheek reconstruction, expansion of the lateral cheek and neck offers an excellent skin match and is easily incorporated into a cervicofacial flap.
- The tissue expander is sized by selecting an expander with a width that is at least equal to the anticipated defect and a length that is slightly longer than the defect.
- Tissue expander placement is planned in such a way that the initial incision can later be utilized for flap advancement.
- The tissue expander is tunneled and placed superficial to the SMAS and platysma in the subcutaneous plane at least 2 cm from the incision.
- Tissue expansion is initiated at 1–2 weeks and takes place weekly with small volume fills. Expansion occurs until the expanded tissue is able to cover the defect plus an additional 25%, to account for primary contracture after expander removal.
- After the desired tissue expansion has occurred, the expander is removed and the flap is designed to include the expanded tissue. Double back-cuts are made for advancement flaps, while a single back-cut is made for rotation flaps. It is critical to transilluminate the flap prior to making the back-cuts in order to identify and protect the axial blood supply.
- If there is an excess of expanded tissue, a small amount of normal tissue is sacrificed prior to flap inset to allow placement of the scars along the aesthetic borders.

Lip Reconstruction

Anatomy

- The layers of the lip are the skin, muscle, submucosa, and mucosa.
- The primary muscle of the lip is the orbicularis oris, which functions to purse the lips together and maintain oral competence.
- The levator labii superioris lies superficial to the orbicularis oris in the upper lip. It is inferior to the nasal ala and continues medially to contribute to the philtral column.
- The upper lip has several cutaneous landmarks (see Fig. 16.5).
  - The vermilion border marks the transition from the red lip to the cutaneous, or white lip.
  - The white roll is the gentle elevation of skin adjacent to the vermilion border and is formed by the pars marginalis of the orbicularis oris.
  - The red line is the border between the wet and dry mucosa of the lip.
  - At the center of the vermilion border is cupid's bow. Superior to cupid's bow on the white lip are paired philtral columns.
- The upper lip can be separated into three subunits: a medial subunit and two mirrored lateral subunits. The medial subunit is border by a philtral column on each side while the lateral subunit lies between the nasolabial fold and the philtral column, seen in Fig. 16.5.
- The blood supply to the lips are the superior and inferior labial arteries, both branches of the facial artery. Both are paired arteries that run between the mucosa and orbicularis and merge at the midline.
- Sensory innervation of the lips and perioral region is derived from the maxillary and mandibular branches of the trigeminal nerve. The motor supply to the muscles of the lip stems

from the buccal and marginal mandibular branches of the facial nerve [11].

General Considerations

- Reconstruction of lip defects are often classified based on the horizontal proportions of the defect relative to the rest of the lip [10]. However, this horizontal classification is relevant only for full-thickness defects of the lip. Isolated defects of the vermilion or the cutaneous lip require separate techniques than those used to reconstruct full-thickness defects. Similarly, full-thickness defects of the lips can sometimes be reconstructed using a combination of techniques to reconstruct the red lip and cutaneous lip separately, rather than performing a more invasive technique such as a lip-switch or advancement flap.
- Partial thickness defects of the mucosa or the cutaneous lip can generally be reconstructed with rotation, advancement, or transposition flaps, taking care to hide the incisions in natural creases such as the nasolabial fold, nasal base, or mental crease [6].
- The RSTLs of the lip lie perpendicular to the course of the orbicularis oris muscle. These correspond with the perioral rhytids often present in elderly patients.
- The continuity of the orbicularis oris muscle must be restored in full-thickness defects of the lip in order to maintain oral competence.

Vermilion Reconstruction

- The mucosal advancement flap is an excellent option to reconstruct partial thickness defects of the vermilion. A flap of mucosa is designed based on the width of the defect, raised in a plane just superficial to the orbicularis, and then advancement anteriorly. The mucosa is elevated all the way to the gingivolabial sulcus to minimize the risk of lip retroversion (Fig. 16.6) [11].
- In order to maximize the flap's blood supply, care should be taken to raise the flap as thick as possible without violating the orbicularis.
- A common complication of the mucosal advancement flap is thinning of the lip. In male patients, this is generally well tolerated and less noticeable. In younger female patients, a dermal fat graft can be placed primarily, or hyaluronic acid filler can be used at a later date, to restore lip fullness [12].
- Smaller defects of the vermilion can be reconstructed with V-to-Y island advancement flaps. A triangle-shaped island flap is advanced vertically to cover small defects and minimize the risk of unsightly scar contracture.
- Horizontal advancement of the vermilion can be used to reconstruct defects of the vermilion that involve less than half the total width of the lip. The incisions are hidden anteriorly along the vermilion border and posteriorly in the labial mucosa, and the flap is raised to include the mucosal portion of the orbicularis oris. For

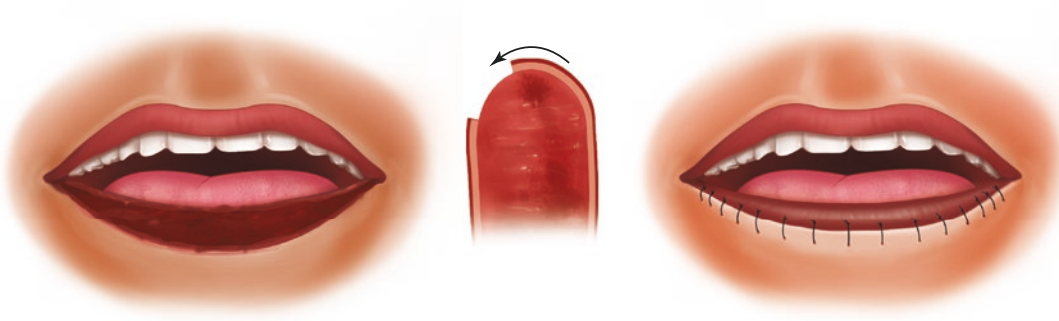

Fig. 16.6 Mucosal advancement flap. A flap of mucosa is designed based on the width of the defect, raised in a plane just superficial to the orbicularis, and then advancement anteriorly

midline vermilion defects, flaps can be raised on both sides.
- A facial artery musculomucosal flap is an excellent option to reconstruct large vermilion defects. It is an axial-patterned flap based off the facial artery and can be harvested as an inferiorly or superiorly based flap. This offers an alternative to delayed tongue flaps and lip-switch flaps that require multiple surgeries and are poorly tolerated by patients in the intermediate stage.

Reconstruction of the Cutaneous Lip

- Ideally, reconstruction of purely cutaneous defects of the lip should be performed with local tissue. When possible, local tissue rearrangement should be limited to the aesthetic subunit affected, and incisions should be placed along subunit borders. For the lateral lip, this includes the nasolabial fold, alar base, and vermilion border, while medially this includes the philtral columns and columellar base [11].
- Defects of the cutaneous lip smaller than 2 cm can be closed primarily with fusiform excision of excess tissue. The wedge excision should be oriented so that the closure runs parallel with the RSTLs of the perioral region. An M-plasty can be used along the superior or inferior aspect of the primary closure to shorten the vertical height of the excision and avoiding crossing the vermilion border or nasal sill (Fig. 16.7).
- For small defects (<2 cm) that directly abut the vermilion border, an O-to-T plasty can be used to avoid crossing the vermillion border. The closure should be oriented so that the horizontal limb of the T lies along the vermillion border and the vertical limb lies parallel to the RSTL (Fig. 16.8) [13].
- Medial defects of the cutaneous lip greater than 2 cm are generally amenable to reconstruction with advancement flaps. For the upper lip, the flap incisions are designed to hide along the vermilion border and the base of the nose, and then the flap is raised in the subcutaneous plane superficial to the orbicularis oris (Fig. 16.9). A perialar crescentic excision in the alarfacial

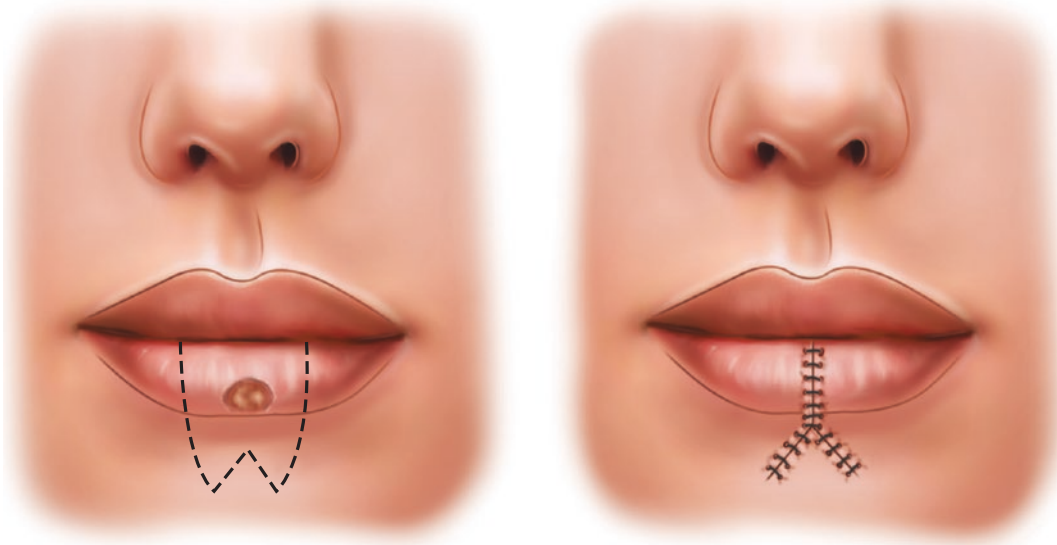

Fig. 16.7 M-plasty lip. The M-plasty of the lip is designed similar to a wedge excision; however, the peak of the wedge incision design should be inverted to create an "M"

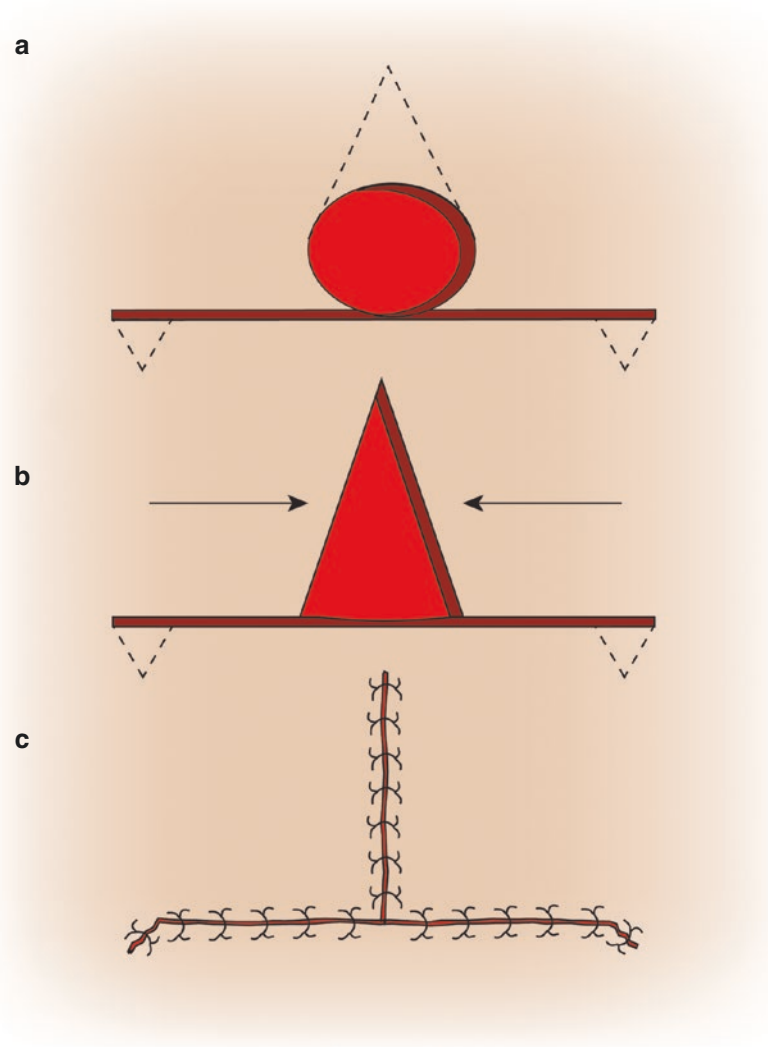

Fig. 16.8 O-to-T plasty. (**a**) Flap design. The *dotted lines* mark the required dog-ear excisions. (**b**) The lateral limbs are advanced and inset medially. Burrow's triangles are incised at the lateral aspect of the inferior limb. (**c**) Appearance after flap inset and excision of Burrow's triangles. (Reprinted by permission from: Springer Nature. Advancement Flaps by Lynn L. Chiu-Collins, Amit D. Bhrany, Craig S. Murakami, et al. © 2013)

groove allows further flap dissection and advancement. For the lower lip, the superior incision is placed at the vermilion border, and the inferior incision is placed in the mental crease. For midline defects that include the majority of the medial subunit and one or both philtral columns, bilateral advancement flap can be performed alone, but this obliterates the philtral columns. Rather, the medial subunit can be reconstructed with a full-thickness skin graft, and then advancement flaps can be used to replace the lateral aspects of the defect, using the interface between flap and graft to replicate the philtral columns [14].

- The nasolabial fold should be utilized to hide defects of the lateral subunit of the upper lip. Inferolaterally based rotation and rotation-advancement flaps utilize the curve of the lip around the commissure to recruit tissue from the cheek. The flap is raised in the subcutaneous plane similar to the medial advancement flaps described above, and the incision is placed in the nasolabial fold. Care should be taken inferiorly to avoid excessively narrowing the flap base, as the nasolabial fold nears the lateral commissure. There the incision should skive laterally to maximize the width of the flap base.

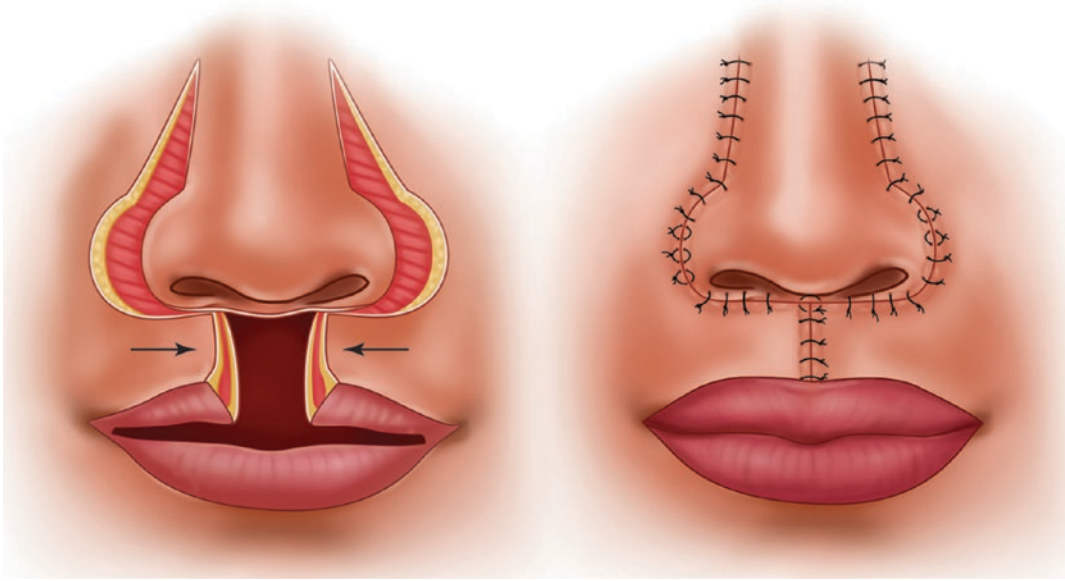

Fig. 16.9 Lip advancement flaps. A perialar crescentic excision is shown, which allows further flap dissection and advancement while hiding the incision in the alarfacial groove. (Reprinted by permission from: Springer Nature. Advancement Flaps by Michael F. Klaassen, Earle Brown, Felix Behan. © 2018)

- Random V-Y island advancement flaps are often described to reconstruct lateral defects of the upper lip; however, these are generally not utilized by the primary author (PL) due to their tenuous blood supply. The flap paradoxically receives its blood supply from the underlying subcutaneous tissue; however, the number of viable perforators may be limited by the size limitations of the flap in this region.

Reconstruction of Full-Thickness Defects

- Full-thickness defects of the lips include skin, muscle, and mucosa. Reconstruction of full-thickness defects require both aesthetic and functional consideration. Not only does the continuity of the three layers need to be reestablished to maintain oral sphincter competence, but the sensory and motor function should be preserved to minimize complications such as drooling, lip retraction, and dysarthria.
- With the increasing prevalence of Mohs surgical defects, it is critical that defects are evaluated on an individual basis. Because of the ability of Mohs surgeons to take multiple tissue biopsy and target specific margins of tumor, defects often present with variable thickness. For example, a defect may involve the lower lip, the oral commissure, and the upper lip, with only a portion of the defect including the full thickness of the lip.
- Defects measuring up to half of the width of the lower lip are sometimes amenable to wedge excision and primary closure. The wedge excision should be oriented with the RSTLs. Midline, these are vertically oriented, while laterally they are obliquely oriented. When closing larger defects primarily, an M-plasty can be used to limit the vertical dimension of the wedge excision.

Abbe Flap

- The traditional Abbe flap is a staged flap based off the inferior or superior labial arteries that

involves transfer of a pedicled full-thickness section of the lip to a cross-lip defect. The pedicle is then divided at a later date.

- The flap can be used to reconstruct defects of up to two-thirds of either lip, depending on the location; however, the author prefers to avoid using the upper lip as a donor site for lower lip reconstruction, due to the notable asymmetry it creates in the upper lip subunits [14].
- The flap has classically been designed to be one-half the width of the defect; however, this may be modified to improve symmetry when reconstructing unilateral defects. The initial defect may be narrowed using bilateral full-thickness advancement flaps, allowing for a smaller donor site defect. Similarly, the donor site can also be closed with bilateral advancement flaps.
- In designing the flap, the height should be equal to the height of the defect, except near the philtral columns, where the flap may be elongated to allow mimicry of the natural philtral column (Fig. 16.10).
- Medial defects should be altered prior to flap design to position the flap borders at the philtral columns. This can be done by expanding the defect to include the entire medial subunit, or using bilateral advancement flaps with perialar crescentic excision to narrow the defect.
- The pedicle can be designed based off the labial artery on the ipsilateral or contralateral side of the defect. Although basing the flap off the ipsilateral side allows for the primary oral opening to be larger, it makes it more difficult to turn the flap into the defect and easier to compress the pedicle during inset. For this reason, we prefer to base the flap off the contralateral side.
- Aggressive dissection of the pedicle should be avoided, as it can disrupt the venous drainage of the flap and lead to flap congestion.
- The pedicle is generally divided at 2 weeks, although this may be variable, given the size of the flap and the tissue quality surrounding the defect. If there is any concern at 2 weeks, the pedicle can be gently compressed on the donor lip side, and division can be delayed if any ischemic flap changes are witnessed.
- Double-opposing Abbe flaps can be used to reconstruct lip defects even greater than two-thirds of the total width of the lip. This technique is preferable to reconstruct the lower lip because the opposing flaps can be designed to hide the donor sites symmetrically along the philtral columns [15].

Estlander Flap

- The Estlander flap is used to reconstruct full-thickness lip defects involving the oral commissure. Similar to the Abbe flap, it is a lid-switch flap based on the labial artery; however, the pedicle in the Estlander flap is incorporated into the reconstruction of the oral commissure. (Fig. 16.11). This allows the flap to be completed in a single stage.
- For the reconstruction of lateral lower lip defects, the flap is oriented to place the donor site in the nasolabial fold. For lateral upper lip defects, the flap is oriented to place the donor site in preexisting marionette lines when present.
- The flap is designed similar to the Abbe flap. The width is designed to be approximately one-half the width of the defect, while the height of the flap is equal to the height of the defect.
- The Estlander flap is not favored by the authors, as it almost universally results in blunting of the reconstructed oral commissure and notable asymmetry of the lip. This may be partially addressed by performing a delayed commissureplasty. This involves excising a triangle of skin lateral to the commissure, dividing the lip at the oral commissure, and performing mucosal advancement flaps superiorly and inferiorly to reconstruct the now deficient vermilion. The height of the skin triangle should be designed so that the reconstructed oral commissure mirrors the dimensions of the contralateral commissure (Fig. 16.12).

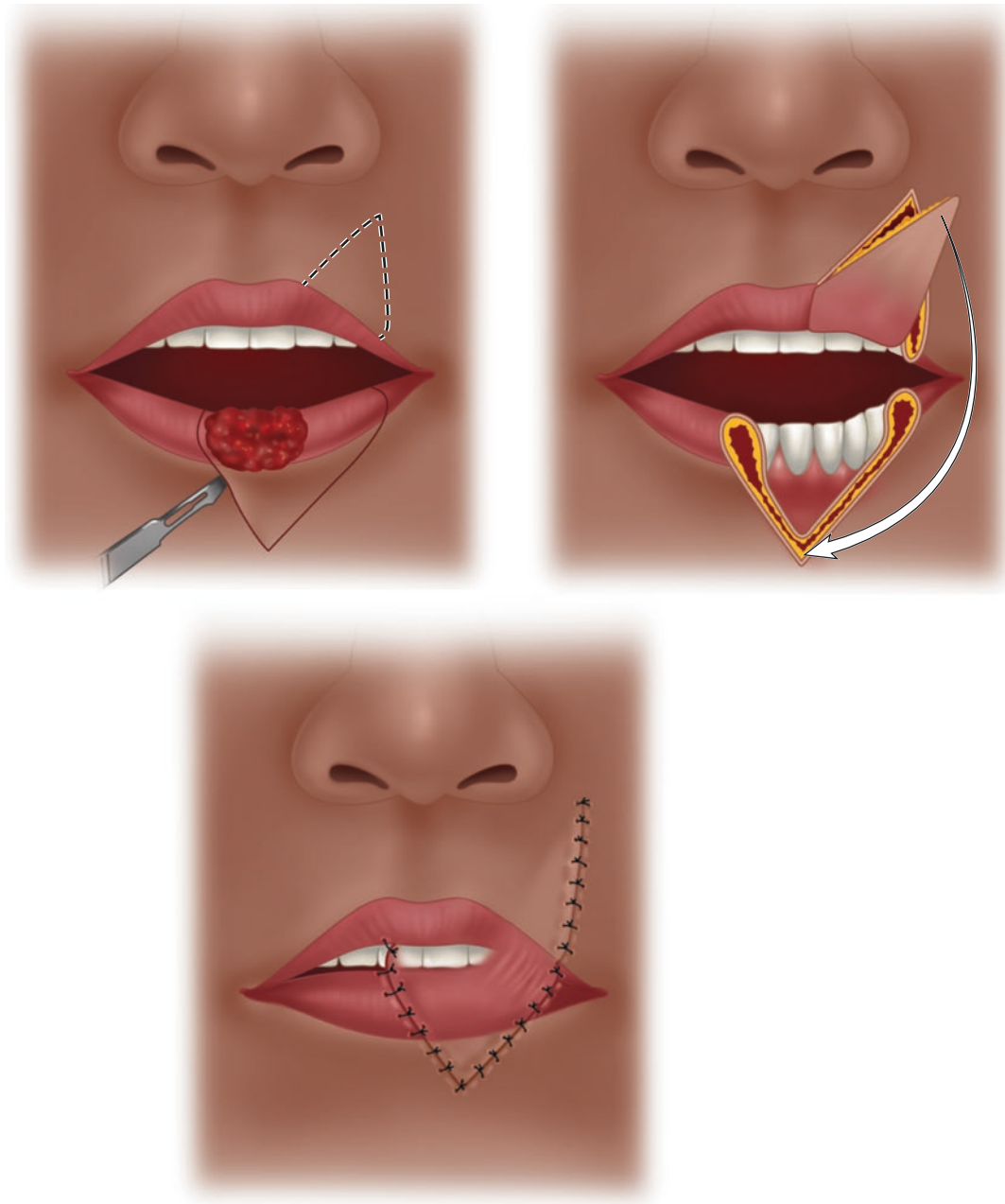

Fig. 16.10 Abbe flap design. A pedicled, full-thickness flap is harvest from the opposing lip, and then rotated into the defect. The flap is designed so that its width is approximately half the width of the defect. The pedicle is then divided at a later date. (Reprinted by permission from: Springer Nature. Abbe Flap by Eric J. Dobratz. © 2013)

Karapandzic Flap

- The Karapandzic flap is a bilateral rotation advancement flap that can be used to reconstruct full-thickness defects of up to two-thirds of the upper or lower lip using preexisting lip stock.
- The primary goal of the flap is functional restoration of the oral sphincter. The motor innervation to the orbicularis is preserved during

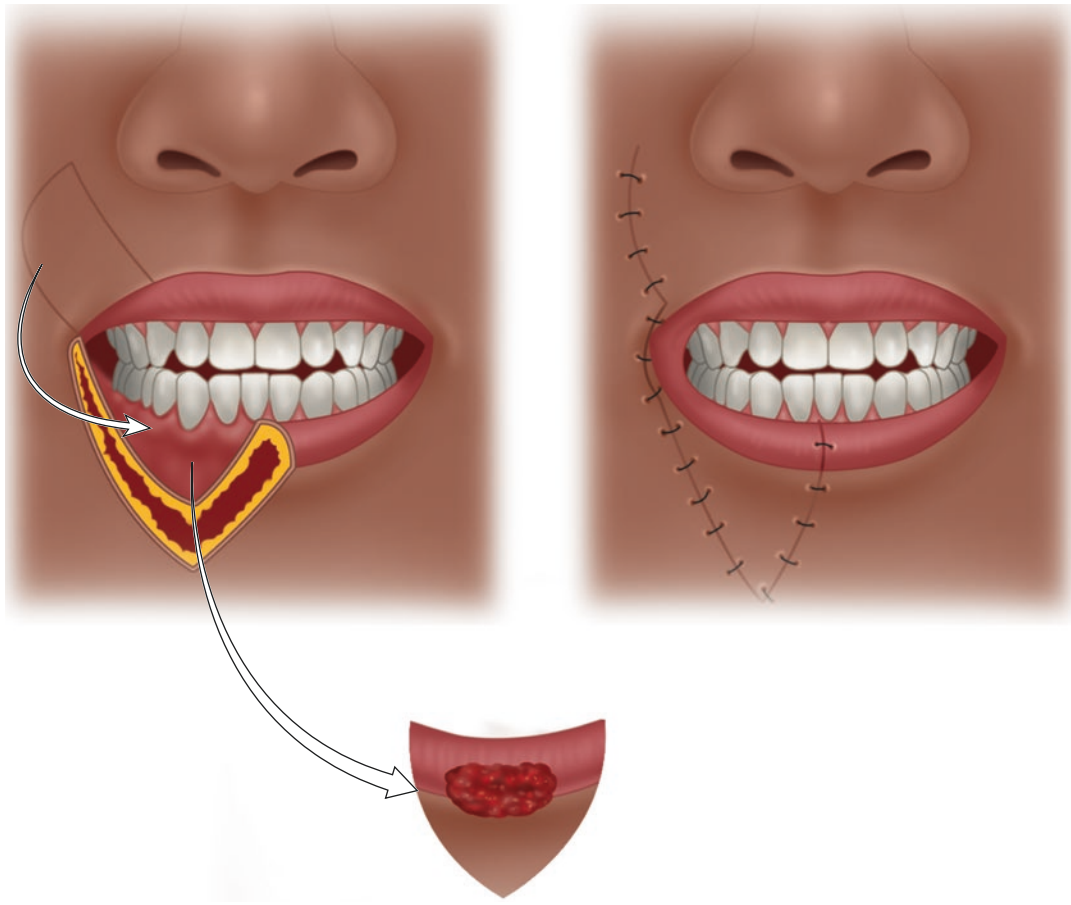

Fig. 16.11 Eastlander flap. The flap is designed and performed in similar fashion to the Abbe flap, except that pedicle is inset into the defect so it does not need to be divided later. Not the blunting of the oral commissure in the illustration

flap dissection, and the muscle is reapproximated at the midline to restore continuity.

- For flap design, lines are drawn at the vertical height of the defect bilaterally, and then extended parallel to the lip around each oral commissure. The flap widths should be equal bilaterally, and care should be taken to avoid narrowing the flap as it circles around the commissure (Fig. 16.13).
- Initially, a skin-only incision is made, and then the underlying subcutaneous tissue and orbicularis is carefully mobilized from the surrounding facial tissue, using blunt dissection and conservative electrocautery. The neurovascular pedicle is found near the oral commissure deep to the orbicularis and should be avoided. The mobility of the orbicularis should be constantly evaluated during flap dissection so that over-dissection of the pedicle or underlying fascial musculature is not performed. The muscles attaching to the modiolus deep should be spared, as this improves restoration of the oral commissures over time. Once the muscle is adequately mobilized, the oral mucosa is conservatively incised. Given the inherent stretch of the oral mucosa, the intraoral incision can be made much smaller than the external incision.
- Microstomia is a common complication of the Karapandzic flap; however, this may self-

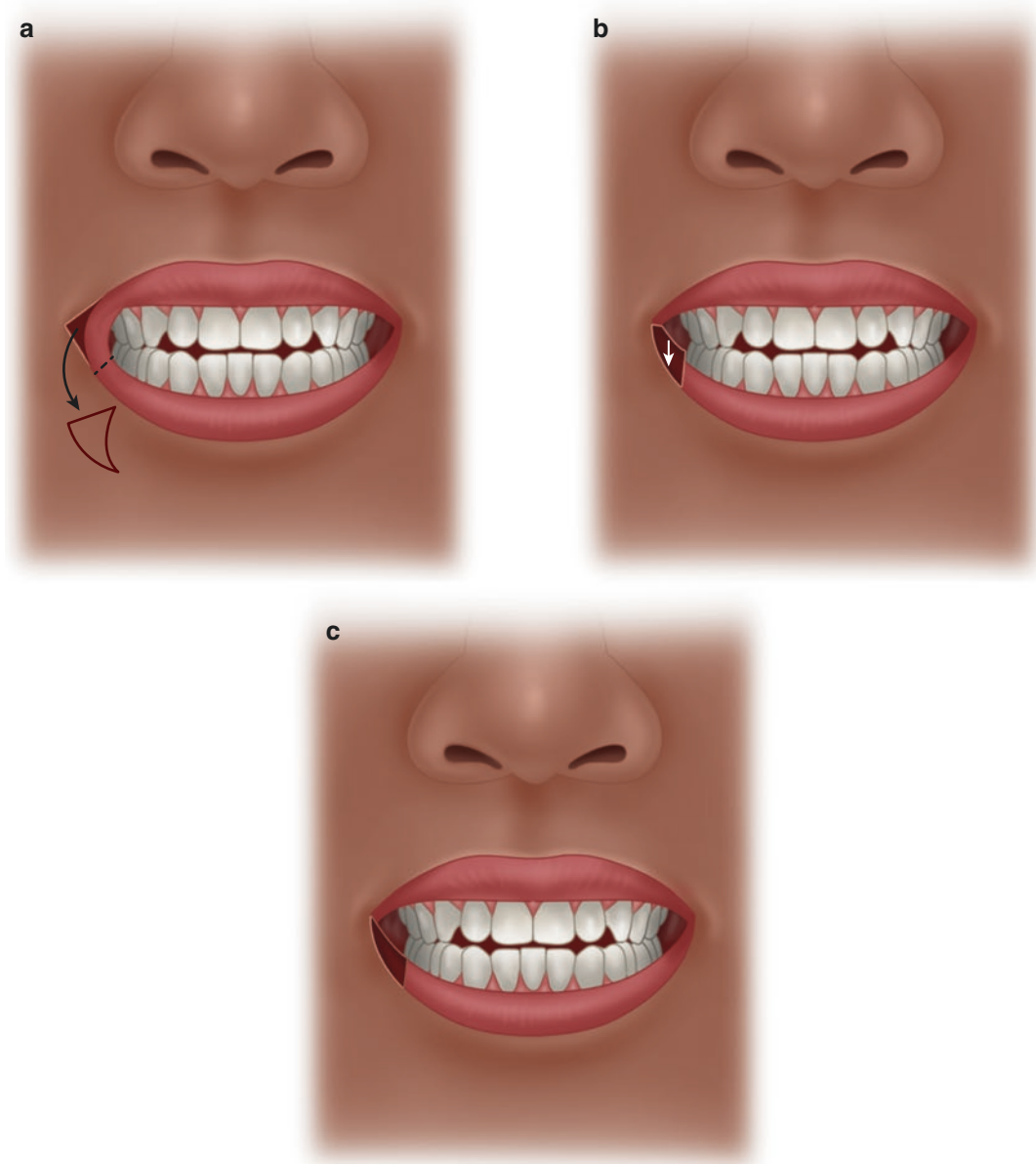

Fig. 16.12 Commissureplasty. (**a**) A triangle of skin is excised lateral to the commissure and the lip is divided at or inferior to the oral commissure. The height of the skin triangle should be designed so that the reconstructed oral commissure mirrors the dimensions of the contralateral commissure. (**b**) Mucosal advancement flaps are then performed to reconstruct the now deficient vermilion. (**c**) The *pink* area represents the reconstructed vermilion after mucosal advancement

resolve over time, as the flaps stretch over time. Because of this, we prefer to defer any revision procedure or lip rebalancing until 9–12 months after the original reconstruction.

- The oral commissures are often blunted postoperatively, but unlike Estlander flaps, the commissures often partially recover due to the preserved deep musculature.

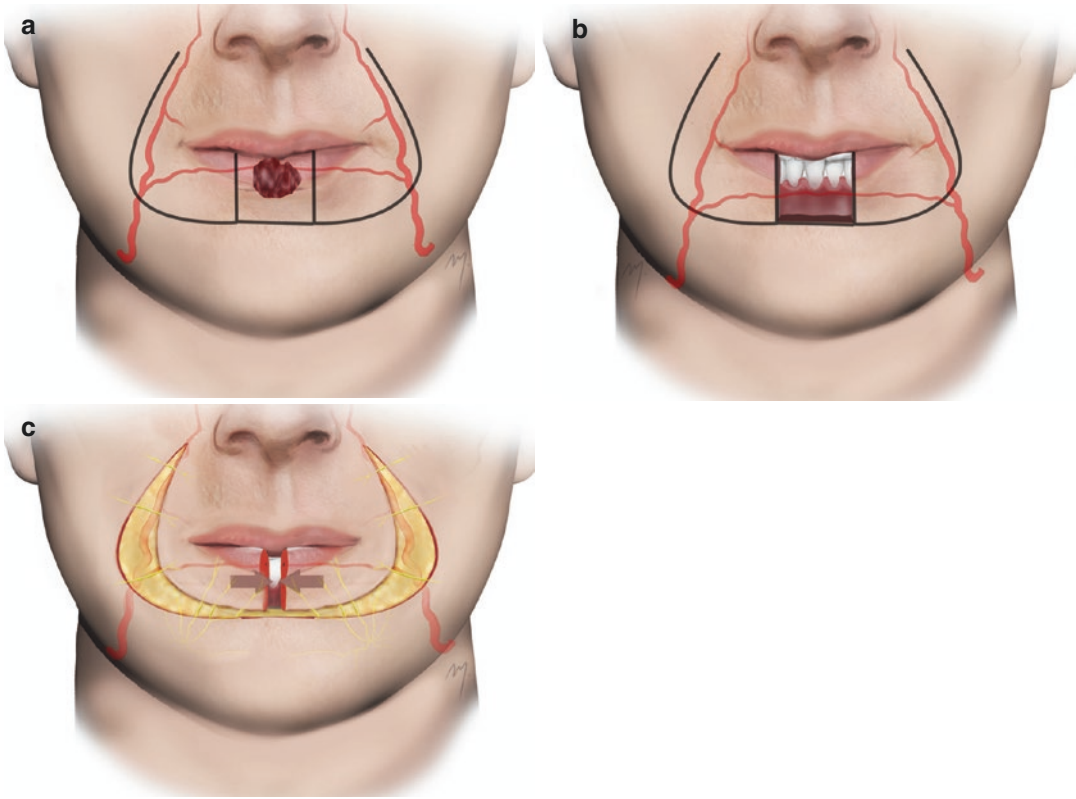

Fig. 16.13 Karapandzic flap design. (**a**) Lines are drawn at the vertical height of the defect bilaterally, and then extended parallel to the lip around each oral commissure. The flap widths should be equal bilaterally, and care should be taken to avoid narrowing the flap as it circles around the commissure to ensure that the vascular pedicles are included in each flap. (**b**) The defect violates the continuity of the oral sphincter. (**c**) The underlying subcutaneous tissue and orbicularis is carefully mobilized from the surrounding facial tissue to allow advancement of the bilateral flaps medially. The neurovascular pedicle is deep to the plane of dissection and thus should be avoided. (Reprinted by permission from: Springer Nature. Lips and Chin by Vasilios K. Thomaidis. © 2014)

Bernard-von Burrow Flap

- Bernard-von Burrow flaps recruit tissue from the cheek using bilateral opposing cheek advancement flaps to reconstruct defects of more than two-thirds of the upper or lower lip.
- Each advancement flap is designed with a width equal to the height of the defect. The horizontal length of each flap is approximately one-half of the total width of the defect. Reconstruction of the upper lip with the bilateral cheek advancement flaps results in excess tissue superior and inferior to the flap base. This excess tissue is addressed with triangular excisions (Burrow's triangles) superior and inferior to the flap, taking care not to narrow the flap base. These triangular excisions are then closed primarily. Because bilateral flaps are raised, a total of four Burrow's triangles are excised (Fig. 16.14).
- Bernard-von Burrow flaps used to reconstruct the lower lip can be performed with only three Burrow's triangles excisions. Superior to the flap, bilateral Burrow's triangles are excised at the base of the flap, while inferiorly, a wedge excision or W-plasty is performed at the midline.
- Rather than distort the chin subunit with the midline wedge excision, the primary author favors the Webster modification when using the Bernard-von Burrow flap for lower lip reconstruction. In this technique, upper and

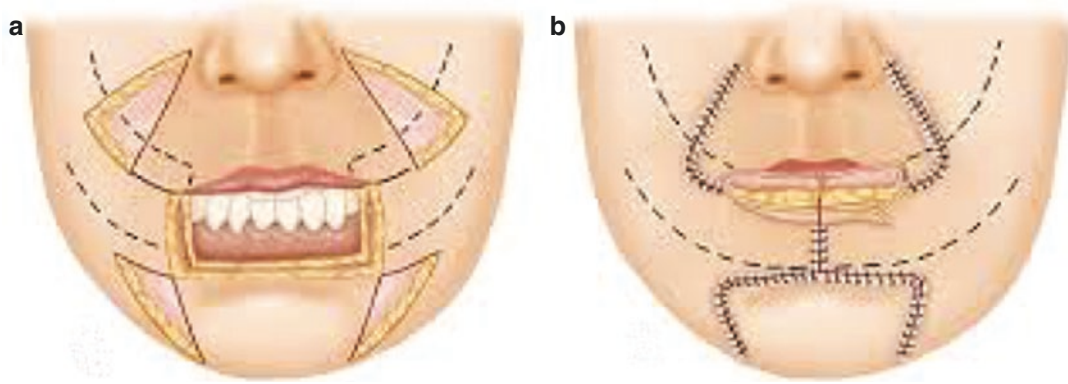

Fig. 16.14 Bernard von-Burrow flap. (**a**) Flap design, including the four opposing Burrow's triangles. The *dotted lines* represent the intraoral relaxing incisions. No Burrow's triangles are required intraorally because dog-ears are well tolerated intraorally. (**b**) After advancement and inset of flaps bilaterally. Microstomia is an unavoidable complication after Bernard von-Burrow flaps. (Republished with permission of McGraw Hill LLC, from Textbook of surgical oncology; chap. 161: Skin closure after resection of skin malignancies, including melanoma. Ross Blagg and Courtney Crombie. (c) 2016; permission conveyed through Copyright Clearance Center, Inc.)

lower Burrow's triangles are designed at the base of the flaps bilaterally, so that scars are hidden in the nasolabial folds and marionette lines. This also preserves the aesthetic chin subunit.

- Similar to the Karapandzic flap, dissection of the skin/subcutaneous tissue and mucosa are performed separately. Conservative blunt dissection is performed of the underlying facial musculature, and incised as needed to allow medial advancement. The mucosal incisions are made after the skin and subcutaneous dissection has been performed, as the distensibility of the mucosa allows the incisions to be much smaller. Lastly, partial thickness Burrow's triangles are excised.
- Because the Bernard-von Burrow flap uses cheek tissue rather than native lip to reconstruct the defect, the functional deficits after reconstruction are often much more pronounced. This includes oral incompetence and difficulty with speech.

Free Tissue Transfer

- For total or near-total lip defects, free tissue transfer may be necessary to reconstruct the defect.
- Traditionally, the flap of choice was the radial forearm flap, with inclusion of the palmaris longus tendon for use as a static sling in lower lip reconstruction.
- Recently, reconstruction of near-total lip defects with a functional gracilis flap followed by skin graft has demonstrated satisfactory functional outcomes and aesthetic results [16].

Conclusion

Wounds of the lips and cheek have both aesthetic and functional implications in a patient's everyday life, making treatment of such wounds a challenge to even the most experienced surgeon. It is vital that these wounds are meticulously evaluated and treated by reconstructive surgeons with a strong knowledge of the tools available for reconstruction. Skillful reconstruction can spare a patient the psychosocial toll of a disfiguring scar, or restore them to their former state with little-to-no effect on speech or eating. Poorly planned or executed surgery can further disfigure a patient and limits subsequent attempts at revision. The intention of this chapter is to provide both experienced and inexperienced surgeons

with the tools necessary to adequately approach complex wounds of the lips and cheek.

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17 Ear Reconstruction: Congenital, Microtia, Otoplasty

John F. Reinisch

Introduction

Congenital ear issues are relatively common. Ear tags, pre-auricular sinus tracts, irregular helical contours, absence of the anti-helical fold, and bifid ear lobes are often seen by surgeons with a pediatric practice. Less common deformities are Stahl's deformity of the superior crus, asymmetric ear size, cryptotia, microtia, and vascular and pigmented birthmarks of the ear.

The paucity of scalp hair in newborns and their initial lack of early interaction make ear deformities particularly noticeable to their parents. In the past, pediatricians reassured parents and encouraged a wait-and-see approach. With a greater awareness of the potential benefit of early ear molding, pediatricians are now referring younger babies with ear deformities to plastic surgeons and otolaryngologists. Prominent ears secondary to conchal bowl hypertrophy, and/or incomplete anti-helical folding, often run in families. Parents who have been teased for their prominent ears as children are often eager to have their own children's ear prominence corrected early to avoid the comments they experienced.

This chapter will offer tips on how to make treatment of the more common ear deformities easier for both the patient's family and the treating surgeon.

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Treatments and Techniques

Pre-Auricular Ear Remnants

These commonly seen lesions are often referred to as "skin tags." However, the term "ear remnants" is more appropriate, as these lesions usually contain a small piece of subcutaneous cartilage in the remnant. Removing these remnants, either by a ligature or by cutting the base flush with the skin surface, will eventually result in a nipple-like protrusion, as the residual cartilage will grow over time.

If seen early, one can remove these remnants inexpensively and without trauma as an office procedure under local anesthesia. The best age for the procedure is in the first month of life, when newborns spend most of their time sleeping and eating. The procedure can be done smoothly, with virtually no discomfort, by applying BLT (benzocaine, lidocaine, and tetracaine) cream. After several minutes, infiltrate 0.5 CCs of 0.5% lidocaine with 1/200,000 parts epinephrine using a 32-gauge needle, and then dim the room lights. After 20 minutes there is sufficient vasoconstriction that cauterization is not necessary. With the infant sleeping or feeding on mother's chest, the remnant is excised

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with the underlying subcutaneous cartilage, using the light from a narrow-beam headlight in the darkened room. The defect is closed with a few buried 6-0 PDS sutures and sealed with Dermabond. The child can bathe, and the sleep-deprived, busy mother does not need to return for suture removal. A photo by text or email is sufficient follow-up.

After 2–3 months, babies are more alert and too interested in their surroundings to be able to easily remove the remnant. At this age, the surgeon's choice is surgery using a traumatic restraint, or a more formal and expensive procedure with general anesthesia.

Ear Molding

Children with helical rim irregularities are referred more frequently because of pediatricians' greater awareness of the effectiveness of early ear molding. Most rim defects can be corrected easily, without the use of expensive commercial medical products. The best-known molding device requires shaving the hair and wearing a cradle over the ear resembling a rectangular headphone. The device is very noticeable and makes bathing and washing the scalp difficult.

The small silicone tubing that comes with the butterfly device used for blood drawing fits the helical concavity nicely and can be secured in place with medical adhesive or inexpensive super glue (Loctite gel super glue) (Fig. 17.1). Rubbing the skin of the ear with acetone on a 2 × 2 gauze helps to remove desquamated surface skin and oil to prolong fixation of the tubing in place for up to 2 weeks. The curvature of the tubing can be modified by placing small snips in its outer edge with fine scissors. In the past, I used the metal from a paper clip to shape the tubing. Without the metal, the tubing may exert a slight dynamic pressure on the rim. The placement of narrow steri-strips perpendicular to the tubing over the helical rim may help to secure the tubing. The tubing can stay in place 10–14 days. One application is often sufficient if started in the first couple weeks of life. If started a few weeks later, the tubing will need to be reapplied.

Fig. 17.1 Tubing, glue, and tape useful for inexpensive molding ear shape deformities in the newborn

A Stahl's deformity can be treated in a similar fashion, using a larger intravenous tubing or silicone impression material (Fig. 17.2).

Prominent ears secondary to the lack of the anti-helical fold can be treated by manually forming the fold and securing it temporarily with a horizontal 4-0 nylon mattress suture. After placing BLT cream on the front and back of the ear, the skin is infiltrated with a small amount of lidocaine 0.5% with 1/200,000 part epinephrine solution through a 32-gauge needle. After allowing time for vasoconstriction, with the newborn on mother's chest, the ears are cleaned with alcohol and a single mattress suture is placed, slightly overcorrecting the absent fold. No dressing is needed. The suture can be removed in three to 4 weeks with the expectation that an anti-helical fold will remain.

The earlier one begins ear molding a newborn's ear cartilage, the shorter the length of treatment. Once a newborn is 2 months of age, the ease and success of the molding correction diminishes.

Fig. 17.2 Packets of silicone impression material (base and catalyst) useful for ear molding, maintaining an ear sulcus by minimizing contracture of a post-auricular skin graft, and preserving ear projection following ear reconstruction

Fig. 17.3 Silicone night mold to maintain post-auricular sulcus. The mold should be worn at night for 4 months following surgery to minimize soft tissue contracture

Cryptotia

There are a number of techniques described for releasing or creating a post-auricular sulcus. The use of a full-thickness skin graft (FTSG) can be done without disturbing the mastoid hairline. The initial release of the sulcus can be lost with contracture of the FTSG.

A helpful adjunct to the release and grafting procedure is the use of a postoperative silicone mold. The mold improves scarring and minimizes the post-auricular graft contraction to maintain the depth of the sulcus. The silicone comes in individual packets as an impression material used for hearing aid fitting. The material can be used to make a mold and should be used at night for 4 months following the sulcus release and graft (Fig. 17.3).

Auricular Size Reduction

The size and shape of normal ears can vary significantly. Young children's ears have a rounder appearance and tend to grow more in the vertical than horizontal dimension with time. With senescence, the ear lobe may also elongate. Earrings can contribute to this lengthening. Lobe reduction is a frequent request of patients having facial rejuvenation, and is not a difficult procedure.

The vertical height of an ear or an enlarged scapha can be reduced with minimal visible scarring (Fig. 17.4). An incision inside the helical rim can be used to elevate an inferiorly based flap of lateral skin and perichondrium. A crescent of scapha cartilage is then excised. Since the helical rim will no longer match the shortened perimeter of the scapha, the helix must be shortened to fit the reduced size of the scapha by excising a full

Fig. 17.4 Patient with ear size asymmetry before (*left*) and after (*right*) ear reduction

thickness rectangle of helical cartilage and skin. The cartilage of the scapha is then approximated to the cartilage of the helix with figure-of-eight sutures to keep the two edges from overlapping. The excess skin of the scapha is trimmed and sutured to the skin of the helix with fine dissolving sutures. The continuity of the helix is reestablished by carefully approximating the cartilage and skin of the rim to avoid a contour irregularity. Since the longer rim incision is concealed, the only visible incision is the short incision across the helix.

Microtia

The parents of a child with microtia consider ear reconstruction to be a cosmetic procedure. They have the understandable expectation that the reconstructed ear will match the normal opposite ear in unilateral cases and be symmetrical and look like normal ears in bilateral cases.

Unfortunately, the results of microtia repair are usually aesthetically disappointing. The reconstructed ear often lacks the projection, definition, and post-auricular sulcus of a normal ear. The poor outcomes occur because microtia is relatively uncommon, because it is a difficult procedure, and because few surgeons have done enough procedures to obtain consistently good results.

There are two structural components required for ear reconstruction. One is a skeletal framework for shape and support. The other is a color-appropriate, non-hair-bearing soft tissue cover. The most common method of reconstruction uses a costal cartilage framework placed under the local mastoid soft tissue. Unfortunately, both the rib cartilage framework and the mastoid skin have significant disadvantages.

Utilization of costal cartilage to construct an ear framework was first popularized by Tanzer over 60 years ago in 1959 [1]. There are several reasons why costal cartilage may not be an ideal supporting framework. The first drawback of costal cartilage is the need to delay ear reconstruction until the child's chest is large enough to donate sufficient cartilage without leaving a noticeable chest contour deformity. The more recent modifications of Tanzer's original procedure have decreased the number of operative stages, but have pushed back the age of cartilage harvest to 10 years or later [2–5]. Unfortunately, reconstruction at this older age is done when children are attending school, are aware and often self-conscious of their small ear, and likely have received questions and comments from peers. A second disadvantage of rib cartilage is the discomfort and need for hospitalization that accompanies its harvest. As surgeons who have spent much of our lives in hospitals, we easily underestimate the frightening and lasting impact hospitalization with an intravenous line and postoperative drains can have on some children. Thirdly, cartilage harvest leaves a permanent chest scar and some degree of chest asymmetry [6] (Fig. 17.5). Finally, a cartilage framework can lose shape and volume over time [7]. This explains why some of the stainless steel wires originally buried within the cartilage may become superficial and protrude through the skin with time.

The disadvantages of the costal cartilage framework are not seen with the use of an implant ear reconstruction. Since rib cartilage is not harvested, ear reconstruction can be done before a patient starts school, becomes self-conscious, and receives negative comments from peers. The implant eliminates the discomfort and chest asymmetry of a costal cartilage harvest and allows ear reconstruction to be done as an outpatient procedure without the expense or trauma of hospitalization. An implant framework maintains its shape, as it does not dissolve or change shape with time.

It should be mentioned that the resistance to using a non-autologous implant framework stems from a history of complications with the use of implants in ear reconstruction. A silastic framework became popular in the 1960s and 1970s because of its flexibility and ease of use [8]. However, the initial enthusiasm for the silastic framework dwindled and was eventually abandoned [9]. The early use of high-density porous polyethylene (HDPE) implants also led to implant exposures and fractures. However, covering the entire implant with a thin two-layered vascularized fascia has virtually eliminated implant exposures [10]. The concerns with size discrepancy and frame fractures are preventable with correct surgical technique, improved implant design, and surgical experience (Fig. 17.6) [11, 12].

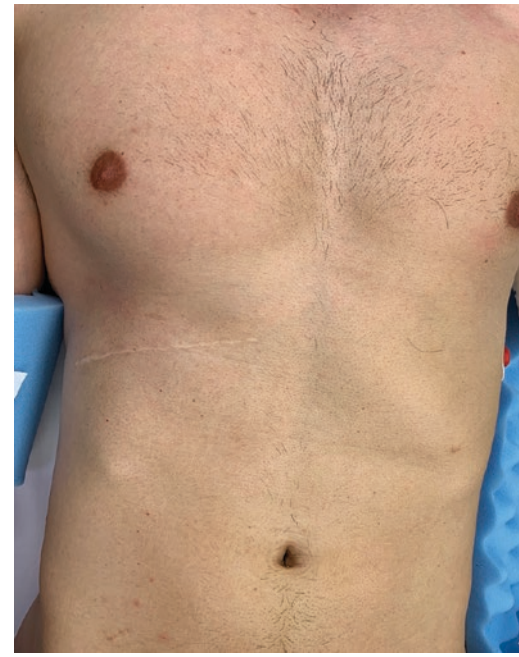

Fig. 17.5 A 29-year-old microtia patient seen 20 years after rib cartilage harvest at age 9.5 years. The chest asymmetry is noticeable

The second required component of ear reconstruction is the soft tissue that covers the framework. The tissue should be thin, glaberous, and have the appropriate color to match the ear lobe and cheek. The tissue pocket used with traditional cartilage reconstruction is limited by the location of the post-auricular hair-bearing scalp. Patients with a low hairline or significant craniofacial microsomia are at risk of having hair-

Fig. 17.6 Patient with left microtia seen at age 4 years (*left*) and at 25 years of age (*right*). His surgery was done at 3 years and 2 months of age. The ear was made 5 mm larger than his right ear at the time of surgery

bearing skin covering the lateral surface of the reconstructed ear. Additionally, the pliability of the post-auricular scalp restricts the size of the pocket into which the cartilage framework is placed. This usually limits the framework projection and mandates at least a second surgery to increase framework prominence with the addition of post-auricular skin to create a retroauricular sulcus. The use of a tissue expander to increase available mastoid skin, or multiple laser sessions to remove scalp hair, further adds to the burden of care needed for traditional ear reconstruction.

The use of vascularized fascia for soft tissue coverage has several advantages over the traditional mastoid skin pocket. The first is its ability to cover both the anterior and posterior surfaces of a projecting framework without tension. This eliminates the need for secondary surgery to increase projection and form a post-auricular sulcus (Fig. 17.7). Furthermore, the fascia coverage allows the ear framework to be positioned symmetrically on cranium with the opposite ear without regard to hairline or presence of scalp hair. This is a great benefit in patients with a low hair-

Fig. 17.7 Ear projection seen at 2 weeks after left ear reconstruction. The use of a large STPF flap allows good projection and a normal post-auricular sulcus

line, significant craniofacial microsomia, or Treacher Collins syndrome. Finally, the fascia covering the framework has a named vascular pedicle which allows a prior, or even a simultaneous atresia repair, without affecting the viability of the covering soft tissue, as may be the case with the use of the mastoid pocket. Evidence suggests that early binaural hearing improves the auditory processing function of the developing brain [13–16] (Fig. 17.8).

It is important to be mindful of the fact your patient must live with the outcome of your surgery. The complication rates reported for any procedure are from experienced surgeons with large case series. Problems seen by less experienced surgeons are always more frequent. Complications for any surgical procedure decrease as the experience of the surgeon increases. The significant benefits of an implant ear reconstruction come with potential complications that are less forgiving than those seen with the traditional autologous reconstruction. The most critical component of the implant ear reconstruction procedure is the elevation of an adequate-sized and well-vascularized superficial temporoparietal fascia (STPF) flap. The best way to avoid problems is to observe the procedure by a surgeon experienced with the technique. Important tips regarding implant placement, flap design, skin coverage, and postoperative care are available in the excellent instructional videos available from both Stryker® and Matrix USA®.

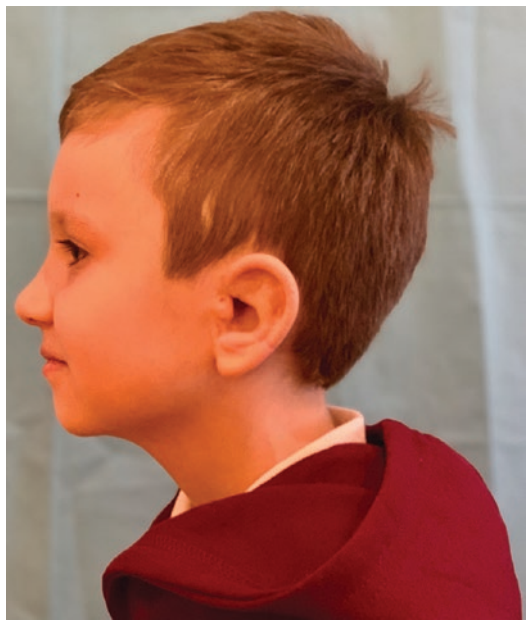

Fig. 17.8 An 8-year-old boy with bilateral microtia seen 5 years after a left combined atresia and microtia repair, and 4.5 years after a right combined atresia and microtia repair

The procedure is easier to do in children under 10 years of age [17]. Due to longer hair, female patients may be more ideal candidates early in one's experience as they can conceal scalp scars if an extra scalp incision is needed to facilitate the harvest of the STPF.

Although the great majority of microtia patients do not have "craniofacial microsomia," they often have subtle ipsilateral cheek hypoplasia, may have facial nerve weakness, and occasionally a degree of macrostomia. Ideally, microtia surgery should not only provide a well-matched ear but also improve facial symmetry.

Two useful adjuncts to microtia reconstruction are the use of fat grafting to improve cheek hypoplasia and the administration of botulinum injections to restore symmetry of facial movement. Abdominal fat can be harvested through a small umbilical stab incision. A minimum of 10 ml of concentrated fat can be reliably harvested, even in very thin children. If additional fat is needed, the upper inner thigh can provide another 10 ml of fat. The subcutaneous donor layer is infiltrated with a dilute Marcaine solution containing 1/800,000 parts epinephrine by diluting 10 ml of 0.25% Marcaine containing 1/200,000 epinephrine with 30 ml of saline. Infiltration of the solution before prepping the patient and waiting a minimum of 45–60 minutes to harvest provides the best fat. When combined with ear reconstruction, the fat adjunctive procedure adds little additional time to the surgery (Fig. 17.9).

Botulinum toxin injection into the lower lip depressors of the opposite lip is another useful adjunct to restore dynamic facial symmetry in patients with marginal mandibular nerve weakness or palsy. One can give parents a preview of its effect by injecting 0.25% plain bupivacaine into the depressors either pre-operatively or in

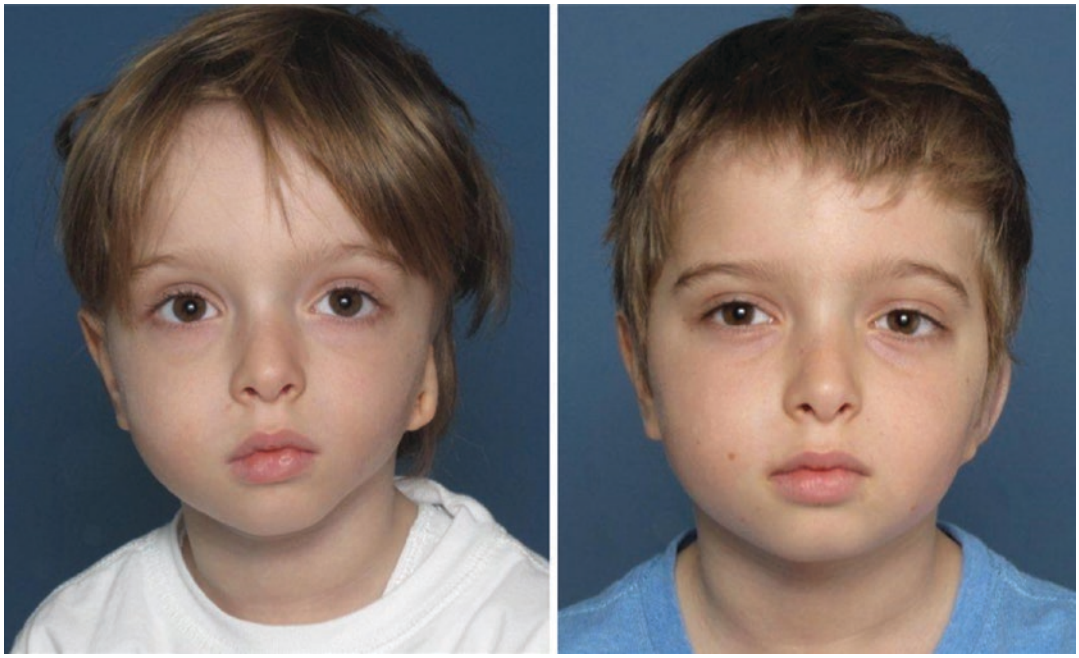

Fig. 17.9 A 4.5-year-old boy with left microtia and cheek hypoplasia before (*left*) and 5 years after (*right*) ear reconstruction and fat grafting to left cheek

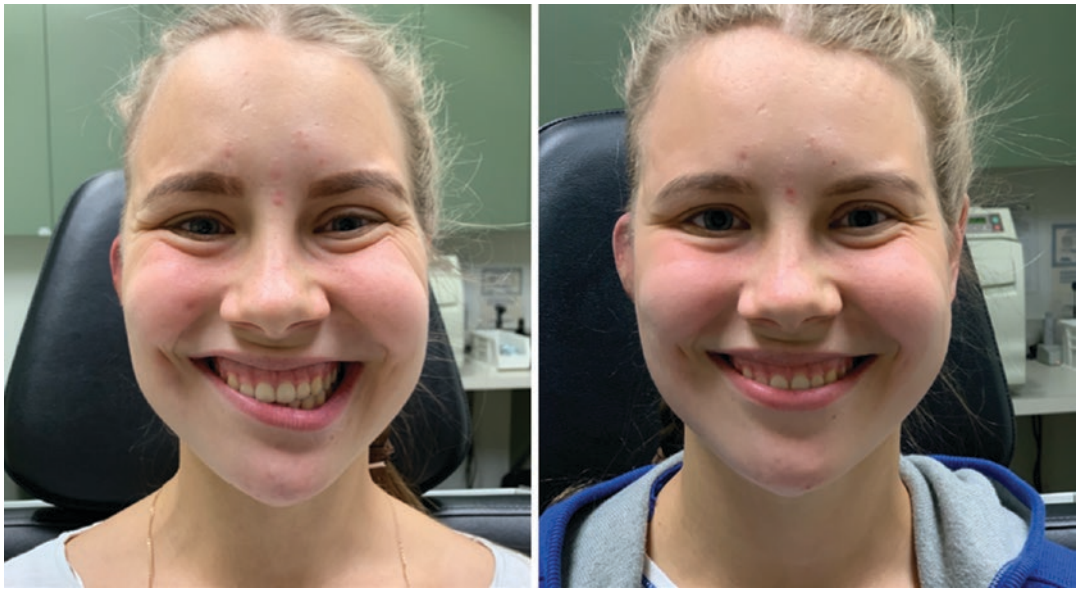

Fig. 17.10 Improved facial symmetry in teenager with right microtia and marginal mandibular nerve palsy

surgery. The effect lasts approximately 4 hours and is accompanied with lip numbness. If parents like the improvement, five units of botulinum toxin can be used either in surgery or postoperatively to help balance the face during animation [18] (Fig. 17.10).

Otoplasty

The great majority of primary otoplasty procedures are done for prominent ears. Excessive ear projection may be seen with an underdeveloped anti-helical fold, an enlarged conchal bowl height secondary to an increased concha to mastoid angle (incorrectly called conchal hypertrophy), and a horizontally oriented lobule. Protruding ears can have one, two, or three of these anatomic features. It is important to correctly determine which of the three potential deforming elements of a prominent ear needs correction.

Many techniques have been described and can be used successfully for correction. The goal of otoplasty is to produce an esthetically pleasing, symmetric, long-lasting result. Otoplasty is not considered a difficult surgery. It is included on the general privilege list for all plastic surgeons. However, the procedure can produce esthetic complications of overcorrection, undercorrection, recurrent projection, and asymmetry. Requests for secondary reconstruction are not infrequent following primary otoplasty. The outcome of an otoplasty is related to the surgeon's skill, experience, and esthetic sense. Cartilage resection is unnecessary and can make secondary reconstruction more difficult (Figs. 17.11 and 17.12).

The flexibility of ear cartilage varies considerably from patient to patient. Ear cartilage tends to be less flexible with age (Fig. 17.13). The creation of an anti-helical fold can be facilitated by scoring the anterior surface of the cartilage with an otobrader (Fig. 17.14). This is easily and quickly accomplished through a 2 cm anterior incision made below the helical rim, after the area to be folded has been marked and infiltrated with an anesthetic solution containing epinephrine.

Fig. 17.11 Overcorrection following otoplasty with cartilage resection. Repair required cartilage grafts for correction

Fig. 17.12 Asymmetry of ears following otoplasty with conchal bowl resection

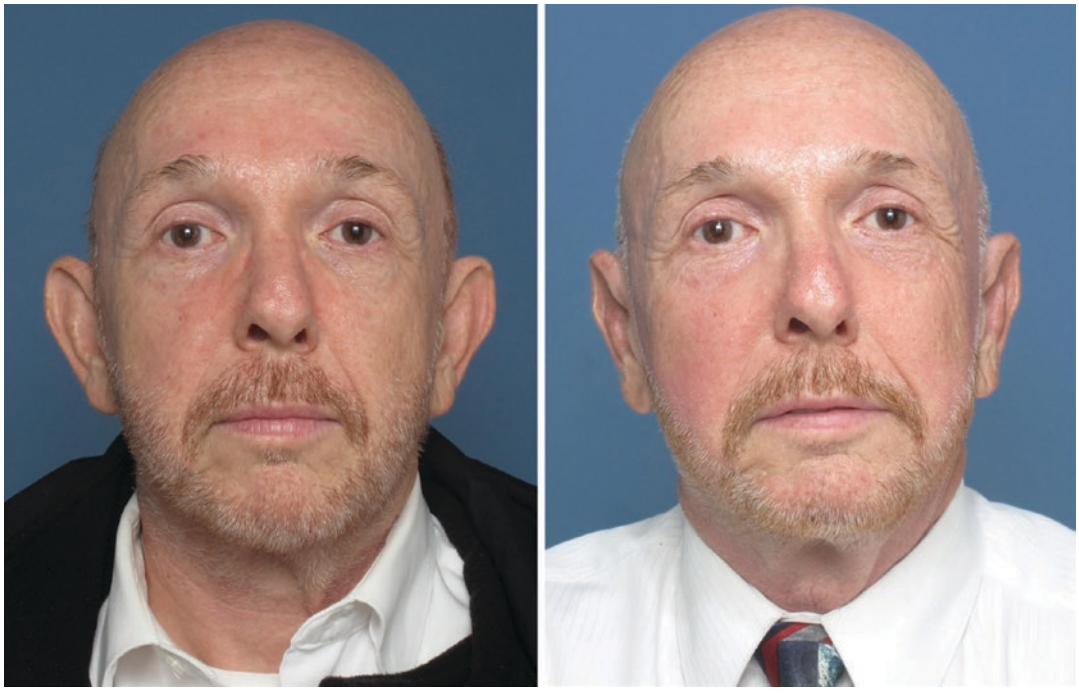

Fig. 17.13 Otobrader useful in scoring the anterior surface of ear cartilage, to facilitate folding of the cartilage to create an anti-helical fold in patients with less flexible cartilage

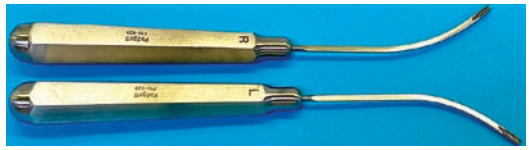

Fig. 17.14 Right and left otobraders used to facilitate scoring the anterior surface of the cartilage over the antihelix through a small incision under the helical rim after the perichondrium is elevated with a freer

Conclusion

Ear deformities are commonly seen by both plastic surgeons and otolaryngologists. This chapter offers tips for making their treatment easier and less arduous for both the patient and treating physician.

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Scalp Reconstruction

18

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Zachary Gala, Mark S. Granick, and Jonathan Keith

General Principles

Defects of the scalp and neurocranium are a common reconstructive challenge encountered by plastic surgeons. Scalp wound etiology commonly includes trauma, burn injuries, oncologic resections, osteomyelitis, and congenital lesions. Scalp reconstructive efforts are aimed at maximizing the interplay of cosmetic appearance and functional utility. The reconstructed scalp must protect the skull and intracranial contents. In oncologic cases, coverage should be obtained with durable tissue that can withstand radiation. Aesthetic goals include using "like tissue" with similar color and thickness, re-creation of a hairline, and restoring hair-bearing scalp.

Management of scalp and calvarial wounds depends on size, location, etiology, and patient factors. The concept of reconstructive ladder—a stepwise algorithm for wound closure—permeates the plastic surgery literature. Though the simplest and most reliable methods should generally be favored, the authors emphasize reconstructing scalp wounds per the "reconstructive elevator" model. That is, the method of reconstruction initially chosen should be tailored to the wound and patient, despite the level of technical complexity. Reconstructive options include wound healing by secondary intention, primary closure, skin grafting, skin substitutes, and local flap coverage. Often, free tissue transfer is both necessary and provides the most durable coverage. The use of tissue expanders for scalp reconstruction has been well described and is a mainstay of restoring hair-bearing scalp to natural hair patterns.

Size of the scalp wound is the most important factor when choosing the appropriate reconstructive option. Though a compendium of options will be discussed below for completeness, the following guidelines are generally recommended: small wounds necessitating surgical intervention may be treated with SkinTE™ (PolarityTE® Inc., Salt Lake City, Utah); medium-sized wounds are managed first with SkinTE™ and/or skin grafts, then expansion as necessary; large wounds are most successfully reconstructed with free flaps, then tissue expansion as necessary.

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Reconstructive Options

Secondary Intention

Healing by secondary intention is an infrequently employed option for scalp defects. The authors

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caution against this method, as it generally gives an inferior result with an unacceptably lengthy time to full coverage, as the relative immobility of the scalp tissue prevents quick contraction. Cosmetic disadvantages include pigmentation abnormalities and tissue alopecia. Allowing for secondary intention healing may be preferentially utilized in cases of very small forehead wounds, excluding the scalp. In these cases, the resulting scar may be aesthetically superior to that from a graft, and hairlessness is ideal [1]. This method requires fastidious local wound care to stave off infection, including daily cleansing and application of moist dressings. Secondary healing should be avoided in all cases of exposed bone, where bone desiccation and osteomyelitis are better prevented with durable coverage.

Vacuum-Assisted Closure (VAC)

It is the opinion of the authors to generally avoid the use of negative-pressure dressings on the scalp. Application and maintenance of a functional seal frequently proves too challenging in hair-bearing regions. VACs primarily demonstrate utility in rare instances requiring wound temporization prior to skin grafting or reconstruction in a bald patient. In that case, a VAC dressing may provide good coverage to local wound care when bone is exposed in a patient awaiting reconstruction due to systemic instability, in process of serial debridement.

Primary Closure

Primary closure techniques are optimal for very small scalp defects 2 cm and smaller [2]. Though concerns for large patchy alopecia and pigmentation mismatch are obviated, this process can result in a scar which spreads over time, may distort scalp contours, and may cause facial asymmetry. Thus, this method should be employed on an individual basis. Particular care must be taken to refrain from displacing the brows and eyelids, and raising the hairline. Thus, vertically oriented defects are more amenable to primary approximation in the anterior scalp and forehead [1]. In general, the scalp tissue is relatively immobile. A tension-free primary closure is seldom attainable. Wide undermining is often necessary to minimize tension closure. Avoiding stress forces of scalp closures is imperative in order to reduce hair follicle loss and anagen phase arrest. Local anesthetic with epinephrine is useful to decrease skin edge bleeding and serves to hydrodissect the subgaleal plane. The galea is the most inelastic layer of the scalp. This layer should be scored in 1 cm intervals perpendicular to the desired direction of tissue gain to increase movement. Each incision affords 1.67 mm in tissue gain [3]. Scoring should be done at the underside of the galea with a scalpel to prevent injury to major vessels running between the galea and subcutaneous layers [2, 4].

The galea is the strength layer of the scalp and should be re-approximated when possible. 3-0 Vicryl suture may be employed for this purpose. There are instances where even scoring this inelastic layer does not afford enough advancement to bring the edges together. The authors recommend closing only the more superficial layers over stretching the galea and closing under tension. Skin staples are recommended for closure of the hair-bearing scalp, as they are non-ischemic and possibly less damaging to the follicles than sutures. Absorbable sutures, such as 4-0 chromic, should be used to close the non-hair-bearing skin whenever possible. If permanent sutures must be used, it is advised to use something with color, such as blue non-absorbable polypropylene, so it can be easily located among the patient's hair. The tails of the sutures should be left long for easy visualization and removal.

SkinTE™ Skin Product

SkinTE™ is an autologous, homologous skin product that facilitates rapid healing of difficult wounds, restoring pigment and adnexal structures of epidermis. It serves as a new type of full-thickness skin graft, with minimal donor morbidity and full restoration of native skin characteristics. The material is derived from the harvest of a small full-thickness skin graft taken

from the patient, usually in the groin region. A wound 100 square centimeters or less requires an elliptical full-thickness skin graft harvest of at least 3 × 1 cm. Substantial subcutaneous fat should be included in this graft. The graft is placed in special packaging provided by the company and overnight shipped to the PolarityTE™ manufacturing site. In approximately 48–72 hours, the company returns the skin material in a syringe for deployment. Deployment is performed in a sterile environment with aseptic technique (1 week to 10 days after harvest) into a wound bed prepared per typical clinical guidelines for any autograft. The product is deployed into the wound bed and evenly distributed with the back of a scalpel or forceps. A non-adherent, moisture-preserving dressing (which may be fenestrated) is placed over the SkinTE™. Over that, a sponge dressing with adhesive silicone borders is applied as a bolster. The wound is then cared for in the manner of any skin graft—the bolster remains in place for at least 5 days before unveiling.

SkinTE™ provides the advantage of reconstructing wounds in a full-thickness manner, with epidermis, dermis, and hypodermis. Hair follicles, native color, and sebaceous glands are regenerated, making this an especially attractive option for hair-bearing areas. An example of the successful use of SkinTE for scalp reconstruction is shown in Case 4. While this new technology has shown very promising results, use in complex scalp wounds, such as areas with exposed calvarium, previous radiation, and infection has yet to be fully studied. These cases should be weighed on a case-by-case basis and may be better suited for free flap reconstruction.

Skin Substitutes

Dermal regeneration templates have proven effective in staged reconstruction of challenging large scalp wounds, especially in systemically compromised patients unable to tolerate flaps. In irradiated patients, local tissue has often been exposed to the radiation field, rendering it a poor choice for expansion and adjacent transfer. Integra® (Integra LifeSciences, Plainsboro Township, NJ), a bilayer dermal template composed of bovine tendon and chondroitin-6-collagen beneath impermeable silicone, can be positioned above bone or soft tissue to facilitate a granulated neo-dermis for these patients. The Integra® slowly vascularizes over a two- to three-week period. After the silicone is removed, it serves as a reliable recipient for a skin graft. Note, using this method regenerates dermis requiring further reconstruction and is not a definitive closure technique. Integra® has been utilized in staged reconstruction with excellent results to cover up to 50% of the scalp area [5].

Integra® does require some underlying perfusion, though it can be used successfully over devascularized regions of up to 1 square centimeter. All wounds should be adequately irrigated and debrided before Integra® placement. For large wounds with denuded calvarium, the outer table of the skull should be burred to punctate bleeding. We suggest scoring or fenestrating the Integra to allow for fluid egress prior to application. The Integra® is placed over the wound bed with the silicone side up and stapled into place after hemostasis is achieved. A VAC dressing or bolster placed over non-adherent gauze is then stapled into place to bolster the region for 2–3 weeks, or until an adequate neo-dermis is observed [6].

Acellular dermal matrix (ADM) products may aid reconstructive efforts for challenging infected, oncologic, and irradiated scalp wounds. Use of ADM maintains tissue planes and provides durable coverage, allowing for resolution of underlying infection and facilitating future surgical reconstruction of calvarium when necessary [7]. ADM provides a scaffold for vascularization and helps regenerate dermis, which can subsequently be grafted. In irradiated and infected wounds, addition of ADM beneath a skin graft is thought to help prevent subsequent ulceration.

Skin Grafting

Skin grafting for scalp reconstruction may yield a rapid, cost-effective form of coverage for medium- (larger than 3 cm) to larger-sized

wounds while tissue is being expanded. This method is seldom an appropriate choice for definitive closure, due to poor aesthetics in hair-bearing regions. The exceptions to this include cases in which nearly the entire hair-bearing skin is compromised. For example, dissecting cellulitis of the scalp and severe hidradenitis can be so extensive as to leave no viable hair-bearing tissue to expand; the use of non-meshed split thickness skin grafts after debridement provides durable coverage to the entire scalp, with relatively low morbidity. The vascular pericranium is an ideal recipient bed for grafting full-thickness defects. Though previously described in the literature, burring the outer table of bone denuded of periosteum in preparation for a split-thickness skin graft has not facilitated an adequate wound bed in the authors' experience. Thus, we recommend proceeding straight to free flap reconstruction when possible in patients with exposed, denuded calvarium. Similarly, surgeons should exercise caution when utilizing grafts in patients treated with radiation; they are not the most durable choice for coverage and frequently break down in that context. Again, free flap coverage should be considered in those instances.

We advise using meshed split-thickness skin grafts meshed in a 1.5:1 ratio over scalp defects when the graft is solely placed to temporize the wound for further reconstruction. When used for definitive reconstruction, we prefer non-meshed split-thickness skin grafts for improved cosmesis. Further, defects that include the forehead should not be meshed, as sheet grafts will improve cosmesis in this area.

Local and Locoregional Flaps

An algorithmic approach to scalp and forehead reconstruction based on wound size and location has been previously described in the literature. While these flaps may be necessary in individualized clinical scenarios, the authors generally prefer SkinTE™, tissue expansion, and/or free flap coverage. We have found local tissue flaps to be less reliable and less aesthetic than the aforementioned. This section will focus on options for reconstructing moderate- to large-sized defects (>2 cm^2) with common locoregional flap options for those patients who are not candidates for SkinTE, tissue expansion, or free flaps.

Basing local tissue flaps axially on a known vessel is imperative; this reduces the risk of dreaded tip necrosis. Thus, the authors do not recommend random patterned locoregional flaps. Having a working knowledge of scalp vascular anatomy and using a Doppler to plan a flap is crucial to safe flap design. We do advocate the use of templates, which can be drawn and cut from esmarch bandage. The rigid curvature of the scalp frequently leads to underestimation of flap size necessary for adequate coverage. Further, it is important to remember that dog ears created at the pivot points of rotated flaps should not be excised at the time of flap reconstruction—they generally settle to an aesthetic contour over time, and trimming them can compromise flap pedicle vascularity.

Anterior Scalp

In this region, care must be taken to avoid distortion of the hairline. Further, the soft tissue in this region is comparatively more adherent. Anterior defects thus typically require local tissue transfer for coverage as well as significant undermining.

- Rotational advancement flaps are good options for moderate-sized defects under 25 cm. Rotational advancement flaps involve triangulating the defect with a semicircular incision behind it; the tissue in the semicircle is undermined beneath the galea and rotated toward the triangle. Bilateral rotation flaps can be designed so as to flank a defect, with the tissue rotated inward to provide equal coverage from both sides [8].
- A Juri flap, based on the posterior parietal branch of the superficial temporal artery, is a curved strip from the parietal scalp that can be rotated anteriorly to transversely cover anterior scalp defects near the hairline. This can be especially useful to restore the hairline itself, though does often produce hair growth in an unnatural direction. Delaying this flap is recommended [1].

- Large defects greater than 50 cm^2 may call for a contralateral rotational flap based on the occipital artery, as well as an ipsilateral rotational flap based on the superficial temporal artery.
- Large defects may also be repaired with the classic Orticochea flap—two large flaps based on the superficial temporal arteries are advanced anteromedially; a third posterior flap based on the occipital arteries is advanced forward to cover the donor defect of the initial two flaps. A skin graft fills in the posterior defect created by advancing the third flap [4].

Parietal Region

The tissue in this region is comparably mobile, owing to the superficial temporoparietal fascia overlying the deep temporal fascia. When utilizing rotational flaps, dog ears should be designed posteriorly when possible.

- For defects between 3 and 25 cm, rotational flaps work well. One rotational flap based on the ipsilateral occipital artery, combined with one based on the contralateral occipital and superficial temporal artery, can provide complete coverage [4].
- Pinwheel flaps may also be utilized for small to moderately sized defects in this region. Pinwheel flaps should contain four semicircular flaps around the defect, each with a length equaling the radius of the wound. These limbs are elevated in the subgaleal plane, scored as necessary, and rotated into the center of the defect for coverage. Elevation should take place in the subcutaneous plane over the temple [4, 9, 10].
- Parietal defects over 50 cm^2 should be approached with skin grafting or tissue expansion [4].

Vertex

This is a difficult region to reconstruct, as the skin here is relatively immobile. Reconstruction often requires wide undermining and advancement of tissue from the occipital and parietal regions.

- Small defects can be closed with elliptical excision in a 3-to-1 ratio of length versus width. Wide undermining and galeal scoring facilitate primary closure.
- Medium-sized defects up to 25 cm^2 may be closed with pinwheel flaps or rhomboid flaps [4].
- Large defects greater than 25 cm^2 may call for the advancement of a large occipital flap with skin grafting or delayed reconstruction with expansion of the donor site defect [4].

Occipital Region

The occiput is moderately mobile and less cosmetically sensitive than the other areas of the scalp. Expansion is recommended in this region when possible.

- Moderate defects may be addressed with rotational flaps, with extension over the trapezius if necessary.
- Orticochea flaps were classically designed for large occipital defects over 25 cm^2. The three-flap technique is preferred for improved perfusion [4].

Free Tissue Transfer

Free tissue transfer is indicated for large defects, especially in areas with absent periosteum or full-thickness calvarial bone defects. Transfer of new well-vascularized tissue is often ideal for total scalp defects, in wounds with osteomyelitis, previous or planned radiation, or in which simpler reconstructive options have failed. The disadvantages of free flaps are that they require extensive training, involve significant donor site morbidity, and can often compromise cosmetic outcomes. However, the combination of temporary wound stabilization with a free flap followed by tissue expansion can give excellent results, as shown in Case 1 (Fig. 18.1a–d).

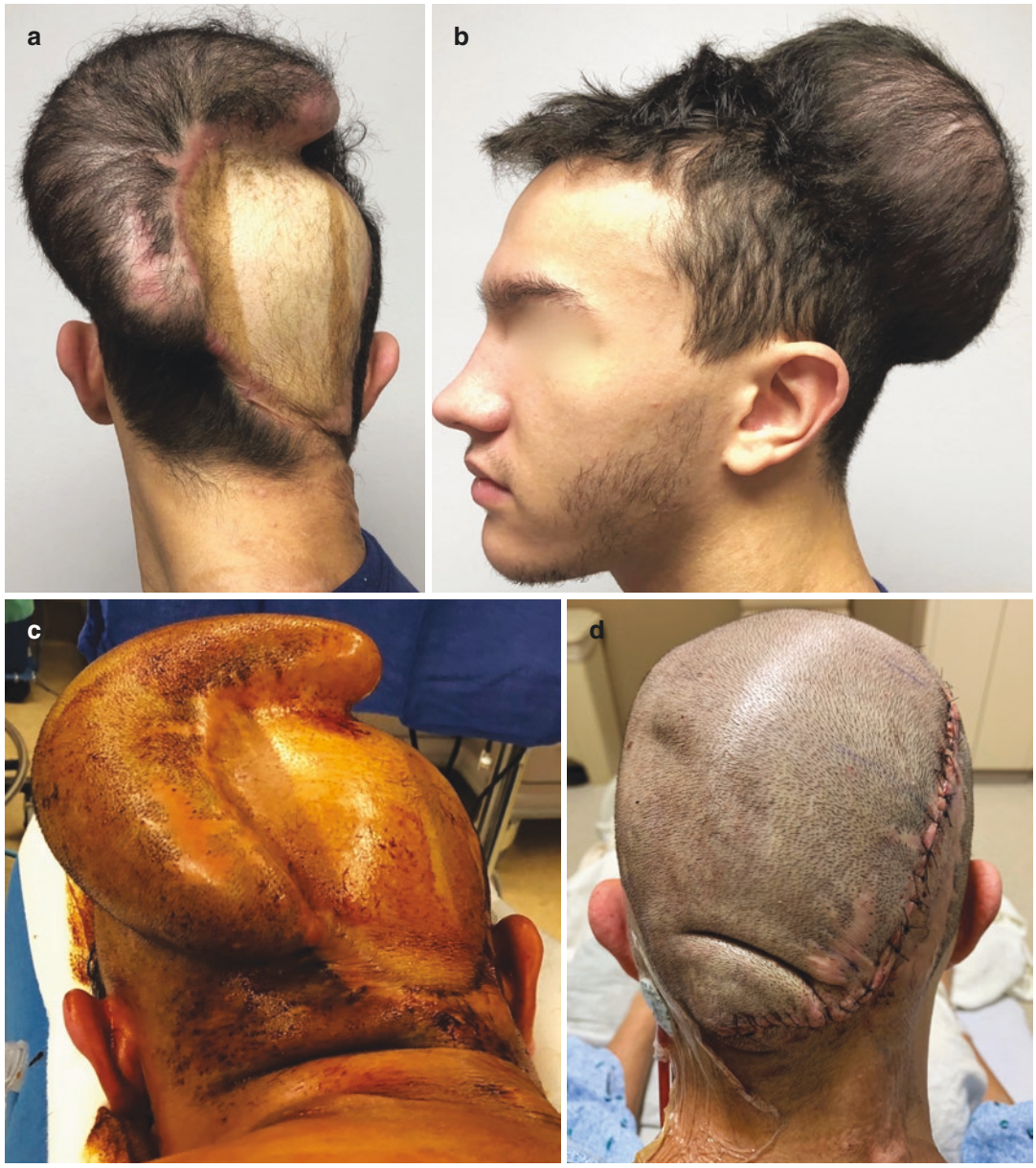


Fig. 18.1 (**a**–**d**) Case 1

A variety of free flaps have been described to reconstruct the scalp, including the latissimus dorsi, rectus abdominis, anterolateral thigh (ALT), radial forearm, omentum, and serratus free flap [11–13]. The latissimus dorsi muscle flap has been well described and is commonly used for total and near-total scalp defects. This is in part due to its robust size, long vascular pedicle, and ability to contour well over the calvarium as the muscle atrophies [13, 14]. However, muscle flaps can cause significant donor site morbidity, can become tenuous as the muscle atrophies, and often also require skin grafting from a second donor site.

It is therefore our preference to use fasciocutaneous flaps for scalp reconstruction, most often

the ALT flap. The ALT flap offers many advantages. It is versatile and offers a large piece of soft tissue that can be harvested as an adipocutaneous, fasciocutaneous, or chimeric flap. It therefore does not usually require an additional skin graft or sacrifice any functional muscles. It can be harvested in the supine position without intraoperative position changes, and is easily re-elevated for any revision surgeries or need for underlying hardware removal. One major disadvantage is the bulkiness of the flap, especially in the Western population. Patients should always be counseled on the potential need for additional debulking and contouring procedures in the future.

Free flaps intended for scalp reconstruction should be designed and oriented based on the recipient vessels. The preferred recipient vessel in our practice is either of the bilateral superficial temporal vessels, as they are convenient in size and location. When these vessels are unavailable, branches from the external carotid artery such as facial, lingual, and superficial thyroid arteries are suitable in caliber, but are farther away from the scalp and may require vein grafts.

Tissue Expansion

Tissue expansion is a technique used to obtain additional tissue via an inflatable silicone elastomer reservoir. This process is particularly useful in reconstruction of the scalp because it can expand the scalp's hair-bearing areas to restore the patient's natural hair patterns. Restoration of hair can be the most important aspect of a cosmetically acceptable outcome for both the patient and the surgeon. Tissue expanders can be used in many places in the body, but the scalp is particularly suited for this technique because the skull provides a rigid base for unidirectional expansion, and the overlying skin is thick, which helps reduce the risk of wound complications and extrusion of the implant.

Expander Choice

The ideal tissue expander can be different in the scalp than in other areas of the body. The expander shape influences the amount of surface area gain, and it has been found that expanders with a round base, a crescentic base, and a rectangular base provide a tissue gain of 25%, 32%, and 38%, respectively [15]. While the rectangular-base expanders may provide more tissue gain, we have found the crescentic-based implants to be more suitable for the round shape of the skull. Implants with integrated ports are used to negate the need for additional undermining and a separate port site. This is especially important when the amount of expandable hair-bearing area is small. The potential height of the expander must be considered, because the projection of the expander is the most important factor in gaining as much expanded tissue as possible [16]. In general, the best expander choice for the scalp is a narrow, tall curvilinear implant with an integrated port.

Expander Placement

The expander should be placed in a hair-bearing area in the subgaleal plane. This plane is easy to undermine because of its relative avascularity. The implant is placed adjacent to the defect to be reconstructed and, if possible, parallel to the longest side of the defect. It is important to not undermine under the actual defect when placing the expander nearby, as you only want to expand the hair-bearing area and not any scar tissue or previously placed flap or graft. An initial filling of the expander can be attempted in conjunction with its placement; however, when there is too much tension, filling should be delayed until healing has occurred. In fact, the authors suggest waiting to expand until the defect is healed, in all cases when possible. An expander placed next to an open wound greatly increases the chances of infection.

Rate of Expansion

In general, slow expansion is optimal for the scalp because of the density of the tissue. Surgeons can fill the expander once weekly, as long as the patient can tolerate it. In certain instances, when the patient lives far away or otherwise cannot conveniently attend regular office visits, the patient or parent can be taught to fill the expander themselves at home. Sufficient expansion can generally be achieved in about six to 8 weeks.

An easy trick to determine when you have sufficiently expanded the tissue is to measure the circumference of expanded tissue in the direction you want to advance it, then subtract the base width. Once this number is equal to or greater than your defect size, you are likely to have enough tissue. When you have reached the optimal fill volume, wait about 4 weeks after final expansion before removal of the expander and advancement of the scalp flap. The surgeon must account for scar formation along the base of the expanded tissue, as well as capsule formation around the expander; this may prevent the expanded tissue from lying flat along the contours of the calvarium. Taking this into consideration, the surgeon must plan for expanding enough skin to create a flap to cover the donor site when possible, in addition to filling the scalp defect. Thus, overestimating the amount of tissue needed is preferable to expanding solely on measurement of the defect.

Tissue Expander Complications

Wound-healing complications and exposure of the implant may occur during the expansion process. In the event of tissue expander exposure, if there are no signs of infection, schedule the patient for the operating room. After removing the tissue expander, evaluate the defect and close the wound, if possible, with the amount of expanded tissue. If closure is not possible and more tissue expansion is needed, the already expanded tissue may be advanced as much as possible to reconstruct as much of the defect as possible, and a new expander may be placed back into the same pocket. Tissue expansion may resume in the new expander as soon as incisions are healed. When infection has occurred, remove the tissue expander, wash out the pocket with antibiotic solution, and advance and close as much as possible. Do not replace with a new tissue expander in an acutely infected wound. Wait about 3 months before placement of a new tissue expander.

Approach to Large Defects and Case Examples

For large defects, the first step is to attain initial coverage and wound stabilization. It is the preference of the authors to attain initial coverage of large defects with either skin grafts or local or free flaps. This initial coverage will serve to stabilize the wound and prevent further complications, such as desiccation and infection. The choice of coverage will be dependent upon the size and characteristics of the defect. If the defect is large with intact periosteum, a split-thickness skin graft (STSG) is preferred. Large wounds that are not suitable for grafting are usually treated with a free flap. The wound is then allowed to heal completely before moving on to the next stage of reconstruction, which is to restore hair-bearing scalp. These principles are highlighted in the following case examples. In addition, the successful use of SkinTE to restore hair-bearing scalp is highlighted in Case 4.

Case Examples

Case 1 (Fig. 18.1a–d) A 17-year-old male sustained a large scalp and calvarial wound after electrocution with a high-voltage cable box. The initial wound was debrided and covered with a large ALT flap from the right thigh (previous skin graft donor sites are visible on the ALT). After allowing to heal, tissue expansion was used to restore hair-bearing scalp. The residual dog ear was managed at a later date.

Case 2 (Fig. 18.2a–d) A young girl was mauled by a dog, and initially reconstructed with primary closure and skin grafting. Hair-bearing scalp was then restored via tissue expansion.

Case 3 (Fig. 18.3a–f). A female patient with recurrent dermatofibrosarcoma protuberans had a radical excision and reconstruction with a latissimus muscle flap and split thickness skin graft. An anterior hairline was then restored with tissue expansion.

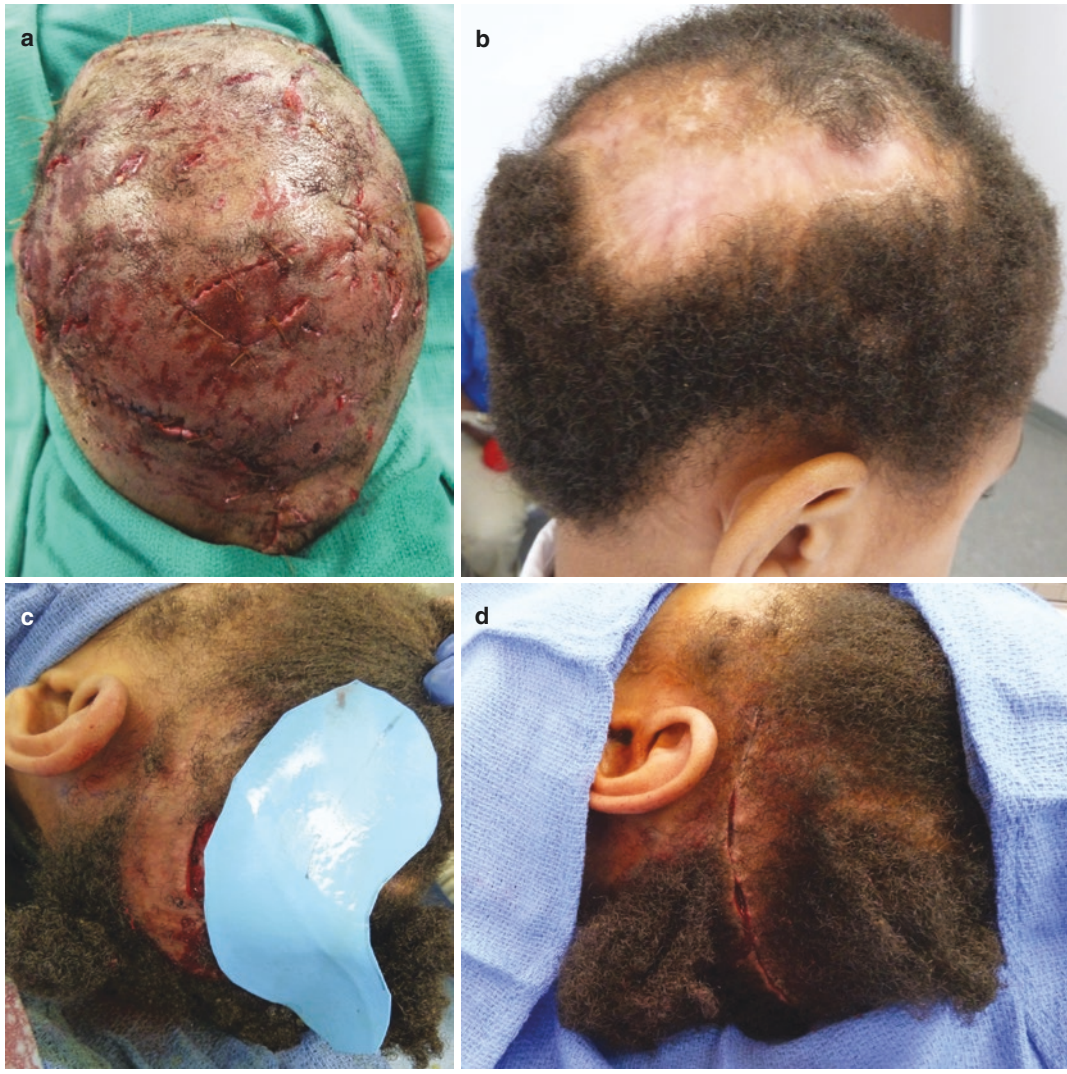


Fig. 18.2 (**a**–**d**) Case 2

Case 4 (Fig. 18.4a–c) A 73-year-old male patient on immunosuppression presented with 2 cm x 2 cm squamous cell carcinoma near the scalp vertex. He had a history of multiple malignant lesions of the scalp and body, which had been previously excised with subsequent skin graft reconstruction. This, in addition to his immunocompromised state, made him a poor candidate for further skin grafting (patient had used optimal donor sites) and flap reconstruction. SkinTE™ was deployed over intact pericranium into the defect after excision, which measured 3 cm in greatest diameter. Patient demonstrated complete healing at his three-week postoperative follow-up, with no further episodes of infection or ulceration.

Case 5 (Fig. 18.5a–d). A male patient in his 80s presented with a chronic, open scalp wound with exposed bone for 5 years, complicated by recurrent episodes of infection and osteomyelitis. The defect was initially caused by an excision of squamous cell carcinoma from the right temporoparietal region. The region had been irradiated. Attempts to reconstruct the defect with a skin graft immediately after excision failed, given the unfavorable wound environment. A free

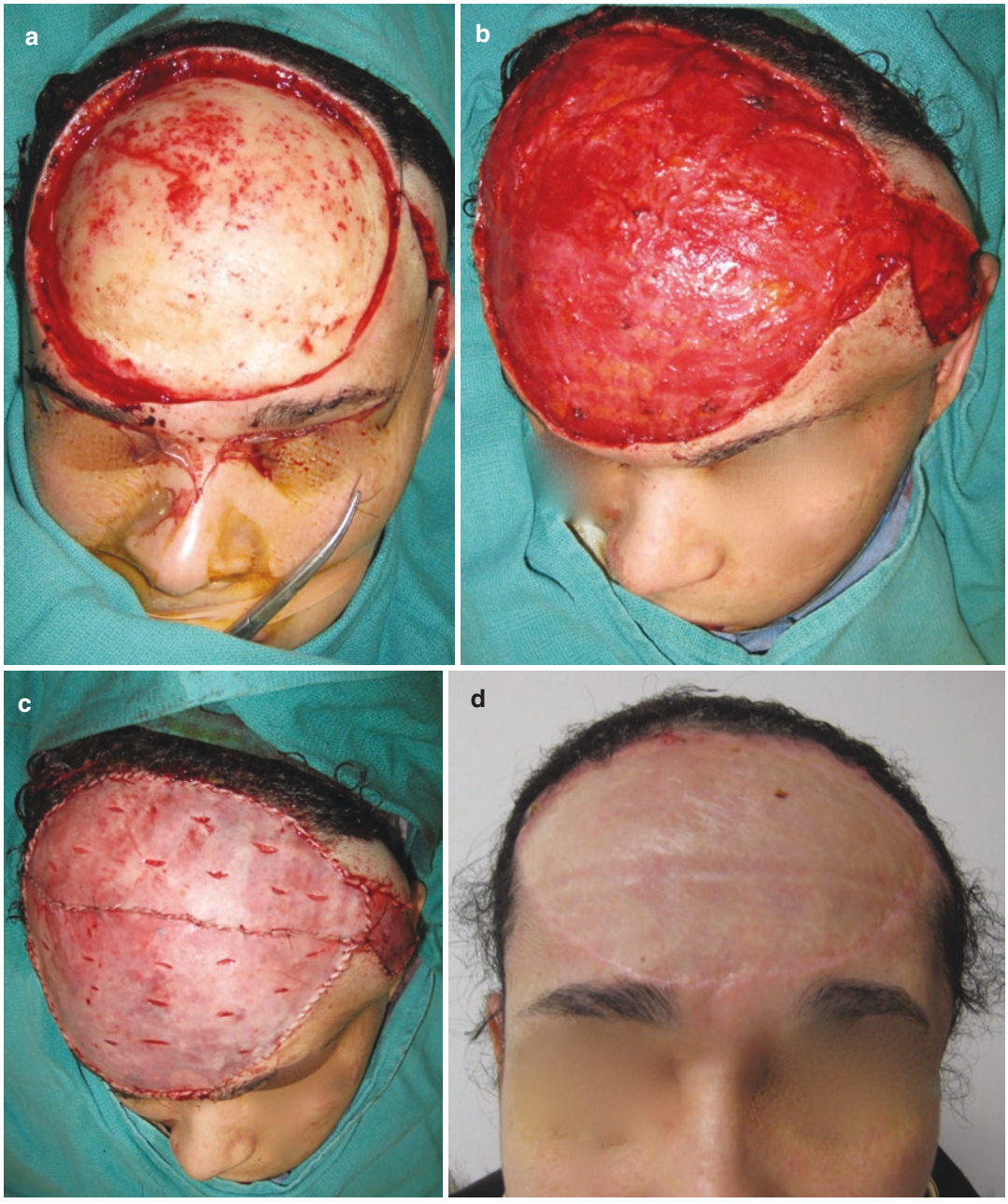
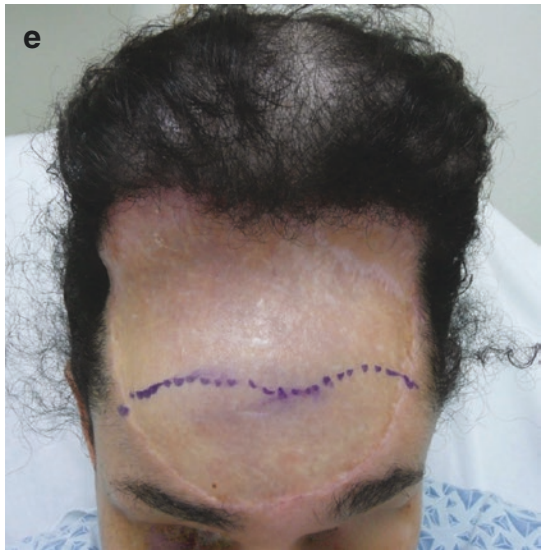


Fig. 18.3 (**a**–**f**) Case 3



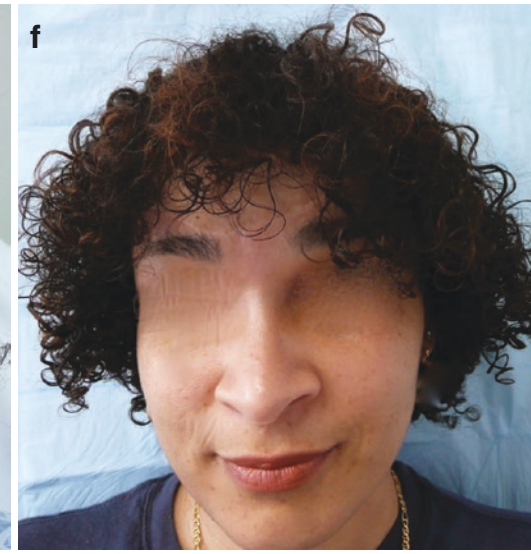
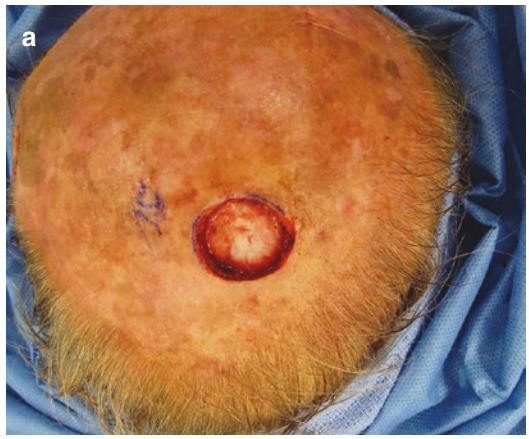
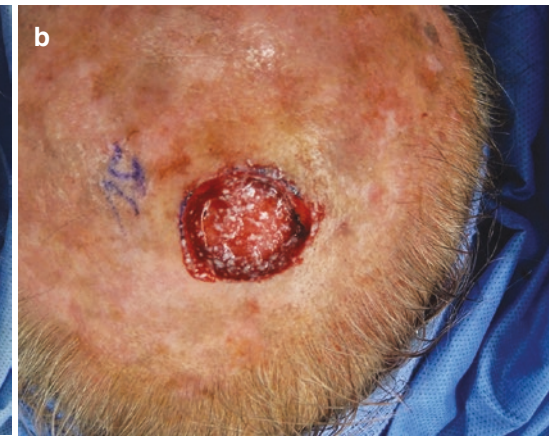


Fig. 18.3 (continued)





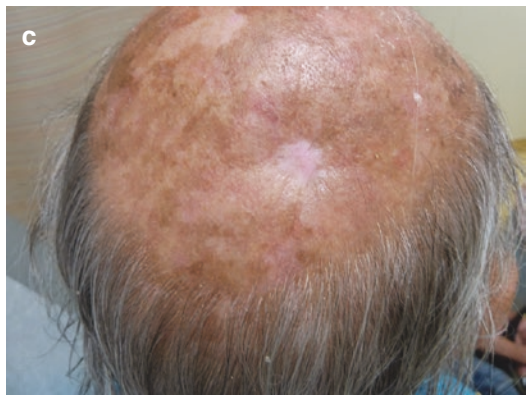


Fig. 18.4 (**a**) Demonstrates patient's remaining defect, 3 cm in diameter after excision with margins. Pericranium was left intact. (**b**) Patient's same scalp defect at the unveiling of the SkinTE™, 5 days subsequent to deployment. Small *white* "skin islands" within the wound elute cytokines that promote epithelialization from each island. (**c**) Patient at 3 weeks after deployment of SkinTE™, demonstrating complete, full-thickness healing

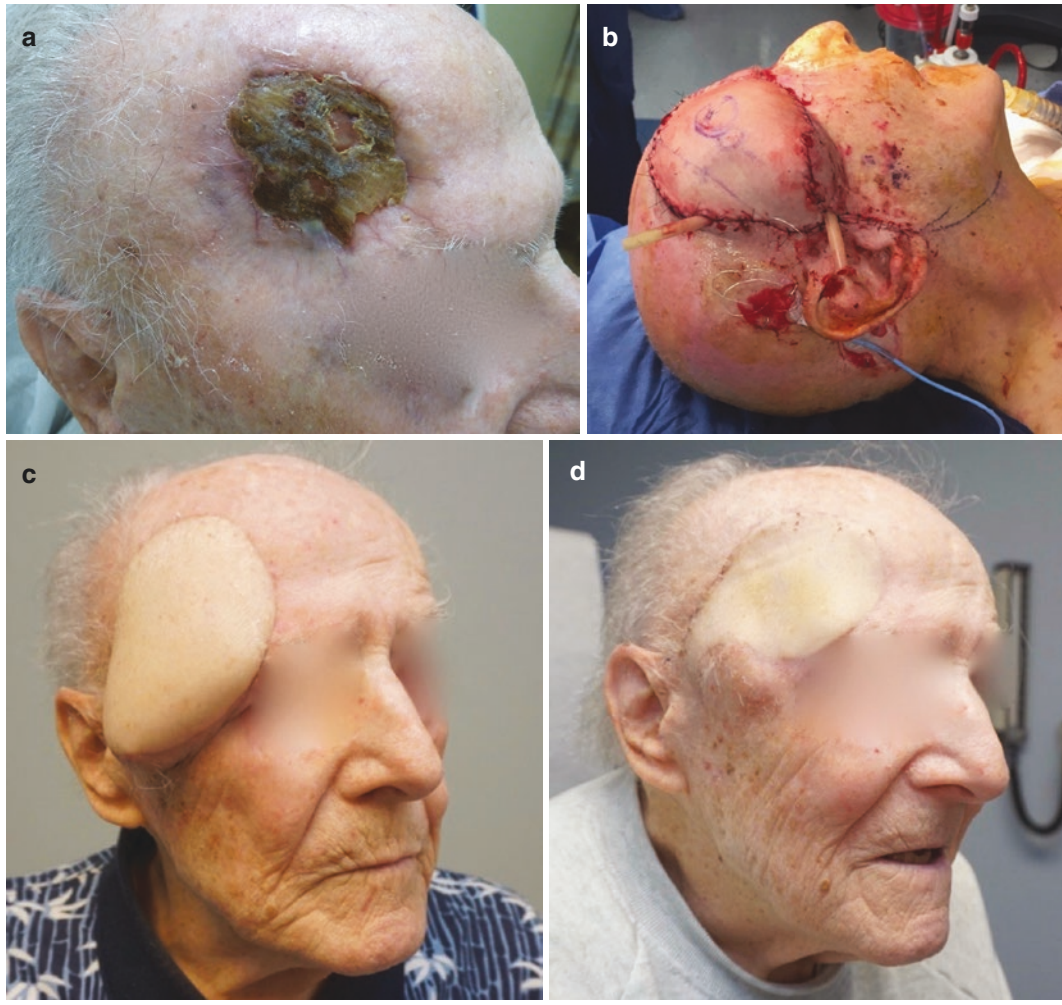


Fig. 18.5 (**a**) Patient prior to reconstruction. (**b**) Intraoperative image of patient immediately after inset of anterolateral thigh flap to right temporoparietal scalp defect. (**c**) Patient 6 months after free anterolateral thigh flap scalp reconstruction, prior to revision. (**d**) Patient 1 month postoperatively from free flap revision and liposuction

anterolateral thigh flap was used for coverage after radical debridement. Revision and liposuction to the flap was performed 6 months after flap reconstruction to improve contour and cosmesis. This reconstruction proved successful, with no subsequent episodes of ulceration or infection.

Conclusion

The aesthetics and relative immobility of the scalp make it a challenging region to reconstruct. The authors have found it useful to focus on defect size as a starting point for operative planning. Most importantly, each reconstruction should be considered under the model of the "reconstructive elevator," where the defect and patient characteristics determine the complexity of the repair—there is no need to trial less technically demanding modalities should the size and depth of a wound require, for example, a free flap. That being said, staged procedures are often safe and effective and produce cosmetically pleasing results. Hair-bearing regions may be completely restored with the use of tissue expansion and subsequent tissue transfer. We encourage surgeons to take a holistic view of their

patients and discuss surgical goals extensively when embarking on these oftentimes difficult cases.

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Thoracic and Abdominal Wall Reconstruction

19

Sahil K. Kapur, Alexander F. Mericli, and Charles E. Butler

Introduction

The thorax and abdominal wall fulfill a number of vital anatomic and physiologic roles, fundamental to normal function. As such, thoracic and abdominal reconstruction share a relatively unique distinction in plastic surgery, since the creation of a reliable, durable, wound closure can be truly a life-saving procedure. The two most common abdominal wall reconstructive indications are either related to ventral hernia or an oncologic defect. There are generally four indications for thoracic reconstruction: oncologic resection defect, soft tissue or skeletal radiation injury, trauma, or infection (Table 19.1). Although differing in anatomic location as well as etiology, the reconstruction of the chest, sternum, and abdominal wall share many of the same key principles, including adequate debridement, load-bearing structural reconstruction, and recruitment of well-vascularized soft tissue to manage dead space, protect vital structures, and provide external coverage.

Table 19.1 Common etiologies of thoracic defects requiring reconstruction

Malignant neoplasm
Locally advanced tumor
Breast carcinoma
Lung carcinoma
Primary tumor
Soft tissue sarcoma
Chondrosarcoma
Ewing sarcoma
Metastatic tumor
Sarcoma
Renal cell carcinoma
Colorectal tumor
Benign neoplasm
Osteochondroma
Chondroma
Fibrous dysplasia
Desmoid
Infection
Necrotizing soft tissue
Costochondritis
Osteomyelitis
Trauma
Osteoradionecrosis

Thoracic Reconstruction

Technique I: Oncologic Chest Wall Defect—Lateral

Depending of the extent of disease, oncologic chest wall defects may be minor—limited to the skin and subcutaneous tissue—or can be mas-

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sive, involving the full thickness of the thorax including ribs, musculature, and/or lung. Regarding the former, the general principles illustrated by the reconstructive ladder can serve as a useful framework; however, for extensive defects, a more nuanced approach is beneficial.

The indications for skeletal chest wall reconstruction are controversial and should be determined on an individual basis. In general, guidelines suggest that defects with a diameter of at least 5 cm, or involving three or more adjacent ribs, will benefit from a rigid or semirigid reconstruction [1–3], aiding pulmonary mechanics, protecting the lung and/or heart, and maintaining a normal chest contour. Posterior chest wall defects, as well as those that have been irradiated, can typically tolerate a larger resection without the need for semirigid structural reconstruction. A variety of synthetic, bioprosthetic, rigid, and semirigid materials have been described, each with advantages and disadvantages (Table 19.2).

Table 19.2 Materials used for skeletal chest wall reconstruction

Material	Rigidity	Advantages	Disadvantages
Polyethylene	Semirigid	Inexpensive Macroporous, permitting ingrowth	Prone to fraying and fragmentation Contraindicated in contaminated/complex wounds Infection usually necessitates removal
Polypropylene	Semirigid	Inexpensive Macroporous, permitting ingrowth Double-knitted; flexible in two dimensions	Contraindicated in contaminated/complex wounds Infection usually necessitates removal
Expanded polytetrafluoroethylene	Semirigid	Watertight seal Ease of handling	Encapsulates; no tissue ingrowth Seroma formation Contraindicated in contaminated/complex wounds Infection usually necessitates removal
Methylmethacrylate	Rigid when sandwiched between two synthetic meshes	Used in combination with porous synthetic mesh Can be molded to chest contour	Cures by exothermic reaction, putting tissues at risk for thermal injury May fracture Rigidity is nonanatomic (contoured) No tissue ingrowth Seroma formation
Bioprosthetic	Semirigid	Semirigid, dynamic Incorporates into host tissues Decreased risk of infection Can be used in irradiated wounds Infection/exposure does not necessitate removal	Expensive Will not maintain chest contour in large defects
Titanium rib plating	Rigid	Anatomic design, recreating chest contour and physiologic compliance Improved pulmonary function	Expensive Long-term durability unknown Requires an underlay synthetic or bioprosthetic mesh for pleural reconstruction Requires specialty instrumentation Radiopaque

Tips

- Communicate with the thoracic surgeon preoperatively to ensure that the latissimus dorsi and serratus anterior muscles can be spared during the thoracotomy. The latissimus, in particular, is often transected during a thoracotomy, often rendering it useless for reconstructive purposes.
- If skeletal chest wall reconstruction is necessary, determine if a rigid or semirigid reconstruction would be best. Rigid reconstructions are most useful for larger defects and are commonly achieved with a "polypropylene-methylmethacrylate sandwich," layering the acrylic resin between polypropylene mesh. Special care must be taken with methylmethacrylate, as it cures through an exothermic reaction; thermal injury is possible if precautions are not taken.
- Titanium plating systems are another option for rigid reconstruction. The plates are fixated to the anterior and posterior margins of the cut ribs, with the plate spanning the defect. Often, a synthetic or biologic mesh is used in concert with these plating systems, in order to prevent lung herniation. Rib plating is favored for particularly large resections and multi-rib defects involving the more inferior (5–9) ribs, due to their important role in respiratory mechanics. Several studies have demonstrated improved pulmonary function with rib plating [4–7].
- Semirigid reconstructions can be performed with either synthetic or bioprosthetic mesh. Bioprosthetic mesh is often recommended in clean-contaminated and contaminated cases.
- Bioprosthetic and/or synthetic chest wall mesh is secured to the defect margins with interrupted circum-rib #1 permanent monofilament sutures (polypropylene or nylon). The mesh should be secured as a bridged repair, with 3–5 cm of overlap under the musculoskeletal chest wall border. The construct is precisely tailored so that there is no redundancy (Fig. 19.1).
- Most cases of chest wall mesh infection are preceded by necrosis of the overlying soft tissue. Therefore, it is absolutely important that any mesh construct be covered with well-vascularized soft tissue. If the skin of the chest wall has been previously irradiated or scarred from prior surgeries, the plastic surgeon should consider using a pedicled regional muscle flap to interpose between the mesh and the skin for additional coverage (Fig. 19.2a and b). Common flaps for this purpose are listed in Table 19.3.

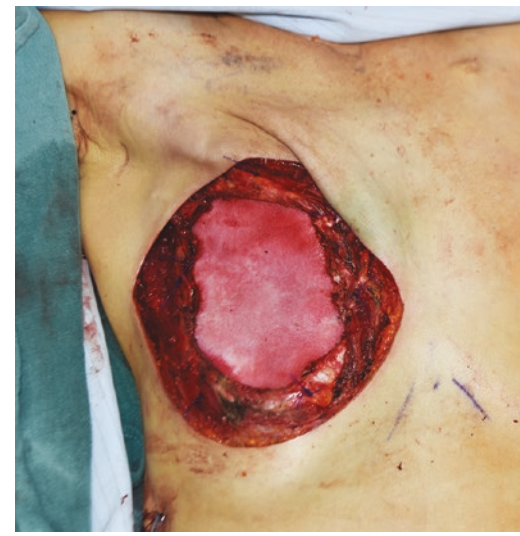

Fig. 19.1 Intraoperative photograph of a biologic mesh inset as an underlay for skeletal chest wall reconstruction after extirpation of a chondrosarcoma, necessitating an en bloc resection involving three consecutive ribs

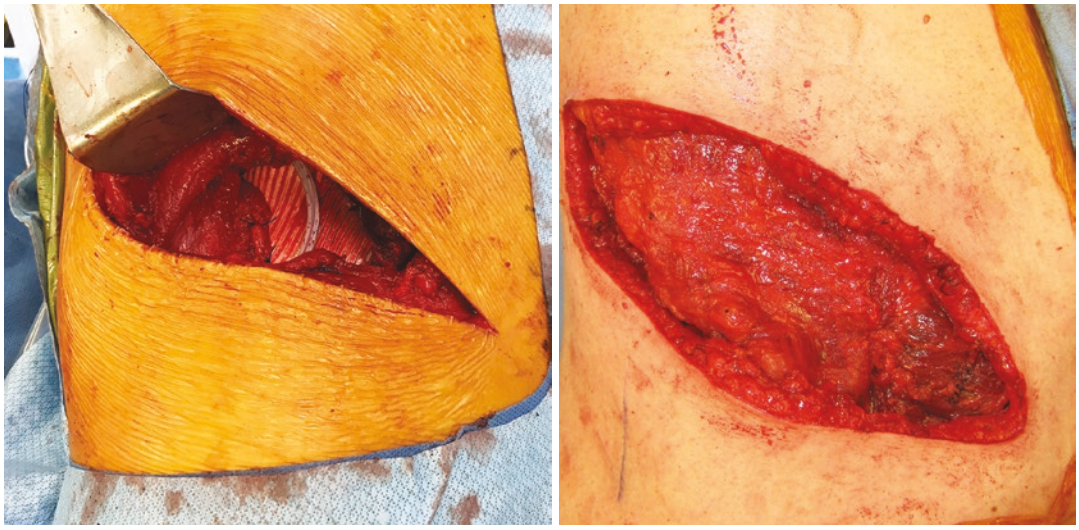

Fig. 19.2 Intraoperative photograph of a pedicled latissimus dorsi muscle flap, inset to interpose between a bridged synthetic mesh chest wall repair and the overlying skin

Table 19.3 Common regional flaps used for chest wall coverage

Flap	Included tissues	Approximate size (cm)	Vascular supply	Common applications
Pectoralis major	Muscle or myocutaneous	15 × 23	Thoracoacromial Internal mammary perforators	Anterior chest Sternal wound Intrathoracic space
Serratus anterior	Muscle or myocutaneous	15 × 20	Serratus branch of thoracodorsal Lateral thoracic vessels	Intrathoracic space
Latissimus dorsi	Muscle or myocutaneous	25 × 35	Thoracodorsal vessels Intercostal and lumbar perforators	Anterior, lateral, and posterior chest Intrathoracic space
Rectus abdominis	Muscle or myocutaneous	25 × 6	Deep inferior and superior epigastric vessels	Anterior chest Sternal wound
External oblique	Muscle or myocutaneous	15 × 30	Lumbar perforators	Inferior third of anterior chest
Omentum	Visceral adipose	Variable	Right or left gastroepiploic	Sternal wound Intrathoracic space
TDAP[a]	Fasciocutaneous	8 × 35	Thoracodorsal	Anterior, lateral, and posterior chest
IAP[b]	Fasciocutaneous	5 × 15	Intercostal perforator	Small anterior chest wounds

[a]Thoracodorsal artery perforator flap
[b]Intercostal artery perforator flap

Technique II: Sternal Defect

Most commonly, sternal wound reconstruction is required as part of the surgical treatment of an infected median sternotomy incision. Pairolero and Arnold classified sternal wound infections into three distinct subtypes [8]. Only types 2 and 3 require operative treatment: type 2 is best described as an acutely purulent infection, whereas type 3 is more indolent, and typically indicative of osteomyelitis, costochondritis, or retained foreign body. In general, at least one

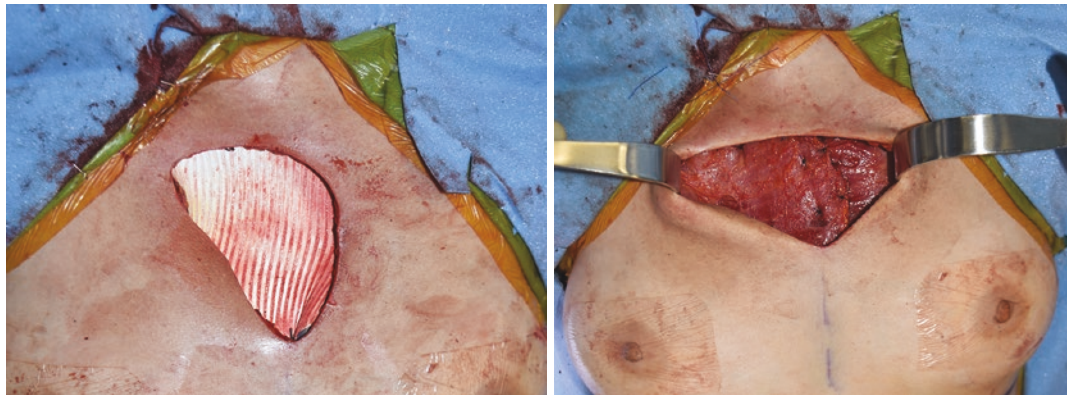

Fig. 19.3 Intraoperative photograph of bilateral pectoralis major muscle flaps used to interpose between a bridged synthetic mesh sternectomy/manubriumectomy repair and the overlying skin

operative debridement is required prior to definitive wound reconstruction. Indeed, adequate debridement is the cornerstone of the surgical management of the infected sternal wound.

Midline sternal defects may also occur after partial or total sternectomy for oncologic purposes. Similar to the lateral chest wall, metastatic tumors are the most common indication for oncologic sternectomy, followed by primary bone or soft tissue tumors and osteoradionecrosis [9]. The pectoralis major muscle flap (Fig. 19.3a and b) is a reliable option for soft tissue reconstruction after oncologic sternectomy.

Tips

- In patients with suspected sternal wound infection, a CT scan of the chest can be helpful for identifying drainable abscesses. If osteomyelitis is suspected, an MRI permits visualizing the extent and location.
- The initial debridement should be aggressive, including removal of all nonviable soft tissue, cartilage, and bone, until uniform bleeding is appreciated from the remaining wound base. All hardware and sternal wires should be removed. Cultures should be sent to the microbiology lab. It is helpful to paint the entire wound cavity with methylene blue dye, in order to be certain that all exposed tissue is debrided.
- If definitive reconstruction is not possible at the time of the first debridement, negative pressure wound therapy may be utilized to temporize the wound and stabilize the tissues. Negative pressure wound therapy has been shown to decrease the number of days between the initial operative debridement and definitive closure, expedites the formation of granulation tissue within the wound, encourages angiogenesis, promotes wound contraction, and reduces the number and frequency of dressing changes [10].
- Rigid sternal fixation—titanium plating or wires—after sternal wound infection is controversial. Some surgeons prefer to eliminate the presence of foreign bodies within the wound, opting for soft tissue flaps only. Others adhere to the principles of osteosynthesis, believing that reducing micromotion at the sternotomy site will contribute to a decreased infection risk. Ultimately, the decision for or against fixation should be made in concert with the cardiothoracic surgeon.
- Pectoralis major muscle advancement flaps are the workhorse for sternal defect soft tissue reconstruction. Based on the thoracoacromial vessels, the muscle can

be disinserted from the humerus and advanced medially.
- Unilateral or bilateral pectoralis major advancement flaps can resurface the superior two-thirds of the defect, but are not ideal if defect has a significant dead space component.
- If the wound is a deep cavity, or is located more inferiorly, a turnover pectoralis major flap based on the internal mammary perforating vessels may be a better option. However, a turnover flap is contraindicated if the internal mammary artery on that side was used for coronary revascularization.
- Secondary options for sternal wound reconstruction include a superiorly based rectus abdominis muscle or myocutaneous flap, omental flap, or any variety of free tissue transfer.
- An omental flap can be routed transdiaphragmatically, or through an iatrogenically created epigastric hernia. The chest wall skin can be closed over the omentum flap, or it can be skin grafted.
- Free flap options for the midline chest include thigh-based and abdominally based flaps. This eliminates the need for a position change, such as would be required for a latissimus flap harvest. Recipient vessel options include the internal mammary vessels, thoracoacromials, transverse cervicals, or a branch of the external carotid (typically with a vein graft for added pedicle length).

Technique III: Intrathoracic Reconstruction for Bronchopleural Fistula Repair

Intrathoracic—or pleural cavity—reconstruction is often associated with an empyema or bronchopleural fistula (Fig. 19.4). These complications are highly morbid and associated with a mortality rate of up to 50% if not appropriately treated [11]. Because the pleural cavity is a noncollapsible space, deep infections are unlikely to resolve unless the thoracic volume is either collapsed down and/or filled with vascularized tissue. There are a multitude of flap options for intrathoracic reconstruction, including the latissimus dorsi, serratus anterior, rectus abdominis, and pectoralis major muscles, as well as the pedicled omentum flap. After an adequate debridement, such flaps can assist in healing an empyema cavity or seal a dehisced bronchial stump.

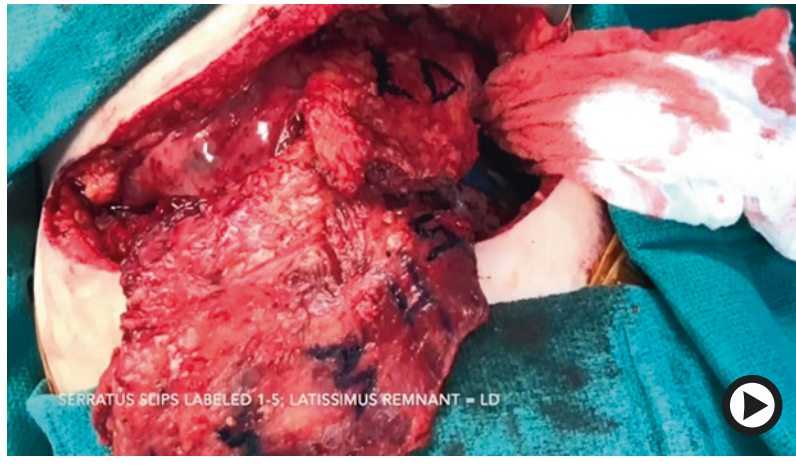

Fig. 19.4 Video of a pedicled serratus anterior muscle flap for intrathoraric bronchopleural fistula repair (▶ https://doi.org/10.1007/000-3tr)

Tips

- After performing a latissimus dorsi muscle-sparing thoracotomy, the chest cavity is entered most commonly between the fifth and sixth ribs, and the pleural cavity debridement is completed by the thoracic surgeon. A segment of rib can be removed to allow the flap to enter the chest cavity.
- If there is intrapleural dead space as a result of a pneumonectomy or pulmonary scarring, it is helpful to estimate the flap volume needed to fill the cavity. To do so, the lung should be fully inflated and saline is poured into the chest, noting the liquid volume needed to fill the space. Assuming a muscle thickness of 1.5 cm for the serratus or latissimus, the flap length and width can be measured to calculate flap volume. Defects of 300 cc or less can be adequately filled with a pedicled serratus flap, whereas larger defects will likely require a latissimus dorsi, chimeric latissimus-serratus flap, or omental flap.
- Because intrathoracic reconstructions are most commonly performed in order to treat a complication resulting from a prior thoracotomy, the latissimus is often not available for use, having already been transected. Therefore, the serratus anterior muscle flap may be more clinically relevant.
- Skin flaps are elevated in the suprafascial plane. The latissimus dorsi remnant is elevated off the superficial surface of the serratus anterior, as is the pectoralis major muscle, anteriorly.
- The serratus anterior muscle is a type III muscle flap, with a codominant blood supply via the serratus branch of the thoracodorsal vessels and the lateral thoracic vessels, both of which run on the superficial surface of the muscle. The location of these vessels can be confirmed with Doppler ultrasonography intraoperatively. The serratus branch is somewhat longer, allowing for a greater arc of rotation; therefore, most serratus flaps are designed using the serratus branch of the thoracodorsal vessels as the pedicle. The long thoracic nerve supplies motor input to the muscle, and runs parallel to the lateral thoracic vessels.
- As long as the superior three to four slips of the serratus anterior muscle are maintained, scapula winging should not occur. The inferior four to five slips are elevated off the chest wall and ribs, in an anterior-to-posterior direction. The lateral thoracic vessels are divided to increase the flap's reach. Figure 19.5 shows a chimeric muscle flap, including the inferior five slips of the serratus anterior muscle and the superior remnant of the latissimus dorsi (the latissimus had been transected in a prior thoracotomy). Only the slips corresponding to those in the flap are disinserted from the scapula. Similarly, the long thoracic nerve to the slips not included in the flap should be maintained.
- The pedicle is circumferentially dissected superiorly toward the axillary vessels. If added flap volume is needed, the latissimus dorsi muscle can also be included to make this a chimeric flap. Alternatively, if volume is not a concern, the branch to the latissimus dorsi can be divided to increase pedicle length for the serratus muscle flap.
- At the level of the flap pedicle, a 4–6 cm segment of second rib and the associated intercostal musculature is removed to create a chest wall window. The muscle flap is carefully passed through this window into the pleural cavity, ensuring that there is no tension on the pedicle.
- With the assistance of thoracic surgery, the flap is secured within the pleural cavity with sutures, positioning it over areas of concern (bronchopleural fistula, empyema, etc.) as necessary.

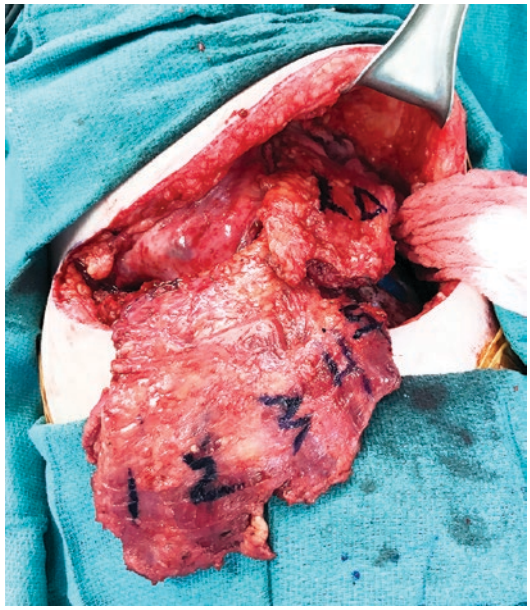

Fig. 19.5 Intraoperative photograph of a chimeric muscle flap including the inferior five slips of the serratus anterior muscle and the superior remnant of the latissimus dorsi. This flap will be transferred intrathoracically, between the second and third rib interspace, to repair a bronchopleural fistula

Abdominal Wall Reconstruction

Ventral abdominal wall reconstruction is usually carried out in the setting of a ventral hernia, an oncologic defect, or as a preventative measure to reduce the risk of hernia formation. Outcomes can be improved by developing the appropriate strategy or technique for each phase of this operation.

Phase 1: Prehabilitation

When planning elective abdominal wall reconstruction, modifiable risk factors such as serum blood glucose control, hemoglobin A1C, body mass index (BMI), and tobacco use should be optimized.

Tips

- Postoperative hyperglycemia greater than 200 mg/dl and HbA1c greater than 6.5 have been associated with an increased risk of surgical site complications. In our protocol, we attempt to maintain postoperative glucose control between 120 and 160 mg/dl and prefer HbA1c less than 7.3 [12–14].
- Obesity is associated with increased surgical site occurrences and hernia recurrence [15]. A recent study of 511 patients from our institution showed a significantly higher risk of surgical site occurrence, but not of hernia recurrence [16]. The inflection point was found to be at BMI of 32. While many of the patients in this study had a BMI of less than 40, BMI of greater than 40 has been shown to increase hernia recurrence rates in multiple studies [17]. While not always possible in the oncologic setting, if there is time to optimize, patients should meet with a nutritionist to develop an appropriate diet- and exercise-controlled weight loss regimen.
- Some patients may benefit from bariatric surgery prior to elective ventral hernia repair.
- Smoking has been shown to increase wound complication rates in multiple studies and randomized controlled trials. Each week of smoking cessation can significantly reduce the risk of complications [18]. Nicotine replacement therapies have not been shown to increase complication rates [19]. Patients should meet with a tobacco cessation team to stop smoking for at least four weeks prior to surgery and in the postoperative period.

Phase 2: Fascial Evaluation

Once the tumor resection has been completed or the hernias have been reduced, the abdominal fascial integrity is evaluated.

Tips

- Defects along the midline laparotomy closure are formed from attenuation and scarring of the line alba. This attenuated tissue is resected until substantial tissue is reached along the medial border of the rectus abdominis muscles.
- Superficial soft tissues are elevated off the anterior rectus sheath for 3–5 cm from the medial borders of the rectus complex. This reduces tension on the fascia and also allows room for placement of sutures. Kocher clamps are placed on either fascial edge to assess tension on the midline. If there is too much tension on the midline closure, surgeons should consider tension reduction techniques and make every attempt to achieve primary fascial closure.
- Primary fascial closure has been shown to have a significantly lower hernia recurrence and wound complication rate compared to a bridged repair. It is therefore necessary to consider component separation techniques prior to resorting to a bridged closure [20, 21].

Phase 3: Component Separation

Anterior component separation was first described in the 1950s and then popularized by Ramirez in 1990. Soft tissue flaps are elevated laterally off the rectus complex until the linea semilunaris is reached. A longitudinal incision is then made in the external oblique aponeurosis 1.5 cm lateral to the linea semilunaris and is continued from above the costal margin to the level of the inguinal ligament. Dissection between the external and internal oblique muscles is then performed. For retrorectus repairs, the posterior rectus sheath is incised near the midline and separated from the rectus abdominis muscles. These maneuvers reduce the lateral pull of the external oblique on the midline and allow for more medial advancement of the rectus complex (3 cm at the epigastrum, 5 cm in the middle, and 2 cm inferiorly on each side) [22].

The main disadvantage of traditional anterior component separation is the need to elevate large soft tissue flaps. This requires ligation of periumbilical perforators, which lead to relative flap ischemia. The extensive area of dissection also creates significant dead space. Consequently, high rates of wound complications ranging from 24 to 50% are seen with this method [23, 24]. As a result, multiple perforator-sparing, endoscopic, and non-endoscopic minimally invasive techniques have been described [25–28].

Tips

- In the minimally invasive component separation (MICS) technique, a transverse subcutaneous tunnel (3 cm wide and 2 cm inferior to the costal margin) extending from the midline to the linea semilunaris is created. With the help of a lighted retractor, a 2-cm-wide subcutaneous tunnel overlying the linea semilunaris, running longitudinally from 12 cm superior to the costal margin to the level of the inguinal ligament is dissected (Fig. 19.6) [25].
- A longitudinal incision through the external oblique aponeurosis is made 1.5 cm lateral to the linea semilunaris. A Yankauer suction handle is inserted through this incision into the plane between the external oblique and internal oblique aponeurosis, and a sweeping motion is used to open the space between these layers. With the Yankauer pushed medially against the linea semilunaris and the rectus complex, the external oblique is incised longitudinally, extending from the 12 cm superior to the costal margin to the inguinal ligament (Fig. 19.7) [25].
- The lateral access tunnel is closed down with quilting sutures from the subcutaneous tissue to the musculofascia. Drains are placed along the component separation donor sites and the midline. Mesh can be placed in the preperitoneal, rectrorectus, or intraperitoneal plane (Fig. 19.8).

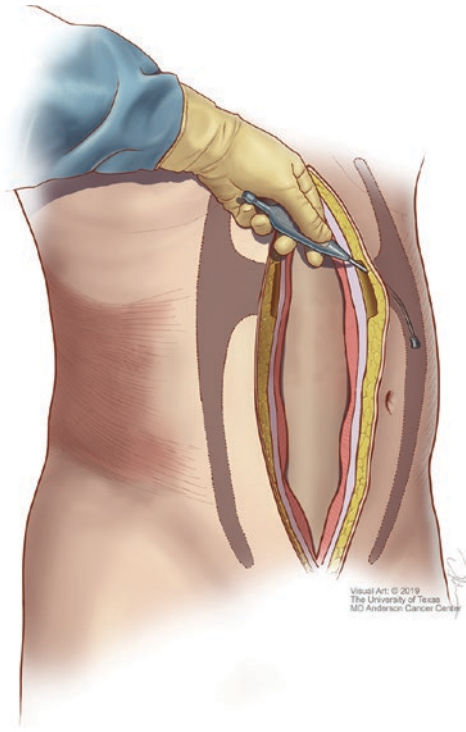

Fig. 19.6 MICS technique: demonstrating minimal subcutaneous dissection. © 2019 The University of Texas M.D. Anderson Cancer Center

These minimally invasive modifications to traditional component separation have reduced incidence of wound complications. A recent review comparing outcomes of traditional anterior component separation with the MICS technique demonstrated lower incidence of wound complications (14% vs. 32%; $p < 0.026$) [29].

Another commonly used technique of component separation has been described as posterior component separation (PCS) or the transversus abdominis release (TAR) [30].

Tips

- In this technique, the posterior rectus sheath is dissected from the rectus abdominis muscle from medial to lateral until the thoracoabdominal intercostal nerves entering the muscle are visualized.
- The posterior leaflet of the internal oblique aponeurosis is then incised medial to these nerves (to preserve innervation of the rectus muscle com-

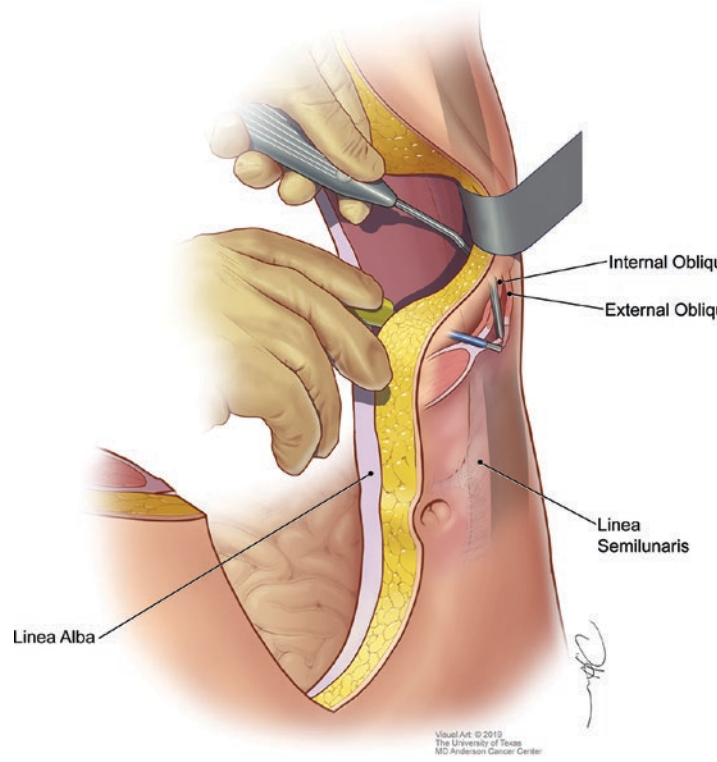

Fig. 19.7 MICS technique: external oblique aponeurosis is accessed through the lateral tunnels. The fascia is then incised 1.5 cm lateral to the linea semilunaris. © 2019 The University of Texas M.D. Anderson Cancer Center

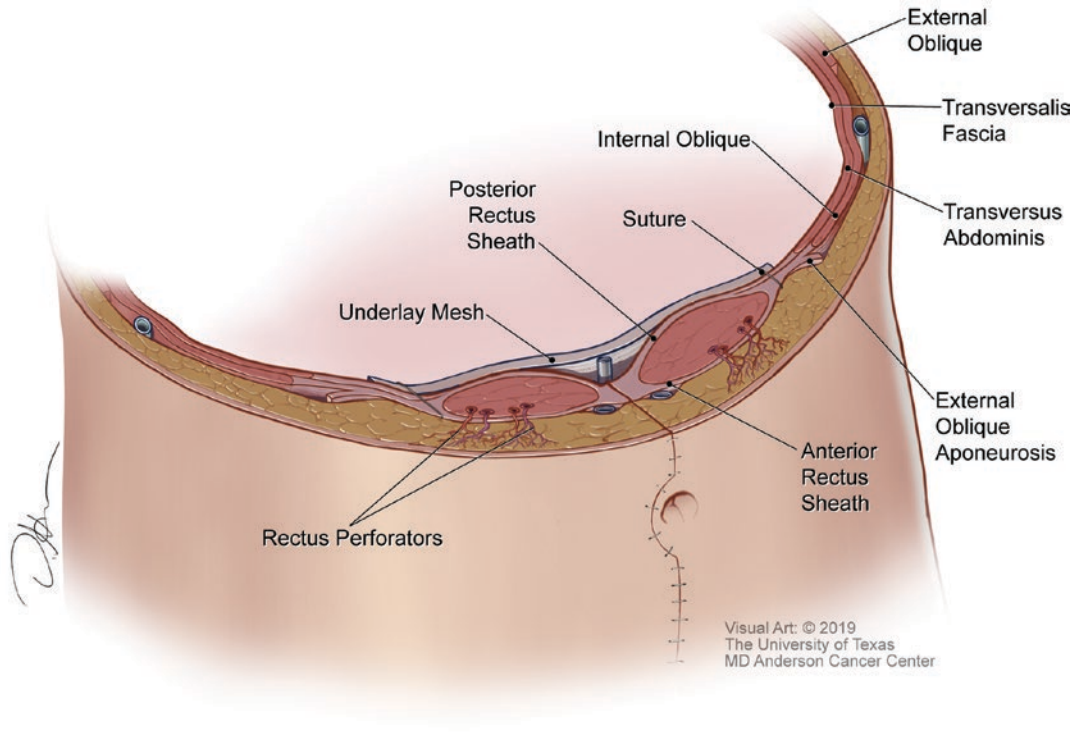

Fig. 19.8 MICS technique with placement of underlay mesh and drains. © 2019 The University of Texas M.D. Anderson Cancer Center

plex) to expose the transversus abdominis muscle and fascia.

- The muscle fibers of the transversus abdominis are then incised to expose the transversalis fascia. This allows access to the plane that lies between the transversus abdominis and the transversalis fascia. The muscle fibers of the transversus abdominis are found more medially along the superior abdominal wall and, therefore, this is an easier location to identify and incise these fibers. The transversus abdominis muscle is then incised longitudinally from the costal margin to the level of the pubis. The avascular plane between the transversalis fascia and the transversus abdominis can be dissected as laterally as needed (as lateral as the psoas musculature) (Fig. 19.9).
- The medial edges of the posterior rectus sheath are then sutured together and a large sheet of mesh is placed in this wide retrorectus/TAR plane (Fig. 19.10) [30].

Both techniques (MICS and PCS/TAR) have been successful in reducing midline tension. A recently published study showed no significant difference in complication profile or recurrence rates between TAR and MICS. Anecdotally, the MICS technique may yield a greater magnitude of medial advancement than the PCS/TAR technique, but better prospective randomized studies are needed to compare these techniques.

Phase 4: Mesh Type and Placement

The superiority of mesh reinforcement over suture repair in the management of ventral abdominal

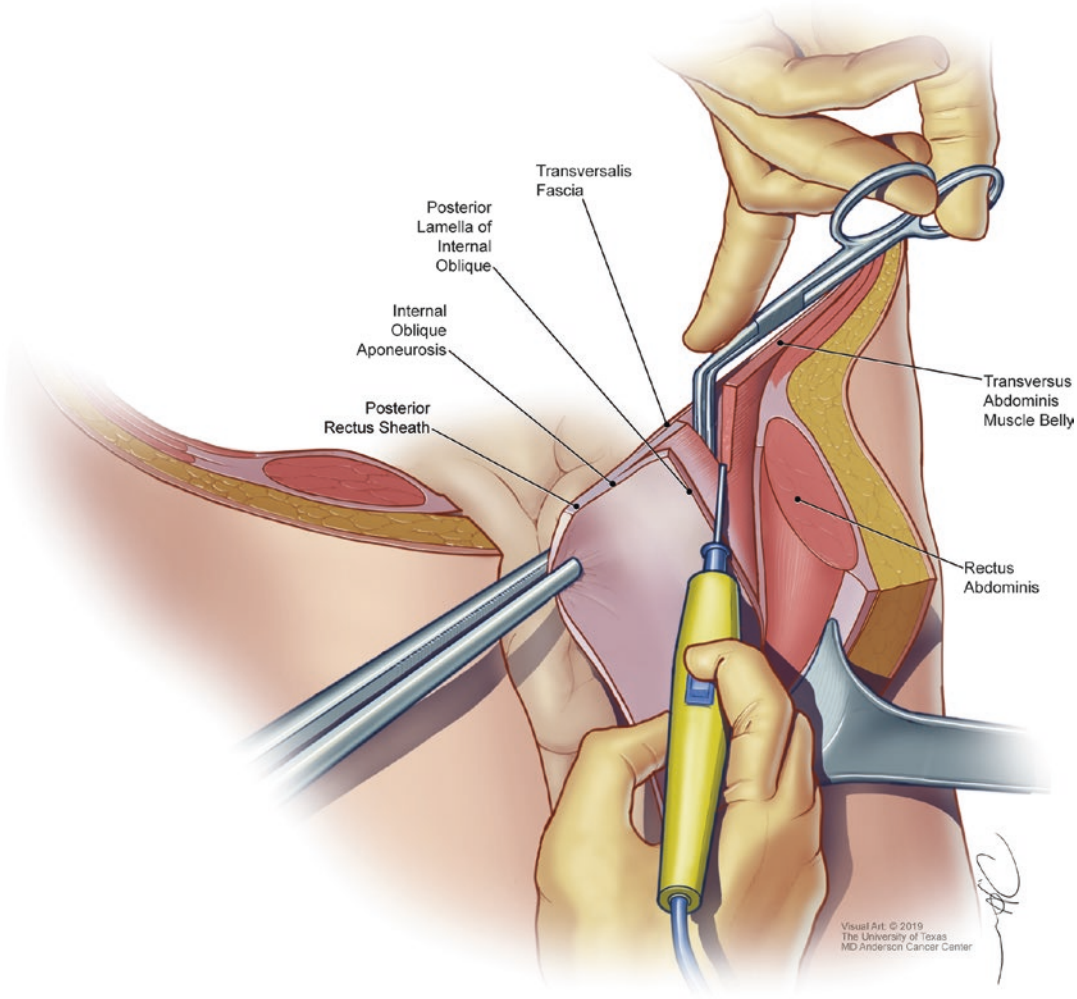

Fig. 19.9 TAR technique demonstrating release of transversus abdominis muscle. © 2019 The University of Texas M.D. Anderson Cancer Center

wall hernias has been clearly demonstrated. Mesh reinforcement has been shown to reduce hernia recurrence by approximately 50% in 3- and 10-year follow-up studies [31, 32]. There are two main categories of mesh in use today: synthetic and biologic mesh. Synthetic mesh materials vary with respect to mesh weight and pore size. Lightweight and large-pore size mesh materials are associated with better mesh integration, less scar formation, and better abdominal wall compliance, but they also have a higher incidence of mesh rupture (for lightweight). Large-pore, midweight mesh is currently commonly used. Heavyweight and small-pore size mesh material are much stronger, but can lead to large amounts of fibrosis and reduced compliance of the reinforced abdominal wall [33, 34]. The other major concern with synthetic materials is that they can be associated with biofilm formation, which makes it hard to clear infection without explantation [35]. Furthermore, stricture and scar formation occur when the mesh is in direct contact with bowel, which can lead to adhesions and/or fistula formation.

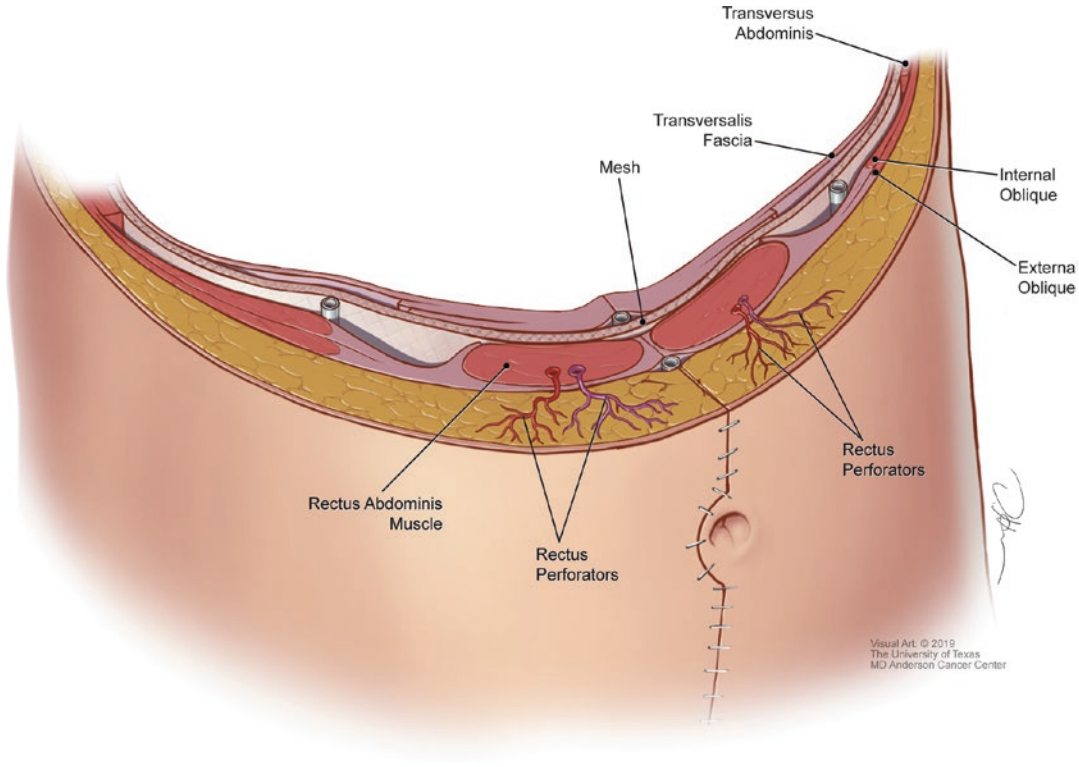

Fig. 19.10 TAR technique with placement of large sheet of mesh retrorectus/TAR plane. © 2019 The University of Texas M.D. Anderson Cancer Center

Some of these major drawbacks of synthetic mesh material fueled growth and popularity of biologic or bioprosthetic mesh. Many of these meshes are made from acellular dermal matrix from porcine, bovine, or human origin [36]. The increased elastin content in human acellular dermis is associated with increased stretch and consequent bulge formation over time; however, this is not seen with porcine- and bovine-based materials [37, 38]. Recent studies have demonstrated that the use of bioprosthetic mesh material in wounds with increased contamination does not result in a significantly higher overall surgical site infection (SSI) and hernia recurrence rate [39, 40]. The Ventral Hernia Working Group (VHWG) recommends the use of biologic mesh in wounds with grade 3 or grade 4 contamination [41].

Tips

- Biologic mesh is generally recommended when there is increased risk of wound contamination or unavoidable bowel exposure to mesh. Synthetic mesh can be used in wounds that are otherwise clean and where mesh can be placed in a protected space, such as the retrorectus plane.
- Mesh should be anchored to the static pillars of support of the ventral abdominal wall, which include the linea semilunaris. Anchoring the mesh to fixation points allows it to assume a more load-bearing role than a load-sharing role.

- In order to anchor the mesh to the linea semilunaris without elevating large soft tissue flaps, a minimally invasive technique is used. A heavy suture such as 1 polypropylene or 1 polydioxanone is preplaced on the mesh. The Carter Thomason suture passer is then passed through a stab incision in the skin to deliver the suture through the abdominal wall fascia.

Phase 5: Soft Tissue Reconstruction

In addition to reconstructing the musculofascial component of the abdominal wall, certain scenarios necessitate the need to reconstruct the overlying soft tissue as well. These situations are commonly seen when the skin and soft tissue of the abdominal wall has been excised in conjunction with tumor resection, or if the vascularity has been compromised due to radiation injury or scarring from prior surgical resection [42].

Tips

- Small defects can be reconstructed with rotation advancement flaps, such as bipedicled flaps, keystone flaps, or hatchet flaps.
- For large defects, pedicled or free flaps are necessary. When considering options for reconstruction, the abdominal wall can be subdivided into four zones: epigastric, periumbilical, hypogastric, and lateral.
- Epigastric defects: pedicled options are limited. Thigh-based free flaps, such as the anterolateral thigh flaps, can be used and vascularized using the internal mammary vessels or vein grafts to the femoral vessels.
- Lateral defects: pedicled flap options include pedicled latissimus dorsi and/or serratus muscle flaps. A position change to lateral decubitus is often required for flap elevation. If the flap has insufficient reach, then vein grafts are needed to extend the reach of the flap.
- Periumbilical defects: these defects are generally out of reach of pedicled flaps. Free tissue transfer can be performed using the deep inferior epigastric vessels as recipients. If the deep inferior epigastric vessels are not available, an arteriovenous loop, created by connecting the saphenous vein to a branch off the superficial femoral artery, can be transferred into the abdomen to serve as recipient vessels.
- Hypogastric defects: these defects are usually low enough to allow reconstruction with pedicled thigh-based flaps. The anterolateral thigh flap can be harvested as a pedicled flap and transferred under the rectus femoris and sartorius muscle to reach the defect site.
- In certain cases, excess tissue can lead to excessive dead space. A vertical or transverse panniculectomy can be designed to remove some of this excess tissue. Combining panniculectomy with abdominal wall reconstruction has been shown to have higher rates of wound morbidity, but similar overall complication and hernia recurrence rates.

Conclusion

The main guiding principles necessary for reconstruction of defects of the trunk include creation of adequate load-bearing structural support, along with dead space obliteration and wound coverage with well-vascularized tissue. These broad reconstructive ideas are used to develop detailed tips and tricks that can be applied to reconstruction of thoracic and abdominal wall defects. To better understand these surgical principles, thoracic defects are broadly classified into lateral defects, sternal defects, and intrathoracic defects. Ventral abdominal wall reconstruction is

subdivided into its surgical phases, such as fascial management, component separation, mesh selection, and soft tissue coverage, and surgical strategies specific to each phase are discussed. These principles should guide and help optimize outcomes in thoracic and abdominal wall reconstruction.

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Migraine/Headache Surgery

20

Lisa Gfrerer and William Gerald Austen Jr.

Patient Selection

The most important variable to ensure successful outcomes in migraine/headache surgery is patient selection. There are several components that should be taken into consideration when choosing appropriate surgical candidates. First, remember PAINS (Fig. 20.1) for identification of candidates for migraine surgery [1]:

Pain point (identifiable with one finger).
Appropriate symptoms (constellation).
Injectables improve pain.
Neurologist confirmed diagnosis.
Sketch matching.

Pain Sketches

Patient-drawn pain sketches that indicate where the pain starts and to where it radiates are extremely helpful in understanding symptoms and selecting surgical candidates. Every trigger site has typical and atypical pain patterns (Figs. 20.2 and 20.3). Patients who draw atypical sketches have been shown to have worse outcomes [2]. Criteria for atypical pain sketches are as follows:

1. Facial pain that is not located at or above the eyebrows/forehead or temples (e.g., cheek, jaw, anterior neck).
2. Pain that starts in an atypical location that does not correspond to a trigger. Ensure that the patient does not have nummular headache by Doppler ultrasound [3].
3. Diffuse pain that is not localized.

Nerve Blocks

Although Botulinum toxin, type A (BT-A) can be used to identify trigger sites, cost of serial injections and time requirement limit its use. We have found nerve blocks to be more informative immediately after injection, allowing for instant identification of all trigger sites at the time of initial consultation. Patients are asked to point to the site of pain with one finger, and local anesthetic is injected at this site. Elimination of pain after injection is a good indicator that the targeted nerve is compressed. However, a negative response does not exclude nerve compression, given that chronic irritation may not be resolved by one injection.

Silent Occipital Neuralgia

In our experience, patients with frontal pain who are not symptomatic at the occipital site may be

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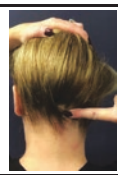
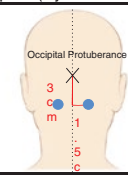
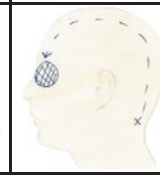
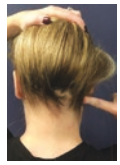
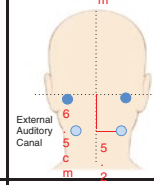
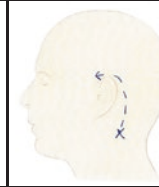
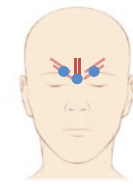
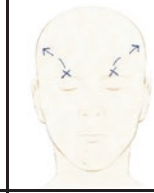
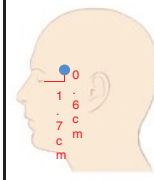
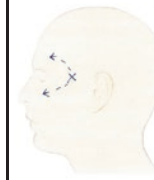
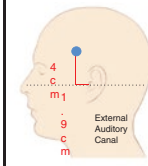
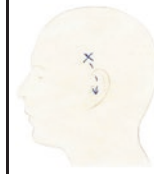
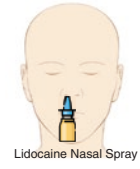
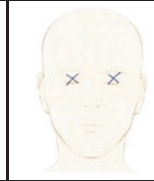
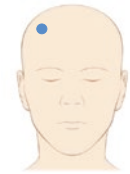
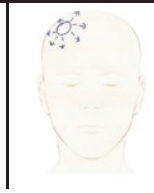
	Pain point	**A**ppropriate symptoms	**I**njectables improve pain (injection sites)	**N**eurologist diagnosis	**S**ketch matching
Occipital- GON		• Pain starts 3.5cm caudal to occipital protuberance and 1.5cm from the midline • Pain radiates to the forehead/behind the eye • h/o head/neck trauma common • Tight neck muscles • Triggered by stress/exercise/heavy lifting • Hot/compresses/pressure helps • Doppler often identifiable at most tender spot		• Migraine • Occipital neuralgia • Cervicogenic headache	
Occipital- LON		• Pain starts more lateral then the GON • Ear pain can occur • Vertigo common		• Migraine • Occipital neuralgia • Cervicogenic headache	
Frontal- SON/STN		• Pain starts at or above the eyebrows • Pain can radiate towards the temples • Deep frown lines can be present • Eyelid ptosis common • Doppler signal often present at most tender site • Hot/cold compresses/pressure helps • Stress can trigger pain		• Migraine • Trigeminal neuralgia	
Temporal- ZT		• Pain starts ~17mm lateral and 6mm cephalad to the lateral canthus • h/o teeth grinding common • Pain starts in the morning • Temporalis/masseter tender to touch • Doppler signal often present • Hot/cold compresses/pressure helps • Stress can trigger pain		• Migraine • Trigeminal neuralgia	
Temporal- AT		• Pain starts cephalad to the ZT • Typically confined to the hair bearing area • Oftentimes mistaken for temporomandibular joint disorders • Doppler signal often present		• Migraine • Trigeminal neuralgia	
Rhinogenic		• Pain starts behind the eye • Pain is present in the morning and can wake patients up at night • Weather/allergies/hormone changes influence pain • On CT, deviated septum/turbinate hypertrophy/ Haller's cell can be seen • Rhinorrhea can occur		• Migraine • Sinus Headache	
Nummular		• Pain occurs in a small area on the scalp • Parietal location common, but can occur anywhere on the scalp • Doppler signal can be detected • Rhinorrhea can occur		• Migraine • Nummular headache	

Fig. 20.1 PAINS. **P**–Pain point. Patients are asked to point to where the pain starts with one finger. Characteristic pain points are illustrated; however, variability exists. For the GON, pain usually starts at the exit point of the GON 3 cm caudal to the occipital protuberance and 1.5 cm lateral to the midline. LON pain is very variable, but usually located lateral to GON pain. STN/ SON pain is at or above the eyebrow. ZT pain is usually in the non-hair-bearing area of the scalp, whereas AT pain is in the hair-bearing scalp. Rhinogenic pain is perceived behind the eye. Nummular pain can be anywhere across the scalp, but is oftentimes seen in the parietal scalp. **A—**Appropriate symptoms. See this column for symptoms most commonly associated with triggers. **I—**Injectables improve pain. Blue points indicate injection sites. For the GON, start by injecting the point of maximum pain, which may

affected by silent occipital neuralgia. To distinguish frontal pain stemming from the supraorbital/supratrochlear nerves from occipital pain radiating to the frontal area, patients should undergo injections at the greater occipital nerve site. If frontal symptoms improve after occipital injection, GON compression should be suspected.

Technical Considerations

Exploring Nerve Entrapment Directly at the Pain Site

For both nerve blocks and surgical intervention, ask the patient to point to the site of pain with one finger. Typically, this is where the affected nerve can be found. For the frontal trigger site (supraorbital nerve and supratrochlear nerve [SON/STN]) and the greater occipital nerve (GON) trigger site, nerve exploration follows described techniques based on anatomic location of the nerves [4–6]. For the smaller trigger sites—auriculotemporal (AT), zygomaticotemporal (ZT), lesser occipital (LON), and nummular headache—exploration at the site of pain is more reliable.

Approaching the Frontal and Temporal Trigger Site through an Upper Blepharoplasty Incision

Both the frontal trigger site (SON/STN) and temporal trigger site (ZT) can be accessed through an upper blepharoplasty incision (Fig. 20.4) [3]. After release of the SON/STN, careful dissection is carried out along the inferior lateral orbital rim over the deep temporal fascia (protecting the facial nerve) to access ZT/AT at the patient's point of pain.

Postoperative Pain Management

Postoperative pain management should include all medications that the patient was on preoperatively. The patient should not wean off any headache medications independently, but under the supervision of their neurologist. We have found that addition of gabapentin is helpful for postoperative pain management. Patients who are not on gabapentin are started on 100 mg TID for around 4 weeks after surgery. Patients who are already on gabapentin should have their dose increased in the postoperative period.

be at or cephalad to the exit site of the GON from the semispinalis muscle (3 cm caudal to the occipital protuberance and 1.5 cm lateral to the midline). If the patient is still in pain, inject at the anatomic exit site of the nerve. For the LON, inject exactly to where the patient points with their finger. The usual injection point is higher (dark blue point) than the exit point of the LON from the sternocleidomastoid muscle (light blue point). SON/STN injection points are over the bilateral corrugator muscles and the procerus muscle. Again, patient pain points should guide the surgeon. ZT and AT injection sites are highly variable and correspond with the specific site of pain and oftentimes a positive Doppler signal. As an anatomic reference point, the ZT exits the temporalis fascia 17 mm lateral and 6 mm cephalad to the lateral canthus. This is oftentimes an area of pain. Similarly, the AT crosses the superficial temporal artery on average 19 mm lateral and 40 mm cephalad to the external auditory canal. Pain is often perceived in this area. At the rhinogenic site, lidocaine sprays can be used to determine pain relief. For nummular trigger sites, inject exactly at the point of pain/positive Doppler sign. **N—**Neurologist diagnosis. It is critical for patients to have a diagnosis of migraine by their neurologist before they are seen in the office. At the occipital site, occipital neuralgia or cervicogenic headache is also a common diagnosis. Patients are often misdiagnosed with trigeminal neuralgia, and therefore should also be seen for evaluation. **S—**Sketch matching. As part of patient screening prior to the office visit, we find it very helpful to have patients draw where their pain starts and where it goes to. Oftentimes a diagnosis can be made just by looking at the sketch. (Used with permission under Creative Commons 4.0 license [https://journals.lww.com/prsgo/Pages/openaccess.aspx] from Gfrerer L, Austen W Jr, Janis J. Migraine surgery. Plast Reconstr Surg Glob Open. 2019;7(7):e2291. Available at: https://journals.lww.com/prsgo/fulltext/2019/07000/migraine_surgery.15.aspx)

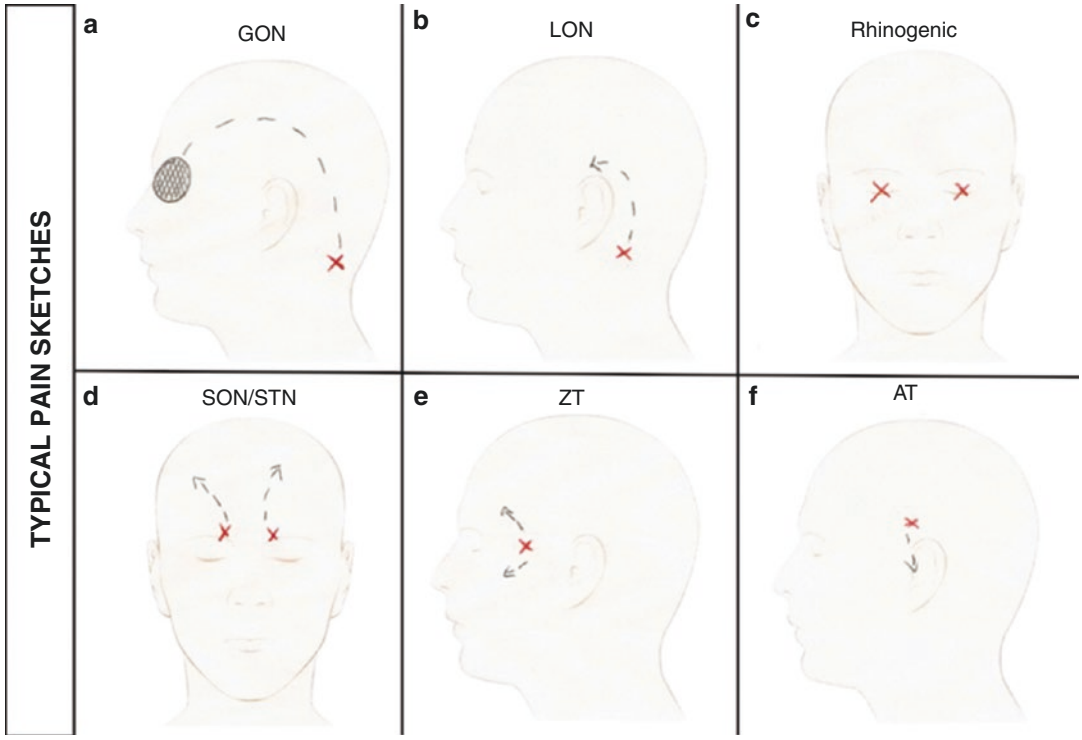


Fig. 20.2 Typical pain patterns. Typical pain sketches for pain at the (**a**) greater occipital nerve; (**b**) lesser occipital nerve; (**c**) rhinogenic; (**d**) supraorbital/supratrochlear nerve; (**e**) zygomaticotemporal nerve; (**f**) auriculotemporal nerve

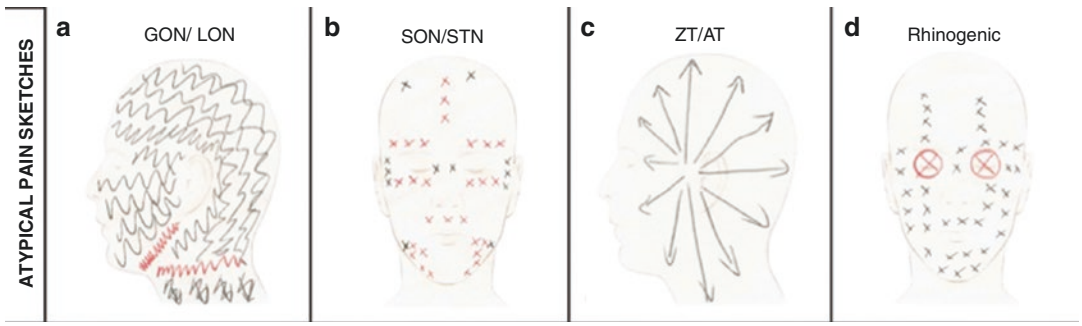


Fig. 20.3 Atypical pain patterns. Atypical pain sketches for pain at the (**a**) occipital site; (**b**) frontal site; (**c**) temporal sites; (**d**) rhinogenic site

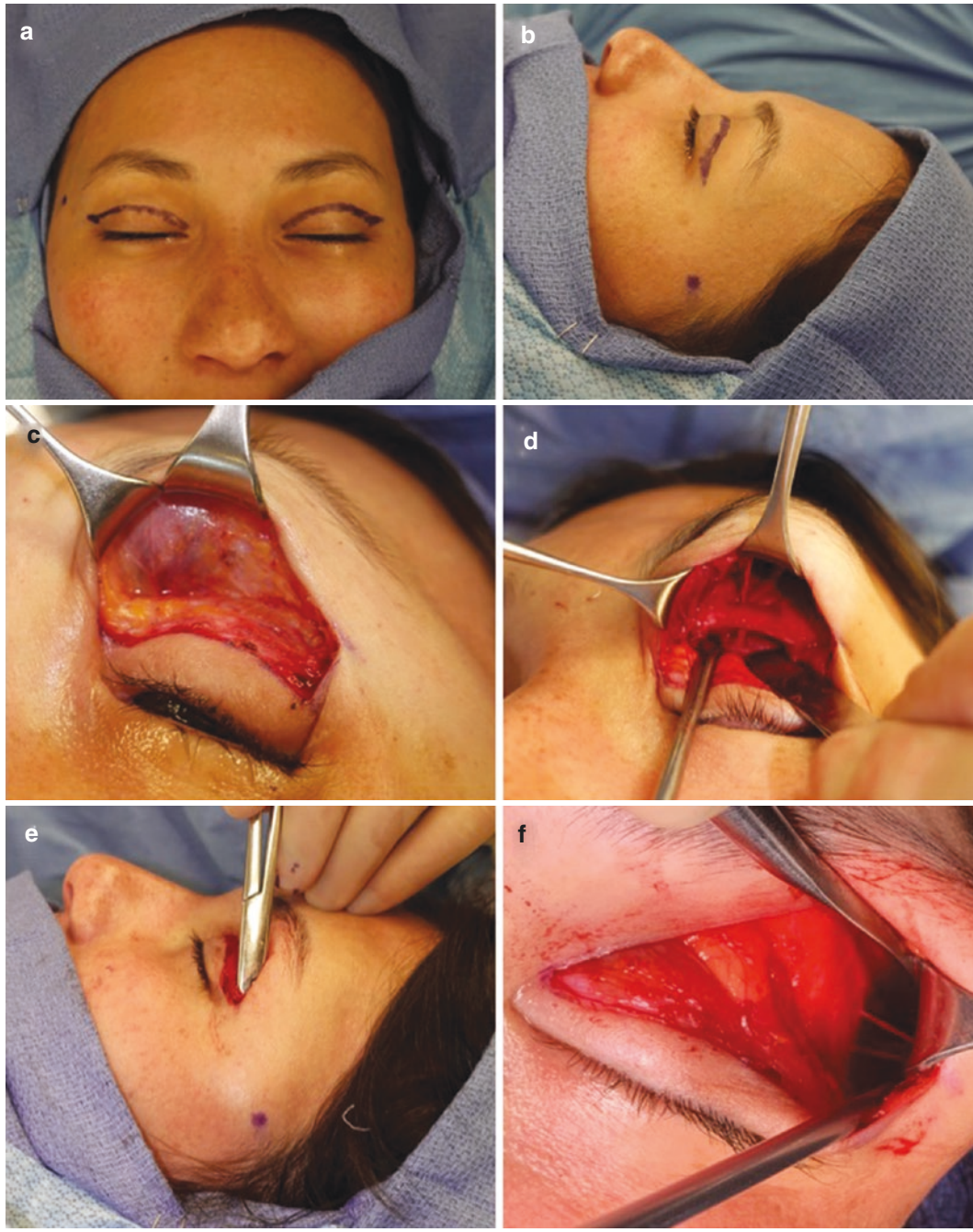


Fig. 20.4 Approach to the frontal (SON/STN) and temporal (ZT) trigger site through upper blepharoplasty incision. Markings for (**a**) upper blepharoplasty incision and (**b**) pain point at the temporal site (ZT). Exposure through the eyelid to (**c**) corrugator muscle and (**d**) supratrochlear/supraorbital nerves. This patient had a supraorbital foramen that was opened with an osteotome. (**e**, **f**) Demonstration of access to the ZT through an upper blepharoplasty incision

Conclusion

Headache surgery has evolved as a treatment method for select patients with debilitating migraines/headaches/occipital neuralgia. This chapter shares important insights, as well as tips and tricks, on migraine surgery to help surgeons achieve successful outcomes.

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Lower Extremity Reconstruction: Local Flaps, Free Tissue Transfers

21

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Lower Extremity Reconstructive Principles.

Although significant advances have been made in lower extremity reconstruction, the basic principles that guide management remain largely unchanged. In general, the lowest option on the reconstructive ladder that allows for adequate soft tissue coverage should be the reconstruction of choice [1]. However, prior to any reconstruction, the surgeons must evaluate the defect to assess for missing components, determine if local or distant tissue will be needed, and identify recipient vessels in the case of tissue transfer. Our orthoplastic approach to lower extremity reconstruction has been previously described (Fig. 21.1) [2]. In keeping with the teachings of Marko Godina, thorough debridement of all nonviable tissue and implants is critical to future reconstruction success [3]. This may require more than one operation, temporary "wet-to-wet" dressing changes, antibiotic bead placement, or negative-pressure wound therapy (NPWT). Use of NPWT in lower extremity salvage has been shown to reduce complication rates [4–6]. The NPWT should be changed every 24–48 hours to assess need for additional debridement or readiness for a step forward in management.

In cases of trauma, determining the severity of injury based on Gustilo-Anderson classification is critical [7–9]. A Gustilo-Anderson IIIA may just need fracture stabilization, debridement, and closure with primary/local soft tissue coverage. A higher-grade Gustilo-Anderson IIIC will need emergent revascularization as a first step. It is important to note that a vascular injury should raise suspicion for possible nerve injury. Sharp nerve transections may be repaired primarily, but if the mechanism is a crush, avulsion, or blast injury, tagging the nerve and delayed repair is preferred [10]. The concept that initial limb

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_21) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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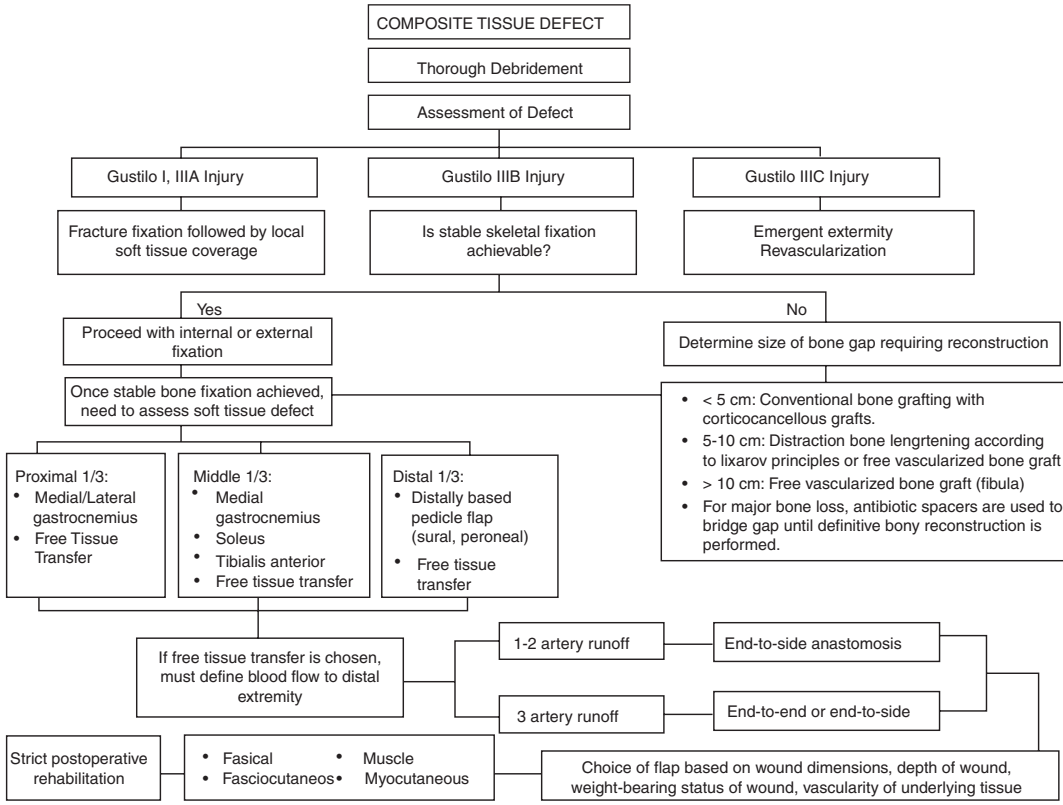

Fig. 21.1 Algorithm for orthoplastic management of composite defects of the lower extremity below the knee. (Used with permission from Sbitany et al. [2])

insensibility is an indication for amputation is no longer correct [11]. Data from the Lower Extremity Assessment Project (LEAP) demonstrated that 67% of patients who were insensate at presentation ultimately developed return of plantar sensation at 2 years [12]. Our experience has been consistent with their findings, as we have observed recovery of nerve function several years following high-energy injury.

Vascular injury serves as a surrogate marker for trauma severity and also hinders long-term function [13, 14]. Methods of assessing vascular competency include physical exam, ankle-branchial indices, and/or computed tomography (CT) angiogram [15–17]. CT angiogram is useful in determining inflow, runoff, and any potential injuries or interruptions in blood flow. Duplex ultrasonography will help assess patency of venous outflow. Any concern during the work-up warrants a consultation with a vascular surgeon. High index of suspicion is necessary in patients with preexisting diabetes, peripheral vascular disease, venous insufficiency, advanced age, or smoking history. Endovascular angioplasty, stenting, and/or bypass procedures may be necessary prior to reconstruction [16]. If emergent revascularization is necessary, external fixation can be used to achieve bony stabilization, keeping in mind the exposure necessary for the vascular bypass. In cases of oncologic reconstruction, tumor vessel invasion should be anticipated, along with a plan to reestablish distal blood flow.

The posterior tibial artery is the most commonly selected recipient target for free flap reconstruction, while the anterior tibial artery is preferred for the dorsum of the foot, the lateral

malleolus, and lower leg, or if the patient is supine [18]. We prefer reconstruction with autologous conduit over prosthetic options if a bypass is necessary prior to or at the time of reconstruction. We also prefer end-to-side anastomosis in order to prevent interruptions in distal perfusion. Further, anastomosis outside of the zone of injury or at a disease-free site is paramount to successful free tissue transfer in the lower extremity [19, 20]. When the recipient vessel is not in continuity due to injury or tumor resection, the anastomosis may be performed end-to-end. Single-vessel limbs may be suitable for flow-through free flaps (Fig. 21.2).

Arbetigemenschaft fur Osteosynthesfragen group (AO) for the Study of Internal Fixation set forth management principles for bony stabilization: (1) fracture reduction and fixation to restore anatomical relationships; (2) fixation providing absolute or relative stability as the fracture patient and injury requires; (3) preservation of blood supply to soft tissues and bone by careful handling and gentle reduction techniques; and (4) early mobilization and rehabilitation of the injured part and patient as a whole. Injuries without any missing bone segment can be stabilized with intramedullary rods or external fixation, or plating. A combination of antibiotic-impregnated spacer grafts and non-vascularized corticocancellous bone graft may be used for reconstruction if a long-bone defect is present, but less than 5 cm in length. For defects greater than 5 cm, vascularized bone graft is preferred (e.g., free fibula discussed later in this chapter). Other options include the iliac crest, rib, radius, scapula, and medial geniculate system (medial femoral condyle). Thin-wire fixation (the Ilizarov method) in addition to distraction osteogenesis and bone transport has also been used successfully for defects greater than 5 cm, with good long-term outcomes. However, this comes with the downside of a potentially long distraction period, and additional soft tissue coverage may be necessary [21]. Reconstruction of a joint can be achieved with endoprosthetic implants, osteoarticular allografts, rotationplasty, and arthrodesis.

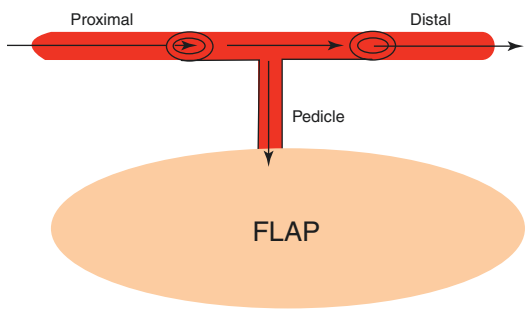

Fig. 21.2 Diagram of flow-through flap that can be used for single-vessel limbs

Next, soft tissue coverage should be achieved as soon as feasible. Although Godina demonstrated decreased nonunion, infection, and osteomyelitis in patients undergoing soft-tissue coverage within 3 days of injury, delay beyond that time may offer similar promising results [3, 22–25]. Our preference on timing for soft tissue reconstruction is ideally within 7 days of injury. However, timing of soft tissue coverage should be determined based on wound characteristics and overall condition of the patient.

Flap Selection

One way to categorize flaps is to arrange them according to the tissue they contain, such as cutaneous, muscle, myocutaneous, fasciocutaneous, fascial, or bone. The debate of muscle versus fasciocutaneous flaps for lower limb reconstruction continues, but there are some advantages to both [26]. Muscle flaps such as the latissimus are well vascularized and have a large surface area that contours to irregular or large wound beds. Traditionally, muscle flaps have been used for exposed hardware and osteomyelitis. They are also first-line for wound beds when future radiotherapy is planned, in order to avoid nonunion, fracture, or exposed hardware [27, 28]. Perforator flaps have increased in use over the past several decades, and allow for longer pedicled length due to an intramuscular dissection, preservation of source artery, decreased donor-site morbidity, and optimal aesthetic results [29]. Cutaneous flaps such as the scapular, radial forearm, or anterolateral thigh flap provide pliability and good aesthetic results. Fasciocutaneous flaps,

such as the medial sural artery perforator (MSAP) and anterolateral thigh (ALT), are good choices over exposed hardware, for wounds of the plantar weight-bearing surface of the foot, and around the metaphyseal regions of the ankle and knee, as will be discussed [10]. These flaps are more easily re-elevated in the case of secondary procedures compared with muscle flaps. Also, if a patient requires free tissue transfer for limb salvage or reconstruction, it is likely in the case of flap failure that a second flap be considered. Although this chapter is not meant to be an exhaustive review of all flap types, commonly used flaps for lower extremity reconstruction are described in more detail below, as well as pearls of practice based on evidence and experience.

Locoregional Flaps

There are many local and regional flaps that can be utilized for soft tissue coverage of the lower extremity, including advancement, rotation, and transposition flaps. Flaps can include cutaneous, fasciocutaneous, muscle, or musculocutaneous components. Local cutaneous flaps can be based on axial or random pattern circulation. Random pattern flaps are limited by their arc of rotation, size, and width-to-length ratio design [30]. We find it valuable to use a hand-held Doppler probe to mark out all perforators surrounding the defect requiring coverage, and try to incorporate one or more of these perforating vessels into our local flap designs when feasible. This avoids reliance on entirely random pattern perfusion, and facilitates precise flap design that incorporates more robust blood supply.

V-Y flap is a random pattern flap that offers sensate coverage of the lower extremity including the thigh, knee, lower leg, foot, and ankle [31, 32]. The V-Y design also offers excellent contour and minimal aesthetic morbidity, and elevation of the flap is straightforward. However, it is not typically suitable for larger defects, given its restricted mobility. Bi-pedicle and keystone flaps are also gaining popularity as local flap options for lower limb wounds [33–35]. We agree with others that the reliability of the perforator supply for keystone flaps is such that we do not perform preoperative imaging nor do we localize or skeletonize perforators [35].

A flap can be designed as a propeller, such that it can be rotated based on a single perforator complex up to 180 degrees [36, 37]. The propeller flap is commonly based on peroneal and posterior tibial artery perforators, and is an option for the majority of coverage of the lower limb, below the knee, and including the forefoot [38]. Propeller flaps are versatile and can reach as distal as the lateral malleolus, Achilles tendon, and dorsum of the foot [39]. However, such a design is not typically a first choice if other more reliable flaps are available, as our institution recently noted partial flap loss as high as 16% for propeller flaps in lower extremity reconstruction [40]. Prior to completely islandizing the flap and skeletonizing the perforator, we prefer to leave it as a peninsula flap to allow for more robust venous drainage, and accept a small dog-ear with rotation up to 90 degrees. Further rotation usually requires full islandization of the flap to allow for rotation, and if venous congestion is observed, the perforator is skeletonized and dissected more proximally to allow for more comfortable rotation without kinking.

Thigh

There are a variety of flap options when reconstructing thigh defects. Given the plentiful soft tissue and muscles of the thigh, the majority of defects can be reconstructed by locoregional means [41]. Local tissue rearrangements such as rotational, keystone, or V-Y flaps are simple options when possible [10]. A recent review of reconstruction following soft tissue sarcoma resection demonstrated that pedicled thigh muscle (rectus femoris and vastus lateralis) and rectus abdominis flaps were most commonly used for the proximal third of the thigh, pedicled thigh muscle flaps for the middle third, and pedicled gastrocnemius for the lower third [41]. Predictors of free flap reconstruction included location in

the middle third of the thigh and wide defects (13.6 cm for free flaps vs. 8.9 cm for all other types of reconstruction) [41]. Regardless of the etiology, in general, free flaps are used for larger thigh defects and have also been described to restore function. Examples of the latter include the reconstruction of an anterior thigh defect with innervated latissimus dorsi flap, and restoration of knee extension [42], or with contralateral ALT with TFL and motorized vastus lateralis [43]. Gluteus maximus can be used to cover defects over the trochanter/hip, upper thigh, perineum, and has proven successful for patients with recurrent instability or recalcitrant periprosthetic joint infections related to total hip arthroplasty [44, 45]. It can be raised either off of one of the gluteal arteries with the muscle-split preserving function and tissue to cover either anterior or posterior defects, or based on the lateral femoral circumflex artery to allow posterior thigh coverage [44]. In ambulatory patients, however, every attempt is made to avoid significant muscle sacrifice in order to preserve maximal limb function.

The ALT is an ideal soft tissue workhorse flap well-known to all reconstructive surgeons [46]. The dominant pedicle of the ALT flap is the descending branch of the lateral femoral circumflex artery and its venae comitantes that traverse in an oblique fashion in the groove between the vastus lateralis and rectus femoris. It is innervated by the lateral femoral cutaneous nerve of the thigh. Depending on the location of the defect to be reconstructed, a pedicled reverse-flow (RF-ALT) or free ALT are commonly used and versatile flap options [39]. The ALT flap is outlined along the axis of ASIS to the superolateral corner of patella, and septocutaneous or musculocutaneous perforators can be identified prior to incision with the aid of a Doppler (Fig. 21.3). An 8 x 25 cm skin paddle can be raised, allowing for primary closure of the donor site in the vast majority of cases. A subfascial dissection should be performed so that the fascia can be used for layered closured during insetting, or for anchoring purposes. Various amounts of vastus lateralis muscle around the cutaneous perforator and the descending branch can be included in the harvest when muscle is needed. A proximally based pedicled ALT can be used to cover defects of the trochanter and ischial tuberosity, and a distally based design may reach as far the lateral knee and proximal tibia for coverage. Prior to donor site closure, we place a drain in the intramuscular dead space.

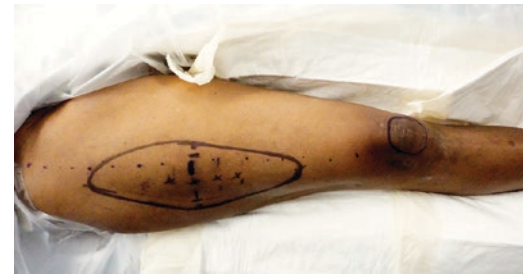

Fig. 21.3 The ALT flap is outlined along the axis of ASIS to the superolateral corner of patella, and septocutaneous or musculocutaneous perforators can be identified prior to incision with the aid of a Doppler. An 8 × 25 cm skin paddle can be raised, allowing for primary closure of the donor site, or a skin graft may be needed

Medial thigh flap can be used to cover wounds in the groin, and can be fashioned up to 10 x 20 cm in size. It is referred to more commonly as the anteromedial thigh (AMT) flap when raised anteriorly using the lateral femoral circumflex artery. Posteromedial thigh (PMT) flap is based on the deep femoral or medial circumflex femoral artery, and can be elevated as high as the gluteal crease to cover defects from the groin to the popliteal fossa [47]. The defect can usually be closed if the width is less than 10 cm. Other flaps based on the lateral circumflex femoral artery system include the vastus lateralis, tensor fascia lata (TFL), and rectus femoris flaps. The vastus lateralis is commonly used for closure of trochanteric pressure sores and salvage of hip wounds. TFL has a constant/reliable perforator anatomy and is a good backup when ALT is not an option [48, 49]. As a pedicled flap, it can reach the ischium and groin, and can incorporate skin and/or iliac bone for osteomusculocutaneous coverage of defects in the proximal lower limb. However, TFL is not typically a first choice, as it has a thin/small muscle belly and long fascial extension [50]. The rectus femoris has been criticized for significant donor site morbidity, and may reduce knee extension up to 20% [51, 52].

The gracilis muscle or myocutaneous flap is based on terminal branch of the medial circumflex femoral artery, and can be used for perineal and ischial coverage. Although this flap lacks bulk, it is a reliable option for some defects and has a relatively straightforward anatomic dissection with minimal donor site morbidity.

Upper and Middle One-Third of Leg

Traditionally, the hemi-soleus and gastrocnemius pedicled flaps have been used for upper and middle one-third defects of the lower extremity. The gastrocnemius is used for proximal tibia, knee, and patellar tendon coverage, and can be mobilized to allow suprapatellar distal femur coverage. The soleus can be used for defects of the middle third of the lower leg, and can be split to form a hemisoleus flap, given its dual pedicle supply and bipennate morphology [53]. The use of the soleus has been criticized for loss of venous return and the risk of ankle flexion weakness following harvest.

Advances in surgical technique have allowed for the use of perforator-based local flaps such as propeller and reverse flow flaps [54]. When used for smaller defects in this region, the propeller flap provides good functional and aesthetic results. However, larger defects require the use of skin graft for donor site coverage [55]. The previously discussed MSAP flap can be anterograde to cover defects of the anterior and posterior upper third of the leg. If harvested with a width of <4–5 cm, primary closure is possible.

Knee

V-Y perforator flaps around the knee can be designed based on numerous local fascial feeders [31]. In the setting of exposed knee joint or hardware, coverage with more substantial well-vascularized tissue is essential. The gastrocnemius offers separate muscle or musculocutaneous flaps to be raised on pedicles along the lateral or medial sural arteries. The median raphe is split to allow for medial or lateral gastrocnemius harvest and rotation, and the distal tendinous portion is divided. Gastrocnemius flap is the workhorse flap for popliteal/knee region coverage, but also for distal femur and proximal tibia. The medial muscle offers greater surface area (ranges from 5 to 9 cm in width and from 13 to 20 cm in length) for coverage and a larger arc of rotation. The lateral muscle is limited by the fibular head and comes with the potential risk of common peroneal nerve injury. The gastrocnemius flap can only be employed in scenarios where soleus is intact, as rehabilitation and walking are dependent on ankle plantar flexion. Additional length is achieved by scoring the muscular fascia transversely on the superficial and deep surfaces, or by releasing the origin on the femur [56].

Perforator flaps have many desirable traits for knee soft tissue coverage [57–59]. Perforator flaps by definition will minimize muscle function loss and may offer a better aesthetic outcome. A cutaneous flap is more flexible, allowing better joint range of motion. Peripheral neovascularization is also more predictable and re-elevation can be easily and safely performed for purposes of secondary procedures [60]. There are several reliable perforator flaps in the knee region. Proximal or distal-based peninsular flaps based on perforators of genicular branches, or similarly small island advancement flaps, or keystone flaps may be possible for smaller defects [61, 62]. The lateral genicular artery flap can also be used to reconstruct defects of the knee and lower thigh [63]. It is favored for this purpose due to its fast and easy harvest and good aesthetic results [63, 64]. The skin island is designed on the lateral aspect of the lower thigh and is based on perforating branch of the superior genicular artery. The flap is raised as an island and the donor site is closed primarily. The previously mentioned MSAP flap can be harvested on the same source pedicle as the gastrocnemius without including the muscle itself [65]. The pedicle can be 9–16 cm in length, depending on the location of the chosen perforator and flap design about that perforator [66]. In fact, some consider the MSAP flap now to be a new soft tissue "workhorse" flap [67]. However, it is not free of risks, and delay is always an

option to improve axial vascularization prior to transfer.

For larger defects, another option could be a distally based ALT flap. The RF-ALT is a popular choice given its large skin flap size, long pedicle, and the ability to couple TFL with the flap for extensor mechanism reconstruction [68–70]. The RF-ALT is based on a communication of either the deep femoral artery or lateral superior genicular artery with the lateral circumflex femoral artery. Again, we caution that prior orthopedic interventions or trauma may have injured the distal collateral circulation [71]. Note that if the skin perforator arises from an oblique branch and not the descending branch of the lateral circumflex femoral, or if the perforator has a more distal location, this alternative may not even safely reach the knee region [72]. In addition, there is the risk of venous congestion [73]. We strongly recommend supercharging with the saphenous vein, as congestion rates have been reported as high as 50% with the RF-ALT [39]. These risks may be reduced by transferring the ALT flap as free tissue.

MSAP perforators are considered somewhat more fragile and diminutive compared to those of the ALT flap, requiring more delicate technique, in spite of the absence of any microanastomosis [74]. There is also considerable anatomical variability of the location of medial sural artery perforators [75]. As mentioned previously, the medial gastrocnemius is the most commonly used flap for knee coverage, and derives its blood supply from the medial sural artery and vein. As a consequence of this shared blood supply, the MSAP is not an option in patients who have had a failed prior gastrocnemius flap. Also, dense scaring and a poor soft tissue envelope will require greater tissue bulk or surface area than can be provided by the MSAP flap. A visible donor site scar from primary closure or skin graft for either the MSAP or ALT flap will cause a non-aesthetic result that, for some, may be unacceptable. We have also noticed that prophylactic soft tissue coverage with the local MSAP or ALT free flap in high-risk patients prior to definitive knee arthroplasty essentially eliminates future related complications and infection risk.

Distal One-Third of the Leg

Fasciocutaneous or adipofascial pedicled flaps can be based proximally or distally on perforating vessels of the posterior tibial and peroneal arteries. The dissection is relatively straightforward, and provides adequate coverage for small-medium sized defects of the distal lower extremity, including the Achilles tendon [76]. The pedicled peroneal artery perforator (PAP) and posterior tibial artery perforator flap (PTAP) are valuable reconstructive flaps in a surgeon's armamentarium in this region [77, 78]. The pedicled PAP flap can be designed as a propeller, peninsular, advancement, proximally, or distally based island flap and can cover defects in the pretibial area [78]. PAP flaps have been reported to have a higher rate of venous congestion than other flaps, particularly when used as a propeller flap [39, 77]. PTAP flap is commonly raised as a propeller, peninsular, or distally based island flap, and has the advantage of being both thin and pliable. With a skin paddle up to 6 x 18 cm, it can cover anterior shin, medial malleolus, and Achilles territories [22, 79, 80]. Other pedicled-perforator flaps, such as the lateral sural artery perforator flap, lateral superior genicular artery flap, and anterior tibial artery perforator flap, are less commonly used in our practice. Skin grafting of the secondary defect will be necessary for most of the abovementioned pedicled perforator flaps.

The paucity of soft tissue of the distal third of the extremity restricts local transfer and mobilization, and free flap coverage is most often needed. Muscle or myocutaneous free flap options include the gracilis, latissimus, and rectus abdominis. Although the ALT is the most commonly used perforator free flap in our practice, the PMT and AMT are also good options [81]. Other perforator flaps that can be used for lower extremity transfer include the thoracodorsal artery perforator (TDAP) flap and the superficial circumflex artery perforator (SCIP) flap. For tendon reconstruction, the deep fascia of the ALT and TFL can also be used as a substitute [82]. Thinning of these flaps and ease of elevation for secondary procedures further makes them ideal

for reconstruction of the extremity [55]. Also, their pedicles are usually a good size match for recipient anterior or posterior tibial vessels in the leg. The Achilles tendon itself can be reconstructed with autograft, such as vascularized fascia lata or allograft [82–84].

Foot and Ankle

One area that merits additional special consideration is reconstruction of the foot and ankle area. The dorsal surface is characterized by paucity of soft tissues and highly visible contours, and is critical for proper shoe fitting. The plantar surface is glabrous and must withstand sheer forces and direct weight-bearing, making durable coverage essential. It is important to avoid common pitfalls of reconstruction including thin flaps or flaps with too much mobility when reconstructing weight-bearing units, or bulky flaps for the reconstruction of dorsal foot and ankle subunits [85].

Local flaps of the foot are limited by their small size and arc of rotation, and are primarily used to fill rear or midfoot defects. Some surgeons prefer exsanguination of the extremity prior to foot and ankle local flap dissection, whereas others simply elevate and squeeze the leg prior to dissection and elevation of their flaps. Local muscle flaps include the abductor digiti mini and abductor hallucis, and flexor digitorum brevis flaps can be used to cover small heel defects. The flexor digitorum brevis is accessed thru a midplantar incision extending all the way back to the calcaneus, and should be elevated with the plantar fascia. This muscle is small, but can be used to resurface the heel in instances of calcaneal infections, or for coverage following tarsal tunnel release and neurolysis. The extensor digitorum brevis originates form the talus and the dorsolateral surface of the calcaneus, and can be used to cover the lateral malleolus [86, 87]. Elevation of the flap is based on the lateral tarsal artery. Following inset of the flap to the desired defect, we do recommend leaving a drain to help fill the dead space left at the donor site. A neurovascular island flap can be elevated from the lateral side of the great toe for coverage of plantar and metatarsal head ulcers. A V-Y advancement flap based on perforators off of the medial plantar artery may also be used in diabetic patients for coverage of metatarsal head ulcers.

All lower extremity reconstructive surgeons should be familiar with the “instep” or medial plantar artery flap. It has the advantage of providing sensate, similar-thickness, plantar-based skin for resurfacing of small defects up to 6 x 12 cm on the heel when planned as a rotational flap, or on the medial aspect of the first and second metatarsal area as a V-Y advancement [10, 88–90]. Branches of the medial plantar nerve can be taken with this flap to provide for sensation, which is important for coverage of the weight-bearing heel. The pedicle of the flap lies between the flexor digitorum brevis and abductor hallucis. It is important to note that the abductor hallucis will need to be divided in order to facilitate enough arc of rotation (Fig. 21.4a, b, c). When extending the incision proximally into the tarsal tunnel, it is important to preserve medial calcaneal nerves to avoid potential numbness in the area of neuroma formation. A split thickness skin graft can be used for the donor site, with application of a bolster dressing, and offloading typically for a period of 3 weeks. Alternatives to this flap should be considered in diabetic patients with Charcot foot, given the related donor site.

Other local flaps for heel coverage include the reverse sural flap, peroneal artery flap, dorsalis pedis flap, supramalleolar flap, anterior tibial fasciocutaneous flap, and abductor myocutaneous flap. The lateral supramalleolar flap, a fascial turnover flap, is distally based upon the perforating branch of the peroneal artery 5 cm above the lateral malleolus, and provides up to 8 x 6 cm of dorsal foot and ankle coverage [91, 92]. The lateral calcaneal artery perforator flap can be used to reconstruct small defects of lateral ankle and hindfoot, with insignificant donor site morbidity [93, 94]. The previously mentioned sural flap, when distally based on a reverse flow through the peroneal artery and the communicating vascular medial sural network, can cover defects of the ankle and heel [95]. Important landmarks are the lesser saphenous vein and sural nerve, which should bisect the cutaneous paddle. A wide fas-

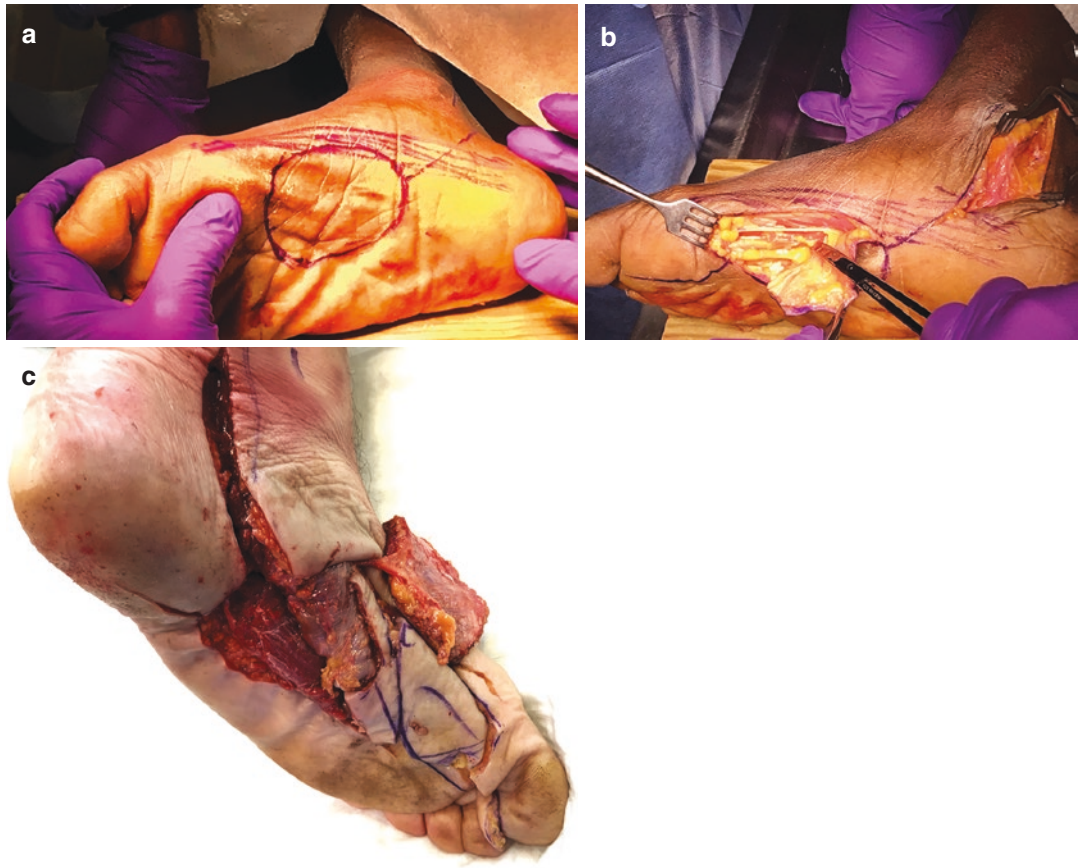

Fig. 21.4 Medial plantar artery "instep" flap. (**a**) Preoperative marking of the flap including the overlying abductor hallucis longus muscle superiorly that will need to be divided. (**b**) Proximal dissection for tarsal tunnel release and neurolysis. (**c**) Final flap following dissection, with reflection and demonstration of the pedicle

cial cuff can be fashioned to help avoid congestion. The dorsalis pedis pedicled fasciocutaneous flap can also be used to cover defects of the anterior, lateral, or medial ankle.

It is common to have an associated long bone fracture with a traumatic ankle wound, making dependable coverage even more critical. Wounds of the dorsal surface expose underlying bone and tendons, and are most often treated with free tissue transfer [96]. Common recipient vessels in this area include the anterior tibial artery (or dorsalis pedis extension), posterior tibial artery, and the saphenous/lesser saphenous vein. Many orthoplastic surgeons prefer the use of free muscle flaps with overlying split-thickness skin grafts, such as the gracilis, latissimus dorsi, and rectus abdominis flaps. Others support the use of fasciocutaneous flaps, such as parascapular, radial forearm, and ALT. Our experience suggests no difference with respect to reulceration rate or gait pattern when comparing muscle or fasciocutaneous flaps. Despite no cutaneous sensation, muscle flaps and skin grafts are an adequate way to reconstruct the heel, allowing significant weight bearing without breakdown [97]. Also, although neurotized fasciocutaneous flaps have better immediate outcomes within the first year, data suggests no relationship between sensibility and stability beyond that time [98, 99].

The bones that most commonly require reconstruction, either due to avascular necrosis or nonunion, are the talus and navicular. The iliac bone crest and medial femoral condyle (MFC) flaps can be used if the defect is <3–4 cm, and the fib-

ula can be used for larger sized defects [100]. The MFC is commonly employed at our institution in patients with complex hindfoot pathology who require additional vascularized bone in order to optimize the potential for osseous healing and successful orthopedic treatment. Unpublished data (Stranix, et al.) suggests that osseous union can be achieved in >90% of these patients, and risk factors for nonunion include obesity BMI > 35 and history of prior failed arthrodesis.

One additional option for metatarsal bony reconstruction is osteocutaneous radial forearm flap. This flap provides a thin fasciocutaneous skin paddle ideal for the dorsal foot, long reliable vascular pedicle, and can be harvested with a length of the distal radius approximately 8–10 cm in length and 1–1.5 cm in width [101–103]. The available bone stock is of reasonable length to be used for metatarsal reconstruction. Risk of fracture of the radius can occur when performing osteotomies for bone harvest, and special care must be taken to avoid this complication.

An interdisciplinary approach for the foot and ankle is critical, as issues with weight bearing may be due to bony, ligament, or muscle abnormalities rather than flap choice. Flap debulking should not be regarded as a complication, as it is often necessary to optimize function and form for shoe fitting. Orthotics may be necessary to improve gait, and shoe inserts may help distribute weight. Reconstruction is only part of the treatment algorithm, and it should be followed by meticulous foot care and long-term vigilance. Plantar flaps are prone to breakdown, and therefore we have a strict non-weight bearing protocol for the first 6 weeks following reconstruction, and close follow-up cannot be stressed enough.

Osteocutaneous Flaps for Lower Extremity Reconstruction

We present a detailed description of two commonly used osteocutaneous flaps in our practice, the MFC (also known as medial genicular artery flap) and the fibula free flap.

Free Medial Femoral Condyle Flap

Given the rich vascular supply of the medial condyle and reliability of its pedicle, the MFC (Fig. 21.5) was first described as a pedicled flap. The flap is based upon the descending genicular artery, which is a branch of the superficial femoral artery, and on the superomedial genicular artery, which is a medial branch of the popliteal artery. It has been utilized for larger bone grafting procedures as well as for osseous defects measuring up to ~4 cm in largest dimension [104, 105]. It can be harvested as an osteogenic periosteal, an osteoperiosteal, or a cutaneous osteoperiosteal flap. In addition to its uses in upper extremity reconstruction, the MFC flap has been recently described as a method of supplying well-vascularized corticoperiosteum in treating recalcitrant nonunions of the femur, tibia, and foot/ankle [106]. This flap has reliable anatomy, and technical pearls for its harvest include:

- Prior to the initiation of the procedure, the distal femur, proximal tibia, knee joint and medial collateral ligament of the knee are all marked (Fig. 21.6a). An incision is made toward the posterior border of the femur across the medial femoral condyle. Dissection is carried down to the vastus medialis fascia, which is incised for a subfascial dissection (Fig. 21.6b). The vastus medialis is retracted anteriorly, which reveals the dominant descending geniculate pedicle running along the femur and paralleling the adductor tendon (Fig. 21.6c).

Fig. 21.5 Shown here is the dissection and harvest of the medial femoral condyle flap based on the descending genicular artery (▶ https://doi.org/10.1007/000-3ts)

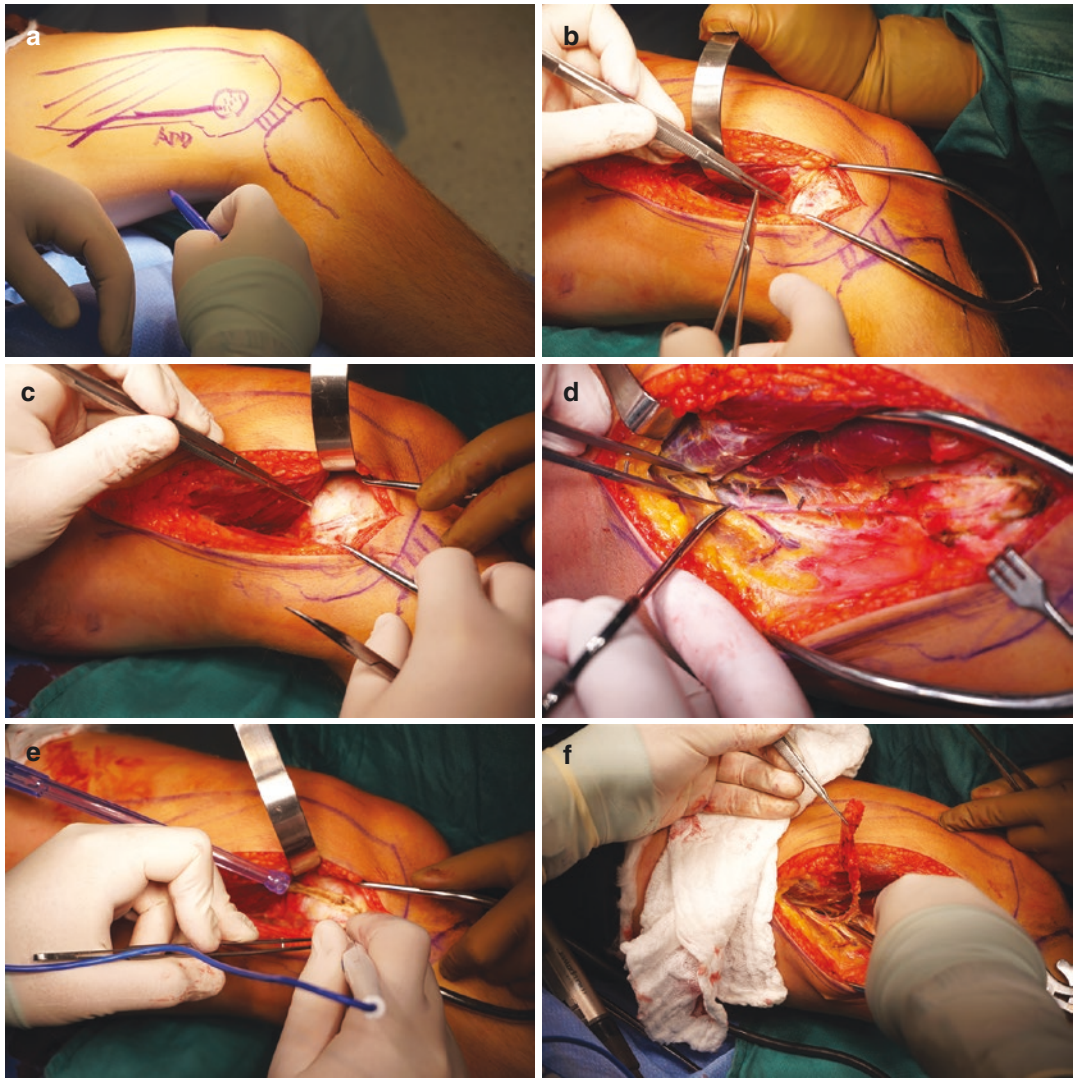

Fig. 21.6 (**a**) Prior to the initiation of the procedure, the distal femur, proximal tibia, knee joint, and medial collateral ligament of the knee are all marked. (**b**) An incision is made toward the posterior border of the femur across the medial femoral condyle Dissection is carried down to the vastus medialis fascia, which is incised for a subfascial dissection. (**c**) The vastus medialis is retracted anteriorly, which reveals the dominant descending geniculate pedicle running along the femur and paralleling the adductor tendon. (**d**) Once the pedicle is located, follow it proximally to the take-off of the superficial femoral artery. (**e**) The periosteum for the bone flap over the medial femoral condyle is incised with electrocautery. (**f**) An oscillating saw and/or osteotome are then used to raise the bone flap. The pedicle is carefully isolated with a swath of periosteum

- For more difficult dissections, the exposure can extend over the face of the MFC where the pedicle fans out and can be traced back proximally. Once the pedicle is located, follow it proximally to the take-off of the superficial femoral artery (Fig. 21.6d). If designing a chimeric flap, special care should be taken to preserve any cutaneous and muscle vascular branches. The periosteum for the bone flap over the medial femoral condyle is incised with electrocautery (Fig. 21.6e). An oscillating saw and/or osteotome are then

used to raise the bone flap. The pedicle is carefully isolated with a swath of periosteum (Fig. 21.6f).

- It is at this point that the nondominant pedicle of the medial superior geniculate artery is often encountered heading toward the popliteal fossa. It is clipped and ligated, or preserved if the descending genicular artery is not present, or of sufficient size so that it can be used. At the completion of flap harvest, gelfoam and bone wax are then placed in the bone defect and the leg is closed over a drain.

Free Fibula Osteocutaneous Flap

The vascularized fibula bone flap has been used extensively due to its predictable dissection, acceptable donor site morbidity, and size. It is the most commonly used vascular bone graft for intercalary reconstructions of the femur and tibia [107]. It has a reliable vascular supply from peroneal artery perforators, and can be used with varying muscle and skin components. It can be harvested with a skin paddle and/or part of soleus or gastrocnemius muscles, making it particularly useful in patients with combined bony and soft-tissue defects. With its long-cylindrical shape, ability to hypertrophy, and strength, this flap also serves as a suitable autograft for reconstruction of the mid-tibia [107]. If the tibial defect involves the articular surface, the reconstruction may be combined with an endoprosthesis. Ipsilateral, pedicled fibula is a reasonable technique for tibial shaft reconstruction or knee arthrodesis. However, additional soft-tissue coverage may be necessary. It is important to keep in mind that a free-fibula harvest from the ipsilateral extremity avoids any possibility of related complications in the normal extremity. The fibula should be considered the first choice for autologous vascularized reconstruction of the femur. Additional cross-sectional strength for this purpose may be obtained by making a "double-barrel" fibular segment. We typically resect 1–2 cm of bone if fashioning a double-barrel fibula, so as not to have the pedicle on too much tension when the segment is folded. Also, a combination of free fibula transfer and distraction osteogenesis has been used effectively over the past 15 years [108].

We commonly use a free fibula graft for bone defects greater than 4 cm. Even when skin is unnecessary for defect reconstruction, we will take a small cutaneous paddle for monitoring purposes. When used for these large defects, the osteocutaneous fibula flap can provide up to 18–26 cm of intercalary vascularized bone. The blood supply to the diaphysis of the fibula is based on an endosteal and musculoperiosteal components that are both provided by the peroneal artery and vein. If a significant portion of the fibular diaphysis is needed, then both the peroneal and anterior tibial arteries must be included with the graft to ensure survival. The defect following fibular harvest rarely hinders the patient's postoperative functioning.

The Capanna technique of massive allograft with free fibular reconstruction is a well-established technique with long-term success >90%, and should be considered in cases of large bony resection such as following oncologic surgery [109, 110]. Such a technique offers a quicker recovery, as there is no requisite wait period for fibular hypertrophy.

Pearls of this flap/dissection include the following:

- The length of the fibula is outlined and a 6 cm of bone is marked proximally to protect the common peroneal nerve and distally to maintain ankle stability. Incision is made directly over the mid-point of the fibula, carried from the neck and distally toward the ankle. The crural fascia is raised over the peroneal muscles from anterior to posterior.
- Septocutaneous perforators are identified in the distal third region of the fibula, and a skin paddle is designed based on these perforators. The peroneal muscles are reflected anteriorly off of the fibula, leaving a 3 mm cuff of muscle on the bone to protect the periosteum. Proximally, the common peroneal nerve is identified and preserved/protected.
- The anterior intermuscular septum is incised and the anterior compartment muscles are swept off of the interosseus membrane. The

interosseus membrane is then incised, and osteotomies are made proximally and distally.
- A bone clamp is used to roll the fibula posteriorly in order to locate the pedicle distally for ligation. The flap is then dissected from distal to proximal, taking care to identify and individually ligate any small branches coming from the pedicle.
- A small cuff of soleus and flexor hallucis longus should be left on the flap to protect the periosteum. To maximize pedicle length, the dissection of the pedicle should be carried as close to the tibioperoneal trunk as possible.
- Once the flap is harvested, the FHL is resuspended and a layered closure is performed over a drain.

A prolonged period of non-weight bearing following free fibula reconstruction of the femur/tibia is necessary until there is adequate hypertrophy of the fibular segment and union to the native femur. Otherwise, the reconstruction is prone to early fracture. Gradual weight bearing begins after bony/soft tissue healing is complete, typically around 6 months postoperatively. Radiographs are then taken every month to ensure ongoing hypertrophy of the fibula.

Postoperative Care

For the most part, clinical exam remains the gold standard following flap reconstruction. This includes assessing for capillary refill, skin color, and skin tone. Monitoring the inflow to a free-flap is prudent while the patient is in the hospital, and may allow for earlier detection and salvage in the event of flap circulation compromise [111, 112]. In fact, some high-volume microvascular centers have early monitoring protocols where flaps are checked at frequent intervals in the early postop period by the involved surgeons in order to be able to better detect early compromise. Identifying a perforating vessel that can be easily auscultated with an external hand-held Doppler is the most routine method of surveillance. Other methods of monitoring, such as transcutaneous oxygen monitoring (Vioptix) and Cook-Swartz Doppler, should not replace clinical exam, as false-positive alarms may result in needless take-backs [113]. Care should be taken in using the cook probe on small vessels, in that the silastic cuff can shift and obstruct flow. If a venous cook probe is also used, it may take 10–12 hours for the venous signal to be audible.

An external fixator can be applied to a foot and ankle reconstruction to act as a kickstand to offload pressure, particularly around the Achilles and posterior heel region. There may be long periods of non-weight bearing status and leg elevation to allow for fracture and soft-tissue healing, and patients' expectations should be set early. Timing of progression to a dependent position of the lower extremity free flap remains an area of significant debate. Flap swelling can result if dangled too early, with additional related sequelae, including potential venous compromise. It is our practice to wait approximately 2 to 3 weeks before beginning a dangling protocol, but this is dependent on whether a skin or muscle flap is used. Also, for cases of oncologic reconstruction, we prefer to wait at least 4 weeks prior to radiation in order to allow for sufficient wound healing.

The other components of monitoring patients who have undergone skeletal reconstruction typically include serial conventional radiographs or CT/MRI cross-sectional imaging to assess for osseous healing. Plain films are used for follow-up, and cross-sectional imaging is typically reserved for surveillance of these patients who underwent reconstruction after resection of malignancy, or for those patients experiencing an associated complication of their skeletal reconstruction. Bone scans may also have a role for assessing viability of the skeletal construct.

Conclusion

The orthoplastic approach to lower extremity reconstruction is a collaborative model of orthopedic and plastic surgeons working together to expedite and optimize care of undergoing lower extremity reconstruction. One should not forget

the aesthetic considerations in addition to functional restoration. One of the most important lessons learned in lower extremity reconstruction, particularly in the case of the patient with osteomyelitis, is that the treating surgeon should enter into a contract with the patient. An estimated and realistic time should be determined for how long it may take to return the patient to function. In the case of chronic osteomyelitis, the requirements for free tissue transfer and subsequent intercalary bone reconstruction can take weeks to months, particularly if distraction osteogenesis is used for bone reconstruction. Defining patient expectations is just as important as operative technique and flap selection.

There is no doubt that the lower extremity reconstructive ladder continues to expand, with newer techniques such as osseointegration, targeted muscle reinnervation, and composite allotransplantation adding to the higher rungs. The success of vascularized composite allotransplantation will depend on advances in immunosuppression, nerve regeneration, and comparison with ever-increasing sophistication of lower extremity prosthetics.

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Pressure Injuries

22

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Introduction

A pressure injury (PI) is defined as localized damage to the skin and/or underlying soft tissue, usually occurring over a bony prominence or under a medical or other device. The decision to change the term *ulcer* to the term *injury* was based on a consensus meeting held in 2016 by the National Pressure Ulcer Advisory Panel (NPUAP) [1]. It was determined that the term *ulcer* does not accurately describe the physical presentation of a Stage-1 pressure injury or a deep-tissue pressure injury (DTPI). Furthermore, histopathological work indicates that small changes in pressure-related injuries start in the tissue prior to the changes being visible on physical examination [2]. An ulcer cannot be present without an injury, but an injury can be present without an ulcer.

The NPUAP staging system, considered the most widely accepted pressure sore staging system, was also revised in 2016 to incorporate the current understanding and etiology of pressure injuries, and to clarify the anatomical features present or absent in each stage of injury [1]. Roman numerals were changed to Arabic numerals in the names of the different stages in order to clarify and reduce the potential for confusion between similar terms used in health care, such as a Stage IV and intravenous (IV). Each stage of pressure injury was validated using photographs and new staging definitions (Fig. 22.1). If the extent of tissue damage within the ulcer cannot be confirmed because it is obscured by slough or eschar, this is termed an unstageable pressure injury. Deep tissue pressure injuries present with a localized area of persistent non-blanchable deep red, maroon, or purple discoloration. This injury results from prolonged pressure and shear forces at the bone-muscle interface.

When encountering patients with pressure injuries, one must know and understand the incidence, risk factors, causes, treatments, and prevention protocols for these patients. The treatment and prevention requires a multidisciplinary approach, often with the plastic surgeon consulted for reconstruction of the soft-tissue defect and wound care.

Economic Impact

Pressure injuries represent a substantial financial burden for patients and healthcare systems

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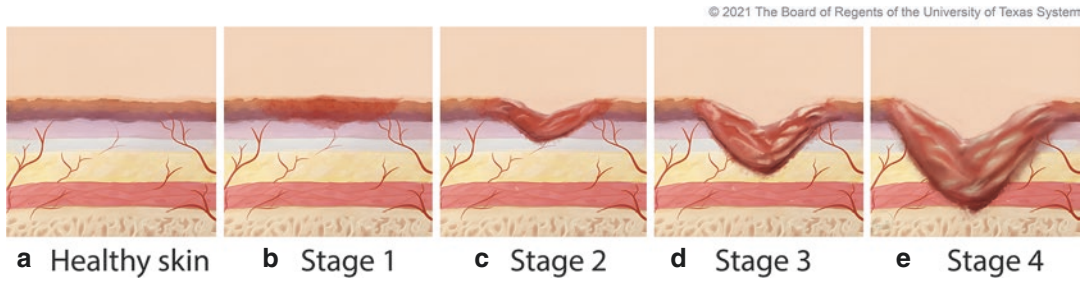

Fig. 22.1 (**a**) Healthy skin; (**b**) Stage 1 pressure injury: non-blanchable erythema of intact skin; (**c**) Stage 2 pressure injury: partial-thickness skin loss with exposed dermis; (**d**) Stage 3 pressure injury: full-thickness skin loss with exposed adipose tissue; (**e**) Stage 4 pressure injury: full-thickness loss of skin and tissue with exposed fascia, muscle, tendon, ligament, cartilage, or bone depending on anatomic location

alike. Previous estimates of the national cost of treating hospital-acquired pressure injuries ranged from $3.3 billion to $11 billion annually [3, 4]. In comparison, claims by Medicare beneficiaries showed that chronic pressure injury care accounted for about $22 billion [5]. A recent study using economic simulation methods suggested that pressure injuries could cost $10,708 per patient on average, exceeding a total of approximately $26.8 billion in the United States annually [6]. Patients with PIs burden the system with increased rates of hospital admission and length of stay compared with patients without PIs (14.1 days versus 5.0 days) [7]. Failure to prevent PIs also presents a substantial liability, with 87% of lawsuits favoring long-term care patients [8]. In 2008, the Centers for Medicare and Medicaid Services deemed PIs reasonably preventable and halted additional reimbursement for the treatment of hospital-acquired Stage 3 or 4 pressure injuries, even if clinicians deem them unavoidable [9]. This compounded the challenge of PI prevention with the essential task of documentation of PIs present on admission. While reduced reimbursements should provide an impetus to hospitals to strengthen their strategies aimed at reducing the development of PIs, the annual cost of PIs has continued to climb. The solution to this rapidly growing concern is complex; however, prevention efforts and decreasing the probability or PI progression across stages have been demonstrated to have the greatest effect on lowering costs associated with PIs [10].

Incidence and Prevalence

Although precise determination of the incidence and prevalence of pressure injuries is difficult, given the substantial variation in description and reporting across institutions, it is estimated that PIs affect greater than 2.5 million people in the United States each year. Recent data demonstrate that overall prevalence rates of PIs declined from 13.5% in 2006 to 9.3% in 2015 regardless of facility type and patient population [11]. Patients in long-term acute-care facilities had the highest PI risk and highest overall prevalence of any care setting. Braden scale scores remained stable during this time, indicating that these declines were not due to a lower pressure injury risk, but likely the result of better pressure injury prevention practices [12]. Since the enactment of the Centers for Medicare and Medicaid Services nonpayment policy for hospital-acquired PIs in 2008, the incidence of hospital-acquired PIs has decreased significantly from 11.8 cases per 1000 inpatients in 2008 to 0.8 cases per 1000 in 2012 [13]. While the prevalence of PIs continues to decline, the high morbidity and mortality associated with PIs are well documented, contributing to over 60,000 deaths per year in the United States, according to the National Pressure Ulcer Advisory Panel.

Prevention Strategies

Effective prevention of pressure injuries begins with identification of high-risk patients. Several scales (Table 22.1) have been proposed in the lit-

Table 22.1 Risk assessment scales for pressure injuries

RAS	Components	Scoring	Collective data
Braden scale	Sensory perception, moisture, activity, mobility, nutrition, friction, and shear	6–23; score of ≤18 indicates higher risk	Based on 16 studies: Median sensitivity was 0.74 (range, 0.33–1.0) and median specificity 0.68 (range, 0.34–0.86)
Norton scale	Activity, mobility, physical condition, mental state, incontinence	5–20; score of ≤14 indicates higher risk	Based on 5 studies: Median sensitivity was 0.75 (range 0.0–0.89) and median specificity 0.68 (range, 0.59–0.95)
Waterlow scale	Sex and age, build/weight for height (BMI), skin type/visual risk areas, continence, mobility, appetite, medication, special risks: Tissue malnutrition, neurological deficit, major surgery, or trauma	1–64; score of ≥10 indicates higher risk	Based on 2 studies: Sensitivities were 0.88 and 1.0, and specificities 0.13 and 0.2
Cubbin and Jackson scale (specific for ICU patients)	Age, weight, skin condition, mental state, mobility, nutrition, respiration, incontinence, hygiene, hemodynamic state, use of blood products, medical history, oxygen requirements, surgery within 24 hours, and hypothermia	9–48; score of ≤24 indicates higher risk	Based on 3 studies: Median sensitivity, 0.89 (range, 0.83–0.95); median specificity, 0.61 (range, 0.42–0.82)

From Tran JP, McLaughlin JM, Li RT, Phillips LG. Prevention of pressure ulcers in the acute care setting: new innovations and technologies. *Plastic and Reconstructive Surgery*. 138(3S):232S–240S. Copyright 2016 by the American Society of Plastic Surgeons. Reprinted with permission of Wolters Kluwer Health Inc.

erature as risk-assessment tools for PI formation. However, none has been shown to be highly effective in predicting the incidence, which is likely due to the multifactorial nature of pressure injuries. The Braden scale has been the most thoroughly studied risk-assessment scale for PI prevention and has a median sensitivity of 74% and a median specificity of 68% [1, 7–9]. Proper risk assessment and implementation of prevention strategies for pressure injuries are crucial to providing comprehensive care while reducing healthcare costs. Prevention strategies and goals of preoperative care are outlined below.

Preoperative Care

The goals of preoperative care are:

1. Control of current pressure sore.
2. Prevention of other pressure sores.
3. Prepare patient for or with nutrition and comorbidity optimization, and appropriate socioeconomic resources for success.

Comorbidities

Identification and optimization of acute and chronic conditions in the patient is of utmost importance. PI patients usually present with multiple comorbidities and affected wound healing, particularly: diabetes mellitus, anemia, and immunosuppression issues (secondary to transplant, autoimmune disease, or medical condition). Medical and nonoperative management can be aided by the help of a multidisciplinary team. This involves the help of the PCP as well as anesthesia colleagues to determine if a patient is optimized prior to scheduling for surgery. In diabetics, glucose levels should be manageable without drastic fluctuations and/or recent changes to

medical regimen. Glycosylated hemoglobin (HbA1c) should ideally be optimized to around 6%, as hyperglycemia or HbA1c >7.0% slows wound healing and increases the risk of wound dehiscence and infection. Anemia can be an indicator of poor nutrition or chronic blood loss and should be worked up and corrected prior to surgical intervention.

Stooling should also be controlled prior to pursuing surgery, either with a reliable digital stimulation regimen or a diverting colostomy if uncontrollably incontinent. If incontinent, stool may soil the pressure sore flap, causing infection and dehiscence. Urine incontinence should also be managed in these patients, due to the effect of moisture and chronic colonization, which may also be detrimental for wound healing. Diverting ileostomies or strict Foley catheter care is of utmost importance prior to considering surgical closure or procedures in PI patients.

Nutrition Optimization

Nutrition is essential to the success of a pressure sore flap. Serum albumin should be maintained above 2.0 g/dL. Prealbumin goal should be at or above 20 mg/dL. At times, a goal prealbumin of 20 mg/dL may be unobtainable. In such a situation, the prealbumin should be followed serially and a maximum lab value should be recorded and maintained. For example, at times the highest a patient will reach over months to a year may be 18 mg/dL. It is satisfactory to proceed with a prealbumin of 18 as long as the patient understands he/she will have to continuously and compliantly supplement postoperatively to maintain this level. Prealbumin labs should also be trended weekly after surgery to ensure that the patient's nutrition is maintained in the recovery process. A requirement of 1.5–3.0 g/kg/d of protein to restore lost lean body mass and 25–35 cal/kg of non-protein calories should be delivered daily.

Pressure injury patients also require an adequate supply of protein and micronutrients such as zinc, calcium, iron, copper, and vitamins A and C. This can be achieved through diet and/or daily multivitamin supplementation. In the author's practice, we order double-portioned meals (diabetic, cardiac, or renal diet if applicable, as well as a multivitamin tablet containing zinc) while in the hospital and remind patients daily of the important role they play in recovery.

Infection Control and Prevention

In order to achieve infection control, the patient must have adequate hygiene, prevention of pressure, soiling contamination, and other organ infections. Compression of soft tissue impairs lymphatic drainage, leading to edema, ischemia, and, ultimately, infection. It is known that bacterial counts increase in compressed areas. Soiling of the wound with urine or stool will also potentially infect the pressure sore. Control of incontinence is imperative prior to surgery. This can be achieved via straight catheter or condom catheter if needed, and a digital stimulation regimen or diverting colostomy. Additionally, other organ infections, such as pulmonary and urinary sources, cause seeding and subsequent infection of pressure sores. It is imperative to identify and treat these infections quickly. The patient must be free of other infections prior to proceeding with surgical intervention [16].

The pressure injury should also be assessed on physical exam for any nonviable tissue and infection. The removal of all nonviable tissue is the essential first step. If the patient is non-sensate, at times they can tolerate a bedside excisional debridement. If this is not the case, debridement in the operating room may be necessary prior to closure. If the patient is not an operative candidate (i.e., on palliative care, unlikely to survive anesthesia, or does not want surgery), a collagenase such as Santyl may be used for chemical debridement. On initial and all subsequent debridements, quantitative culture should be obtained. More than 10^5 organisms per gram of tissue on quantitative culture is diagnostic for invasive infection and is predictive of failure of surgical closure. Swab cultures are not useful, as they often represent only surface contaminants.

Osteomyelitis should also be worked up in a nonhealing or worsening pressure injury. MRI of the sacrum can be ordered to evaluate and localize osteomyelitis. Bone biopsy is the gold standard to identify causative organisms and rule in osteomyelitis. If there is osteomyelitis, and the patient is an operative candidate, the infected bone should be removed prior to flap closure. Infectious disease colleagues can also help in guiding intravenous antibiotic therapy and duration of treatment for osteomyelitis. Topical antimicrobials can also be used to control local infection; however, they should not be used alone in the treatment of osteomyelitis (see Table 22.2). The patient should be followed closely to see if the wound is dynamic and responding to the current wound regimen. If the wound becomes static, the regimen should be changed to account for the character of the wound.

Pressure Prevention

It is imperative that the patient and their support staff or family understands that they will need to be vigilant about pressure prevention for the remainder of their lives, whether or not they undergo surgical intervention. They should strive to relieve pressure over a particular prominence for five minutes every 2 hours in a sitting or lying position. In doing this, they will prevent ischemia and breakdown. If paraplegic or nonambulatory, patients should obtain a low air-loss mattress and Roho cushion for chairs and wheelchairs. Other adjuncts such as foam mattress tops exist; however, they are not as beneficial as a true low air-loss mattress.

Spasm Control

Spasticity is common in patients with spinal cord injuries. Prevalence ranges from 50% to 100% in thoracolumbar and cervical lesions, respectively. Spasm increases shear forces, which increases the likelihood of breakdown. Treatment of muscle spasticity should be implemented before and after a pressure sore flap. Baclofen, diazepam, and/or dantrolene can be used for medical management. If medical therapy fails, surgical intervention may be required, including peripheral nerve blocks, epidural stimulators, baclofen

Table 22.2 Pressure injury/ulcer wound dressings

Mechanical	Type	Products	Indications	Contraindications
	Gauze and Kerlex	Kerlex, 4x4 Gauze, Xeroform®	Stage I–IV Reduces dead space, provides and retains moisture, mechanical debridement	Moisture rich wounds, infected skin and maceration
	Transparent films	Tegaderm®, Opsite, BioOcclusive	Stage I, II Ulcer Friction Protection Microbial and contamination barrier	Exudative wounds, skin infection
	Hydrocolloids	DuoDerm®, Nu-Derm®	Stage II–III, Low to moderate drainage	High drainage Infected ulcer Wounds with cavities
	Alginates	Algiderm, Sorbsan, Melgisorb	Stage III, IV High draining ulcer	Dry or superficial wounds
Active	Antimicrobial	Melgisorb ag®, Acticoat, Silvadene	Ulcer with evidence of local infection and exudates	Systemic infection, leukopenia
	Collagen dressing	BGC matrix®; collagen matrix; FIBRACOL®; Prisma® matrix; Puracol®; Stimulen™ triple Helix collagen dressing	High draining wounds, stage III–IV, wounds with high exudate	Bovine or porcine allergy, non-debrided wounds (dry eschar)

pumps, and rhizotomy. See Table 22.3 for dosing regimens of common antispasmodics.

Contractures

Bedridden patients tend to develop joint contractures via tightening of both muscles and joint capsules. They are common in hip flexors and contribute to the formation of trochanteric, knee, and ankle pressure injuries. First-line treatment is physical therapy in order to stretch out and relieve the contracture. If physical therapy fails to improve contractures, orthopedic consultation for tenotomy may be considered.

Surgical Planning

In order to achieve successful surgical intervention, appropriate timing is paramount. The surgeon must have all of the aforementioned aspects of the patient's care optimized prior to proceeding to the operating room. In addition to regular preoperative evaluation (ASA class and evaluation from the anesthesiologist, DVT prophylaxis, comorbidity optimization), the possibility of autonomic dysreflexia should be assessed in patients with spinal cord injuries, as this can result in problematic bradycardia and hypotension, or tachycardia and hypertension, if not properly treated. Additionally, the anesthesia team should try to avoid the use of succinylcholine in patients with spinal cord injuries, as this can produce detrimental hyperkalemia.

When planning the flap or closure, the surgeon must keep in mind that the recurrence rate, especially in nonambulatory patients, can be as high as 91%. As a result, decision to use a flap that can be re-rotated and does not preclude or prevent future flap options must be considered. In general, when deciding on flap options, fasciocutaneous flaps with adequate blood supply are a suitable option in ambulatory patients, as they do not require sacrifice of muscle. In nonambulatory patients, however, musculocutaneous flaps may be a better option, as they have been shown to have superior blood supply and bulk of tissue in some cases. Skin grafting and primary closure have not shown much success.

Once in the operating room, patients should be appropriately positioned with flexion across the joint of interest to reflect the tension that may ensue on the flap postoperatively. The patient must also be padded appropriately in order to avoid pressure on bony prominences or against devices and/or lines commonly used in the operating room. At the conclusion of the procedure, patients should be immediately transferred off of the operating table onto the low air-loss mattress in the expected postoperative position, taking care to minimize pressure on the flap.

Operative Management

Debridement

Debridement of pressure injuries removes necrotic tissue and decreases bacterial count and biofilm,

Table 22.3 Spasticity control

Medical	Medication	Trade name
	Diazepam	Valium®
	Clonazepam	Klonopin®
	Baclofen	Lioresal®
	Gabapentin	Neurontin®
	Dandrolene sodium	Dantrium®
Surgical/procedural	Neurolysis/neuromodulator	Botox®, Myobloc® phenol, EtOH, lidocaine
	Intrathecal infections	Intrathecal baclofen therapy (ITB) (baclofen/phenol)
	Neurosurgery	(e.g., selective dorsal rhizotomy
	Orthopedic	-contracture release (tendon lengthening/release) -Girdlestone procedure (proximal femorectomy)

while subsequently preparing the wound for closure. Methods of debridement include sharp, mechanical, enzymatic, and autolytic. In some cases, more than one of the methods may be used simultaneously in the course of treatment. Extent of injury and sensation is paramount in deciding between bedside versus operative debridement. In the author's practice, bedside debridement by first contact provider is often employed for initial management in insensate patients. The need for operative debridement may then be deemed necessary to provide adequate assessment, hemorrhage control, and exploration of difficult wounds.

Complete excision of the pseudobursa is a key practice in the reconstruction process. Multiple techniques have been reported in the literature to accomplish this, such as infiltration of wetting solution, and methylene blue/gentian violet coating to identify planes and guide excision [14, 15]. In the author's practice, a gauze is used to lightly paint the bursa cavity to avoid staining of healthy tissue, subsequently closing the cavity and removing it in en bloc fashion. Any tissue removed should be sent for microbiological and surgical pathology assessment, and appropriate therapy should be instituted with culture-specific medications. Postoperatively, the wound is packed and dressings changed every 6–8 hours until the tissue is deemed ready for final reconstruction.

Ostectomy

Removal of the bony prominence is an integral aspect of surgical treatment; however, this must be performed with extreme care. Radical ostectomy should be avoided so as to prevent excessive bleeding, skeletal instability, and redistribution of pressure points to adjacent areas. A commonly cited example of this phenomenon is the total ischiectomy for an ischial pressure injury, which often results in a contralateral ischial pressure injury. Bilateral ischiectomy has been proposed as a solution; however, the redistribution of pressure has been shown to cause perineal ulceration and urethral fistulas. Therefore, it is essential to debride the minimal amount of bone necessary when debriding ischial pressure injuries [16, 17].

Closure

When planning a surgical strategy, the surgeon should consider not only the present surgery, but also the need for subsequent surgical procedures. The choice of closure strategy depends not only on the location, size, and depth of the ulcer but also on the previous surgeries performed. Primary closure should be avoided, as pressure injuries usually have an absolute tissue deficiency. Simply pulling the tissue over a bony prominence together will almost certainly lead to tension and dehiscence. Important considerations for flap design include size and depth of the ulcer, quality and pliability of the surrounding skin, presence of previous surgical scars, and the ambulatory status of the patient.

Classically, musculocutaneous flaps were preferentially used when bulk tissue was required to obliterate dead space. However, it has been demonstrated that the muscle used in these flaps undergoes considerable atrophy over time and has decreased tolerance to pressure compared to fasciocutaneous flaps, which makes them more susceptible to recurrence [18–20]. Furthermore, musculocutaneous flaps result in donor-site morbidity, and in an ambulatory patient it is vital not to further impair mobility. Excessive blood loss and limitations in flap design are other important drawbacks. Fasciocutaneous flaps offer an adequate blood supply, durable coverage, minimal potential for a functional deformity, and more closely reconstruct the normal anatomic arrangement over bony prominences. Yamamoto et al. [21] concluded that fasciocutaneous flaps have better long-term results than myocutaneous flaps when used for pressure sore reconstruction.

Gluteal perforator-based flaps have also gained popularity since they were first described for reconstruction of sacral pressure sores by Koshima and colleagues [22] in 1993. The superiority of fasciocutaneous or perforator flaps in pressure injury reconstruction remains controver-

sial. A recent study that compared outcomes between musculocutaneous flaps, fasciocutaneous flaps, and freestyle perforator flaps for pressure injury reconstruction found no statistical significance regarding complication rate or flap necrosis rate among different groups [23].

Ischial Defects

Ischial pressure injuries develop in patients who remain in the seated position for prolonged periods of time, such as wheelchair-bound patients. Recurrence is high among this population and has been quoted to be between 19% and 77% [24, 25]. Given the high recurrence rate, flap design should allow coverage of the pressure injury but should not prevent the use of other flaps in the future.

Closure of ischial defects is most commonly achieved with fasciocutaneous flaps or myocutaneous flaps. Commonly used flaps include the gluteal fasciocutaneous flap and gluteal myocutaneous rotation flap. Posterior fasciocutaneous V-Y advancement flaps and posterior hamstring myocutaneous V-Y flaps also provide good tissue for coverage; however, they can often leave a wound under tension, and care must be taken in patient positioning in the postoperative period. The tensor fascia lata (TFL) flap can occasionally be used, although the distance does not provide the adequate bulk for distal or extensive injuries [26].

Sacral Defects

Sacral pressure injuries occur in patients in the supine position and commonly manifest in those in the acute-care setting. The two "workhorse flaps" for sacral wound coverage are largely considered to be the gluteal V-Y advancement flap and the gluteal rotation flap. These flaps provide both musculocutaneous and fasciocutaneous options and may be re-advanced if necessary. In a comparison of these flaps by Djedovic and colleagues [27], they demonstrated that significantly more V-Y flaps were needed to cover an almost half-as-large defect compared to a gluteal rotational flap (50.4 versus 94.8 cm^2). This observation may be attributed to a limited range of motion of the V-Y flap, necessitating the dissection of bilateral V-Y flaps to yield a tension-free closure at the wound edges. Other flaps available include the transverse and vertical lumbosacral flaps, based on lumbar-perforating vessels, although these have significantly less bulk and, consequently, are less useful in deeper wounds.

Trochanteric Defects

Trochanteric pressure injuries develop in patients who lie in the lateral position, especially in those who have significant hip flexion contractures. The most common flaps for reconstruction are the TFL flap and vastus lateralis flap. Perforator flap reconstruction has also been employed, but is less commonly used. The TFL flap must be used with caution in large defects, due to the random nature of the blood supply at the distal aspect of the flap, and sometimes may necessitate a delay procedure. Rotation of this flap results in a T-shaped junction between the flap and the primarily closed donor site, making it prone to dehiscence. The donor site is often skin grafted to avoid dehiscence [28].

Other Considerations

Important considerations for flap design include size and depth of the ulcer, quality and pliability of the surrounding skin, presence of previous surgical scars, and the ambulatory status of the patient. For more complex, deeper, or larger wounds, a combination of flaps may need to be employed.

Only the most common pressure sores have been discussed in this chapter; however, if an anatomical location can serve as a pressure point, then it has the potential to develop a wound when subjected to unrelieved pressure. Some less common pressure sores, like those at the ear or scapula, often can be closed primarily or with local tissue rearrangement. Heel pressure sores are difficult to treat, and avoidance and early identification are key to prevent these injuries.

In extreme cases of pelvic girdle or lower extremity pressure sores, it may be necessary to consider total thigh flaps in which the femur is removed and the thigh tissue is used to close the wound. However, this should not be used as a first-stage procedure, and commonly a staged reconstruction would be appropriate for patients in these conditions [28].

Postoperative Care

Many of the preoperative care considerations are echoed in the postoperative window. Optimization of nutrition, management of comorbidities, and infection control are vastly important in the postoperative period. Careful nursing care is critical to postoperative success. Drains are placed intraoperatively to remove serous fluid and to aid in apposition of the flaps to the wound bed. Control of urine, stool, and sources of moisture will prevent infection and maceration. The use of absorptive nonocclusive dressings and negative-pressure wound therapy devices have added to the armamentarium of the reconstructive surgeon.

The most important aspect of the postoperative period is pressure offloading, specifically around the surgical site or suture lines. Patients are positioned to avoid pressure on the operative site, with turning every 2 hours, and use of low-air-loss mattresses when available. Patients are kept in the postoperative position, with no pressure allowed on the surgical site for 2–3 weeks. Assessment of wheelchairs or beds should be evaluated to ensure fit and pressure distribution. There is no consensus on reseating protocols, but it is agreed that reseating must be gradual. A common protocol starts with 30 minutes the first day and then adds a half-hour increment daily, if tolerated without compromise of the surgical site [26–29].

Conclusion

Advances in the understanding of pathophysiological mechanisms underlying pressure injury development have been reflected in the new definition and staging system by the NPUAP. Management of the pressure-injury patient is multifaceted, with the outcomes related to the patient's comorbidities, concurrent infections, and social factors such as accessibility to supportive care, compliance, and substance abuse. Given these concerns and the high recurrence rate, conservative management of pressure injuries continues to be a well-traveled path. Effective pressure-injury prevention begins with risk identification and nutritional assessment, followed by the implementation of support surfaces, prophylactic dressings, and repositioning regimens for appropriate patients. Preventative strategies and local wound care, coordinated with a knowledgeable team, are essential. Once surgical intervention is decided on, appropriate timing, planning, flap choice, and postoperative care are crucial to minimize recurrence. As evidence-based medicine and limitations in healthcare spending continue to evolve, the holistic approach to the pressure-injury patient is vital.

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Facial Paralysis

23

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Introduction

Facial paralysis is a complex condition that results from lack of development or an injury to the facial nerve. The facial nerve has its nucleus in the brain stem and courses intracranially and then intratemporally until it exits the stylomastoid foramen to branch out to the different mimetic muscle components of the face. During early fetal life, the facial or seventh nerve may not develop properly in the brainstem, it can also be injured during birth from external pressure. After birth, it can be damaged within the brain itself, during its course to the face, or after it exits the skull base and disperses to the musculature of the face. It can also be injured by tumor surgery, trauma, or disease, or have its function altered by inflammatory processes such as Bell's palsy.

Facial paralysis can thus be congenital, or present at birth. Unilateral congenital facial paralysis is referred to as developmental facial palsy, whereby all or selected branches of the nerve do not develop normally. This results in focal muscle malfunction and facial asymmetry, with functional and psychosocial consequences. If the developmental facial palsy is bilateral, it is often accompanied by weakness of the sixth nerve as well, in a syndrome known as Moebius syndrome. Moebius syndrome is usually bilateral and usually severe, but may be asymmetrical and incomplete, with more significant involvement of the upper component of the face than the lower. Developmental facial palsy and Moebius syndrome are the two most common situations in which we see congenital facial paralysis.

The acquired form presents after birth and again may be one-sided (unilateral) or bilateral. It can be a result of trauma, including surgical trauma, to the facial nerve in its intracranial portion, intratemporal portion, or extracranial portion. The damage leads to weakness or non-function of the musculature of the face and subsequent problems related to function, comfort, and psychosocial well-being. Bilateral

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acquired facial paralysis is rare, but can occur as a result of intracranial tumors or bilateral inflammatory processes.

The clinical effects of facial paralysis can be devastating. The most serious functional consequences occur as a result of acquired facial paralyses, which are complete. In these situations, the facial musculature will not function, leading to a lack of eyebrow elevation, a lack of eyelid closure and corneal exposure, a lack of nasal sphincter opening, and in the region of the mouth, drooling from oral incompetence, speech problems, particularly related to bilabial speech, and dental decay as a result of exposure. Facial paralysis can affect the comfort of the patient with irritating, painful eye symptoms as a result of lack of corneal lubrication and lack of corneal protection. A dry but tearing eye is common. Nasal obstruction is often present and particularly disquieting at night. In and around the mouth, oral incompetence and lack of food control can lead to painful irritation around the mouth, and troublesome biting of the affected cheek. In addition to problems related to function and comfort, the facial paralysis patient experiences problems in the psychosocial realm. There is often a facial droop, with facial asymmetry and a lack of facial expression on the affected side. Not only is the face distorted at rest, but attempts to smile or express emotion are not possible, and can lead to social isolation and depression due to impaired body image and low self-esteem.

Facial paralysis presents in a wide spectrum of involvement, from minimal weakness to complete lack of muscle function, and from minimal excursion of the affected commissure to hyperkinetic activity and excessive muscle pull on the affected side. This latter condition, known as hyperkinesis, is often associated with synkinesis, when all components of the facial musculature fire together. These problems are often a consequence of facial nerve reinnervation after an inflammatory process such as Bell's palsy. Fortunately, this is rare, but it is extremely disconcerting when it occurs and very difficult to correct.

There are several complex procedures designed to aid the facial paralysis patient, and these will be outlined in detail. Nothing is perfect, and there should be a mutual expectation between the clinician and patient that the reconstructed result will not be "normal" or "perfect." However, we have come a long way in our assessment, treatment, and understanding of the facial paralysis patient. We will start with the anatomy of the structures involved with reconstruction and then discuss our approach in selecting nerves and muscles for reanimation.

Anatomy

Facial Nerve

The facial nerve is the seventh cranial nerve, arising from the pons in the brainstem. It can be broadly divided into intracranial, intratemporal, and extracranial segments. In a clinical context, the extracranial segments of the facial nerve are the most relevant in the reconstruction of facial paralysis.

The extratemporal component of the facial nerve begins as it exits the skull through the stylomastoid foramen. The first branch arising from the extratemporal facial nerve is the posterior auricular nerve, which provides motor innervation to the auricular muscles, as well as the occipital portion of the occipitofrontalis, and sensory innervation to portions of the ear. Prior to entering the parotid gland, the facial nerve travels between the posterior belly of the digastric and the stylohyoid, giving off motor branches to each of these muscles. As it continues anteriorly, the facial nerve lies between the superficial and deep lobes of the parotid gland, where it divides into two major branches—a cephalic temporofacial branch and caudal cervicofacial branch. Approaching the anterior border of the parotid gland, these branches then divide into the temporal (or frontal) branch, zygomatic branch, buccal branch, marginal mandibular branch, and cervical branch. These branches then innervate the muscles of facial expression on their deep surfaces, with the exception of mentalis, buccinator, and levator anguli oris, which are innervated by the facial nerve on their superficial surface.

Reconstructing the lower third of the face in facial paralysis principally involves recreating the action of the zygomaticus major and zygomaticus minor musculature. These muscles serve to draw the commissure of the mouth into the superior, posterior, and lateral vector. The innervation of the zygomaticus musculature is variable, with contributions from either the zygomatic or buccal branches of the facial nerve [1]. There is usually redundancy in the innervation of the zygomaticus musculature, permitting sacrifice of a selected branch for use as a motor donor without compromising function of the normal side of the face.

Gracilis

The gracilis is one of six muscles that form the adductor complex of the hip, originating from the ischiopubic ramus and inserting on the medial aspect of the tibia as part of the pes anserinus. Classified as a Mathes-Nahai type II muscle, the primary pedicle lies superiorly and is supplied by the medial circumflex femoral artery in most circumstances, although direct supply from the profunda femoris artery has also been described. The minor pedicles are typically supplied by branches from both the profunda femoris artery as well as superficial femoral artery. Innervation is provided by a branch of the obturator nerve and typically enters the muscle proximal to the vascular pedicle.

Donor site morbidity of gracilis harvest is relatively low and is primarily associated with concerns regarding the cosmesis of the scar. Although some studies have demonstrated a mild decrease in measured hip adduction strength, this is often not noticed by patients in their day-to-day activities.

Sural Nerve

The sural nerve has been well established as a suitable donor for nerve autograft, owing to its low donor morbidity, reliable anatomy, and generous length. It is a sensory-only nerve that provides innervation to the posterolateral portion of the calf, and the lateral portions of the ankle, heel, and midfoot. In most patients, the sural nerve is formed by the confluence of both the medial and lateral sural cutaneous nerves. However, it is also recognized that the sural nerve occasionally receives contribution exclusively from the medial or the lateral sural cutaneous branches [2] (Fig. 23.1). Proximally, the sural nerve lies between the medial and lateral heads of the gastrocnemius, deep to the fascia. As it proceeds into the distal third of the lower leg, the sural nerve pierces the fascia to lie superficially, in the subcutaneous plane. At the ankle, it travels between the lateral malleolus and Achilles tendon before giving off its terminal branches to the skin of the lateral ankle, heel, and foot.

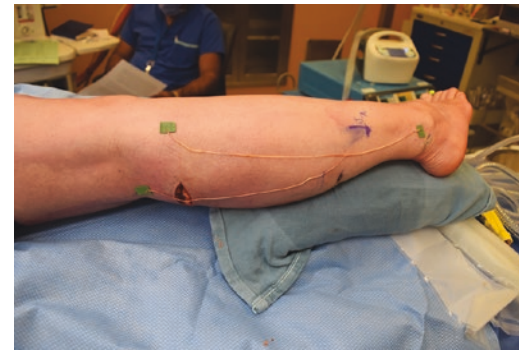

Fig. 23.1 Contributions to the sural nerve from the peroneal and tibial nerves can be variable. This photograph depicts a sural nerve graft, which has equal contributions from both peroneal and tibial nerve components

Selecting an Appropriate Donor Nerve and Ensuring Adequate Neural Input

Our preference is to utilize a cross-face nerve graft powered by the unparalyzed side of the face whenever possible. This is based upon our philosophy that the ability to generate a spontaneous smile consistent with the patient's emotions and the social context around them is as important as the ability to physically form a smile. By utilizing the intact facial nerve on the contralateral side, the patient is able to generate a smile using the transplanted muscle with minimal retraining.

For cross-face nerve grafting, the ideal donor motor nerve is a facial nerve branch which provides robust activation of the zygomaticus major, zygomaticus minor, and levator labii musculature. Branches that cause activation of nasalis, orbicularis oculi, orbicularis oris, risorus, or the depressor labii inferioris should be avoided because of their antagonistic actions, which can cause issues with distortion of the reconstructed smile and difficulty with emotional spontaneity. A nerve stimulator is used to ensure that there are redundant branches which will continue to provide innervation to the zygomaticus major and minor muscles on the non-paralyzed side of the face.

Although our preference is to use a cross-face nerve graft to innervate our muscle transplants, the motor nerve to masseter remains a valuable source of neural input, especially in cases of bilateral facial palsy, revision cases, or in older patients where stronger neural input is required to overcome significant soft tissue ptosis. The motor nerve to masseter is able to provide stronger neural output owing to its higher axonal density; Snyder-Warwick et al. found that the motor nerve to masseter had an average myelinated fiber count of 5289 per mm^2 as opposed to an average of 1647 per mm^2 at the distal end of a cross-face nerve graft [3]. In clinical studies of unilateral facial paralysis, muscle transplants innervated by the motor nerve to masseter were able to generate 90% of the excursion measured on the non-paralyzed side, compared to 50–75% of normal side excursion when innervated by a cross-face nerve graft.

The disadvantage in axonal density of the cross-face nerve graft can be mitigated using several techniques, which we routinely utilize in our reconstructions. Firstly, once the desired donor facial nerve branch is identified, we perform retrograde dissection of this branch into the parotid gland for a short distance. Most significantly, this intraparotid dissection significantly improves axonal counts, which has been associated with improved aesthetic outcomes following reconstruction [4, 5]. This back dissection also provides ancillary benefit by improving exposure of the facial nerve for coaptation to the nerve graft. Secondly, minimizing the length of the sural nerve used to bridge between the donor facial nerve branch and the contralateral upper buccal sulcus will reduce the amount of axonal density drop-off at the distal end of the nerve graft. We also prefer to use the proximal portion of the sural nerve for grafting, as this provides a better size match to the donor facial nerve branches, as well as increased axonal counts, compared to the distal sural nerve. Electrical stimulation has been well established in laboratory models and shown promise in clinical applications by increasing the number of axons which cross the site of coaptation and ultimately reach their target. We routinely stimulate the donor branch of the facial nerve prior to division and coaptation for1 hour at 20 Hz—a paradigm which has been validated in the literature [6–11]. The voltage is titrated such that there is visible contraction of the facial muscles. Finally, we have recently begun to coaptate the distal end of the sural nerve branch to a terminal branch of the infraorbital nerve on the paralyzed side of the face. In a rat model, coaptation of a sensory nerve to a nerve graft in an end-to-side manner improved nerve regeneration, as well as functional outcomes, by providing trophic factors which counteract the effects of chronic denervation on the distal end of the nerve graft [12]. The addition of this step adds minimal time to the procedure, and patients have not reported any appreciable alteration in the sensation of their upper lip.

Cross-Face Nerve Grafting

We perform our cross-face nerve grafting with the patient in the supine position. This permits two teams to work simultaneously, and without having to reposition the patient intraoperatively. One team procures the sural nerve graft, while the second team exposes the normal functioning side of the face for nerve mapping and motor nerve selection. By flexing the patient's knee, and flexing and internally rotating at the hip, this provides sufficient exposure of the lower extremity to permit sural nerve harvest without the need for prone positioning. If necessary, a gel roll can also be placed underneath the ipsilateral hip to cant

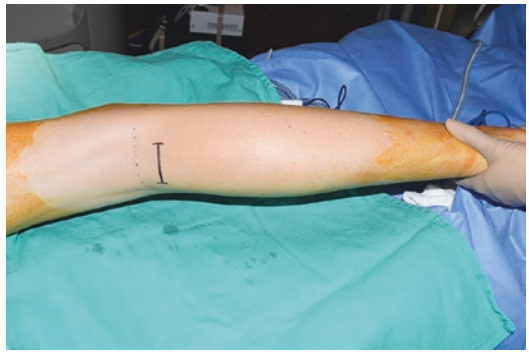

Fig. 23.2 Markings for the proximal incision for sural nerve harvest. A transverse incision is marked 4 cm distal to the flexion crease of the knee, centered on the midline axis of the lower leg

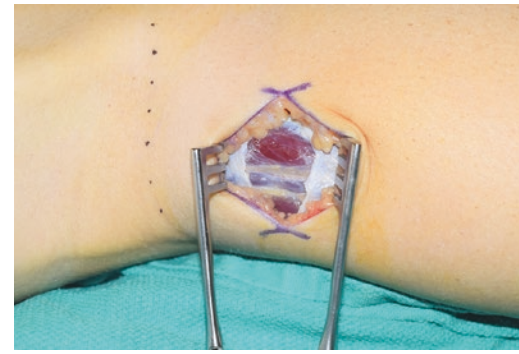

Fig. 23.3 The fascia overlying the gastrocnemius muscle has been incised, exposing the medial and lateral heads of the gastrocnemius muscle. A thin strip of fat can be seen between the heads of the gastrocnemius muscle

the pelvis to further improve exposure and access to the posterolateral leg.

Sural Nerve Harvest

The entire leg is circumferentially prepared and draped. A sterile tourniquet is used in order to optimize visualization during the dissection, and this is applied to the proximal thigh after appropriate padding. A transverse incision is marked distal to the flexion crease of the knee, centered on the midline axis of the lower leg (Fig. 23.2). In teenagers and adults, this is typically a 4 cm incision that lies 4 cm distal to the crease; the incision should be adjusted appropriately for younger children. The leg is then exsanguinated by elevation, and the tourniquet inflated to provide pressure that is 150 mmHg above the patient's systolic blood pressure.

The skin incision is made using a scalpel, and then subcutaneous dissection is carried out using tenotomy scissors until the fascia overlying the gastrocnemius is encountered. Meticulous hemostasis throughout the dissection aids with visualization of anatomic structures and landmarks. The fascia overlying the gastrocnemius muscle is transversely incised for several centimeters, and the interval between the medial and lateral gastrocnemius muscle bellies is identified (Fig. 23.3).

There is usually a thin strip of fat which lies between the medial and lateral heads of the gastrocnemius, and this can assist with identification of the midline, especially in larger patients. This interval is opened bluntly, and right-angle retractors are used to provide visualization during this dissection. The sural nerve and its contribution from the medial sural cutaneous nerve can be visualized in this interval, running next to the lesser saphenous vein. Although we do not routinely do so, a nerve stimulator can be used to differentiate the purely sensory sural nerve, which should not elicit any muscle twitching, from the tibial nerve. The nerve is dissected retrograde to its take-off from the tibial nerve. If needed, the sural nerve can be neurolyzed from the tibial nerve to the level of the distal thigh for additional length, but this is typically not necessary for cross-face nerve grafting. Occasionally, the sural nerve and its contribution from the medial sural cutaneous branch is quite small. In these situations, the contribution from the lateral sural cutaneous nerve should be identified and dissected to its take-off from the common peroneal nerve.

Once the proximal sural nerve has been adequately exposed, it is divided under direct vision. The free margin of the sural nerve is delivered through the nerve stripper, and Jake forceps or fine mosquito is applied to allow a surgical assistant to maintain gentle proximal traction (Fig. 23.4). The tip of the nerve stripper is passed deep to the fascia overlying the gastrocnemius and is gently advanced (Fig. 23.5). If resistance is

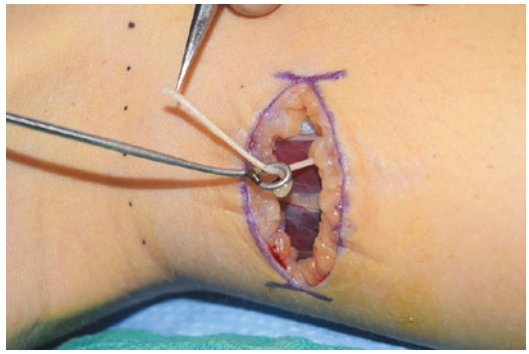

Fig. 23.4 The proximal portion of the sural nerve graft is passed through the nerve stripper

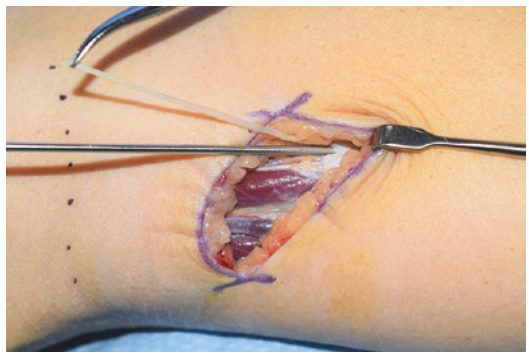

Fig. 23.5 The tip of the nerve stripper is passed deep to the fascia overlying the gastrocnemius fascia, and is advanced distally

encountered, the orientation of the nerve stripper should be checked to ensure that it is angled parallel to the long axis of the calf, and parallel to the skin.

Approximately 12 cm of nerve graft is needed in children 5 years or older, although this measurement should be confirmed by the team operating on the face. Once sufficient length of sural nerve has been freed, the tip of the nerve stripper is palpated through the skin, and a counter-incision is made (Fig. 23.6). Blunt dissection is carried through this incision to locate the tip of the nerve stripper (Fig. 23.7). At this point, the sural nerve can be delivered through this distal incision, and removed from the nerve stripper. The sural nerve can be dissected further distally if needed, before it is transected under direct vision (Fig. 23.8). The proximal end of the nerve graft is marked with ink.

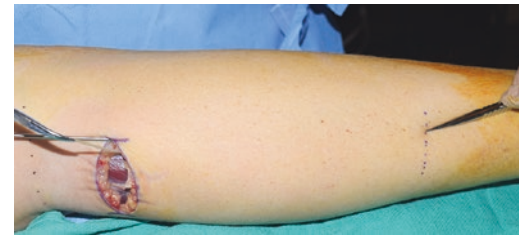

Fig. 23.6 Once a sufficient length of nerve has been stripped, the tip of the nerve stripper can be palpated, and a counter incision is marked

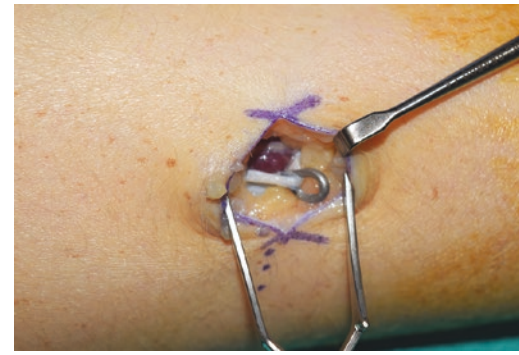

Fig. 23.7 Once the counter incision has been made distally, the tip of the nerve stripper is identified

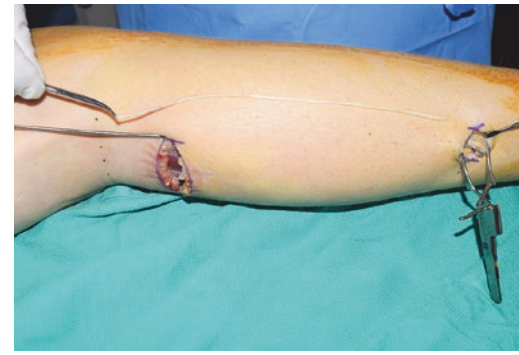

Fig. 23.8 The sural nerve graft has been transected distally, and delivered from the wound

The nerve graft is brought onto the side table, where it is cleaned of adventitial tissue, and a small segment of proximal nerve is sharply excised, where it was crushed by the Jake forceps or mosquito. The nerve graft is wrapped in a saline-dampened piece of gauze before being banked in a safe location on the surgical table.

The pneumatic tourniquet is let down to ensure that any bleeding is appropriately controlled, and then layered closure is performed using absorbable sutures. The leg is then dressed based on surgeon preference; we usually utilize a small amount of skin adhesive over the incision before applying a trimmed piece of gauze and a transparent occlusive dressing.

Facial Nerve Mapping

The unparalyzed side of the face is marked using an extended rhytidectomy incision, with a short submandibular extension to improve exposure (Fig. 23.9). Our preference is to carry the rhytidectomy incision onto the tragus itself, in order to place the postoperative scar in a less conspicuous area. Based on anatomical studies [13], we find it useful to mark a point halfway between the helical root and the oral commissure; this point approximates the location of a donor facial nerve branch which can be used for cross-face nerve grafting, and a useful guide for dissection (Fig. 23.10).

The extended rhytidectomy incision line is infiltrated with 1:400000 epinephrine to aid with hemostasis and improve visualization during the dissection. It is important to not infiltrate the surgical site with local anesthetic, as the sodium channel blockade will impede the ability to utilize a nerve stimulator for facial nerve mapping

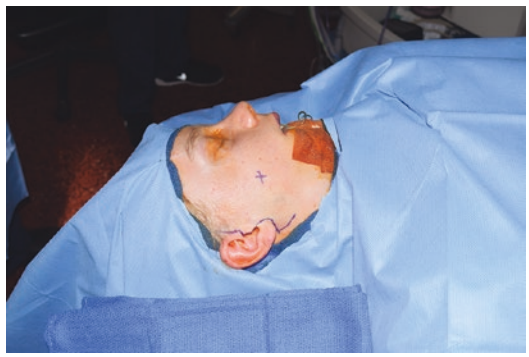

Fig. 23.9 An extended rhytidectomy incision has been marked for facial exposure. The estimated location of the donor branch of the facial nerve is seen marked with an X on the cheek

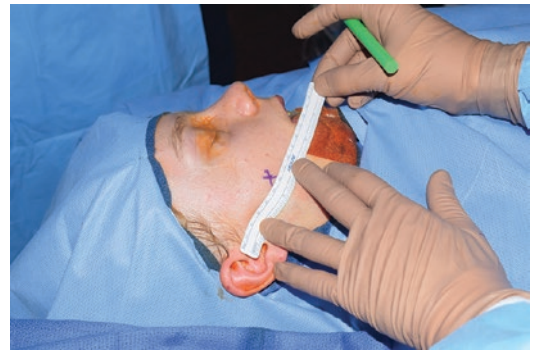

Fig. 23.10 The location of the donor branch of the facial nerve branch which will be used for cross-face nerve grafting can be estimated by marking a point halfway between the helical root and ipsilateral oral commissure

later in the procedure. Incisions are made through the skin, and then dissection anterior in a subcutaneous plane, superficial to the parotid fascia. The initial subcutaneous dissection is done sharply with a scalpel, but as the anterior border of the parotid / landmarked point between the helical root and oral commissure is approached, we transition to blunt dissection using tenotomy scissors. As the anterior border of the parotid is approached, fibrous bands can sometimes be difficult to distinguish from branches of the facial nerve; in these circumstances, the nerve stimulator can be used to assist with identification of structures prior to their division.

As the various branches of the facial nerve are dissected, they are stimulated to determine which muscles they innervate. From this, a facial nerve map is created such that the ideal donor branch, which provides zygomaticus major and minor activation with minimal antagonistic action, can be identified as a suitable donor motor nerve for cross-face nerve grafting (Fig. 23.11a, b, and c). Ideally, a redundant branch which also provides zygomaticus major and minor innervation is identified, so that the clinician can be certain that there will be residual innervation to the muscle after dividing the donor motor nerve branch.

Once the donor branch of the facial nerve has been selected, it is dissected retrograde into the parotid for several millimeters in order to increase axonal density, providing a better size match to the sural nerve graft, and improving visualization

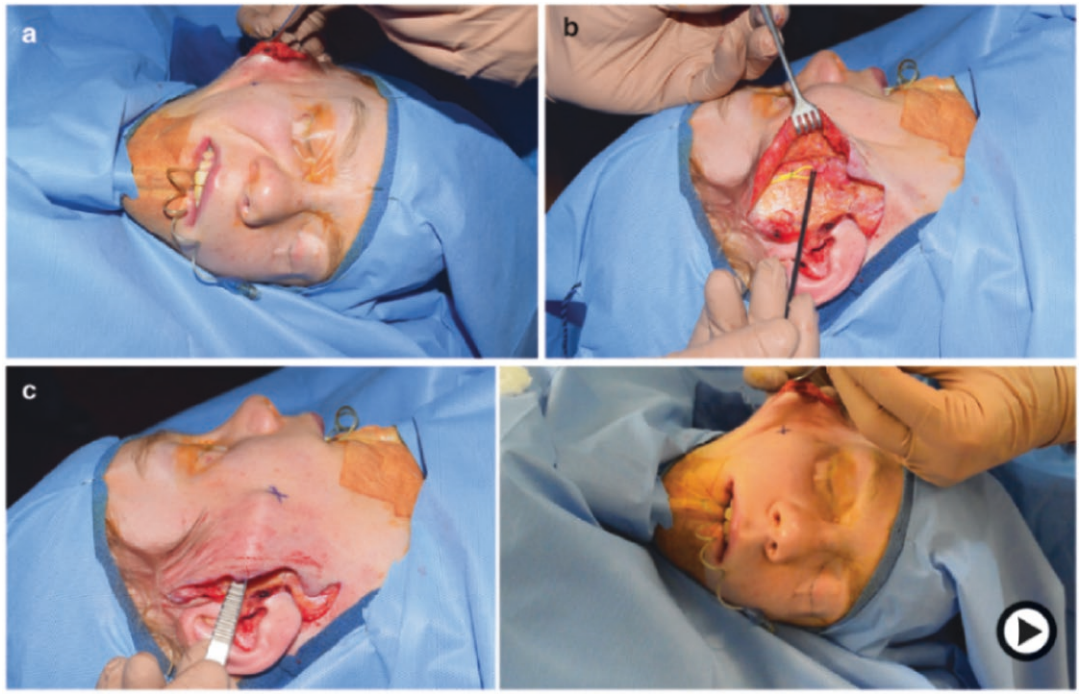

Fig. 23.11 (**a**–**c**) (**a**) The donor facial nerve branch that has been selected for usage for cross-face nerve grafting is stimulated. Good oral commissure movement with minimal antagonistic muscle action is seen. (**b**) The selected facial nerve branch can be seen between the tips of the nerve stimulator. The nerve branch has been dissected retrograde into the parotid over several millimeters. (**c**) The location of the identified nerve branch to be used for cross-face nerve grafting is demonstrated to correspond well to the preoperative marking for the estimated location of the donor nerve branch (▶ https://doi.org/10.1007/000-3ty)

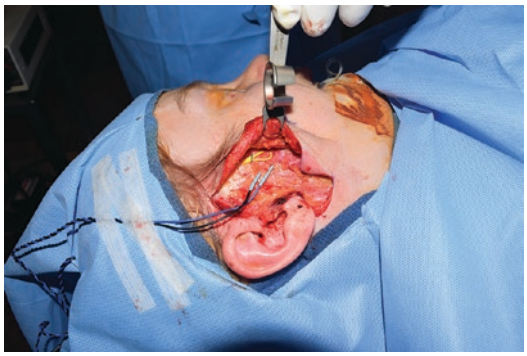

Fig. 23.12 The nerve stimulator leads are applied to the facial nerve branch selected for cross-face nerve grafting, and the nerve is stimulated for 1 hour at 20 Hz

for neurorraphy (Fig. 23.12). Prior to division of the facial nerve branch, the nerve is stimulated for 1 hour at 20 Hz, with the amperage titrated to provide visible twitching of the facial musculature. A damp gauze is placed in the surgical site during the stimulation to avoid tissue dessication. Once the stimulation is complete, the donor facial nerve branch is divided.

An incision is made in the upper buccal sulcus at the level of the canine on the paralyzed side of the face. Submucosal dissection is carried out using tenotomy scissors to identify terminal branches of the infraorbital nerve (Fig. 23.13). One or two of these branches can be divided and used later for coaptation to the distal end of the nerve graft to enhance axonal regeneration down the length of the sural nerve graft (Fig. 23.14). The tissues are then dissected down to the level of the periosteum. Fine Jake forceps are used to create a supraperiosteal tunnel which connects the upper buccal sulcus exposure with the facial exposure on the non-paralyzed side (Fig. 23.15). The sural nerve graft is passed through this tunnel using the Jake

forceps, and positioned to ensure that the coaptation to the donor facial nerve branch will be tension free, and any excess nerve graft is trimmed if necessary (Fig. 23.16a and b).

The sural nerve is coapted to the donor branch of the facial nerve under the operating microscope (Fig. 23.17a and b). By using a minimal amount of suture—only enough to position and orient the nerve—the neurorraphy can be completed in a rapid fashion by using fibrin glue (Fig. 23.18). We have found that the use of fibrin glue also allows more precise alignment of the nerve ends during coaptation. The distal end of the sural nerve graft is coapted in a similar manner to the terminal branches of the infraorbital nerve that were previously identified. To aid with localization of the distal end of the sural nerve graft in the second stage, we mark its location using a small non-absorbing suture, or a surgical clip, or a combination of the two.

The oral incision is closed using resorbing sutures, ensuring that the closure is watertight. It is important to perform this closure under direct vision to ensure that the nerve graft is not inadvertently caught by the needle or suture when the mucosa is closed. The facial exposure is checked for hemostasis, and closed in a layered fashion using interrupted deep dermal sutures, followed by a running subcuticular closure using resorbable monofilament suture. We do not routinely employ a drain as part of our closure. A reminder is written on a piece of surgical tape and applied to the face to remind the patient, family, and care team to avoid applying pressure to the operative site. We admit our patients postoperatively to ensure that their pain is controlled and that they are independently ambulating prior to discharge. Typical admission length is two to 3 days. Patients are instructed to remain on a soft diet for 3 weeks, and to rinse their mouth with 0.12% chlorhexidine glu-

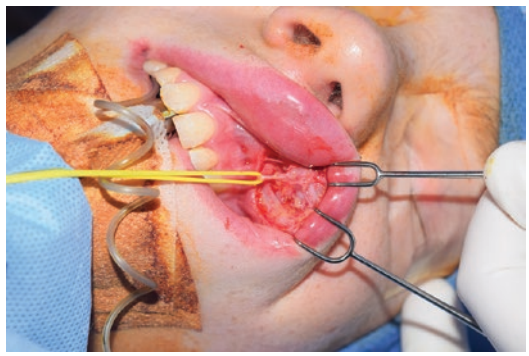

Fig. 23.13 Terminal branches of the infraorbital nerve to the upper lip are dissected and identified

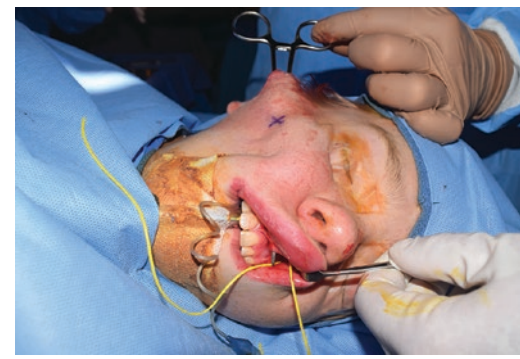

Fig. 23.15 Fine Jake forceps are used to create a tunnel between the facial and upper buccal sulcus exposures

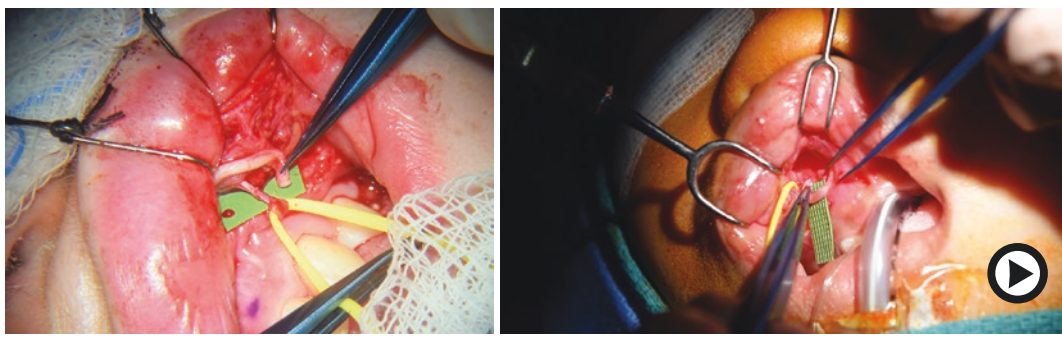

Fig. 23.14 Terminal branches of the infraorbital nerve are divided for coaptation to the distal end of the cross-face nerve graft to improve axonal regeneration (▶ https://doi.org/10.1007/000-3tv)

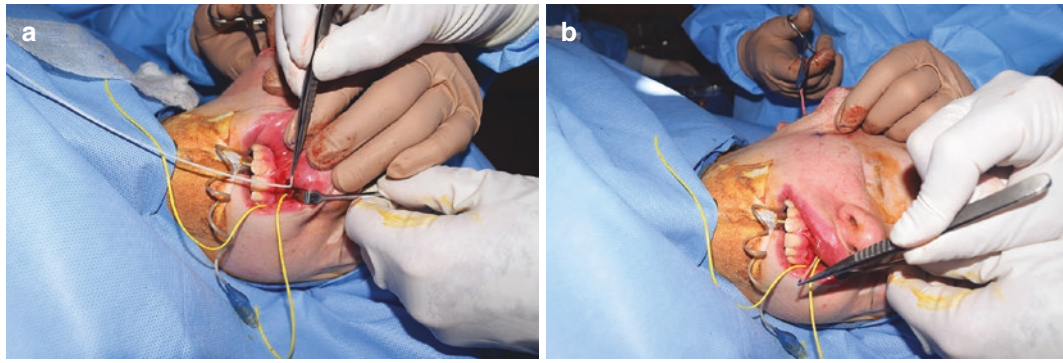

Fig. 23.16 (**a**, **b**) The sural nerve graft is passed through the tunnel connecting the facial and upper buccal sulcus exposures using Jake forceps

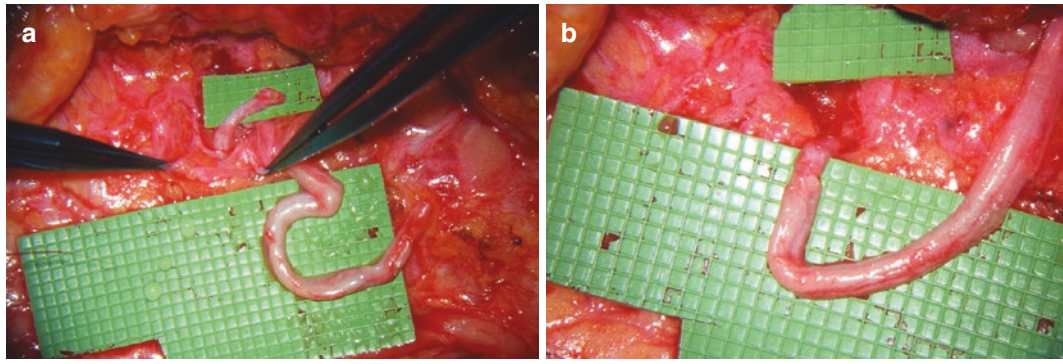

Fig. 23.17 (**a**, **b**) The donor branch of the facial nerve is divided and coapted to the sural nerve graft

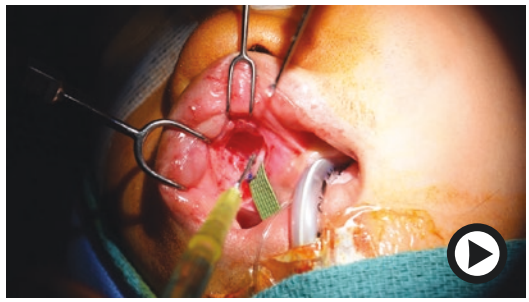

Fig. 23.18 The nerve coaptations are performed using fibrin glue. Note that we prefer to use two syringes, each loaded with one of the two components of the fibrin mixture. Single drops of each component allow more precise application of the fibrin glue (▶ https://doi.org/10.1007/000-3tw)

conate solution three times a day, to minimize the risk of intraoral wound healing complications. Patients are also discharged with a prescription to complete a one-week course of prophylactic antibiotics—our preference is to use cephalexin.

Free Functional Muscle Transfer

For two-stage facial reanimation, the free functional muscle transfer usually takes place approximately 1 year after the cross-face nerve grafting. The degree of axonal regeneration through the sural nerve graft can be clinically tracked by the progression of a Tinel's sign down the length of the graft. In cases of bilateral facial paralysis, our approach is to focus on unilateral reconstruction in a single procedure, to allow the surgical team to focus their efforts on providing an optimal reconstruction. Once the transplanted muscle has reinnervated, and the patient has convalesced from the first muscle transplant, the contralateral smile is reconstructed in a second procedure, typically at least 2 months following the first muscle transplant.

In the preoperative area, baseline photographs and preliminary facial markings are made. For

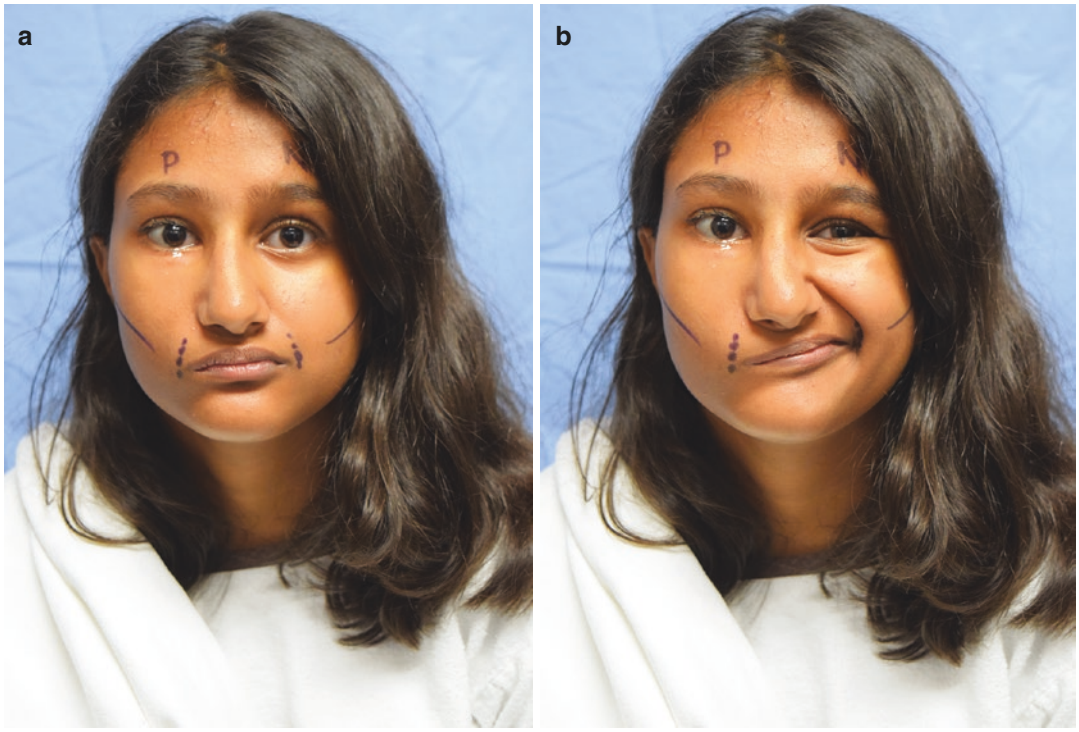

Fig. 23.19 (**a**, **b**) Preoperative markings indicating the location of the nasolabial fold on the unparalyzed side of the face, and the proposed location of the reconstructed nasolabial fold on the paralyzed side of the face

patients with unilateral facial paralysis, the nasolabial crease on the non-paralyzed side is marked, and the vector of pull on the crease when the patient is asked to smile is noted. These markings are then transposed and marked onto the paralyzed side to serve as a guide for intraoperative placement of anchoring sutures (Fig. 23.19a and b). In patients with bilateral facial paralysis, the proposed nasolabial crease placement is marked in the preoperative holding area, and checked for position and symmetry (Fig. 23.20). The facial artery is also palpated at the point it crosses the inferior border of the mandible, and this is also marked.

As with cross-face nerve grafting, a two-team approach is utilized in order to minimize operative time; one team will focus on procuring the gracilis, while the other team will prepare the facial pocket, anchoring sutures and recipient vessels in anticipation for the transplanted muscle. The patient is positioned supine, and the operating table is oriented to permit both teams unrestricted access to their respective operative sites (**Video 4** and Fig. 23.21).

Fig. 23.20 In patients with Moebius syndrome, surface landmarks such as skin creases or wrinkles, which are normally used to guide placement of the nasolabial creases, may be absent. In these cases, the proposed placement of the nasolabial crease is marked on one side, and then symmetrically transposed onto the contralateral side to allow visual confirmation of appropriate placement and vector

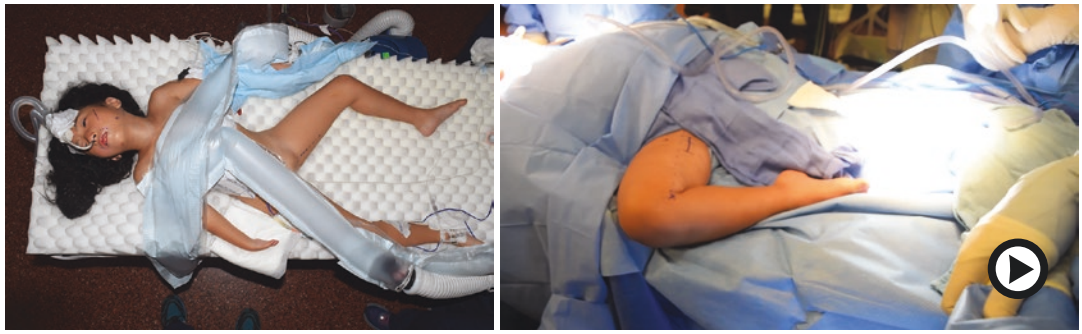

Fig. 23.21 The patient is positioned supine. The endotracheal tube, warming blankets, ECG leads, and Foley catheter are arranged to permit unrestricted access to the surgical sites (▶ https://doi.org/10.1007/000-3tx)

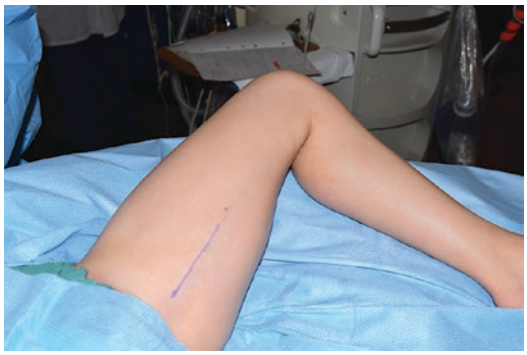

Fig. 23.22 A 10-cm incision is marked on the medial aspect of the thigh. This mark is made approximately one finger width posterior to the long axis of the adductor longus muscle

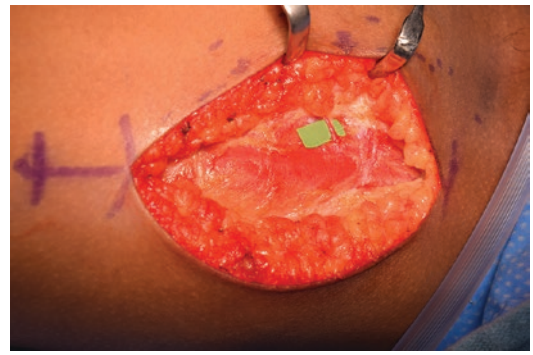

Fig. 23.23 Occasionally, a skin perforator can be seen piercing through the gracilis (seen traveling across the green microscope background). This perforator often corresponds to the location of the vascular pedicle on the deep surface of the muscle and can help guide dissection

Gracilis Harvest

The course of adductor longus can typically be palpated by flexing and externally rotating the hip. The gracilis typically lies approximately one to two centimeters posterior to this axis. In thinner patients, the interval between adductor longus and gracilis can be palpated, and in this case, this interval can be marked as the axis for exposure. The vascular pedicle to the gracilis typically enters at a point 8–10 cm distal to the muscle origin at the ischiopubic ramus, and this can be marked to guide dissection. A 10-cm longitudinal incision is marked parallel to the anticipated location of the gracilis, and centered over the predicted location of the vascular pedicle entering the muscle (Fig. 23.22). We do not use a pneumatic tourniquet during our muscle harvest.

The skin is incised using a blade, and subcutaneous dissection is performed using a combination of tenotomy scissors and monopolar cautery, down to the level of the fascia overlying the gracilis. Occasionally, a perforator can be seen piercing the fascia to supply the overlying tissues (Fig. 23.23); when present, this perforator provides a reasonable approximation to where the vascular pedicle enters the gracilis muscle, which can aid dissection. The fascia overlying the gracilis is opened along the length of the incision, and the interval between the adductor longus and gracilis is identified. Typically, there will be a thin strip of fat that can be identified, representing the interval of interest.

Dissection is carried out in this interval from distal to proximal, to identify the vascular pedi-

cle. Visualization is aided by having the assistant retract the adductor longus anteriorly and the gracilis posteriorly. The vascular pedicle, originating from the medial circumflex vessels, should be identified entering the gracilis at a 90-degree angle to the longitudinal axis of the muscle. As dissection continues proximally, the obturator nerve supplying the gracilis can be identified, coursing toward the muscle at an oblique angle (Fig. 23.24). Once the neurovascular pedicles have been identified, the gracilis is circumferentially dissected free from surrounding tissues along the length of the exposure. The vascular pedicle is dissected retrograde to its take-off from the femoral vessels, in order to maximize available length. During this dissection, large branches to the adductor longus are seen, and these should be carefully ligated and divided to provide sufficient pedicle length. The obturator nerve branch supplying the gracilis is dissected proximally to the level of the obturator foramen, neurolyzing the branch from the main obturator nerve bundle as necessary. Although proximal dissection of the nerve to the level of the obturator foramen can be challenging, the extra time spent to dissect the maximal length of nerve possible will permit tension-free, and technically easier, neurorraphy later in the case, especially in patients where the muscle transplant will be innervated by a cross-face nerve graft.

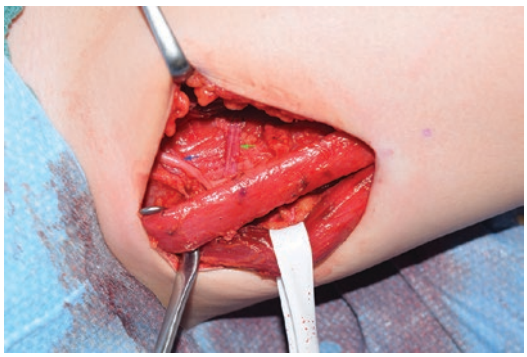

Fig. 23.24 The neurovascular supply to the gracilis has been dissected. The vascular pedicle is seen entering more distally (green arrow), while the nerve can be seen entering more proximally (blue arrow)

The deep surface of the gracilis where the neurovascular pedicle enters is carefully examined, as this area will determine the segment of gracilis that will be used in the transplant. Firstly, the position of the pedicle relative to the lateral margins of the muscle will determine which portions of the gracilis can be excluded from harvest, which is a critical step in reducing the amount of cheek bulk in the final reconstruction. Usually, only 30–40% of the width of the gracilis is harvested, leaving the posterior segment, or sometimes both the anterior and posterior segments, behind (**Video 5** and Fig. 23.25). Tenotomy scissors or fine Jake forceps can be used to carefully dissect the muscle fibers longitudinally until the desired segmentation is achieved, ensuring that the neurovascular supply to the segment to be used is not damaged or excluded. In young children, we typically aim to harvest a segment of muscle that is less than 10 grams, while in older children, we aim for a mass less than 20 grams.

Secondly, the cranial-caudal relationship of the pedicle within the segment of gracilis to be harvested will vary, depending on the donor motor

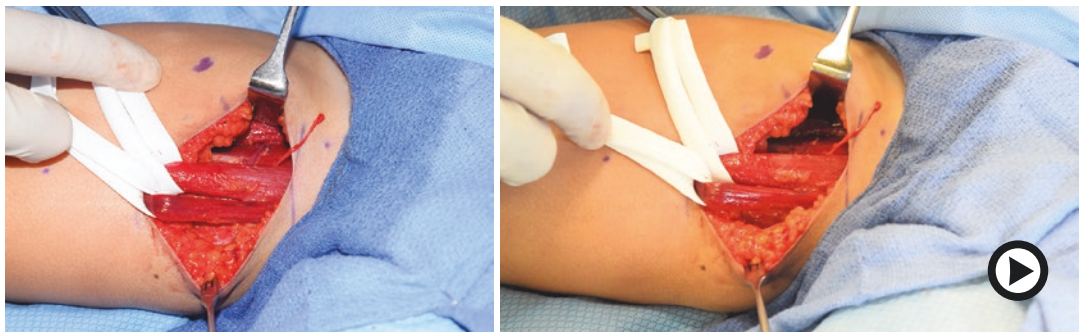

Fig. 23.25 The gracilis is segmentalized to minimize the amount of bulk in the recipient site (▶ https://doi.org/10.1007/000-3tt)

nerve used to innervate the muscle. For muscle transplants innervated by cross-face nerve grafts, the pedicle is biased toward the proximal end of the segment to be harvested (Fig. 23.26); this permits the neurovascular pedicle to be placed closer to the oral commissure, which facilitates nerve coaptation to the cross-face nerve graft in the upper buccal sulcus, while also decreasing the distance for nerve regeneration (Fig. 23.27). Conversely, for muscle transplants innervated by the motor nerve to masseter, the pedicle is biased toward the distal end of the muscle segment to be harvested, situating the nerve to the gracilis closer to the location of the motor nerve to masseter.

Once the desired segment of the gracilis has been identified, the length of muscle to be harvested is determined. The team responsible for the facial exposure provides a measurement between the helical root and the oral commissure, and 2 cm is added to this to account for placement of anchoring sutures for the new origin and insertion of the transplanted muscle. The segmental gracilis is divided both proximally and distally using heavy scissors. The nerve is transected as proximally as possible to provide maximal length. The vascular pedicle is appropriately controlled using vascular clips, and then divided to provide as much vessel length as possible (Fig. 23.28). At this point, the segmental gracilis is delivered from the thigh, and weighed using a scale (Fig. 23.29). If desired, a nerve stimulator

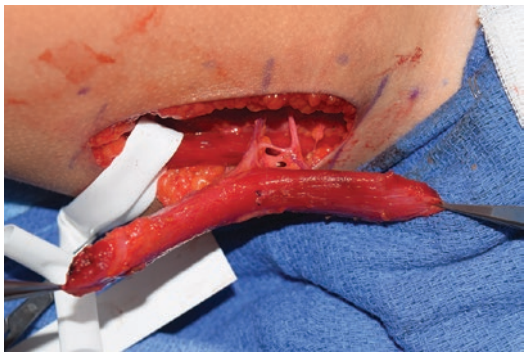

Fig. 23.26 In this case, the muscle transplant will be innervated by a cross-face nerve graft. The neurovascular pedicle has been slightly biased toward the proximal end of the muscle segment to facilitate vascular anastomosis and neurorraphy

Fig. 23.27 This image depicts the typical arrangement of the neural and vascular anastomoses in a muscle transplant innervated by a cross-face nerve graft

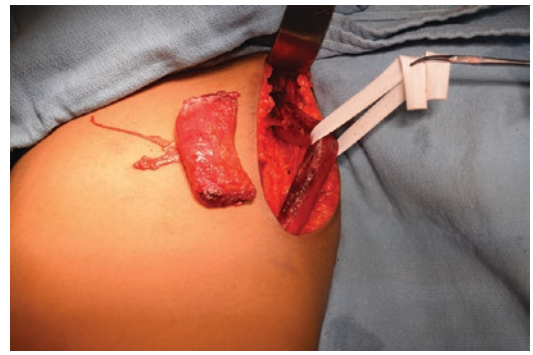

Fig. 23.28 The segment of gracilis to be transplanted to the face has been divided, and its neurovascular pedicle divided as proximally as possible to provide as much length as possible for subsequent neurorraphy and vascular anastomosis

Fig. 23.29 The segmental gracilis transplant is weighed. In young children, we aim for a weight of 10 grams or less, while in older children, we aim for a muscle weight of 20 grams or less

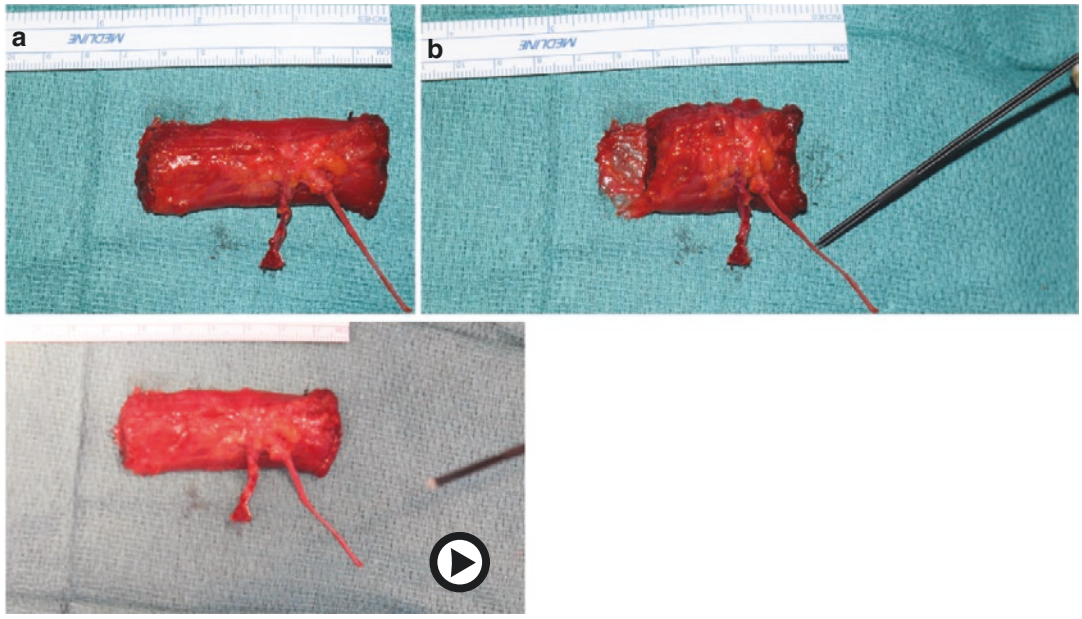

Fig. 23.30 (**a**, **b**) The segmental gracilis transplant can be stimulated ex vivo to confirm that the transplant remains well innervated (▶ https://doi.org/10.1007/000-3tz)

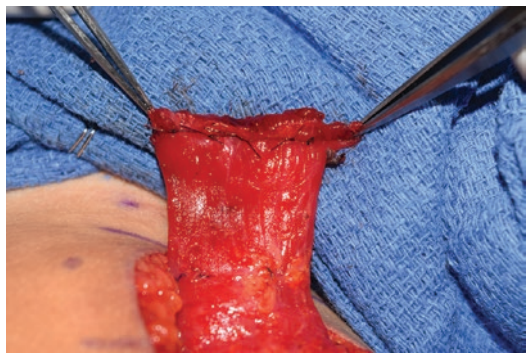

Fig. 23.31 4–0 Vicryl horizontal mattress sutures are placed approximately 1 cm away from the distal edge of the gracilis. These will reduce the risk of the anchoring sutures pulling through the muscle and resulting in malposition of the reconstructed smile

can be used to stimulate the gracilis ex vivo in order to confirm innervation and contractility of the muscle to be transplanted (**Video 6** and Fig. 23.30a, b). 4–0 Vicryl sutures are placed in a horizontal mattress fashion in the distal end of the muscle, where it will be anchored to the oral commissure, approximately 1 cm away from the end of the muscle (Fig. 23.31). The number of horizontal sutures placed is one more than the number of anchoring sutures placed in the oral commissure; i.e. if three anchoring sutures are placed at the oral commissure, four horizontal mattress sutures should be placed. These horizontal mattress sutures reduce the likelihood that the anchoring sutures at the oral commissure will pull through the muscle.

While the gracilis is being inset into the recipient site, the donor site is irrigated and meticulously checked for hemostasis. The fascia over top of the gracilis which was previously divided is reapproximated in a figure of eight fashion using resorbable sutures. Following this, the wound is closed in layers using resorbable sutures, starting with the superficial fascial system, followed by deep dermal, and then cutaneous, closure. We do not routinely use drains in our closure. The closed incision is then dressed using gauze, and covered with a transparent occlusive dressing.

Facial Exposure

A pretrichial, tragal edge, extended rhytidectomy incision is marked, ending in a submandibular

extension which gently curves anteriorly to parallel the inferior border of the mandible for several centimeters. The superior extent of the incision should extend just anterior to the sideburn to permit exposure of the temporal fascia. The proposed markings are infiltrated with dilute epinephrine (1:400,000) to aid with hemostasis. Skin incisions are made with a scalpel, and then the flap is raised in a subcutaneous plane, remaining superficial to the parotid fascia. Dissection proceeds anteriorly until the oral commissure is reached.

During this dissection, the buccal fat pad is excised, facilitating exposure of the facial vessels, and also serving an important function of minimizing cheek bulk once the gracilis is inset. Care should be taken to not only identify the facial vessels but to also preserve the transverse facial vessels, which can be utilized for vascular anastomosis in situations where the facial vessels are inadequate. In our experience, identification and protection of the transverse facial vessels is especially critical in patients with Moebius syndrome, where the facial vein can be hypoplastic, or in some cases, completely absent; by contrast, the facial artery is almost always available. Our preference is to utilize the facial artery and vein, given its good size match to the vessels to the gracilis, and its favorable position relative to the site of neurorraphy. The facial vein usually assumes a relatively vertical course, paralleling the anterior border of the masseter, while the facial artery is oriented more obliquely toward the oral commissure (Fig. 23.32). Once the facial flap is developed, the deep subcutaneous fat can be conservatively excised in order to further diminish cheek bulk over the muscle transplant. This should be done sparingly, as exposure of the dermis can result in scarring, which can cause tethering of the overlying skin flap to the gracilis, leading to facial deformity during animation.

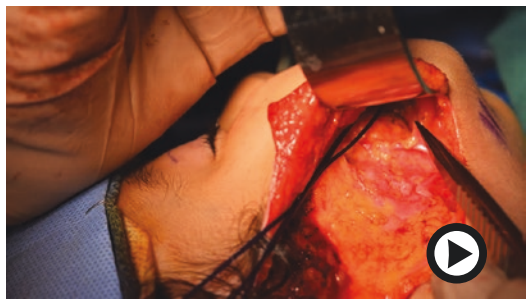

Fig. 23.32 This clip demonstrates the relative positions of the facial artery and vein in the facial exposure as it is prepared for inset of the muscle transplant (▶ https://doi.org/10.1007/000-3v0)

Placement of Anchoring Sutures

Once the exposure has been completed, sutures are placed to reconstruct the proposed nasolabial crease. This is one of the most time-consuming steps in the reconstruction and should not be rushed, as meticulous suture placement is critical to an excellent postoperative result. We typically place three anchor sutures—one in the oral commissure and two in the region of the upper lip and cheek—using a heavy reabsorbable suture such as #1 or #2 Vicryl. In cases where there is significant ptosis of the lower lip, placement of an additional suture in this region can be useful to restore appropriate resting position. The depth of the suture bites is an important consideration. Anchoring sutures which are placed too close to the dermis will cause pucking of the skin and eversion of the upper lip; conversely, sutures placed too deep will produce inversion. In cases of acquired paralysis, the native perioral musculature can be a useful guide for placement of these sutures; however, these landmarks are often absent in congenital facial paralysis. Final placement of the sutures can be confirmed by applying gentle traction, simulating the pull of the transplanted muscle, and confirming that the desired nasolabial crease and smile vector has been achieved (Fig. 23.33a and b).

Donor Motor Nerve Exposure

For two-stage reconstructions with a cross-face nerve graft, the upper buccal sulcus adjacent to the canine root on the paralyzed side is infiltrated with dilute epinephrine solution. The mucosa is incised, and submucosal dissection proceeds bluntly to identify the end of the sural nerve graft,

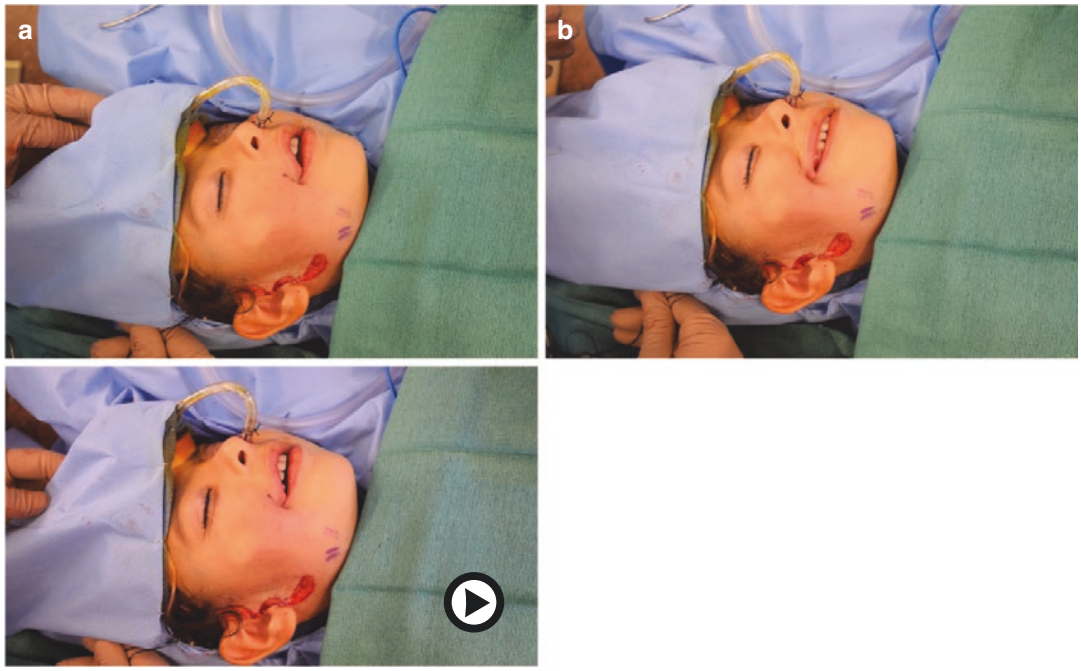

Fig. 23.33 (**a**) The anchoring sutures at the oral commissure have been placed. With gentle traction (**b**), the desired nasolabial crease and smile vector should be achieved, with no inversion or eversion of the oral commissure (▶ https://doi.org/10.1007/000-3v1)

aided by placement of non-absorbable sutures and/or vascular clips in the first-stage procedure. If the distal end of the sural nerve graft was previously anastomosed to branches of the infraorbital nerve, this is sharply divided (Fig. 23.34a and b). Fine Jake forceps are used to create a submucosal, but supraperiosteal, tunnel which connects the upper buccal sulcus to the facial exposure. This tunnel should be wide enough to accommodate the obturator nerve supplying the gracilis without compression.

For reconstructions innervated by the motor nerve to masseter, the location of the donor motor branch to the masseter can be approximated by landmarking a point 3 cm anterior to the tragus, 1 cm inferior to the zygomatic arch, and 1 cm deep to the SMAS [14]. At this point, blunt dissection is carried through the superficial and intermediate lobes of the masseter. A nerve stimulator can be used within the dissection pocket to aid with localization of the donor nerve branch between the intermediate and deep lobes of the masseter. Once identified, the nerve should be visualized traveling in a superolateral to inferomedial direction. The nerve is transected distally and brought to the surface of the masseter in preparation for neurorraphy. Occasionally, in muscle transplants innervated by the motor nerve the masseter, it may be beneficial to shorten the obturator nerve branch supplying the gracilis, in order to minimize the distance over which the nerve regenerates.

Inset of the Muscle

The anchoring sutures are passed behind the row of horizontal mattress sutures in the gracilis in a figure of eight manner. Once all sutures have been placed, the muscle is then parachuted into the pocket, ensuring that the muscle is securely tightened against the deep surface of the commissure. Once again, careful attention to technique is necessary to minimize the risk of delayed malpositioning of the muscle. If the muscle is to be powered by a cross-face nerve graft, fine Jake

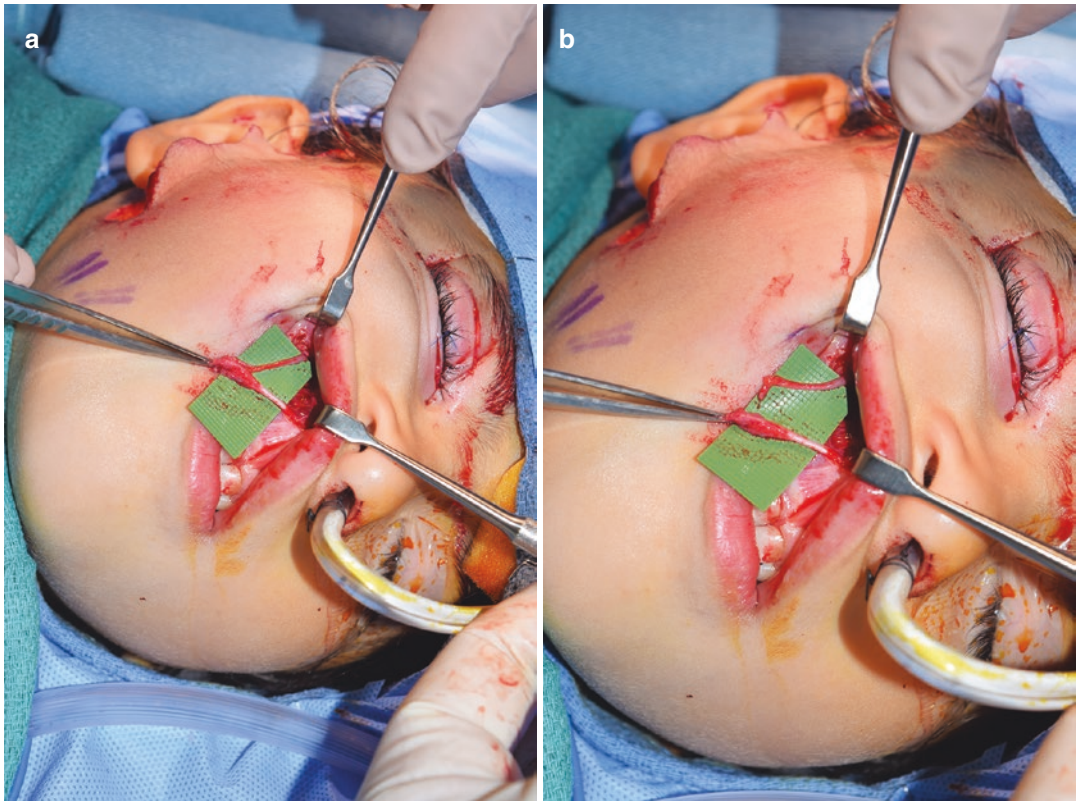

Fig. 23.34 (**a**) The distal end of the cross-face nerve graft can be seen here, anastomosed to a branch of the infraorbital nerve. (**b**) The anastomosis is sharply taken down to expose the distal end of the cross-face nerve graft

forceps are used to bring the obturator nerve through the previously created tunnel, into the upper buccal sulcus exposure.

Micro-Anastomosis, Muscle Anchoring, and Closure

The operative microscope is brought in, and the ends of the donor and recipient nerve and vessels are inspected. Sharp resection of the nerve ends is performed until healthy fascicular anatomy is seen. Redundant vessel and nerve length should be addressed at this point, keeping in mind that sufficient length should remain to permit tension-free anastomoses. The vein is typically coapted prior to the facial artery. Once blood flow has been re-established through the transplanted muscle, the operating microscope is shifted to the upper buccal sulcus, where nerve coaptation is performed using a combination of 10–0 nylon sutures as well as fast-set fibrin glue.

The free end of the gracilis is now anchored to its new origin at the temporal fascia, just superior to the zygomatic arch, using #1 or #2 Vicryl sutures place in a horizontal mattress fashion (Fig. 23.35a and b). The muscle is fanned over a wide area while it is sutured to its new insertion in order to decrease bulk in the temporal region. Once inset, the tension of the muscle usually results in a mild to moderate resting smile on the reconstructed side—this will relax into a natural resting position several weeks postoperatively.

The facial exposure is irrigated with normal saline, and hemostasis is checked. We typically insert a quarter-inch Penrose drain, introduced through a separate stab incision behind the lobule of the ear, and secure this with a loosely tied suture. The rhytidectomy incision is closed in layers with resorbable sutures, and surgical tape

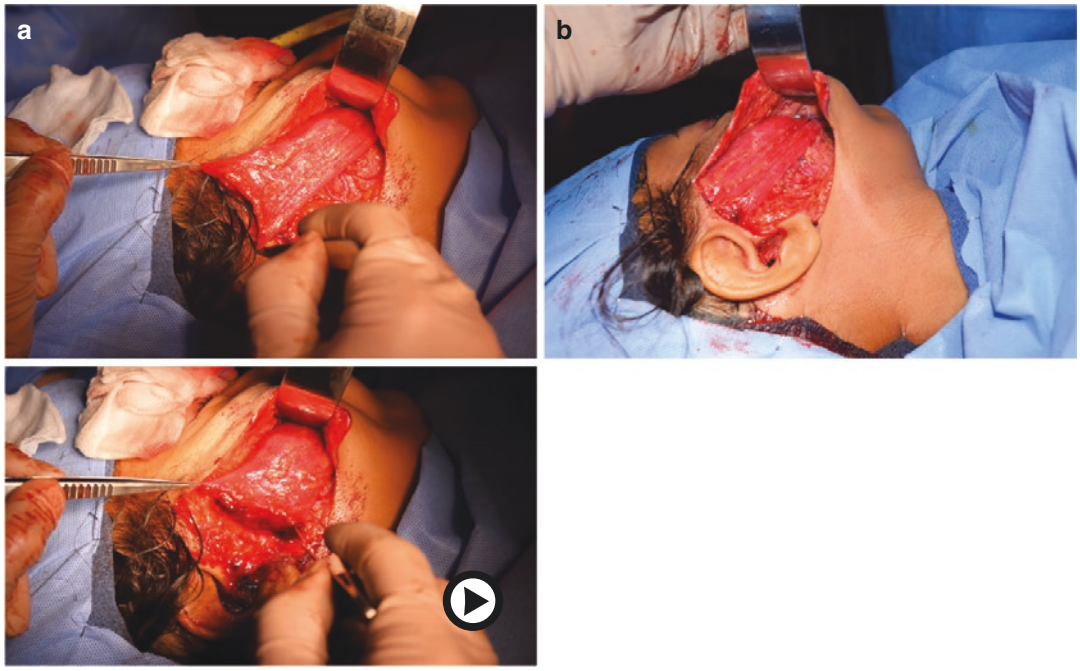

Fig. 23.35 (**a**) The free end of the gracilis is anchored with heavy sutures to its new origin at the temporalis fascia just above the zygomatic arch. (**b**) The final position of the muscle, with its insertion at the reconstructed nasolabial fold can be seen (▶ https://doi.org/10.1007/000-3v2)

is applied over top of the closure line. The intraoral incision is closed under direct vision with reabsorbable sutures, ensuring that the nerves are not inadvertently caught by the suture during closure.

A custom thermoplastic hook, preoperatively fashioned by occupational therapy, is fitted to provide a degree of posterolateral traction on the oral commissure in order to offload tension on the reconstruction. Tension is provided on the hook using elastics, and the elastic is anchored to the hair-bearing scalp using a silk suture. A reminder to the patient family and medical staff to avoid pressure is written on a surgical tape, and applied to the operative side of the face.

Postoperative Care

Patients undergoing cross-face nerve grafting are typically admitted overnight and kept on a soft diet for three to four weeks to permit healing of the intraoral incisions. They are provided with a short course of prophylactic antibiotics, as well as chlorhexidine mouthwash to maintain oral hygiene.

Following gracilis muscle transplantation, patients are placed on a caffeine-free soft diet and remain on bed rest for the first evening following the reconstruction. The Foley is kept in situ while on bed rest and is typically removed on postoperative day one. We routinely prescribe patients with a short course of prophylactic antibiotics, and chlorhexidine mouthwash to maintain oral hygiene. Patients are typically admitted for three to 5 days, contingent on their analgesic needs, and their ability to independently ambulate safely.

For muscle transplants innervated by the motor nerve to masseter, movement can be seen within 2 to 4 months. Two-stage reconstruction with cross-face nerve grafting will usually yield detectable motion at 6 months, and maximal excursion 18 months postoperatively.

Complications and Secondary Surgery

Postoperative complications are relatively uncommon in facial reanimation. Early complications typically encompass hematoma, seroma, and infection. There should be a low threshold to treat early complications with a takeback to the operating theater for exploration and management. Delayed treatment can significantly compromise the reconstructive outcome.

Late complications are very challenging to correct. Consequently, meticulous attention to detail during the initial reconstruction should be taken to minimize the risk of late postoperative complications. We have found the following considerations to be particularly valuable in order to optimize the postoperative result in facial paralysis reconstruction:

1. Appropriate selection of the donor motor nerve, and ensuring adequate neural input.
2. Ensuring proper positioning of the muscle with the correct vector of pull.
3. Ensuring proper tensioning of the muscle.
4. Minimizing the amount of cheek bulk.

The most common issue encountered is excess soft tissue bulk on the reconstructed side of the face. Although sometimes unavoidable, excess bulk is attributed to inadequate segmentation of the muscle prior to transplant, insufficient removal of the buccal fat pad, or insufficient removal of subcutaneous fat in the skin flap. Addressing excess facial bulk is challenging, as it requires re-elevation of the facial flap, and then performing tangential excision of the subcutaneous flap and/or transplanted muscle. Overaggressive thinning of the cheek flap, however, must be avoided, as scarring of the exposed dermis to the muscle surface can cause contour irregularities during animation.

Issues with muscle tension, inappropriate vector of pull, or disruptions of the muscle insertion are very challenging to address and should involve a thorough discussion of risk versus benefit with the patient. Secondary correction of these issues requires re-elevation of not only the skin flap but the muscle transplant as well, though a scarred field. Outcomes following revision for these reasons are variable and unpredictable. Elevation of the deep surface of the gracilis must be done carefully to avoid disruption of not only the neurovascular supply to the transplanted muscle but to avoid iatrogenic injury to intact facial nerve branches. In some cases, it may be possible to release the insertion of the gracilis to its soft tissue attachments and place new anchoring sutures to secure the muscle into its desired position. Occasionally, it may be necessary to utilize tendon or fascial grafts in situations where adjustment of the muscle insertions results in excess tension on the oral commissure at rest.

Inadequate muscle excursion is a vexing problem for both the patient and clinician, as the cause may not be easily identified. For milder cases, nonsurgical treatments such as biofeedback and therapy may be beneficial. More severe cases may require operative exploration to examine the viability of the transplanted muscle, as well as the quality of the neural input to the muscle. If the muscle itself is healthy, and a neural input problem is suspected, options would include repeat cross-face nerve grafting, or selection of an alternate motor donor such as the motor nerve to masseter. In situations where the muscle itself appears fibrotic, better outcomes may be achieved by completely excising the previously transplanted muscle, and performing either a new muscle transplant alone or a new muscle transplant along with a new source of neural input.

Dynamic Reconstruction for Incomplete Facial Paralysis

Incomplete facial paralysis is a unique entity that differs from the complete form in several aspects. It has been defined as a state of facial paralysis in which a degree of residual facial nerve function is present. Clinically, it may be defined as a state of facial paralysis in which the affected hemi-face produces some muscle activity; however, the movement it provides is ineffective and obviously asymmetrical. The residual function observed in incomplete paralysis derives from

the presence of some functional facial nerve axons on the affected hemi-face. In the context of facial reanimation, one may presume that these functional axons can be utilized and their neural power augmented, thus maintaining and even enhancing spontaneous facial movement (Fig. 23.36a, b, and c).

According to the etiology of paralysis and pattern of injury, the level of incompleteness of the paralysis may vary considerably; hence, the clinical spectrum is wide. Due to the presence of some neural activity, facial musculature tone is maintained to some degree, complete atrophy is uncommon, and symmetry at rest is usually satis-

Fig. 23.36 (**a**, **b**, **c**) A patient with incomplete facial paralysis is seen before reconstruction (**a**), and following reconstruction (**b**), with segmental gracilis muscle transfer innervated by the ipsilateral buccal-zygomatic facial nerve branches. (**c**) The schematic of the reconstruction is depicted

factory. Asymmetry on facial animation is a key feature; however, in contrast to complete paralysis, the degree of asymmetry is much more variable. Moreover, some of the clinical manifestations of complete paralysis, such as impaired ocular protection, oral incontinence, speech difficulties, and nasal air flow obstruction, are usually less prominent.

Surgical Technique

The procedure described here aims to utilize the partially active buccal-zygomatic branches and to augment the spontaneous facial mimic function they produce via a free gracilis muscle transfer. The gracilis muscle is harvested and tailored in size to the patient's proportions. The buccal-zygomatic branches responsible for the movement that was detected preoperatively are identified intraoperatively using a nerve stimulator. There is usually more than one small branch responsible for that residual motion. One of these branches is transected and coapted to the gracilis motor nerve via an end-to-end anastomosis. When only one partially functional nerve is found, it is not transected but split longitudinally. The free end of the nerve to gracilis is split as well. End-to-end coaptation is performed between the free end of the split buccal-zygomatic branch and one of the two split ends of the nerve to gracilis. The other split end of the nerve to gracilis is coapted by end-to-side coaptation to the remaining fascicles of the buccal-zygomatic nerve that were left uninterrupted. This is in order to maximize facial nerve axonal lode to the gracilis flap. In order to avoid damaging the existing residual motor function, the dissection zone is limited to the region between the zygomatic arch and Stensen's duct, both for nerve identification and gracilis muscle inset. In contrast to the standard procedures, the vascular pedicle of the gracilis flap is preferably anastomosed with the superficial temporal vessels and not the facial vessels; thus, donor vessels dissection is limited, and marginal or mandibular facial nerve branches, if active, are not at risk. In cases in which the superficial temporal vessels are inappropriate for vascular anastomosis (i.e., due to anatomical changes following prior surgery or trauma), dissection is extended, and the facial vessels are used instead. Of note, arterial and venous anastomoses may vary in the same patient according to anatomy and gracilis flap inset properties.

Conclusion

The management of facial paralysis has improved considerably, thanks to the incorporation of microsurgery, innovative techniques to maximize function, and a better understanding of the needs of the facial paralysis patient. From a technical standpoint, each step is critical and must be carried out precisely. Our approach continues to evolve and improve, and expand to other areas such as the eyelids and the lower lip, in addition to our previous prime focus on the mid-face and smile. We now have excellent tools to address the various components of facial paralysis. These tools continue to be refined and augmented so that we can better address the needs of our patients.

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Comprehensive Management of Head and Neck Burn Injuries: From Resurfacing to Reconstruction

C. Scott Hultman and Kevin M. Klifto

Introduction

Burn reconstruction remains very much an art as much as it is a science. Like so many sub-specialty areas in plastic surgery, burn reconstruction attempts to restore form and function in patients with defects that are both objective and subjective and mild and severe. Furthermore, multiple solutions may exist, depending on the patient's expectations and tolerance for risk, combined with the surgeon's skills, experience, and judgment. Alternately, solutions may not yet exist but may become available, after careful introspection.

What makes burn reconstruction so challenging, and so rewarding, is that there is no absolute roadmap for correcting abnormalities. Instead, the surgeon must combine creativity with four-dimensional planning to yield a result that not only will most likely change over time, but that also satisfies the needs of the patient. The surgeon provides hope, while the patient must place trust in the process.

No chapter can thoroughly address the complexities of burn reconstruction from head-to-toe, so instead we will focus on acute and late defects of the head and neck region. Because burn reconstruction is really built on basic principles used across the discipline of plastic surgery, we will first review the foundations for planning and executing these procedures [1–10]. Second, we will spend some time on the acute management of burn injuries, due to our bias that the best reconstructive plan really begins during this initial period; victories and errors that occur early in the healing process can have profound implications on the simplicity or complexity of approaches needed for later reconstruction [11–21]. Third, we will illustrate reconstructive options for specific anatomic areas, providing our perspective on tips and tricks that may not appear in textbooks or journal articles but have accumulated over decades of practice [22–29]. As such, this chapter is not evidence-based, but rather experiential. Mastering burn reconstruction remains an unfinished pursuit, built on layers of learning curves that draw from the rich history and opportunities of plastic surgery.

Principles

1. Seek first to understand fundamental problems. Burn scars almost always involve loss of tissue, including epidermis, dermis, sweat glands, melanocytes, and sometimes fat. Restoring these elements with like elements is the primary goal.

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2. Form and function cannot be separated but must be addressed as two parts of a whole. Nevertheless, start first with function, and the rest will follow.
3. The loss of the skin and its contents can result in not just functional problems, such as contractures and stiffness, but also subjective symptoms of itching and pain.
4. A successful and rewarding practice is built upon the three "As" of availability, affability, and ability, in that order. We add the equally important fourth "A" of accountability, which signifies responsibility and commitment to patients and their families.
5. Keep your clinical skills sharp: practice acute burn care. Following the burn wound over time will provide insights regarding not just wound healing, but also how the patient copes with loss of form and function.
6. Reconstruction should begin right after burn injury and continues until the patient is satisfied. This longitudinal relationship is a source of great joy, but sometimes intermittent frustration, as the patient moves through recovery. Never forget that you can almost always provide relief from pain and suffering, long after the scars have matured and your procedures have been completed.
7. Avoid politics and turf wars when a patient is involved. For plastic surgeons who focus on burn reconstruction, we will always face competition from other experts who may not have more experience than we do: orthopedic hand surgeons, acute care burn surgeons, facial plastic surgeons, pediatric surgeons, and dermatologists. As Kendrick Lamar implores, "Be humble." Another corollary is: do not be hesitate to refer the patient to a subspecialist who really is an expert—and from whom you can learn.
8. Understand what the patient *needs* versus what they *want*, and know the difference.
9. Manage patient expectations and be honest with what you can accomplish.
10. Apply your knowledge and experience from all of plastic surgery. Burn reconstruction utilizes a set of techniques, from skin grafting to microsurgery, to yield a result that addresses the patient's needs and expectations.
11. Remember the lessons of the past, from Sir Harold Gillies ("Plastic surgery is the battle between blood supply and beauty") to Luis Vasconez ("There exists a fine line between spectacular success and phenomenal failure"). If we can see past the horizon, it is only because we stand upon the shoulders of many giants.
12. Plan for the long term, stay flexible, have a lifeboat, and make sure that plan B is not the same as plan A (if plan A does not work).
13. Batch procedures together that make sense, such as bilateral upper eyelids or bilateral lower eyelids, but not both sets together.
14. The most powerful force in the universe, after compound interest, comes from the effects of the Z-plasty. This lengthens the axis of the scar, borrows from tissue that is more pliable, and changes the lines of tension. Scars like this.
15. A series of smaller operations may be safer and more precise than fewer larger ones.
16. Try to do what is simple first, or what is most needed, or what will yield the greatest improvement. Early wins build confidence for both the patient and the surgeon.
17. When reconstructing a nose, an eyelid, a lip, or an ear, consider lining, support, and coverage; you will almost always need these three layers.
18. Take full advantage of adjunctive techniques to improve your results, such as skin care, lasers, and fat grafting.
19. Look for surgical solutions to medical problems, such as the treatment of chronic pain or intractable itching. Nerve decompression and laser resurfacing can solve these "medical" issues, dramatically improving quality of life. If you do not look for surgical solutions, you will miss surgical opportunities.
20. Be open to new techniques and technologies, especially from cosmetic medicine and aesthetic surgery.
21. Patients can be true partners in burn reconstruction. Not only can they inspire the surgeon to seek and develop new solutions, but

patients may bring new ideas to a practice. Listen to them and learn from them.
22. Seek to innovate. Do things better or differently. You can seek advice from a peer or mentor, but ultimately you will need to solve your own problems.
23. Understand that problems have three types of solutions: known solutions, solutions to discover, and no solutions. Your experience will help you sort these problems into these three categories of solutions.
24. Take pictures. Study your pictures. Repeat again, and again.
25. Never say you have nothing left to offer—let the patient come to that conclusion. You can always provide hope. Tomorrow may yield answers to questions, and solutions to problems.

Acute Management

Critical Care

Patients with significant head and neck burn injuries should undergo assessment according to advanced trauma life support (ATLS) protocols. This includes immediate evaluation and treatment of the ABCDEs of ATLS: *A*irway, *B*reathing, *C*irculation and *C*ervical spine, *D*isability, and *E*xposure. The airway must be secured, and any evidence of oropharyngeal edema, soot in the nares, burned periorbital or nasal hairs, or carbonaceous sputum should prompt consideration of intubation. Concomitant facial fractures or active hemorrhage may also lead the surgeon to obtain a surgical airway via either cricothyrotomy or open tracheostomy.

Once the airway is obtained and secured, the patient must be evaluated for inhalation injury, which can occur from direct thermal exposure, carbon monoxide inhalation, or absorption of aerosolized smoke toxins. Bronchoscopy is helpful to establish a baseline diagnosis and follow potential injury to the glottis, trachea, or bronchi, as well as to clear sputum through pulmonary lavage. In terms of ventilator support, patients should be ventilated on low tidal volumes to avoid high peak pressures, using moderate positive end expiratory pressure (PEEP) to maintain oxygenation. Patients are initially started on 100% oxygen to promote dissociation of carboxyhemoglobin, with the goal of weaning oxygen to less than 50% FIO_2 within the first few hours. A cyanokit is also given to bind any absorbed cyanide. Permissive hypercapnia may be necessary to avoid barotrauma as the pulmonary injury declares itself.

The initial assessment must also include consideration for other injuries, especially if the burns are associated with assault, fall, high-speed collision, or explosion. In addition to initial lateral C-spine and AP chest X-rays, patients with significant head and neck burns may benefit from a combination of flexion-extension films or CT versus MR imaging to evaluate for cervical spine injuries. The neck cannot be cleared of underlying ligamentous or disc injury unless the patient is fully awake, has a clear sensorium, and does not have any distracting injuries. Additional studies that should be strongly considered include KUB of the pelvis when the patient first arrives, and then head, chest, and abdominal-pelvic CT scans as indicated. Obtaining a neurologic exam early in the resuscitation phase is critical and should include determination of Glascow Coma Score, assessment of cranial nerve function, and examination of sensory and motor nerves in the extremities.

As the patient is stabilized, several other considerations are important. First, nutrition is begun through an orogastric or nasoduodenal tube. For burns greater than 20% total body surface area, enteral feedings should be part of the initial fluid resuscitation and should be started within 4 hours of injury. Such an approach may seem to be too aggressive, but early enteral feeding provides nutrition to the gut during this time of splanchnic vasoconstriction, may reduce the incidence of bacterial translocation, can help with overall fluid replacement, and may assist with electrolyte management. Second, eye care is paramount to prevent corneal desiccation, ulceration, and potential scarring and/or rupture. To guard against these complications, ophthalmic ointment should be used liberally. For patients who develop eyelid ectropions, suture tarsorrhaphies can be used as a bridge to definitive release and grafting, or semi-perma-

nent tarsorrhaphies can be achieved with tarsoconjunctival flaps. Alternatively, corneal integrity can be preserved by application of amniotic allograft. A third consideration is the avoidance of device-related pressure injuries of the nares, pinnae, oral commissures, and eyelids, as well as occipital pressure necrosis. Prevention of these injuries, through vigilant dressing and wound care, is preferable over later reconstruction of these defects.

Wound Care

The primary goals of wound care for burn injuries of the head and neck include minimization of desiccation, prevention of infection, and promotion of re-epithelialization. Given the rich, redundant blood supply of the face, combined with the high density of hair follicles and sweat glands, most partial-thickness burns will heal by secondary intention. Toward that end, antimicrobial ointments and creams are applied and changed daily. Skin is washed with a dilute chlorhexidine solution, covered with a thin layer of antimicrobial ointment, and then dressed with petrolatum mesh gauze. Bacitracin is an ideal topical agent because of its antibacterial activity against most gram negative and gram positive organisms. Bactroban is our second-line agent, for patients who are colonized or infected with methicillin-resistant *Staphylococcus aureus* (MRSA). Nystatin can be added for superficial fungal infections and is also used for oral hygiene. Sulfamylon is the only agent with good penetration of eschar, reaching the cartilaginous elements of the nose and ears. In general, silver sulfadiazine is not used, due to potential toxicity if exposed to mucous membranes, and also because this agent produces a pseudo-eschar that impairs the assessment of wound healing.

Excision

The decision to operate on fresh burns is based on the depth of the injury, the location, time for wound healing, and complications such as infection or ectropion. Although enzymatic debridement is helpful in other areas of the body, to help determine depth of the burn injury, agents such as nexobrid and santyl are potentially very painful on the face and may cause more harm than good. Furthermore, laser Doppler imaging of head and neck burns, in our practice, has a low positive predictive value for wounds that can heal without surgery. For obvious full-thickness burns of the head and neck, we strongly recommend early excision and coverage, within the first 3–7 days after injury. For partial-thickness burns that may heal by secondary re-epithelialization, we wait up to 3 weeks before deciding about operative excision. Wounds that take longer than 20 days to close have a higher incidence of hypertrophic response, contracture, and altered pigmentation and texture, and should be excised at that time. Sub-units with terminal blood supply, such as the nose or the ears, are allowed to fully demarcate and slough, provided that there is no evidence of cellulitis or purulent necrosis.

Excision is best performed sharply, with a combination of Weck blade, scalpel, curette, scissors, or versajet, removing nonviable tissue, back to fine, punctate bleeding. We prefer to inject these burns with 0.5–1.0% lidocaine with epinephrine, to blunt the afferent signals and minimize hemorrhage. Extreme care must be taken in areas with attenuated tissues, such as the eyelids, mouth, nose, and ears, so that underlying structures are not damaged during excision. For this reason, we avoid using dermabrasion to debride burn wounds, as there have been cases of torn lips and eyelids from using too much pressure on the rotor. Hemostasis is achieved primarily with direct pressure and epinephrine-soaked telfa pads, with only minimal use of monopolar cautery. Electrical burns mandate much more aggressive debridement, which should be staged over the course of several days, and often require exploration of deeper structures when the deep cervical fascia is violated.

Coverage

Options for coverage include biologic versus synthetic matrices, xenografts versus allografts ver-

sus autografts, split- versus full-thickness skin grafts, meshed versus sheet grafts, and local versus regional flaps, all depending on the status of the underlying, exposed tissues. For isolated burns of the head and neck, we prefer to resurface first with meshed pig skin (if available), which provides temporary coverage and permits a test of the wound, reducing the risk of hematoma, and optimizing graft take when the patient undergoes definitive grafting 3–7 days later. In patients with extensive burn injuries and limited donor sites, we prefer to use thawed allograft, which can survive weeks after application, before rejection occurs. When the patient is stabilized and ready for final grafting, we almost always use thick, split-thickness sheet grafts, harvested as close to the face as possible. The scalp is the best donor site, followed by the shoulders or upper back. The subunits of the face are generally grafted in toto, when the wound is greater than 50% of that unit. Full-thickness grafts are only utilized for secondary reconstructions after ectropion or contracture release. Any critically exposed structures, such as the parotid gland, the facial nerve, or the great vessels of the neck, require coverage with vascularized tissue, which includes such muscles as the platysma, the sternocleidomastoid, or the pectoralis. Finally, the role of "off-the-shelf" biologic matrices, for head and neck burn wounds, is not determined and not part of our practice. However, we are encouraged by the possibility of using point-of-care, aerosolized cellular elements for the early resurfacing of partial thickness burn wounds.

Scar Management

After achieving wound closure, scar management becomes a high priority to optimize final form and function. Burn scars may take months to years to mature, but they typically pass through their maximum inflammatory phase 12–24 weeks after re-epithelialization. During this time, a number of interventions are helpful to decrease the potential for hypertrophic scar formation and transformation [30–36]. All patients should have physical therapy and occupational therapy consults, to maintain and gain range of motion, increase strength and conditioning, and control edema. Splinting is required for most neck burns, to prevent cervical contractures. Furthermore, perioral burns can result in microstomia and lip ectropion, both of which can be partially corrected through the use of a customized commissural appliance.

Additional interventions we pursue include the use of silicone sheeting, pressure, and massage. Skin care is critical and involves use of moisturizing lotion with sunblock. For patients with altered pigmentation or abnormal texture, we prescribe a mixture of flucinolone 0.01%, hydroquinone 4%, and tretinoin 0.05% (Triluma), applied topically daily for 6 weeks. For focal, symptomatic hypertrophic scars, we do use steroid injections on occasion, starting with kenalog-10 mixed with a local anesthetic, increasing the dose to kenalog-40 as needed. Of paramount importance is injecting this steroid directly into the parenchyma of the scar; significant resistance should be encountered, along with blanching of the scar. Complications from intra-lesional injection are not benign and can involve fat atrophy, calcification, wound breakdown, hypopigmentation, and even adrenal suppression.

Perhaps the most important adjunct to emerge over the last decade for the management of hypertrophic burn scars is the use of lasers to reverse and attenuate this pathologic, prolonged response to injury. Essentially, lasers target and destroy chromophores within abnormal elements of hypertrophic burn scars. Early in the healing process, when burn scars are at their inflammatory peak, we utilize the pulsed-dye laser (595 nm wavelength) to treat scars that are purple and red, itchy, and still edematous. We utilize a fluence that delivers just enough energy to bruise the skin, typically 4–5 J/cm2 in Fitzpatrick 4–6 patients and 7–8 J/cm2 in Fitzpatrick 1–3 patients. For scars that remain thick and become stiff, painful, and tethered, we use the fractional CO_2 laser (10,600 nm wavelength) to fenestrate the skin and ablate columns of abnormal dermis, typically 0.5–2.0 mm deep, at a density of 5%. We start at energies of 30 mJ per column, until we observe fine, punctate bleeding, increasing energy to 60 or even 90 mJ if necessary, but dropping density to

1–3%. Topical steroids are then massaged into these channels for precise drug delivery. A third category of lasers that are used less often, but are quite helpful, are the laser hair-removal devices. The gold standard is the alexandrite laser (755 nm wavelength), which is used to rupture pigmented hair follicles below the dermis, without damaging the overlying skin. Other alternatives, which include diode and Nd:YAG lasers, are less effective and more unpredictable, as these devices require more energy than the alexandrite to reach and rupture the hair follicles. In our experience, non-laser platforms such as intense pulsed light (IPL) have minimal impact on burn scar management, but carry with them the risks of wound breakdown, and with a significant financial burden, since these devices are considered cosmetic and not reimbursed by insurance.

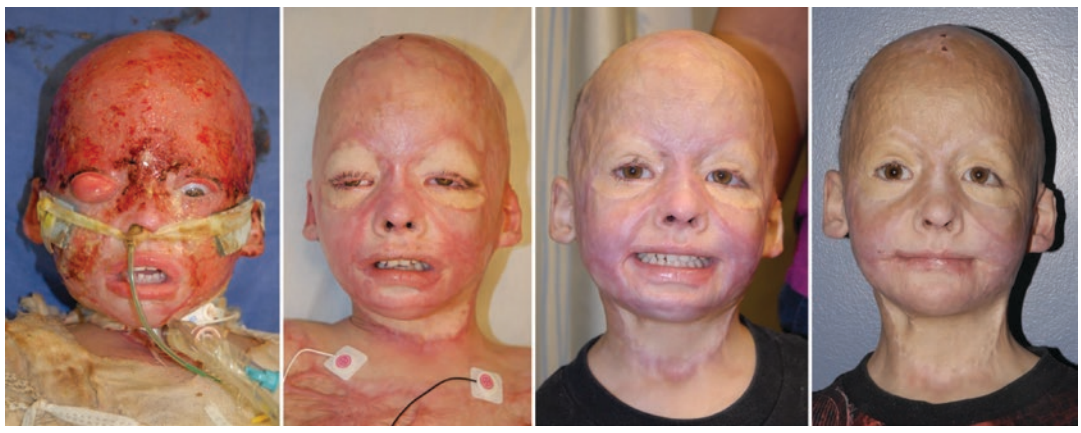
Reconstructive Techniques

Burn reconstruction utilizes all steps of the reconstructive ladder, ranging from skin care to face transplantation [37–40]. The surgeon must decide which techniques will provide the best outcomes, restoring form and function, while minimizing risk. We stress to our patients that time is the most important resource. Time allows scars to mature, complex procedures to build upon prior results, and for patients to focus on long-term goals. We prefer to perform a series of small operations, due in part to often tenuous blood supply to previously injured tissues, but also so that complications are minimized and managed successfully. Toward that end, considerable improvement can be achieved with laser treatment, fat grafting, and nerve release and neuroma resection, all of which can alleviate chronic neuropathic pain, relentless itching, and debilitating paresthesias. Regarding closure options for acute defects or secondary ones after contracture release, the surgeon can safely draw from a list of split- and full-thickness skin grafts, biologic matrices, and even synthetic bilaminate skin substitutes.

Carefully selected adjacent tissue rearrangements can have a powerful effect, by recruiting tissue that is lax and redirecting lines of tension. Specific types of rearrangement that we use include single or contiguous two-flap Z-plasties for focal contractures, w-plasty for scar excision and closure, five-flap jumping man Z-plasty or STARplasty for contractures in concave areas, and V-Y or Y-V plasties when a small amount of tissue needs to be moved, such as the earlobe, the oral commissure, mild lip ectropions, or the nasal base. Moving up the reconstructive ladder, there may be indications for fascial flaps (ear reconstruction), fasciocutaneous flaps (nasal reconstruction), or myocutaneous flaps (neck reconstruction)—or some combination of all three. Free tissue transfer is rarely needed in burn reconstruction of the head and neck but is performed when indicated (coverage of intracranial contents).

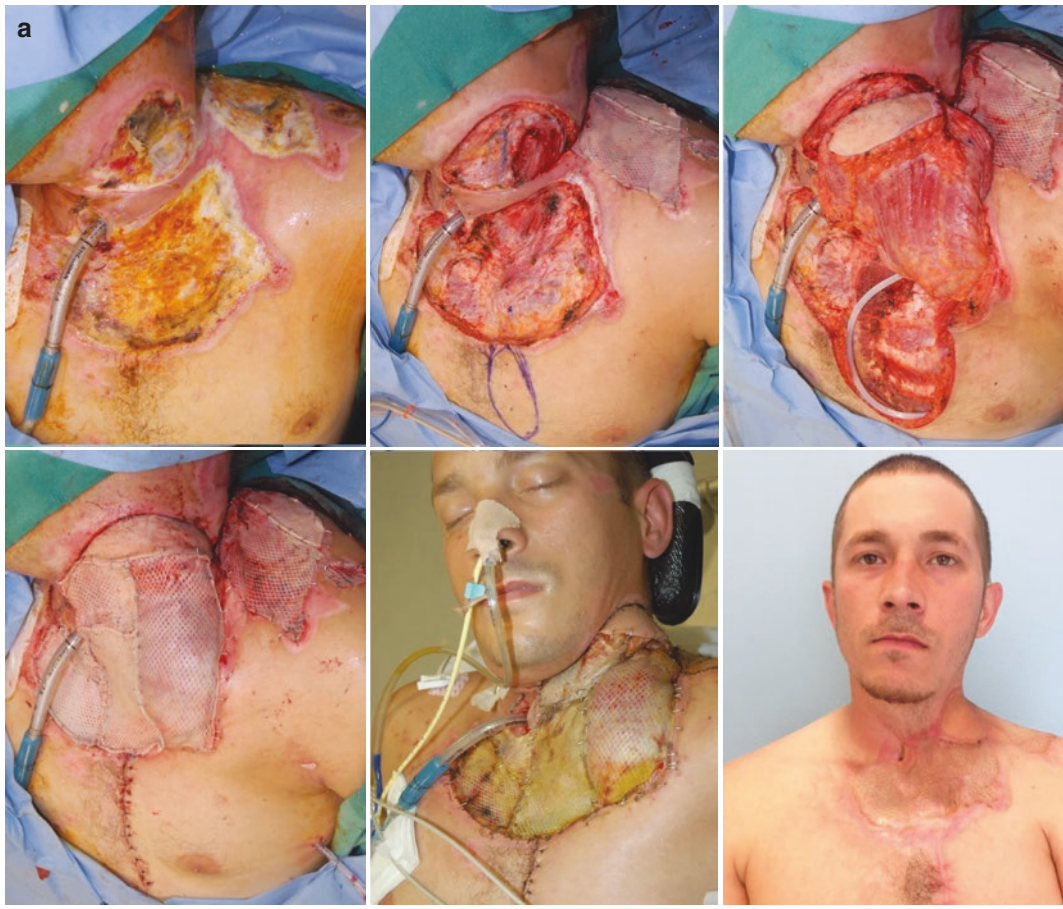
Anatomic Areas

Panfacial Burn



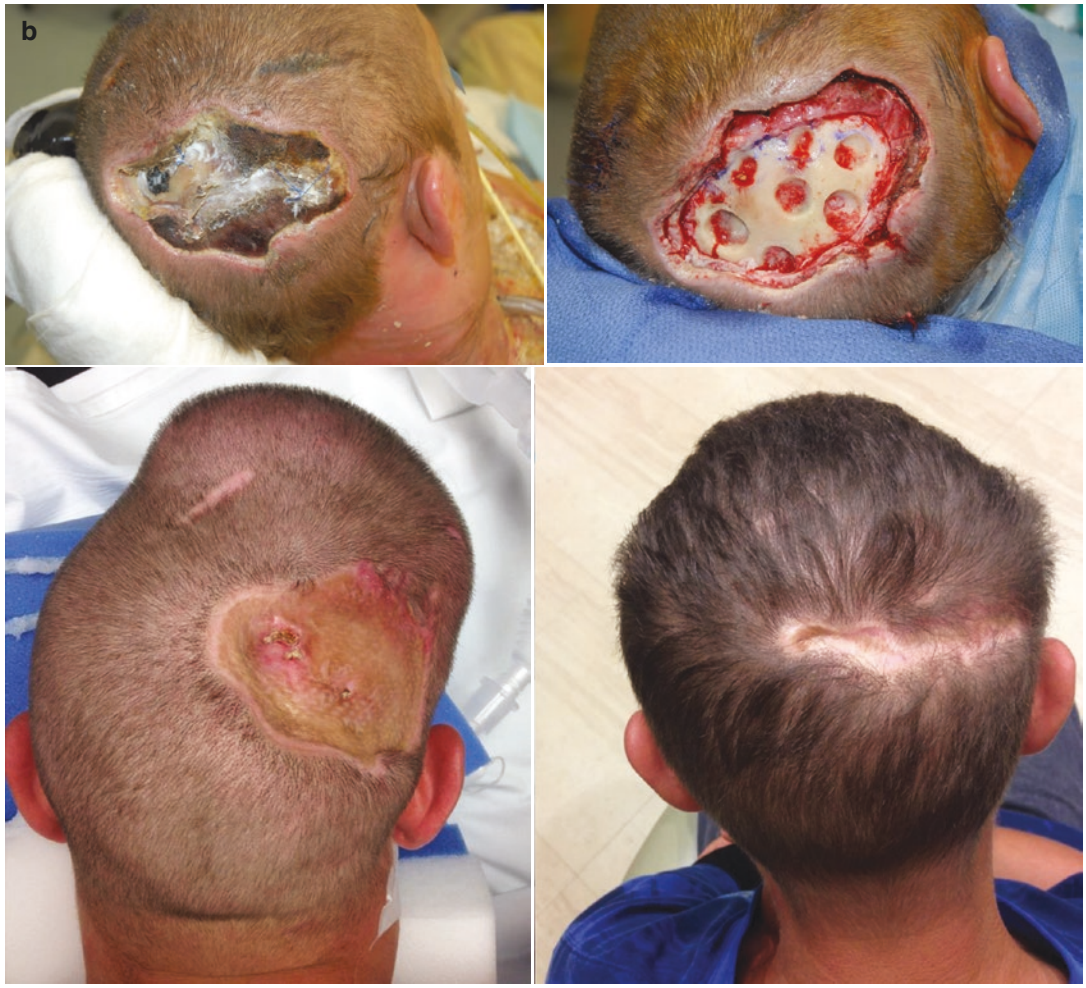
This 3-year-old boy sustained 60% total body surface area burns in a house fire, involving most of his face, neck, and scalp. After resuscitation and stabilization, he had a tracheostomy and underwent excision of burns and coverage with allograft. Set back by multiple pulmonary infections, he had delayed autograft coverage with thin sheet grafts. He then developed bilateral upper and lower eyelid ectropions, with complete eversion of his right upper lid. This was addressed with thick sheet grafts after release and correction of the ectropions. Over the course of several years, he underwent 12 rounds of pulsed-dye laser and fractional CO_2 laser. He also had bilateral anterior neck Z-plasties at the junction between his central skin graft and the lateral neck.

Electrical Injury to the Neck and Occiput



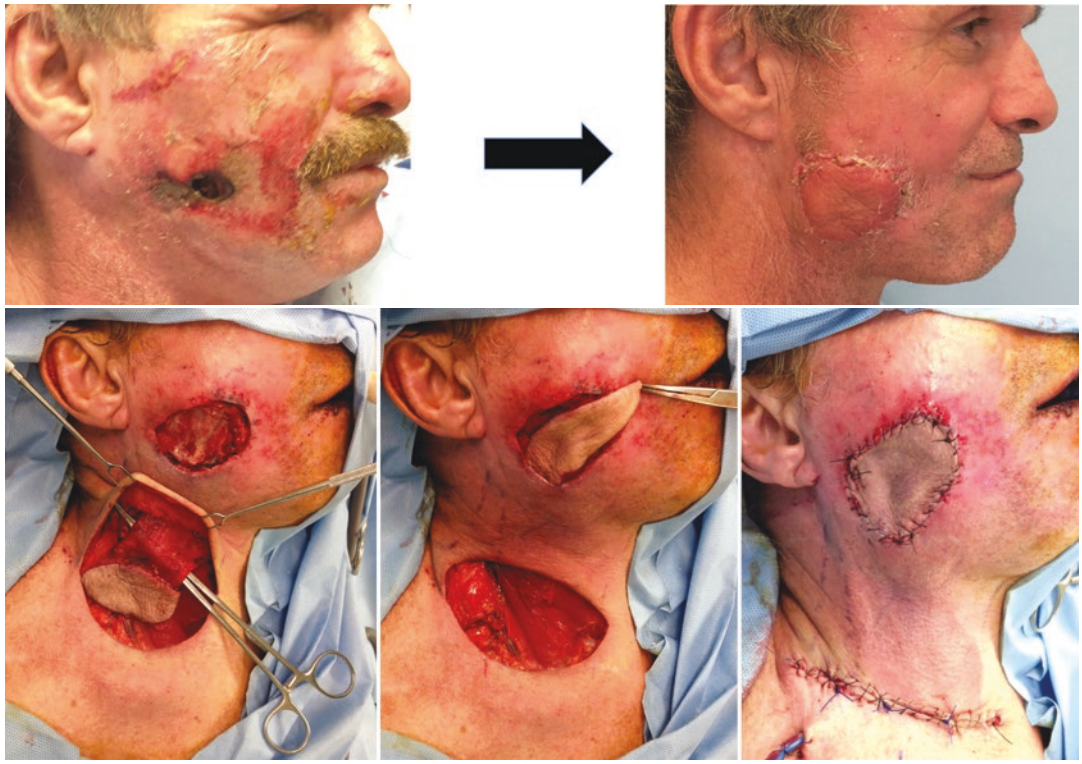
This 30-year-old man sustained fourth-degree electrical injuries to his neck and occiput when he came into contact with a high-voltage fence. After debriding his anterior neck wounds, including nonviable platysma, we used a pectoralis myocutaneous flap and skin grafts to cover his internal jugular vein, and the remnant of his sternocleidomastoid muscle to wrap around the common carotid artery. After initial healing, we returned to the operating theater to denervate the pectoralis muscle, which allowed for atrophy and improved contour.

His occipital burns were also debrided, exposing necrotic outer table, which was burred down to viable diploe. These wounds were eventually closed with a bilaminate skin substi-



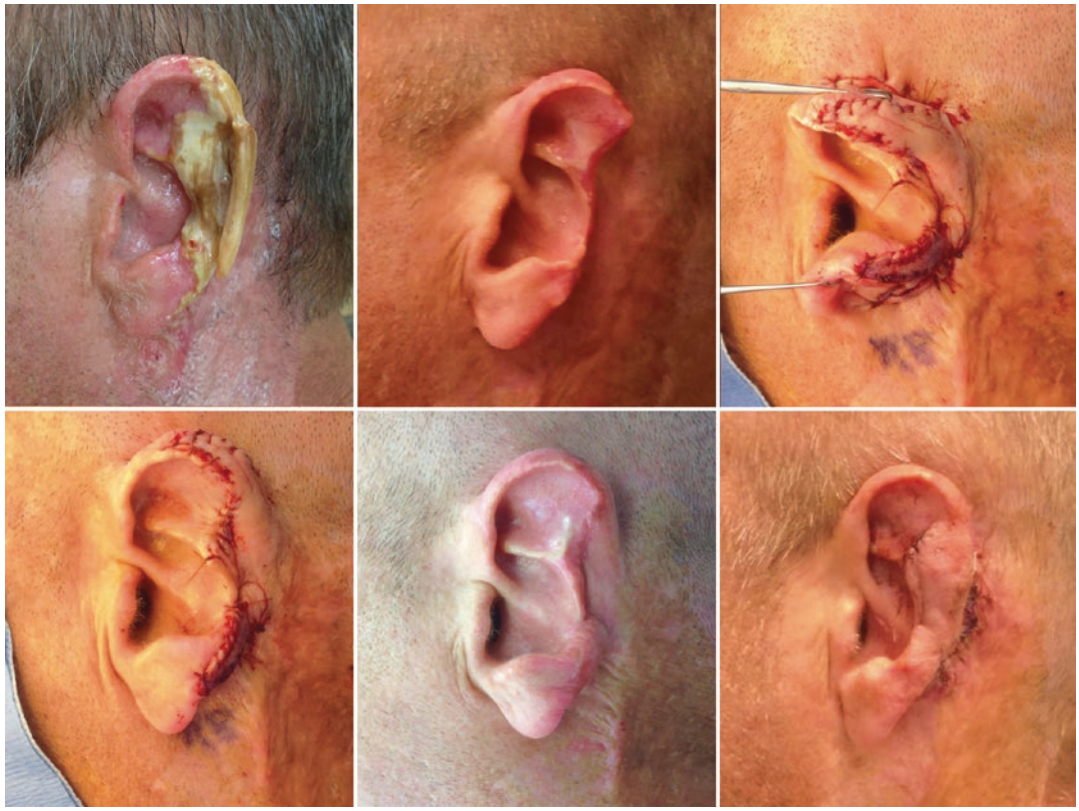
tute that was then grafted several weeks later. Because his wound remained tenuous, with exposed inner table, we placed a rectangular tissue expander through a remote incision. Scalp from the vertex was recruited for definitive closure with a large rotation-advancement flap that included galea. These flaps can be placed under modest tension, and they can be safely secured with pulley sutures, until the suture line is stable.

Cheek with Parotid Injury



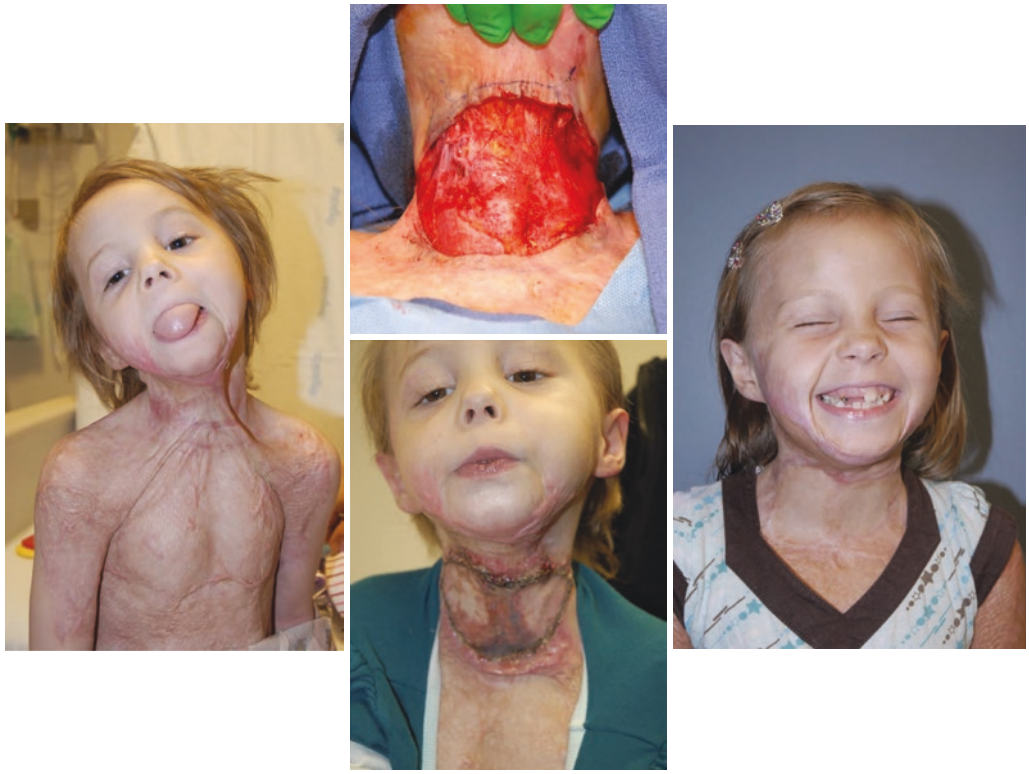
This 60-year-old man was shot at close range with a flare gun. Although his facial nerve was spared, his right parotid continued to secrete saliva through his cheek wound. After debriding the superficial lobe of the parotid gland, we harvested a platysmal myocutaneous flap, based on submental branches of the facial artery, to cover this defect. Specific caveats to consider include leaving drains in place for a controlled fistula, elevating the flap with minimal cautery, and using a wide cuff of muscle to facilitate venous drainage. Frey's syndrome, or gustatory sweating, would be unlikely in this setting, but a biologic matrix could be placed between the raw surface of the parotid and the overlying flap, if this complication were to occur.

Pinna Loss



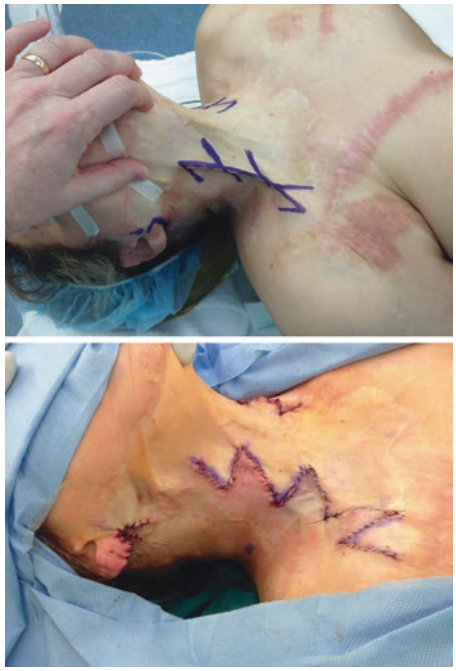
This 55-year-old man sustained full thickness grease burns to the head and neck, with subsequent loss of almost half of his pinna, including cartilage. The wound was treated with sulfamylon and allowed to demarcate, with separation of eschar. After waiting 6 months for the remaining ear to heal, with recovery of the peri-auricular skin, we performed delay of retro-auricular fasciocutaneous flaps, which were later transposed to the superior and inferior portions of the ear. These flaps were then divided at their base, resurfacing the antihelix to re-line the helical rim, followed weeks later by release of the entire ear from the retro-auricular region, full-thickness skin grafting of the posterior conchal bowl, and placement of a cartilage strut graft to reconstruct the junction of the helix and anti-helix.

Neck Contracture, Child



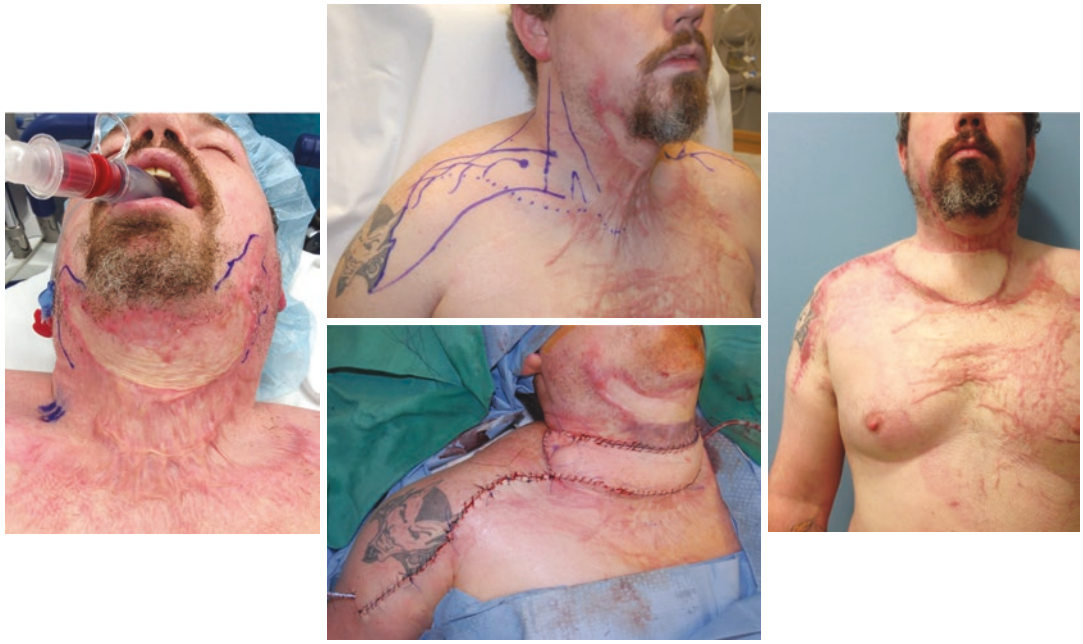
This 6-year-old girl developed a severe neck contracture following deep partial-thickness scald injury, with initial partial-thickness skin grafting to her neck, chest, and shoulders. We pretreated this area with six rounds of pulsed-dye laser and fractional CO_2 laser, to improve the pliability of the submental and chest skin. Neck release was performed, leaving platysma intact, but dividing all adhesions to the overlying scar. She was resurfaced with a full-thickness skin graft from her infra-abdominal region, with the donor site closed using an abdominoplasty template. A large, full-thickness graft is not our first option for neck contractures, but in this child with no comorbidities and need for future growth, we opted such an approach, which was successful. One caveat is that full-thickness grafts usually undergo some form of epidermolysis, but these grafts will re-epithelialize and recover over time and with fastidious wound care.

Neck Contracture, Focal Bands



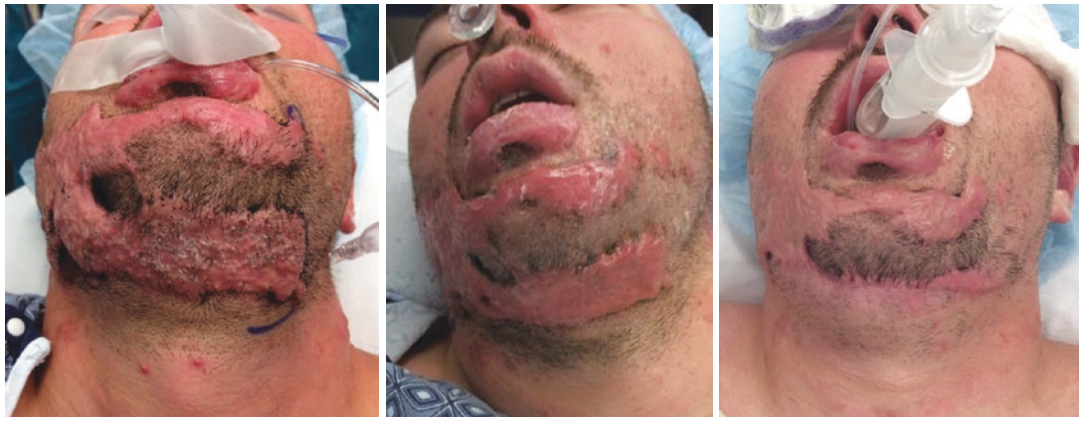
This 45-year-old woman sustained head and neck, breast, and upper extremity burns from an acid attack, and was initially treated in the Middle East. She developed focal neck contractures at the junction of her anterior skin graft and posterior skin, which healed with secondary intention. After undergoing pre-habilitation of her scars with pulsed-dye laser and fractional CO_2 laser, we performed a five-flap jumping man Z-plasty, contiguous with an asymmetric two-flap Z-plasty, to increase the length of the contracture by 30%. An important tip that almost always ensures viability of these Z-plasty flaps is to harvest the burned skin and skin grafts with platysmal fascia. Another trick: For tethered ear lobes, we like to perform a V-Y plasty, which is a powerful maneuver that releases the lobe from its base, providing considerable aesthetic improvements, appreciated by most patients. One last consideration is that releasing a contracture in one area usually reveals another point of constriction, which can be improved with postoperative laser therapy.

Recurrent Neck Contracture



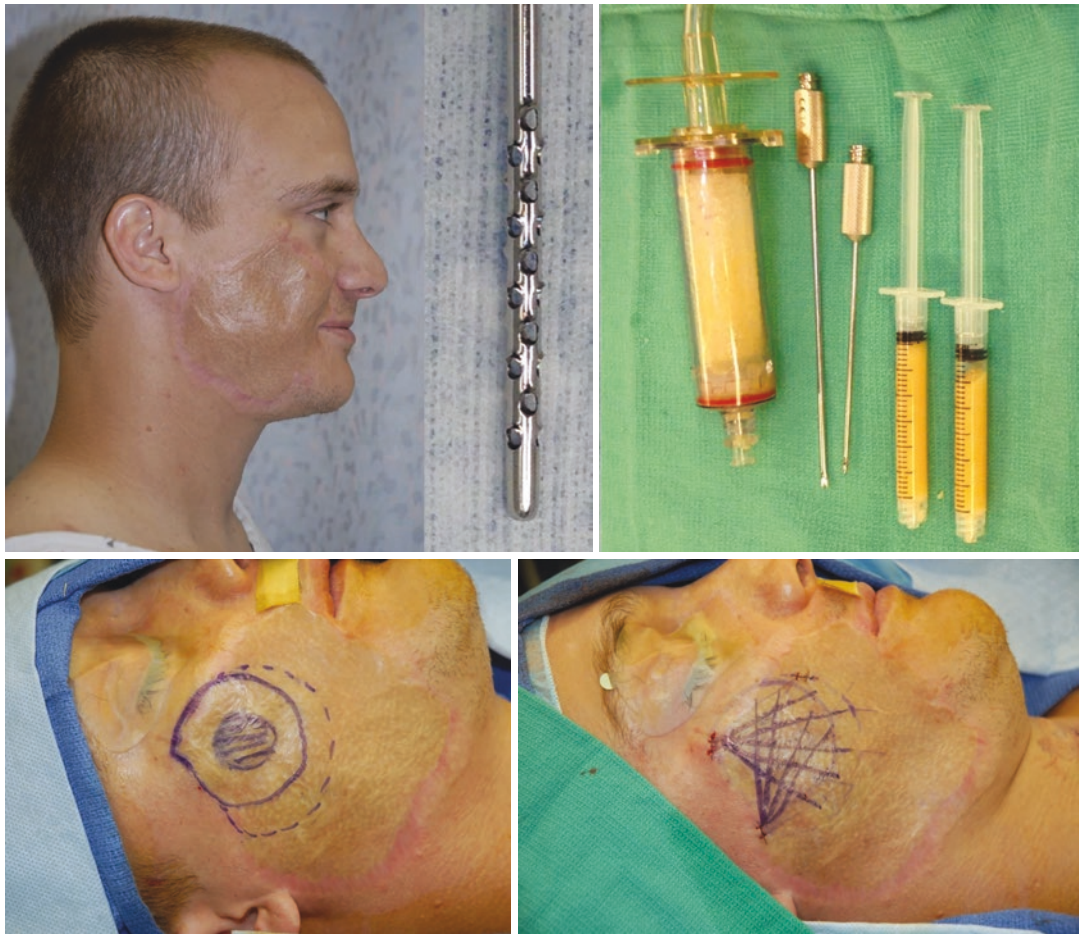
This 32-year-old man sustained deep partial-thickness burns from a house fire, underwent excision and grafting, and developed an initial neck contracture that was released in the submental region and sheet grafted. The anterior base of his neck remained quite tethered, due in part to the further contraction of his chest scars. In one stage, we performed release of the junction between the chest and neck and coverage with an extended supraclavicular fasciocutaneous flap, based on the transverse cervical system. The advantage of using vascularized tissue in this area is that the flap will stretch and widen considerably, as chest scars continue to contract.

Chronic Folliculitis



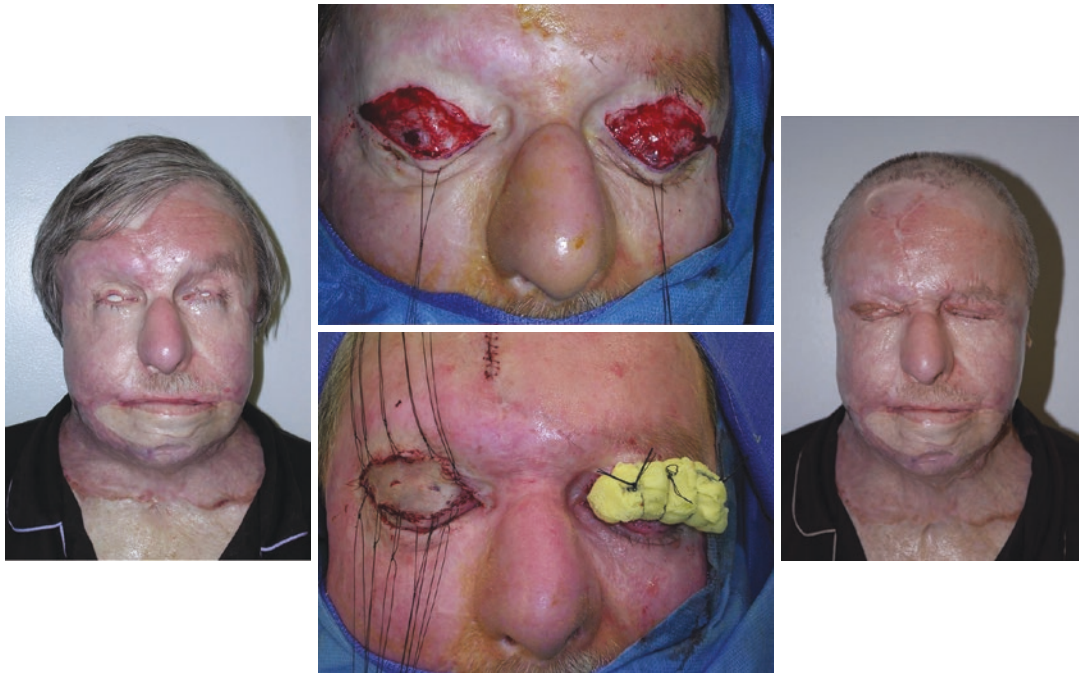
One of the causes of hypertrophic scars, especially in the head and neck beard area for men, is retained hair follicles that continue to grow under the skin and lead to subsequent inflammation, low-grade cellulitis, and micro-abscess formation. An approach that we have abandoned is secondary excision and grafting, due to poor graft take and suboptimal aesthetic result. Instead, we now use a combination of three lasers—the pulsed-dye laser, the fractional CO_2 laser, and the alexandrite laser—to destroy these hair follicles, reduce inflammation, and improve the thickness of these burn scars. These laser therapies also increase the pliability of these areas enough to permit excision and primary closure of residual focal areas. This patient is shown over the course of 18 months of laser therapy for his hypertrophic burn scars, caused by chronic folliculitis.

Concavity Defects, Cheek



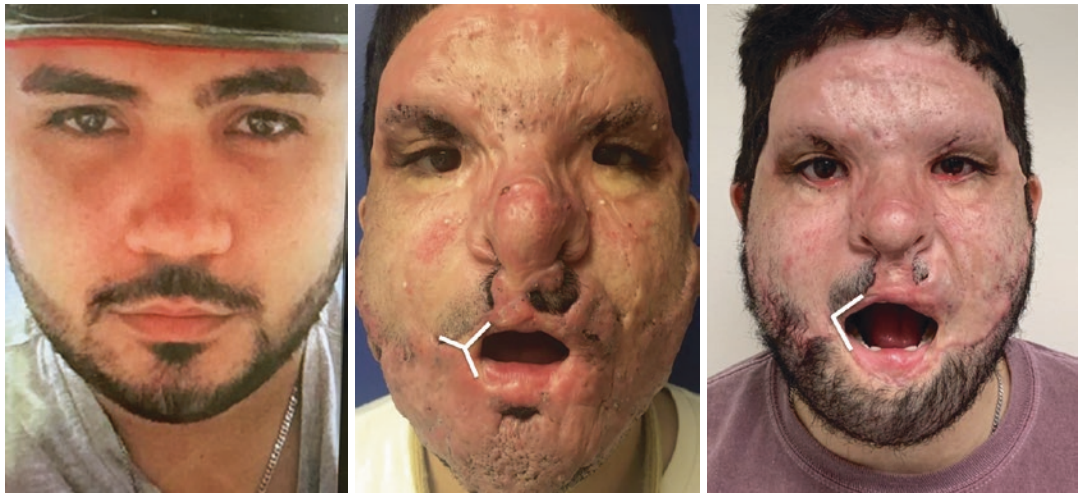
This 26-year-old man with a full-thickness contact burn to his face, who underwent sheet grafting, had a concavity defect to his cheek, where fat had previously been debrided, as part of his fourth-degree burn wound. We performed closed-system fat harvest from the lower abdominal wall, with a <1 mm serrated cannula, and used Coleman microcannulas to transfer 10 cc of washed, filtered, and concentrated lipoaspirate to the face. Fat is laid down in a radial, fanning, matrix fashion in threads of 0.05–0.10 cc aliquots. We initially performed two rounds of fat grafting for burn patients, but we soon realized that engraftment was >80%; therefore, one round may be sufficient. Also, we performed far more fat grafting for refractory itching and pain than for structural indications in burn patients.

Ectropion Release



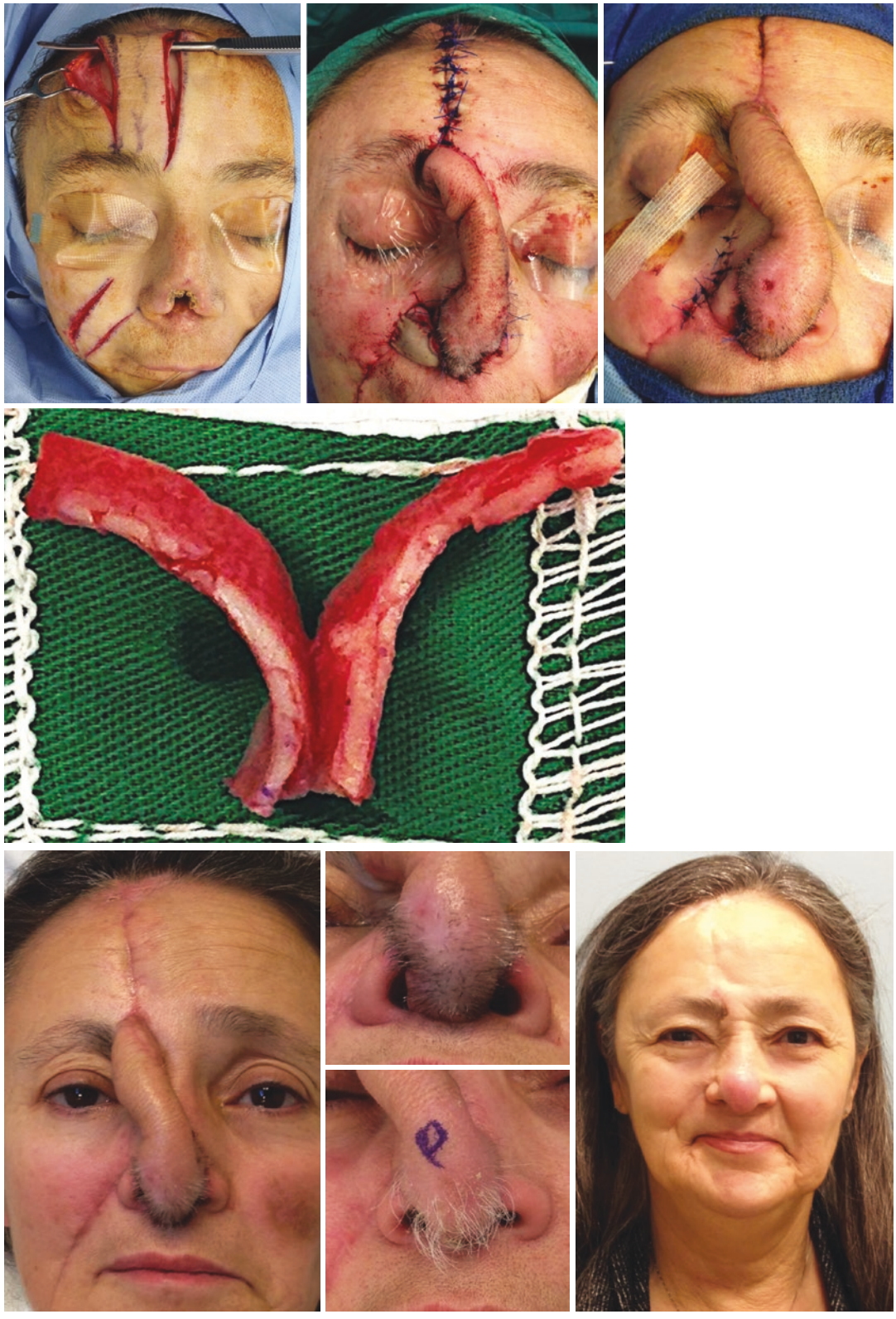
This 70-year-old man sustained a 30% total body surface area (TBSA) burn from a trailer fire, complicated by optic nerve ischemia during a septic episode, leaving him blind. He also had severe exposure keratitis with corneal ulceration and pain, which we treated with semi-permanent tarsoconjunctival flaps. As an outpatient, he later developed upper eyelid ectropions that we released at the level of the orbital septum and covered with full-thickness skin grafts, secured by bolsters. Caveats for eyelid repair include wide horizontal release of the lids, typically 5–6 cm, past the lateral orbital rim; vertical release of the upper eyelid down to the inferior orbital rim; and use of skin from the supra-clavicular fossa, if available. In his case, we instead performed a circumcision and used the foreskin form his penis. Also, we had previously performed nasal reconstruction with a forehead flap, nasal turnover flaps for lining, and cartilage grafts for support.

Microstomia Correction



This 26-year-old man sustained 28% TBSA burns of the head, neck, and hands, when he was involved in a motor vehicle collision. His facial burns were allowed to heal by secondary intention, but he developed severe hypertrophic scars, chronic folliculitis, canthal webs with ectropions, tethered nasal tip, and microstomia. An early priority in what will be a series of head and neck reconstructions is obtaining a secure, stable airway, so we prioritized correction of his microstomia. This was done by using bilateral Y-to-V adjacent tissue rearrangements, in which the lateral elements are incised and released at a 15-degree angle, down to the orbicularis and modiolus. The mucosa is then undermined on the back side of the commissure, until it can be advanced toward the new lateral commissure. This maneuver can add 1 cm of diameter to the upper and lower lip at both commissures, for a potential increase in circumference of 4 cm. We specifically do not divide any orbicularis, but rather stretch this out with a hemostat. Also evident in this case study are the results of the following interventions: release of his nasal tip and columella with creation of a new philtrum using a full-thickness skin graft, five-flap jumping man Z-plasties of his medial canthal webs, and advancement of a large cervicofacial flap to restore cheek and chin. The patient is currently undergoing laser therapy to decrease inflammation, rupture trapped hair follicles, and improve the pliability and texture of his skin, using PDL, alexandrite, and fractional CO_2 lasers, respectively.

Nasal Reconstruction



This 60-year-old woman presented with loss of her nasal tip, caudal septum, and columella, after developing 10% TBSA skin loss from levamisole-induced necrosis of her epidermis, an exfoliative skin disorder mediated by antibodies to impurities found in cocaine. After letting her heal most of her wounds, and allowing her nose to demarcate and slough, we delayed a paramedian forehead flap for coverage and a nasolabial flap for lining and creation of a septum. We specifically performed flap delays with longitudinal, parallel incisions, to open choke zones across angiosomes. In this case, given her propensity toward vasospasm, we performed a delay of the forehead flap that included skin, frontalis muscle, and periosteum. After elevation and transfer of the flaps, including grafting of the raw surfaces of the pedicles, we then performed a series of minor revisions, thinnings, and cartilage placement, until we were satisfied with the final shape of the nose. The flaps were then divided in two stages. Also of note, we had harvested a large forehead flap that included scalp. Pigmented hairs were easily destroyed with the alexandrite laser, but gray hairs had to be removed by direct excision of each of her follicles. A very important takeaway from this case is to preserve blood supply to the construct, until the surgeon and patient are satisfied with the near-final result.

Conclusion

Burn reconstruction utilizes a wide array of approaches to anticipate and meet the four-dimensional needs of patients with defects caused by burn injury. In addition to repairing functional deficits of the lips, nose, eyelids, cheeks, neck, ears, and forehead, the surgeon must optimize aesthetic outcomes as well. Preoperative surgical planning, managing expectations, and anticipating growth are critical to achieving results that can actually improve over time. Noninvasive or minimally invasive adjuncts, such as laser resurfacing, fat grafting, and skin care, can work synergistically with operative interventions, to help restore form and function in burn patients.

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Transgender Surgery: Feminization and Masculinization

25

Loren S. Schechter and Alexander R. Facque

Introduction

In the United States, estimates of the size of the transgender and gender diverse (TGD) population have been reported at 22.9 per 100,000 [1]. Other estimates indicate that 0.6% of the population, [2] approximately 1.4 million adults, identify as transgender [3]. While not all these individuals will seek surgery, many will. This is evidenced by the reported increase in gender confirmation procedures performed in 2018 in the annual statistics report of the American Society of Plastic Surgeons [4]. The most commonly requested gender-affirming procedures for plastic surgeons include: chest masculinization (mastectomy), chest feminization (breast augmentation), and facial feminization.

Terminology

Effective communication is important in building trust between patients and physicians. Language used in the TGD community, including pronoun selection, continues to evolve. Individuals may identify as male, female, both, or neither, and may consider themselves as gender diverse, nonbinary, genderqueer, or gender expansive. A person's pronouns (he/his, she/hers, or the gender neutral they/theirs) cannot be assumed based on the physician's interpretation of the patient's appearance. Asking and correctly using a patient's pronouns will convey respect for gender diversity and foster an environment of trust.

Identifying as a transgender individual, just as identifying as a cisgender individual, is not a medical diagnosis. Individuals identify as transgender when the sex in which they were classified at birth (male/female) is not consistent with their gender identity (which can be male, female, or have components of both or neither). A cisgender individual is an individual in whom the sex identified at birth is aligned with their gender identity. Gender dysphoria refers to the discomfort or distress that is caused by a discrepancy between a person's gender identity and that person's sex assigned at birth [5]. An effort has been made to distinguish the many manifestations of gender diversity found within our society from the diagnosis of gender dysphoria, in order to depathologize the former.

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Patient Selection

To aid with clinical care, The World Professional Association for Transgender Health (WPATH) have created *The Standards of Care* (SOC). These guidelines help to guide assessment and treatment (including surgery) for individuals who experience gender dysphoria. The SOC are designed to provide flexible parameters for professionals involved in the care of TGD individuals. It is important to understand that the SOC are not designed as barriers to care, but to facilitate care on an individualized basis [6].

Surgery on Adolescents

In some individuals, gender dysphoria may intensify in adolescence, as secondary sex characteristics begin to develop. As awareness and acceptance of gender diversity increases, increasing numbers of TGD individuals may transition prior to, or during, high school [7]. Some of these individuals will request medical or surgical treatments to aid with their transition. The SOC also provide assistance when considering surgical interventions in adolescents.

Sensitivity and Terminology Tips

Creating a comfortable and sensitive environment for TGD individuals should be a priority for medical professionals. Many transgender individuals report experiencing discrimination and negative treatment when attempting to access health care. As a result, some individuals are hesitant to seek necessary medical care. Introducing yourself and stating your preferred pronouns helps to invite the patient and their companions to share theirs. Avoid terms such as "transgendered" and "transgenders" in place of "transgender" or "gender diverse" individual. The authors conduct as much of the interview as possible with the patient fully clothed. During the physical examination, a gown is provided so as to minimize physical exposure. The exam is performed, with a chaperone, as expeditiously as possible. When discussing the patient's anatomy, attempt to use terms that align with the patient's desired gender identity. For example, when discussing surgery with transmasculine patients, refer to their chest rather than breasts.

Transmasculine Surgery

Transmasculine surgery may be categorized as chest (subcutaneous mastectomy), genital (e.g., vaginectomy, scrotoplasty, and phalloplasty), and non-chest, nongenital procedures (e.g., pectoral implants and liposuction, lipofilling).

Chest surgery is the most commonly requested surgical intervention. General goals of masculinizing chest surgery include aesthetic contouring of the chest wall by reduction of breast tissue and excess skin, reduction and positioning of the nipple areolar complex (NAC), obliteration of the inframammary fold (IMF), and minimization of chest wall scars and other stigmata of surgery [8]. Not all individuals request NAC reconstruction—this should be verified when discussing surgical options.

Transmasculine Top Surgery

Surgical technique may be divided into two general categories. Double-incision techniques involve an incision along the pectoralis border as well as a circumareolar incision. The NAC reconstruction is most commonly performed as a full-thickness graft; however, pedicled transposition of the NAC is also an option. Limited incision techniques involve a single incision, typically along the inferior border of the areola. In these circumstances, skin is usually not removed. While other incision choices are an option (i.e., circumareolar with vertical or horizontal extensions), these incisions, derived from cisgender mastopexy and reduction techniques, may confer a feminine appearance to the chest. Factors that influence surgical technique include breast volume, skin excess, skin elasticity, and degree of breast ptosis. Some of these factors, such as skin elasticity and breast ptosis, may be affected by preoperative chest binding.

Candidates for a limited-incision approach are those individuals in whom it is anticipated that sufficient skin retraction will occur postoperatively. In general, these are younger patients (perhaps with a history of pubertal suppression) with good skin elasticity and minimal to moderate glandular volume. The presence of breast striae (or a prolonged history of chest binding) may indicate that the patient is not a good candidate for this approach. For most patients, a double incision with free nipple areolar graft technique is chosen. Although it may be possible to preserve NAC sensation with a pedicled NAC transposition technique, the resulting residual chest bulk may be unacceptable, especially in large-chested individuals. Secondary contouring operations are an option, but this, too, should be discussed preoperatively. Liposuction is a useful adjunct for chest wall contouring, as well as for obliteration of the inframammary fold (IMF).

There is no uniformly accepted formula for position of the NAC. There are numerous reports regarding the "ideal" masculine nipple position using different anatomic landmarks. Lindsay described placing the nipple at the level of the 5th rib, 10–11 cm from midline and 2.5 cm from the lateral border of the pectoralis major [8]. According to Peck, the NAC lies within a line that extends from the ASIS to the medial corner of the infraclavicular fossa [9]. In 1996, Beckenstein et al. studied NAC position and size of cisgender males aged 17–30. In their study, the average distance from the nipple to the midclavicle (MC-N) was 18 cm, and the distance of the sternal notch to the nipple (SN-N) was 20 cm. In order to account for height, the formula 7.9 + .17 × Height (inches) was used to determine the distance of MCL-N and 11.1 + .13 × Height for SN-N. Average areolar diameter was 28 mm with a range of 25–30 mm [10].

In 2001, Beer et al. studied 100 cisgender males aged 20–36 using the thoracic circumference and sternal length to triangulate nipple position. They found that 75% of nipples were over the 4th intercostal space. These researchers could not correlate the ASIS or umbilicus with nipple position. They also recommended against using limb-related points, such as the mid-humerus, due to variability of respective limb and torso lengths [11]. In terms of areolar shape, an oval areola was most common (91%) while a round shape occurred in 7% of cases. Areola shape asymmetry was noted in 2% of cases, with patients having one round and one oval NAC. Oval NAC were identified as obliquely oriented, perpendicular to the fibers of the pectoralis major muscle. The average oval areolar dimensions in their study were 27 × 20 mm, and the mean diameter of the round areolae was 23 mm.

Chest surgery is an important, medically necessary procedure for many transgender and gender-diverse individuals. The preoperative discussion should include an understanding of the individual's goals and expectations. In general, the majority of patients undergoing chest masculinization rate their satisfaction as "good" or "very good" following surgery [12]. Complications of chest surgery are commensurate with non-gender related breast surgery. These include: seroma, hematoma, infection, and delayed healing or loss of the NAC. Complications may be reduced with careful preoperative planning (including smoking cessation) and choice of surgical technique.

Phalloplasty

The goals of phalloplasty include creation of an aesthetically pleasing phallus (size and contour), capability for standing urination, rigidity for penetrative intercourse, and both protective and erogenous sensation [13, 14]. Importantly, although protective sensation is important, not all patients seek standing urination or the ability to perform insertive intercourse. As such, each patient's goals should be discussed so as to personalize the surgical approach. Surgical options include both microvascular and pedicled flap techniques. The most common donor sites include the radial forearm and anterolateral thigh fasciocutaneous flaps. Additional muscle and skin flaps, such as the gracillis and superficial circumflex iliac flap, may be used as an adjunct in various circumstances as detailed below.

The most common donor site for the tube-within-a-tube technique is the radial forearm flap (RFF). [15] The tissue is thin, relatively hairless on the volar/ulnar border (urethral portion) of the flap, and has reliable neurovascular anatomy. The forearm flap typically allows a single-stage phalloplasty with construction of the shaft and urethra. Additionally, if desired, a glansplasty can often be performed at the time of the initial phalloplasty. The primary drawback of the forearm flap is the conspicuous donor site. An alternative option is to this approach is the anterolateral thigh flap. Most often, this flap is performed as a pedicled flap. The vascular anatomy is somewhat more variable than the RFF (either septocutaneous or musculocutaneous perforators), and the subcutaneous tissue is typically thicker than the RFF. This may preclude the use of a tube-within-a-tube technique and may necessitate secondary debulking procedures. Also, a glansplasty, if desired, is performed at a later date. Additional phalloplasty options include the use of combined flaps, such as a superficial circumflex iliac perforator flap or RFF for urethral reconstruction, and an ALT flap for shaft reconstruction. Less common options include regional flaps, such as gracilis muscle flaps, used either for phalloplasty or as a treatment for urethral stricture/fistula.

Transfeminine Surgery

Transfeminine Top Surgery

Transfeminine surgical procedures can be classified into breast (chest feminizing breast augmentation), genital (vaginoplasty, orchiectomy); and non-breast, nongenital surgeries (facial feminization). Breast augmentation is commonly requested [16]. While many of the techniques and principles in cisgender breast augmentation are applicable, there are some relevant distinctions. These are generally due to the anatomy of the transfeminine chest wall, and the degree of mammogenesis resulting from feminizing hormones. Although mammogenesis in transfeminine patients receiving estrogens follows a pattern similar to female pubertal mammogenesis [17], for some individuals the resulting breast growth will be inadequate to create an adult, feminine breast [18, 19]. Wierck et al. observed that the breast growth usually begins within 2–3 months after the start of cross-sex hormone therapy (CSHT) and progresses over 2 years [19]. As such, many surgeons, including the WPATH SOC, recommend a 12-month period of feminizing hormone therapy prior to breast augmentation. The goal is to maximize breast growth and achieve skin expansion prior to surgery [6].

The transfeminine chest is wider, with lateralized nipples, decreased nipple-to-inframammary fold (IMF) distance, and a smaller nipple areolar complex (NAC) diameter. Additionally, the skin envelope is typically constricted skin with a larger, and more active, pectoralis muscle. These differences may impact incision choice, implant selection, and pocket location.

The senior author (LSS) typically uses the IMF incision. This is based upon the larger implants and the frequent need to lower the IMF. This incision facilitates placement of larger implants and direction alteration and/or fixation of the fold. Furthermore, this incision is associated with the lower rates of capsular contracture as compared with peri-areolar and transaxillary approaches [20]. The incision is placed inferiorly (most often 1.5–2.0 cm, depending upon implant dimensions) to the existing IMF. This provides skin recruitment from the lower chest/upper abdomen.

The wide chest necessitates an implant with a wide base width [21]. Larger implants are usually chosen so as to compensate for the wide chest and lateralized NAC. The implant is typically centered beneath the NAC. However, even with the larger implants, an exaggerated space between the midline cleavage often occurs. Should the implants be placed in a more medial position, the resulting NAC may be laterally divergent. Secondary procedures, such as autologous fat grafting, may assist with decreasing the deficiency in medial cleavage.

Overall, the majority of patients undergoing chest feminization are satisfied with their final outcome [22]. In a prospective, non-comparative, cohort study Weigert et al. report that the gains in

breast satisfaction, psychosocial well-being, and sexual well-being after breast augmentation are statistically significant and clinically meaningful to the patient [23]. The authors conclude that breast augmentation in transgender women can have a significant and positive impact on a patient's satisfaction with their breasts, psychosocial well-being, and sexual well-being.

Facial Feminization Surgery

Facial feminization surgery represents an array of procedures designed and performed to counteract the bony and soft tissue changes that occur with masculinizing puberty. Prior to surgery, careful analysis and an understanding of the sexual dimorphisms that arise during facial maturation are important. Characteristic changes occur with pubertal development that affects the structure and the shape of the facial bones and soft tissues. Under the effects of masculinizing pubertal hormones, the supra-orbital ridges become prominent, and the jaw widens. This creates a more square-appearing facial shape. In addition, the skin becomes thicker and develops increased hair growth and sebum production. As aging continues, frontal and temporal hair loss results in a longer forehead. Facial feminization procedures include hairline advancement, frontal sinus setback, brow contouring, brow lift, orbital contouring, rhinoplasty, malar lipofilling, lip lift, mandibular angle contouring, genioplasty, and tracheal shave, among others.

Frontal sinus setback may be performed through a bi-coronal approach or an anterior hairline incision. If no hairline advancement is needed, the incision and resultant scar can be placed in the traditional position behind the hairline. With hairline advancement, a trichophytic incision can be made at the hairline, to allow hair growth through the scar postoperatively. Following exposure of the frontal sinuses, nasal endoscopy can be used in order to illuminate the frontal sinus and identify its borders. At this time, the contouring or setback may be performed as is described elsewhere [24–26]. Additional contouring of the superolateral orbit may also be performed to create a more open, youthful, and feminized orbital appearance.

Feminizing rhinoplasty is performed through an open or endonasal approach. Typical components of feminizing rhinoplasty include dorsal hump reduction, nasal bone infracturing, and tip refinement. In addition, the alar bases may need to be reduced. When performed with correction of frontal bossing, the creation of an obtuse nasofrontal angle, as seen in feminized profiles, should be considered. While the goal of a feminizing rhinoplasty is often a "smaller nose," it is important to consider the overall proportions of the face in relation to the nose—this will help to prevent a disharmonious appearance, regardless of the feminized features.

A lip lift may be performed to increase vermillion and maxillary incisor show at repose, a feature which is more typical of feminized faces. A "bullhorn" incision is created by carrying the incision into the nasal sills in order to camouflage the resulting scar [27]. Surgical lip augmentation can also be performed using dermal grafts, harvested from the coronal flap, if available, or with lipofilling. Most frequently, nonsurgical lip augmentation is performed using hyaluronic acid fillers.

A masculine mandible has a wider bi-gonial angle with lipping at the external, inferior border of the angle. This corresponds to the pull of the masseter muscle at this location. The so-called V shape mandibular contouring operation uses an intra-oral approach to either osteotomize or burr the lower border of the mandible [28]. Concurrent genioplasty may also be performed. During these procedures, care is taken to preserve the mental nerve, which is located at the longitudinal axis of the second pre-molar, approximately one fingerbreadth above the inferior border of the mandible. The nerve itself travels inferiorly to the foramen and can be at risk with the osteotomies.

Depending upon the prominence of the thyroid cartilage, a so-called tracheal (or trach) shave, formerly chondrolaryngoplasty, may be performed. The thyroid cartilage prominence is approached through a superior neck crease in the cervicomental angle. Dissection is carried inferiorly to identify the thyroid cartilage immediately

beneath the retracted strap muscles of the neck. Incisions directly over the thyroid cartilage are avoided, as these are associated with a visible and stigmatizing scar that may be mobile while speaking and swallowing. During the procedure, in order to protect the vocal cords, a flexible bronchoscope or laryngoscope can be used in conjunction with a laryngeal mask airway to visualize the vocal folds internally. A 23 g or 25 g needle is inserted externally at the inferior aspect of the planned cartilage resection. The needle can then be visualized internally to determine its relation to the anterior commissure of the true vocal fold in order to ensure that the resection will not destabilize the attachment of the vocal folds [29]. Approximately 2 mm of cartilage should be left above the level of the vocal cord insertion so as to reduce the possibility of postoperative voice changes.

Conclusion

Gender affirming surgery may, with careful consideration, be performed successfully and safely. The surgeon should familiarize themselves with the standards of care, so as to help select surgical candidates. Knowledge of anatomy and sexual dimorphisms will also aid in the surgeon's ability to perform meaningful interventions in this previously marginalized population.

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Part III

Pediatric and Craniomaxillofacial Surgery

Vascular Anomalies

26

Farooq Shahzad and Arun K. Gosain

Introduction

Vascular anomalies are the most common pediatric congenital malformations. The management of vascular anomalies has historically been marred with inconsistencies in terminology, which resulted in incorrect diagnosis and treatment. A major step in streamlining terminology was the classification of vascular anomalies into two groups: tumors and malformations [1]. Vascular tumors exhibit epithelial proliferation. The most common tumors are infantile hemangiomas. Vascular malformations, on the other hand, exhibit normal endothelial turnover. They can undergo cellular hypertrophy. Malformations are classified by the type of vascular channels involved into slow flow (capillary, lymphatic, venous) and fast flow (arteriovenous) malformations. The International Society for Study of Vascular Anomalies (ISSVA) has further refined this classification as our understanding of vascular malformations has improved and new entities have been described (Table 26.1). Detailed and updated classification is available online on the ISSVA website (https://www.issva.org).

This chapter will focus on the most common vascular anomalies and our tips and tricks to simplify correct diagnosis and optimize treatment.

Diagnosis

History

The first step in management of vascular anomalies is accurate diagnosis. Unfortunately, misdiagnosis and incorrect treatment is still all too common. There are two main reasons for this: use of incorrect terminology, and poor knowledge of pathogenesis of vascular anomalies. Medical professionals still refer to all types of vascular anomalies as "hemangiomas" sometimes with other descriptive terms like "strawberry," "cherry," and "cavernous." This leads to a lot of confusion in communication among specialists, which results in inappropriate treatment.

The diagnostic process begins with a good history, which is usually sufficient for the initial diagnosis in the majority of cases. Since infantile hemangiomas are by far the most common of the

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Table 26.1 Simplified version of the ISSVA classification of vascular anomalies

Tumors	Malformations			
	Simple	Combined	of major named vessels	Associated with other anomalies
Benign Infantile hemangioma Congenital hemangioma *Locally aggressive or borderline* Kaposiform hemangioendothelioma *Malignant* Angiosarcoma	Capillary Lymphatic Venous Arteriovenous	Capillary-venous malformation Capillary-lymphatic malformation Capillary-arteriovenous malformation Lymphatic-venous malformation Capillary-lymphatic-venous malformation Capillary-lymphatic-arteriovenous malformation Capillary-venous-arteriovenous malformation Capillary-lymphatic-venous-arteriovenous malformation	*Affect* Lymphatics Veins Arteries *Anomalies of* Origin Course Number Length Diameter Valves Communications Persistence	Klippel-Trenaunay syndrome Parkes Weber syndrome Sturge-Weber syndrome Mafucci syndrome Proteus syndrome

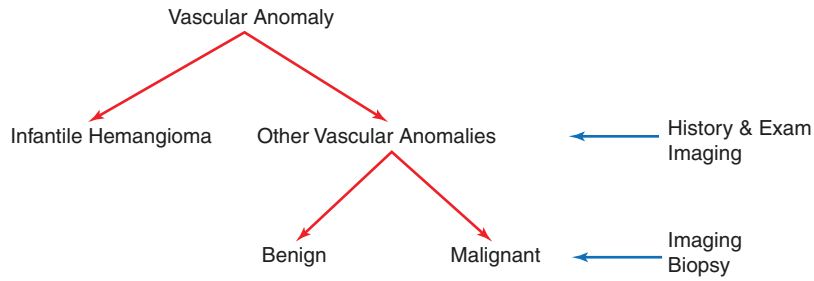

Fig. 26.1 Algorithm for diagnosis of vascular anomalies

vascular anomalies, the first step is to distinguish hemangiomas from all other vascular anomalies (Fig. 26.1). Infantile hemangiomas have a very characteristic history. At birth they appear as blue or red vascular marks. Frequently they are not clinically apparent at birth. They then enter the "proliferative phase" during which rapid growth of the lesion occurs out of proportion to the growth of the child. The expansion of the lesion then stabilizes at around 6–12 months of age. After a variable period of time, the lesion enters the "involution phase," during which time it starts to decrease in size. The median age of involution is 4 years, but the process can sometimes take up to 9 years [2]. The lesion then enters the "involuted phase." After involution, more than half of the lesions leave behind local tissue changes like anetoderma (macular atrophy), fibro fatty residuum, and telangiectasias.

Vascular malformations, on the other hand, are fully formed at birth. They grow larger in proportion with the child. Over time, their relative size can slowly increase. They can undergo more rapid enlargement in response to stimuli like puberty or pregnancy-induced hormonal stimulation, ischemia, trauma, or infections.

Physical Examination

A complete physical examination should be performed, as more than one lesion may be present. There are certain clinical patterns that may be a

harbinger of other associated conditions and warrant further investigation (Table 26.2). The following are characteristic features of the common vascular anomalies:

- Infantile hemangiomas. The appearance of hemangiomas depends on their depth, with the more superficial ones appearing more red, and deeper ones appearing more blue. They may be flat or raised. Skin ulceration may occur in very superficial lesions.
- Congenital hemangiomas. These are fully formed at birth. They appear as red-violet lesions with telangiectasias and a pale halo.
- Lymphatic malformations. These frequently present as localized swellings without any skin color changes. The overlying skin may have small vesicles that can be clear, blue, or purple colored, known as lymphangioma circumscriptum. These vessels usually drain clear lymphatic fluid.
- Capillary malformations. These present as erythematous patches. Over time the area can get thick and raised.
- Venous malformations. These are areas of bluish discoloration that may be flat or raised. They become more prominent with Valsalva maneuver or dependent positioning.
- *Arteriovenous malformations* (*AVM*). These are characterized by warmth of the overlying skin. A thrill or pulsation can be palpated. Ulceration and bleeding can occur in advanced stage.

Imaging

If the diagnosis is still unclear after history and examination, imaging can be performed for further characterization. Imaging may also be obtained to evaluate the extent of the malformation and for planning treatment.

Table 26.2 Conditions associated with vascular anomalies

Clinical appearance	Condition or syndrome	Characteristics	Work-up
Hemangiomas			
Five or more hemangiomas	Diffuse neonatal hemangiomatosis [38]	Hepatic hemangiomas most common Gastrointestinal tract, central nervous system, and lungs less commonly involved Hypothyroidism with diffuse hepatic hemangiomas	Ultrasound liver Other imaging based on symptoms Thyroid function tests
Segmental hemangiomas of the lower face and neck (beard distribution)	Upper airways or subglottic hemangioma [39, 40]	Progressive airway obstruction manifesting clinically as stridor	Endoscopic airway examination
Large facial hemangiomas	PHACE(S) syndrome [41]	Segmental facial hemangioma in trigeminal distribution, plus one other finding: *P*osterior fossa brain malformations *H*emangioma *A*rterial cerebrovascular anomalies *C*oarctation of aorta, cardiac defects *E*ye and endocrine abnormalities *S*ternal clefting, supraumbilical raphe	MRI & MRA of head and neck Ophthalmologic, Cardiac and Endocrine consults

(continued)

Table 26.2 (continued)

Clinical appearance	Condition or syndrome	Characteristics	Work-up
Segmental lumbosacral or perineal hemangiomas	PELVIS syndrome [42]	*P*erineal hemangioma *E*xternal genitalia malformations *L*ipomyelomeningocele *V*esicorenal abnormalities *I*mperforate anus *S*kin tag	Ultrasound of genitourinary system Ultrasound of spine
	SACRAL syndrome [43]	*S*pinal dysraphism *A*nogenital anomalies *C*utaneous anomalies *R*enal and urologic anomalies *A*ngioma of *L*umbosacral localization	
	LUMBAR syndrome [44]	*L*ower body hemangioma and other cutaneous deformities *U*rogenital anomalies Ulceration *M*yelopathy *B*one deformities *A*norectal malformations Arterial anomalies *R*enal anomalies	
Capillary malformations			
Capillary malformation in the V1 (first division of trigeminal nerve) distribution	Sturge-Weber syndrome [45]	Leptomeningeal vascular malformations Seizures Glaucoma	MRI of the brain Ophthalmologic exam
Venous malformations			
Multiple blue cutaneous and/or mucosal venous malformations (nodules or plaques), especially on palms and soles, that may be tender	Blue rubber bleb nevus syndrome [46]	Gastrointestinal lesions leading to blood loss, volvulus, intussusception Other organ systems can be involved	Fecal occult blood testing Gastrointestinal evaluation (upper and lower endoscopy, capsule endoscopy) MRI brain Imaging of other organs as indicated by symptoms

Ultrasound is the first-line imaging modality, as it is noninvasive, quick, inexpensive, and does not require sedation. However, it is a very operator-dependent investigation. A skilled radiologist with experience in imaging vascular anomalies can provide information that frequently clinches the diagnosis. Hemangiomas and arteriovenous malformations exhibit fast flow, while venous and lymphatic malformations exhibit slow flow on ultrasound imaging. In the proliferating phase, infantile hemangiomas appear as well circumscribed hypo- or hyperechoic lesion. Doppler shows high flow vessels with low resistance. Rarely, arteriovenous shunting may be seen, which can mistake the lesion for an AVM [3]. Congenital hemangiomas have sonographic features similar to infantile hemangioma [4]. Arteriovenous malformations appear as a collection of blood vessels with little or no solid component. Doppler shows high diastolic flow in the arteries. The draining veins are arterialized, that is, they have pulsatile flow, which is in contrast to hemangiomas. Venous malformations are hypoechoic compressible lesions that can contain phleboliths. Compressibility is an important feature that distinguishes them from other vascular anomalies.

Tortuous dysplastic venous channels can sometimes be seen. Doppler shows slow or no flow. Lymphatic malformations appear as multilobulated cystic lesion in the case of macrocystic lymphatic malformations, and ill-defined hyperechoic lesions in the case of microcystic lymphatic malformations. Doppler shows vascular channels in the cyst septae. Capillary malformations appear as epidermal or subcutaneous thickening [5]. Ultrasound may be performed if an underlying deeper vascular malformation is suspected.

Magnetic resonance imaging (MRI) is obtained if the diagnosis is still unclear after sonography, or if more information is needed about the extent of the malformation for treatment planning. The indication for the MRI should be clearly communicated to the radiologist, as correct timing of contrast delivery is critical for optimal image acquisition. Dynamic images are obtained in the arterial and venous phases to characterize flow in the lesions. T1-weighted sequences are good to view the anatomy, and T2-weighted fat-suppressed sequences are good to evaluate the extent of the lesions. Newer techniques like dynamic time resolved MR angiography may give better details about lesions [6]. A comprehensive review about imaging characteristics of various vascular anomalies is beyond the scope of this chapter.

Pathology

Biopsy is done if the diagnosis is unclear after imaging. However, due to the vascular nature of these lesions, incisional biopsy is often not feasible, and pathologic diagnosis is often delayed until an excisional biopsy is attempted for symptomatic lesions. The clinical history should be communicated clearly to the pathologist, as histopathologic features of vascular malformations may be nonspecific. We have seen many vascular malformations being read as "hemangioma" and subsequently undergoing inappropriate treatment based on this pathologic diagnosis. Infantile hemangiomas are GLUT 1 positive, in contrast to congenital hemangiomas and other vascular anomalies which are GLUT 1 negative [7]. Molecular testing via whole exome sequencing may identify a gene mutation, which can point toward a diagnosis if histopathology is equivocal. The majority of genetic mutations in vascular anomalies have been shown to affect the tyrosine kinase receptor signaling system via the RAS or PIC3CA pathways [8]. Targeted therapies against specific mutations may be the way we treat vascular anomalies in the future.

Treatment

There are various treatment options available for different vascular anomalies. One way to conceptualize the different options is to consider them as a reconstructive ladder or elevator (Fig. 26.2). All

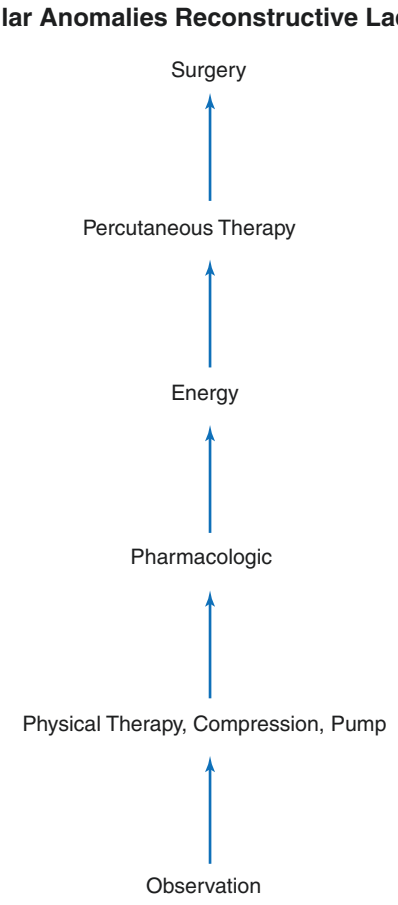

Fig. 26.2 Composition of multidisciplinary vascular anomalies team

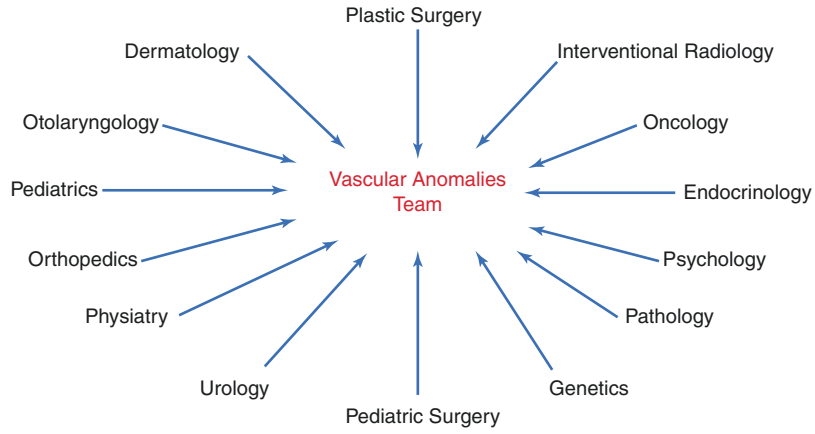

Fig. 26.3 Reconstructive ladder for management of vascular anomalies

different management options are considered, and the best treatment or combination of treatments is chosen. These decisions are best taken in the setting of a multidisciplinary vascular anomalies team (Fig. 26.3). These teams consist of experts from many specialties, including plastic surgery, dermatology, interventional radiology, hematology, physiatry, physical therapy, psychology, and nursing. Other specialties—such as otolaryngology, orthopedics, urology, neurosurgery, and pediatric general surgery—are called upon when their services are needed. This ensures accurate diagnosis and optimal treatment plans for these challenging problems. Any complex or atypical vascular lesion should be referred to a multidisciplinary team.

The following is an overview of the treatment of common vascular anomalies.

Infantile Hemangiomas

Infantile hemangiomas (IH) are the most common vascular anomalies, with an incidence of 4.5% in Caucasian children (Figs. 26.4, and 26.5) [9]. The incidence is lower in African Americans. In preterm babies <1200 g, the incidence is 23% [10]. Hemangiomas are morphologically classified as localized, segmental, or multifocal. The segmental and multifocal varieties can be associ-

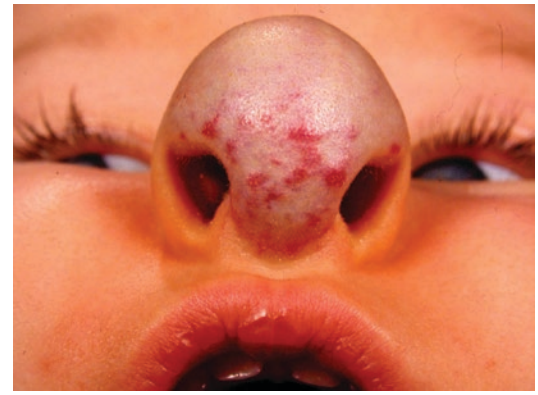

Fig. 26.4 Infantile hemangioma of nose in a 6-month-old boy. The hemangioma is in the proliferative phase

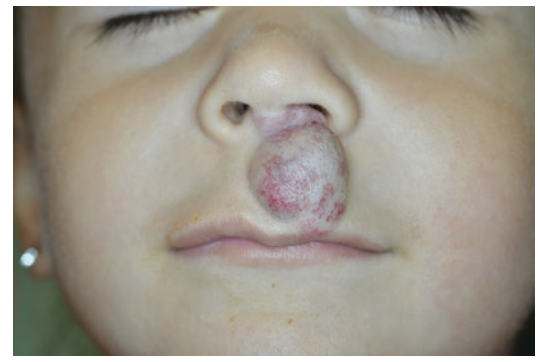

Fig. 26.5 Infantile hemangioma of upper lip in a 3-year-old girl. The hemangioma is in the involutional phase and has left a residual fibrofatty distortion that will not resolve spontaneously

ated with other malformations and further investigation may be warranted (see Table 26.2).

The management of IH depends on their stage. The following is an overview of our management strategy.

Proliferative Phase

Pharmacotherapy

Hemangiomas that are small, deep, and in cosmetically inconsequential locations are managed expectantly. However, if a lesion is in a cosmetically visible location like the face, is large and superficial causing local tissue or organ destruction, or is obstructive or deforming, pharmacologic treatment is undertaken. Steroids have historically been the drugs of choice. They halt growth and hasten involution. Oral prednisolone is started at a dose of 3 mg/kg administered once a day in the morning. After 1–2 months, the dosage is slowly tapered and then eventually discontinued at 10–12 months of age. H2 receptor blockers are also administered concurrently to counteract the gastric side effects of steroids. Other adverse effects from steroid treatment include mood changes, Cushingoid features, and growth restriction. Growth, however, catches up after discontinuation of steroids. Steroids can also be injected intralesionally for small hemangiomas in critical or cosmetically sensitive areas [11]. Injections are performed 4–6 weeks apart for a total of three to five injections. Topical ultrapotent steroids have efficacy for thin superficial hemangiomas [12].

Beta blockers have now superseded steroids as drugs of choice for pharmacologic management of hemangiomas in the proliferative phase. Propranolol was introduced in 2008 for treatment of hemangiomas, and is now considered the first-line therapy in the proliferative phase [13]. It has a 98% response rate [14]. Propranolol is a nonselective beta-antagonist, and thus affects beta-receptors in the cardiovascular system, lungs, and pancreas. The most common adverse effect is sleep disturbances. Other rare but life-threatening side effects are bradycardia, bronchospasm, and hypoglycemia. Treatment is initiated as inpatient for children less than 5 weeks corrected gestational age or with respiratory or cardiac problems; otherwise treatment is started in an outpatient setting with monitoring of blood pressure and heart rate for 2 hours. Baseline EKG is obtained for children at high risk for cardiac disease, for example, those with an arrhythmia or a family history of congenital heart disease. The FDA recommends a starting dose of 0.6 mg/kg twice a day, increasing the dose over 2 weeks to 1.7 mg/kg twice a day (3.4 mg per day). Medication should be administered with feeds to counteract the hypoglycemic effects of propranolol. Duration of therapy is typically 6 months. Rebound growth can occur during tapering or after cessation of therapy; this risk is higher if therapy is stopped before 1 year of age.

Timolol is a nonselective beta blocker that is used for the treatment of glaucoma. Topical timolol has been found to be as effective as systemic propranolol for management of very superficial hemangiomas [15]. There is, however, cutaneous absorption of the drug, with very low levels detected in the blood. The significance of these low levels of timolol in the blood is not known. At this time, topical timolol is considered a safe and efficacious drug for management of superficial hemangiomas.

Propranolol can cross the blood-brain barrier and therefore there are concerns about possible long-term neurologic effects. Nadalol (a nonselective beta-antagonist) and acebutalol (a selective beta-1 antagonist) do not cross the blood-brain barrier, and have been shown to be effective in small noncontrolled studies [16, 17]. Atenolol, a selective beta-1 antagonist that does not cross the blood-brain barrier, has been shown to be as effective as propranolol, but with less reactive airway adverse effects [18]. Till more data is available, propranolol is still considered the systemic pharmacologic treatment of choice.

Surgery

Surgery is not typically performed during the proliferative phase, as the lesion is allowed to involute. However, surgical excision or debulking may be indicated in the following situations:

1. *Ulceration*. The most common complication during hemangioma proliferation is ulceration. This occurs most commonly in the anogenital and perianal regions. It can result in pain and bleeding, which is very distressing to the patient and the parents. The primary management of an ulcerated hemangioma is local wound care with an occlusive dressing to protect the wound from desiccation and friction. Topical lidocaine jelly can be used for pain control. Propranolol helps accelerate involution, and thus promotes healing of ulceration. Therapy with both oral propranolol and prednisone can be effective for ulceration that does not respond to propranolol monotherapy [19]. Pulsed dye laser (PDL) therapy can promote healing of ulceration [20]. Typically, a few treatments are needed, spaced 3–4 weeks apart. Surgical excision can be performed for recalcitrant pain, recurrent bleeding, or if parents are extremely anxious and are unable to perform local wound care.
2. *Obstruction*. Hemangiomas in the head and neck area can cause obstruction of critical structures. Periorbital hemangiomas can cause compression of the cornea, resulting in astigmatism or obstruction of the visual axis resulting in deprivation amblyopia. If not promptly treated, this can be irreversible. Evaluation by a pediatric ophthalmologist is very important. Pharmacotherapy with propranolol is initiated. However, if there is significant compression of the cornea or visual obstruction, especially if it is long-standing, we recommend surgical excision. Surgery for periocular hemangiomas has been shown to be safe in experienced hands [21]. Nasal hemangiomas can obstruct the airways. Similarly, perioral hemangiomas can cause problems with feeding. Pharmacotherapy is usually initiated, but based on severity and duration of symptoms, surgical management can be considered. Hemangiomas in a beard distribution can be concerning for airway involvement, and warrant airway evaluation by an otolaryngologist.

Laser

The use of lasers during the proliferative phase is controversial, as they can cause ulceration and pain. However, they are used by some centers for management of superficial hemangiomas. The 595 nm pulsed dye laser (PDL) has been shown to improve the appearance and involution of superficial hemangiomas [22]. However, its depth of penetration is only 1 mm, and thus it does not affect the deeper components. Some studies have demonstrated the efficacy of adding Nd:YAG laser (wavelength 1064 nm) to PDL therapy, as it can penetrate up to 10 mm and can target the deeper components [23]. PDL can also be used in conjunction with topical or systemic beta blockers, and the combination has been shown to accelerate the involution of hemangiomas [24, 25]. PDL has also been used with topical 5-aminolevulinic acid as a photosensitizer for management of capillary malformations. This combination was shown to be superior to PDL alone in one study [26]. The benefits of laser therapy have to be weighed against their drawbacks, such as risks of anesthesia in an infant, cutaneous scarring, and possible pigmentary changes. For this reason, we do not use laser therapy in the proliferative phase.

Visceral Hemangiomas

Hemangiomas can involve any organ system. Visceral hemangiomas are most commonly located in the liver. Hepatic hemangiomas can be solitary, diffuse, or multifocal. Solitary and diffuse hemangiomas can develop arteriovenous (AV) shunts and cause high output cardiac failure. Pharmacotherapy with oral propranolol or prednisone is initiated. Vincristine is second-line therapy and is used when steroids or beta blockers are ineffective or contraindicated [27]. If there is worsening of heart failure, percutaneous embolization of the AV shunts can be performed [28]. Pharmacotherapy is continued until 1 year of age, when natural involution of the hemangioma starts to occur. Multifocal and diffuse hepatic heman-

giomas can cause severe hypothyroidism due to expression of type 3 deiodinase. Multidisciplinary management is critical for the successful management of this challenging condition.

Involutional and Involuted Phases

During the involutional phase, expectant management is usually undertaken to allow the hemangioma to naturally regress. However, we will frequently perform surgery for an area of significant cosmetic deformity prior to school age, that is, around 4–5 years of age, to normalize appearance and prevent teasing by peers. Redundant and damaged tissue can be surgically excised to improve appearance and contour. The residual superficial capillaries and telangiectasias can be treated with PDL therapy. PDL with a wavelength of 585 nm most closely matches the absorption spectrum of oxyhemoglobin, which is 577 nm.

Newer therapies for hemangioma are being developed. Molecular targets are being investigated in the lab that can be exploited for drug development [29]. Rapamycin (Sirolimus) is an immunosuppressive drug that also has antiangiogenic properties. Rapamycin-loaded polymer-lipid hybrid nanoparticles delivered directly to hemangioma cells as a local controlled release system have been shown to decrease hemangioma volume in vitro and in rat studies [30].

Congenital Hemangiomas

Congenital hemangiomas are fully developed at birth. They appear as raised, red to purple lesions, with superficial telangiectasias and a pale halo around them (Fig. 26.6a, b). They are GLUT-1 negative. There are three types of congenital hemangiomas: (1) rapidly involuting congenital hemangioma (RICH), (2) non-involuting congenital hemangioma (NICH), and (3) partially involuting congenital hemangioma (PICH). RICH undergo rapid involution after birth, which is usually completed by 14 months of age [31]. NICH, on the other hand, do not undergo involution. PICH start as a RICH but fail to completely involute [32]. RICH typically leave behind hypoplastic tissue that can be surgically excised. NICH and PICH can also be treated surgically, once the clinical course and diagnosis are clear.

Lymphatic Malformations

Lymphatic malformations (LMs) are malformed lymphatic structures that get sequestered from the main lymphatic system. LMs are classified as macrocystic, microcystic, or mixed. Cutaneous involvement resulting in small vesicles that can be clear, blue, or purple colored, are known as lymphangioma circumscriptum (Fig. 26.7) [33].

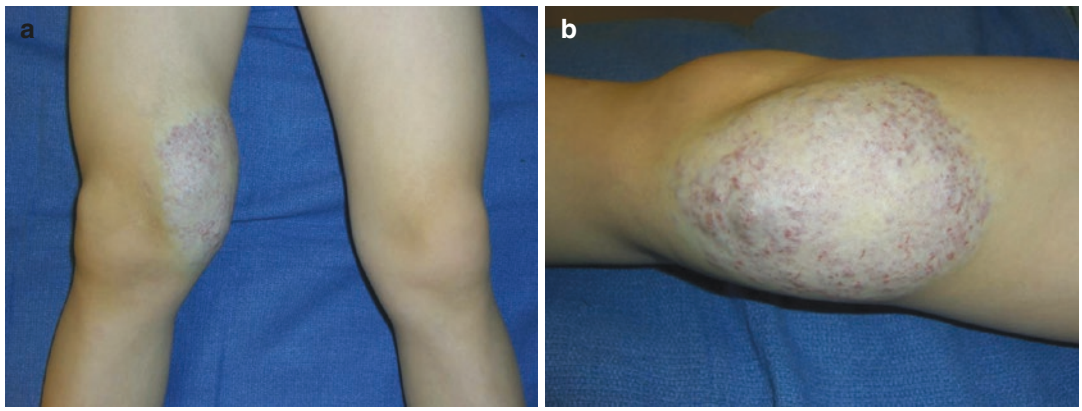

Fig. 26.6 (**a**, **b**) Non-involuting congenital hemangioma (NICH) of the distal right thigh in a 4-year-old boy

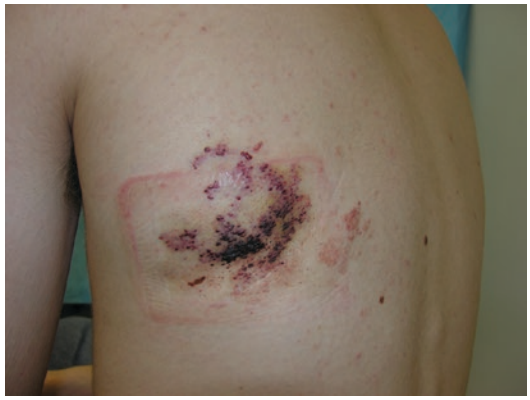

Fig. 26.7 Lymphangioma circumscriptum on the trunk of a 16-year-old boy. (Reprinted with permission from Arneja and Gosain [33])

Macrocystic LMs are those that are amenable to percutaneous sclerotherapy. Lymphatic malformations are noticed in the first 2 years of life and grow very slowly. At times of hormonal change, for example, puberty and pregnancy, they may increase more rapidly in size.

The two main complications of LMs are infection and bleeding, which are characterized by pain and a rapid increase in size. Infections occur in 75% of LMs. The protein-rich fluid in LMs is a good milieu for infectious organisms. Infections are treated with oral and sometimes IV antibiotics. If there have been more than three infections in a year, prophylactic antibiotics are instituted. Intralesional bleeding is managed with rest, analgesics, and antibiotics, as secondary infection may occur.

The most common location for LMs is the head and neck, although they can occur in any part of the body. Cervicofacial LMs can lead to airway embarrassment requiring tracheostomy. Tongue LMs can cause macroglossia. Intraoral LMs result in recurrent infections and poor oral hygiene. Facial LMs may cause overgrowth of the mandible. LMs of the pericardial, pleural, and peritoneal cavities can result in chylous effusions. Visceral involvement can result in protein-losing enteropathy. Gorham Stout disease, also known as vanishing bone disease, is diffuse bony involvement resulting in bone loss and pathologic fractures.

Treatment is performed for large or symptomatic LMs. The following are the main options for treatment.

Sclerotherapy

Sclerotherapy is the first-line treatment. This is typically performed by interventional radiologists under imaging guidance. The macrocysts are accessed percutaneously and the fluid aspirated to collapse the cavity. It is then injected with a sclerosant to cause inflammation to the cyst wall to cause permanent adherence and collapse of the cyst walls. The commonly used sclerosants are doxycycline, sodium tetradecyl sulfate (STS), ethanol, and OK-432. Over time, the cysts can re-expand, and repeat therapy may be needed.

Surgery

Surgery is reserved for mixed LMs after sclerotherapy has treated the macrocysts, for symptomatic microcystic disease. Recurrence is high for incompletely excised LMs and for small localized LMs that can be completely excised. The extent of the malformation can be difficult to gauge on physical exam. We perform an ultrasound of the area on the morning of surgery. The radiologist marks the area of involvement. Thus, the extent of resection can be assessed more accurately and the most suitable access incisions can be planned. During surgery, the border between tissue involved with lymphatic malformation and normal-appearing tissue is identified. If possible, a small rim of normal tissue is excised with the lesion to ensure complete removal. However, if the LM extends to adjacent important structures, complete excision is not attempted, as doing so would result in significant morbidity. A high recurrence rate is accepted, and repeat treatments are performed as indicated by symptoms. Problematic cutaneous vesicles (lymphangioma circumscriptum) can be treated with excision down to fascia, and reconstruction with local flaps or split-thickness skin grafts.

Sirolimus

Sirolimus, also known as Rapamycin, has been shown to result in stabilization or partial remis-

sion of lymphatic malformations [34]. Sirolimus inhibits mammalian target of rapamycin (mTOR), which regulates several functions, including cellular growth and angiogenesis. It is used for the treatment of diffuse or extensive LMs. Blood levels of sirolimus need to be monitored during treatment. The most common adverse effects are neutropenia and dyslipidemia.

Topical sirolimus has also shown efficacy for cutaneous manifestations of LM. Sirolimus 1% ointment has been shown to improve symptoms by decreasing lesion size, infectious episodes, and lymphorhea [35].

Laser

Cutaneous lymphatic vesicles (lymphangioma circumscriptum) can be treated with lasers, which results in symptomatic improvement [36]. Carbon dioxide lasers are most commonly used. Other lasers that have been reported are neodymium: yttrium-aluminum-garnet (Nd: YAG), Alexandrite, and erbium lasers. However, lasers can cause scarring of the treated area. Intraoral vesicles can be treated with radiofrequency ablation.

Capillary Malformations

Capillary malformations (CMs) are dermal vascular anomalies. They present as pink or red cutaneous patches, frequently in a dermatomal distribution. Although they lighten up a little in the first few weeks of life, they gradually darken over time and get thick and nodular. CMs can be associated with hypertrophy of underlying soft tissue and bony skeleton.

Capillary malformations can be a harbinger of an underlying malformation or disorder. A CM in the V1 distribution should raise suspicion for Sturge-Weber syndrome. Features of this syndrome include leptomeningeal vascular malformations, which can result in seizures, strokes, and developmental delay, and ocular abnormalities, which can result in glaucoma and retinal detachment. Lumbosacral CMs can be associated with spinal dysraphism. Capillary malformation-AV malformation (CM-AVM) consists of multiple patches of CM with underlying AV malformations or fistulas.

The following are main treatment options for capillary malformations.

Laser

Laser is the mainstay of treatment for capillary malformations. The pulsed dye laser (PDL) is most commonly used. Treatment results in a favorable response in the majority of patients, although multiple treatments are needed. PDL has a depth of penetration of 1–2 mm and thus only targets superficial vessels. Patients who do not respond well to PDL can be treated with Nd: YAG or Alexandrite laser, as they have a greater depth of penetration. Caution should be excised with these deeper lasers, as they have a greater risk of scarring. Intense pulsed light (IPL) has been used successfully for PDL-resistant capillary malformations, with less risk of local tissue damage [37].

Surgery

Patients with capillary malformations can get significant soft tissue thickening, which can be functionally debilitating and cosmetically unsightly. Surgical excision can be performed to improve contour.

Venous Malformations

Venous malformations (VMs) consist of collections of dilated and thin-walled veins. Cutaneous lesions are most common, although any tissue can be involved. Lesions are bluish in color and increase in size with dependent positioning (Fig. 26.8). Swelling and pain are the most common symptoms. Pain is caused by venous status and formation of phleboliths. Large malformations or those in a visible location can result in a cosmetically unsightly deformity (Fig. 26.9a, b). Extremity VMs can result in limb hypoplasia due to disuse. They can also be part of mixed vascular malformations associated with limb hypertrophy. Approximately 90% of venous malformations are solitary lesions, and 10% are multifocal.

Glomulovenous malformation is an autosomal-dominant condition with multiple small VMs that are painful. Cutaneomucosal venous malformation is an autosomal-dominant condition with multiple small mucocutaneous VMs that are not painful. Blue rubber bleb nevus syndrome consists of multiple small, nodular VMs associated with gastrointestinal malformations. Morbidity is due to gastrointestinal bleeding.

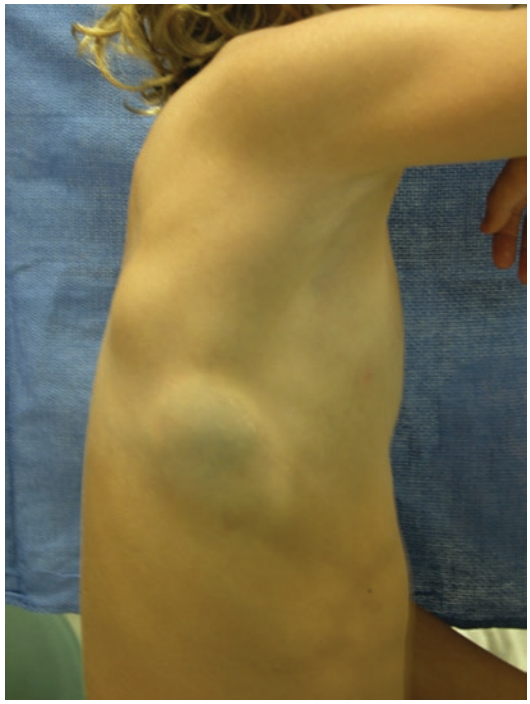

Fig. 26.8 Venous malformation of the trunk in a 4-year-old girl

Treatment of VMs is performed for lesions that are symptomatic or cosmetically unsightly. The following are the main treatment options.

Sclerotherapy

Sclerotherapy is the first-line management. Various sclerosants have been used, for example, STS, absolute ethanol, bleomycin, polidocanol, and ethanolamine oleate. These malformations tend to re-expand after sclerosis, and thus repeat treatments are typically needed. Patients are followed up by the interventional radiologist. Recurrences that are symptomatic are managed with repeat treatment.

Large malformations can cause venous stasis, resulting in localized intravascular coagulation (LIC). Trauma to the malformation, for example, from a surgical procedure or external trauma, can convert this localized consumptive coagulopathy to disseminated intravascular coagulation (DIC). Thus, patients with large malformations should be screened with coagulation studies prior to undergoing an intervention. LIC is manifested by a borderline low platelet count, normal PT and PTT, low fibrinogen and high fibrin degradation products (FDPs), and D-dimer. These patients are given enoxaparin 2 weeks before and after any planned procedure for prophylaxis.

Surgery

Surgery is performed for residual excess tissue after sclerotherapy treatments have been completed. Surgical excision can also be performed for small, localized lesions. Frequently the goal

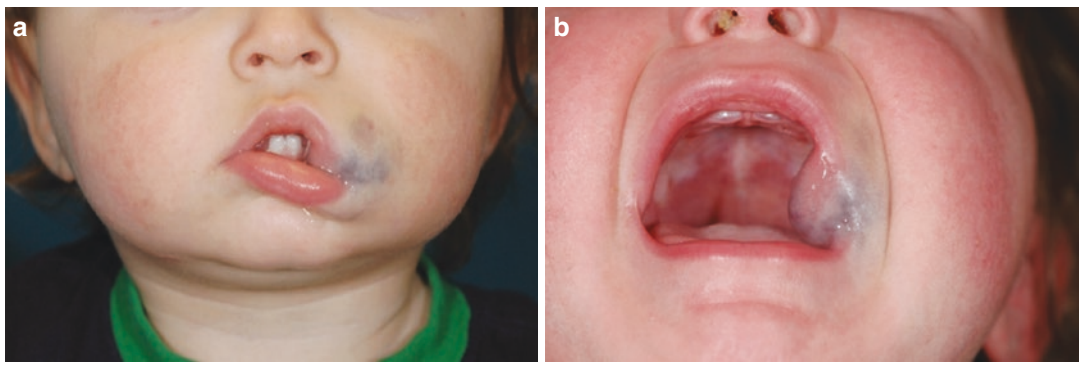

Fig. 26.9 (**a**, **b**) Venous malformation of the oral commissure in a 3-year-old boy

of surgery is to debulk lesions rather than complete excision. Excision of venous malformations can be extremely difficult, as the veins collapse when the vessel wall integrity is violated, resulting in a bleeding cluster of veins with indistinct borders. We have found that preoperative glue embolization greatly facilitates excision (Fig. 26.10a–c). Patients undergo a venogram the morning of or a few days before surgical excision. The venous malformation is injected with n-butylcyanoacrylate (n-BCA). The glue forms a hard mass. Surgical excision is then straightforward, as the solid mass is simply shelled out (Fig. 26.11).

Compression

Compression is a mainstay of management of venous malformations. Compression garments prevent pooling of blood, preventing chronic LIC, venous phleboliths, and pain. Compression can also prevent progressive expansion of lesions. Compression garments must be evaluated twice yearly, or at least annually, as adjustments are needed due to growth of the child. Compression is also provided after sclerotherapy or surgery with a compression wrap, which is then transitioned to a compression garment.

Arteriovenous Malformations (AVMs)

These are fast-flow lesions that consist of abnormal connection between an artery and a vein. If the communication between the artery and vein is direct, it is called an AV fistula, and if they are connected by dysplastic vessels it is called an AV malformation. The epicenter of an AVM is called the nidus. AVMs are by far more common in the central nervous system. Extracranial AVMs are most common in the head and neck region. AVMs slowly expand over time. Trauma, ischemia, and hormonal changes during puberty are stimuli for more rapid expansion. AVMs are classified by the Schobinger staging system, which describes their progressive phases. Stage 1 consists of red-blue areas of skin discoloration that are often mistaken for hemangiomas or capillary malformations (Fig. 26.12). The lesions expand by recruitment of surrounding tissue, aneurysm formation, and thickening of vessels and venous ectasia. The diagnosis becomes clearer during stage 2 when they become warm and have a palpable pulse, bruit, or thrill (Fig. 26.13). Continued expansion and progression leads to Stage 3, which is manifested by pain, ulceration, bleeding, and local tissue destruction. Stage 4 is the decompensated state where high arteriovenous flow leads to congestive heart failure.

The treatment of AVMs is extremely challenging. Embolization and surgery are the main treatment options. Treatment depends on the size of the malformation, its anatomic location, and the Schobinger stage.

Embolization

Embolization is performed as a stand-alone procedure or prior to surgical excision. A number of solid (coils, polyvinyl alcohol particles, gelfoam powder) and liquid (ethanol, Onyx, n-BCA) embolic agents are available. The goal of treatment is to occlude the nidus and the draining veins. Embolization of the feeding artery alone should not be performed, as this renders the malformation inaccessible to future embolization therapy from the same proximal vessel. Large lesions require multiple staged treatments. Embolization alone is performed for lesions not amenable to surgery and for Stage 3 and Stage 4 AVMs for control and palliation. It should be kept in mind that embolization can lead to recruitment of surrounding tissue and enlargement of the malformation. The most common complications of embolization are ulceration, damage to surrounding structures, and edema.

Surgery

Localized Stage 1 and Stage 2 malformations may be excised if it is thought that a complete excision can be performed without causing unacceptable deformity. Since the natural history of AVMs is to enlarge over time, early excision should be considered if possible. Debulking or limited excision of symptomatic lesions may be considered on a case-by-case basis. It must be

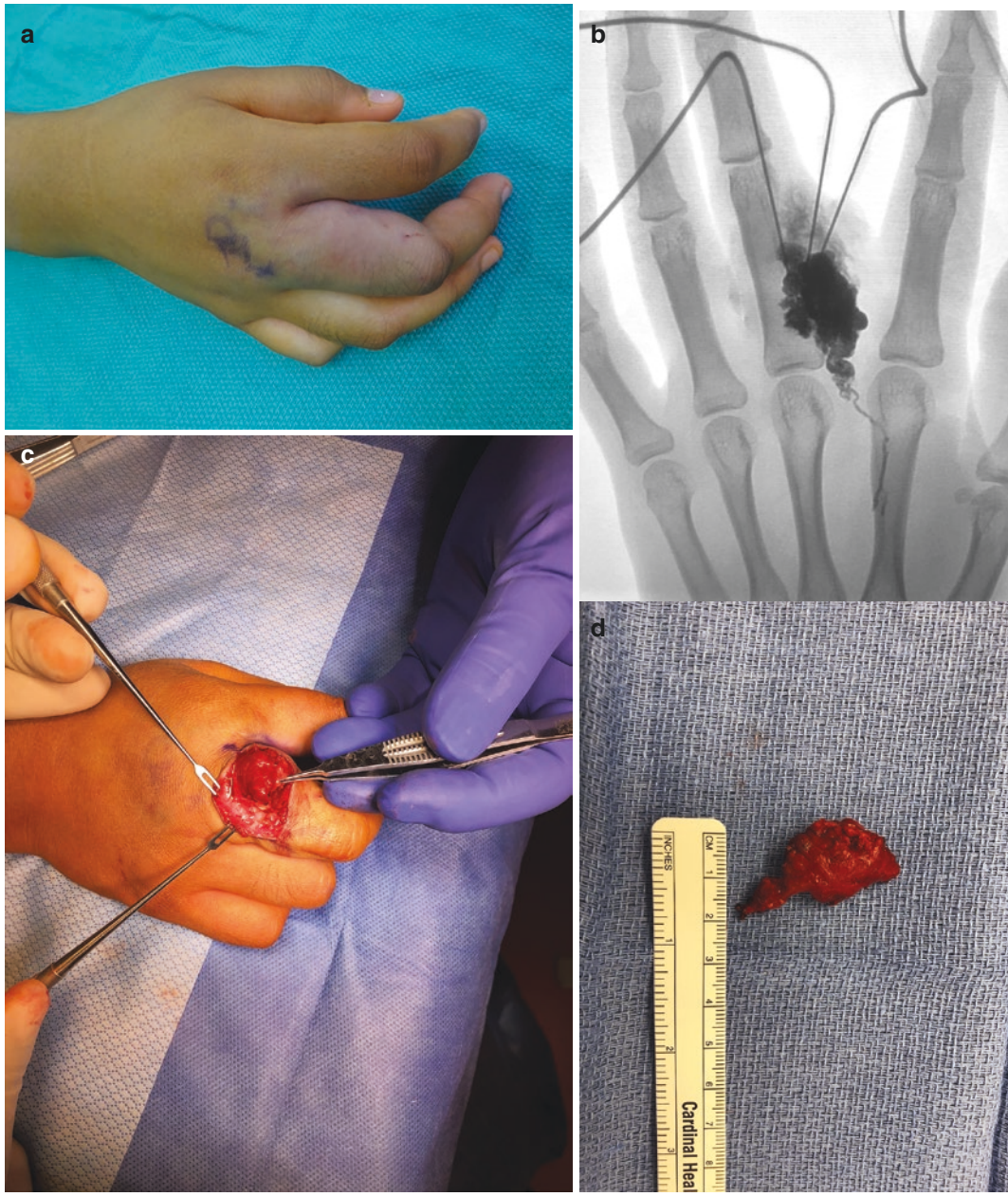

Fig. 26.10 (**a**) Venous malformation involving the proximal phalanx of the right long finger in a young child. (**b**) Venogram demonstrating the venous malformation. The malformation was injected with n-BCA glue. (**c**) Venous malformation exposed via a dorsal approach. The lesion was easily circumscribed and shelled out. (**d**) The specimen after excision

understood, however, that that recurrence and reactive expansion are likely after incomplete excisions. Surgery is very challenging, as the boundaries of the AVM are not clear, and bleeding may be significant. A few strategies have helped us optimize surgical management:

1. Embolization of the nidus is performed 24–72 hours preoperatively to decrease the amount of bleeding.
2. Extremity AVMs are resected under tourniquet control.
3. Blood is made available in case it is needed.

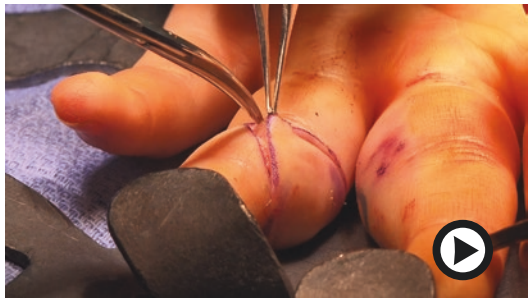

Fig. 26.11 Video demonstrating surgical excision of venous malformation injected with n-BCA glue (▶ https://doi.org/10.1007/000-3v3)

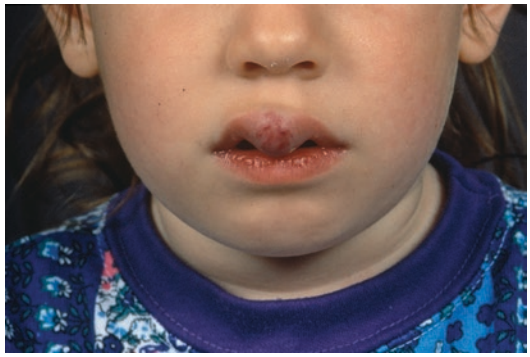

Fig. 26.12 Schobinger Stage 1 AVM of the upper lip in a 3-year-old girl. (Reprinted with permission from Arneja and Gosain [33])

4. Hemostasis is maintained throughout the case. A clean operative field facilitates dissection and alleviates surgeon anxiety. A bipolar electrocautery is key for targeted hemostasis while avoiding inadvertent damage to surrounding structures.
5. Hemostatic agents are frequently needed. We commonly use epinephrine-soaked gauze, Surgical®, fibrin glue, and gelfoam.
6. Resections can be large, requiring reconstruction. The reconstructive decision must factor in the need for future monitoring, as recurrences are frequent. Most recurrences occur within the first few years. Therefore, a simple reconstructive option like a skin graft or prosthesis may allow closer monitoring for recurrence while preserving the best reconstructive choice for a later time, when optimal control of the AVM has been assured.

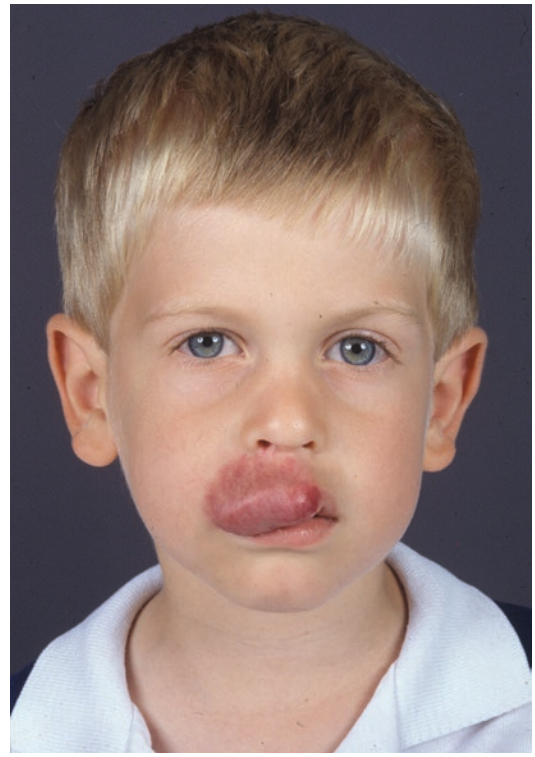

Fig. 26.13 Schobinger Stage 2 AVM of the upper lip in a 4-year-old boy. (Reprinted with permission from Arneja and Gosain [33])

Conclusion

The first step in management of congenital vascular anomalies is accurate diagnosis. Treatment options consist of expectant management, compression, pharmacotherapy, lasers, percutaneous intervention, and surgery. Multidisciplinary vascular anomalies teams pool the expertise of many specialties to optimize patient care.

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Cleft Lip and Palate

27

Lee W. T. Alkureishi and Mimis N. Cohen

Introduction

Clefts of the lip, palate, or a combination of these, represent the second most common birth defect, with an estimated incidence of 1 in 700 live births. The incidence shows a race predilection, with higher rates in Asian and Native American populations (1 in 500), and lower rates in African-derived populations (1 in 2500). In addition, clefts involving the lip show a 2:1 male to female ratio, while clefts of the palate alone show the reverse. For unilateral cleft lip, left side involvement is twice as frequent [1]. Cleft palate alone is less common, with an estimated incidence of 1:2000, which does not differ in incidence across racial groups [2].

Clefts may be categorized as nonsyndromic or syndromic, based on the presence or absence of associated anomalies. Cleft palate alone is more often seen in the context of a syndrome (50%) compared with cleft lip and palate (10%) [3]. Common syndromes associated with cleft lip and/or palate include, among others, Van der Woude syndrome, velocardiofacial syndrome, Stickler syndrome, craniofacial microsomia, Treacher Collins syndrome, Down syndrome and other trisomies, and orofacialdigital syndrome. In addition, clefting can be associated with other patterns of birth malformation such as the Pierre-Robin sequence (PRS) or fetal alcohol syndrome (FAS) [4].

The etiology of nonsyndromic clefting is multifactorial, with environmental factors playing a role. In contrast to many of the well-defined genetic syndromes associated with cleft lip and palate, the genetic basis for nonsyndromic clefts is less clear-cut, and remains the focus of intense study. The use of modern molecular genetic techniques has recently shown great promise in identifying candidate genes such as interferon regulatory factor 6 (IRF6), MAFB, ARHGAP29, 8q24, ventral anterior homeobox 1 (VAX1), and paired box protein 7 (PAX7), and work is underway to further delineate the importance of these genes [5]. In the meantime, however, it is clear there is a significant familial contribution in nonsyndromic cleft lip and palate, with an increased risk of clefting with future pregnancies in affected families. Exposure to certain environmental factors can also increase risks of clefting, as demonstrated by markedly increased incidence of cleft lip following maternal exposure to the anticonvulsant phenytoin (10x) or tobacco (2x) [6].

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Embryology

The embryonic face forms during the fourth to eighth weeks of intrauterine life from fusion of first branchial arch processes around the stomodeum, or primitive oral cavity. The upper lip, alveolus, and primary palate are formed through fusion of the frontonasal process and lateral nasal processes on each side, while the secondary palate posterior to the incisive foramen is formed by the bilateral palatal shelves which arise from the maxillary processes. The fusion of the primary palate is generally complete by week 6 or 7, while secondary palate fusion occurs in week 8. Mesodermal penetration is an important process at the lines of fusion, as failure of this reinforcement is thought to lead to epithelial breakdown and clefting [7].

Classification of Cleft Lip and Palate

Clefts may involve the lip, alveolus, hard palate, soft palate, or a combination of these structures. Clefts may also be unilateral or bilateral, complete or incomplete. Within each type of cleft, there exists a broad spectrum of severity in terms of width and distortion of the anatomy.

Several classification systems have been described in order to better categorize and describe the spectrum of clefting. Perhaps the most useful is Kernahan's "Striped-Y" classification [8], which provides an at-a-glance visual representation of the involved segments of lip, alveolus, and primary and/or secondary palate.

Pearl
We find the Kernahan classification system, and its subsequent modification by Millard [9], to provide the best balance of comprehensive description while maintaining simplicity and ease of use.

Diagnosis of Cleft Lip and Palate

With currently available imaging techniques, clefts of the lip may be diagnosed as early as 11 weeks gestation for transvaginal ultrasound, or 16 weeks gestation for transabdominal ultrasound (Fig. 27.1). The sensitivity of the technique is high, approximately 88%, but can be dependent on the skill of the operator, gestational age, fetal position, amniotic volume, maternal body habitus, and extent of the cleft. Isolated palatal clefts are rarely able to be visualized on ultrasound [10]. The ability to diagnose clefts during pregnancy has important implications in terms of early parental counseling and preparation, as well as potentially guiding further investigation in order to rule out associated anomalies [11]. At our craniofacial center, we have developed a consultation service to meet with prospective families shortly after sonographic diagnosis, to give an overall outline of cleft management, and to introduce families to a support group of families, former patients, and staff.

Pearl
Counseling the family of a child with a cleft ideally begins in the prenatal period, providing invaluable guidance and reassurance to prospective parents, and introducing them to the cleft team.

The Multidisciplinary Cleft Team

The diagnosis of a cleft has important ramifications for the care of the patient, beginning in the immediate neonatal period and continuing throughout childhood into young adulthood. The cleft patient invariably requires frequent evaluation from multiple specialist providers according to each team's protocol, and the ideal model of comprehensive cleft care involves coordination of these multiple consultations into a single multidisciplinary team visit. The Lancaster Cleft Palate Clinic was a pioneer in the development of the

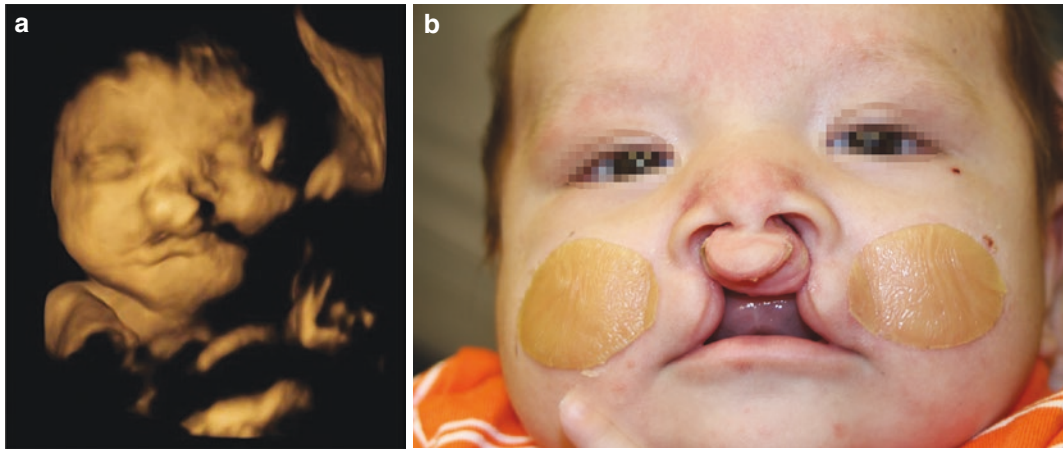

Fig. 27.1 (**a**) Prenatal ultrasound showing bilateral cleft lip; (**b**) clinical photograph of the same patient

multidisciplinary team [12], and subsequently adopted by the Cleft Palate Training Program (now Craniofacial Center) at the University of Illinois [13]. It affords many benefits including minimizing the number of required clinic visits, time off school or work, improving provider communication, optimization of treatment planning, and minimizing the number of interventions. The core members of the cleft team include the craniomaxillofacial surgeon, orthodontist, speech and language pathologist, psychologist, and audiologist. Additional regular team members may include otolaryngologist, pediatrician, geneticist, pediatric dentist, prosthodontist, nurse, nurse practitioner, and social worker. However, patients with clefts can benefit from the skills of a much wider variety of specialist providers, and we count ourselves fortunate at our Craniofacial Center to have access to such a comprehensive team, outlined in Table 27.1, able to provide both evaluation and care in each of the various specialty areas. One of the cornerstones of the multidisciplinary team is the team conference, where recommendations from each of the specialists are discussed in turn, and the optimal treatment plan formulated. Dr Sam Pruzansky, founder of the Craniofacial Center at the University of Illinois, stressed the importance of good communication as a foundation for the delivery of effective team care in his historical review of the development of the cleft team in 1960 [14, 15].

Table 27.1 The craniofacial team providers at the University of Illinois, Chicago

Anaplastologists	Orthodontists
Audiologist	Otolaryngologist
Computer Specialist/Data Analyst	Pediatrician
Craniofacial Basic Researchers	Pediatric Dentist
Geneticist	**Plastic / Craniofacial Surgeons**
Medical Artists	Prosthodontist
Nurse Coordinators	**Psychologist**
Neurosurgeon	Social Worker
Ocularist	**Speech and Language Specialist**

Core team members are in bold

Timing of Interventions

Patients with cleft lip and palate will invariably require several operative interventions in the first two decades of life and beyond. In the case of a patient with a complete cleft, the "known" surgeries include lip repair, palate repair, closure of residual oronasal/nasolabial fistula, and alveolar bone graft surgery. In addition, there are several additional interventions that may become necessary at various points in the child's development. These can include tympanostomy (pressure equalizing) tube placement, surgery for velopharyngeal insufficiency, functional and aesthetic correction of cleft nasal deformity, orthognathic surgery, den-

tal implant placement, and revisional surgeries. In view of this, it is important to plan the sequence of interventions as far as feasible, in order to minimize time in the hospital and time away from *being a child.* Our philosophy is to bundle as many procedures as possible, thus providing service in a timely fashion, minimizing psychological harm to the child from multiple interventions/hospitalizations, reducing expense and time away from school/work. We base our management on well-established and tested protocols of care, and periodically adjust them as needed. An outline of the intervention timeline protocol used in our institution is presented in Table 27.2.

Pearl
Where possible, surgical interventions can be combined in order to minimize anesthesia exposure, recovery time, and time away from school.

Ideally, as long as the infant is otherwise healthy, and has undergone complete pediatric evaluation and necessary vaccinations, we typically proceed with cleft lip repair around 10–12 weeks of age. However, lip repair may reasonably be delayed for a short period while any required PSIO is completed. While earlier lip repairs have been described as early as the first few days of life [16], a lack of convincing data showing the benefits of this approach means that the majority of surgeons continue to wait until the patient is 3–4 months of age. Typically, ear examination and tympanostomy tube placement can be undertaken concurrently as needed. For bilateral lip clefts, it is generally preferable to perform bilateral repairs simultaneously, as this gives the best opportunity to achieve symmetry and establish continuity of the orbicularis oris muscle.

Pearl
Bilateral cleft lip should be repaired simultaneously in order to establish continuity of the orbicularis oris muscle. Failure to do this can result in deformities with mouth animation.

The timing of palate repair is also a controversial topic, albeit for different reasons. Advocates of early palate repair feel that accomplishing this prior to the development of speech gives the best possibility of normal or near-normal articulation [17]. However, this is balanced by the view that earlier palate surgery—particularly those techniques involving denudation of the hard palate and secondary intention healing of large bony areas—can have a detrimental effect on maxillary growth and the ultimate need for orthognathic surgery in the teenage years [18]. In practice, it is our preference to undertake palate repair around 9–10 months of age as a means of balancing these concerns. An exception is for patients with mandibular hypoplasia, for example, Pierre-Robin sequence, in which case it may be beneficial to defer palate repair at least beyond the first birthday to allow further growth. Mandibular

Table 27.2 Timing of surgical interventions for patients with cleft lip and palate

Age range	Scheduled surgical interventions	"As needed" surgical interventions
3–6 Months	Repair of cleft lip	–
9–12 Months	Repair of cleft palate	–
2–5 Years		Speech surgery Intermediate cleft nasal reconstruction
Mixed dentition 7–11 years	Phase I orthodontia Maxillary/alveolar bone graft	–
14–18 Years	–	Functional / aesthetic cleft nasal reconstruction Orthognathic surgery
Any time	–	Maxillary/mandibular distraction
Any time	–	Tympanostomy tube placement

distraction may also be considered, opening the airway prior to palate repair.

Pearl
Repair of cleft palate should be undertaken before the development of compensatory speech articulation patterns, providing the best opportunity for normal speech development.

Cleft Lip

Cleft lip may be unilateral or bilateral, and complete or incomplete. Complete lip clefts extend through the height of the lip into the nostril on the affected side, and as far back as the incisive foramen, while incomplete clefts can range from the *microform* or *forme fruste* lip with notching of the vermilion-cutaneous junction, to near-complete clefts with only a skin bridge at the nasal sill known as a *Simonart's band.* In bilateral cleft lip, the left and right sides are not always involved symmetrically. Incomplete clefts are typically narrower compared with complete clefts, and may not display all aspects of the deformity more typical of complete clefts.

Complete clefts of the lip typically result in predictable anatomical changes, though each of these can be present to varying degrees, dependent on the severity or width of the cleft.

Anatomy of the Unilateral Cleft Lip

The unilateral complete cleft lip is a disruption of the entire height of the lip, nasal sill, and alveolus. The orbicularis oris muscle is unable to cross the cleft, and therefore inserts aberrantly into the base of the nose on either side of the cleft. The width of the cleft is variable, as is the position of the lesser alveolar segment which can be collapsed palatally. The columellar height and philtral column are shortened on the cleft side, and the cupids bow peak is rotated superiorly toward the nose. The nasal tip is flattened. The septum bows into the cleft side, while the caudal extent of the septum and nasal tip deviate to the non-cleft side. The lateral crus of the lower lateral cartilage is flattened and displaced laterally, inferiorly, and posteriorly [19] (Fig. 27.2).

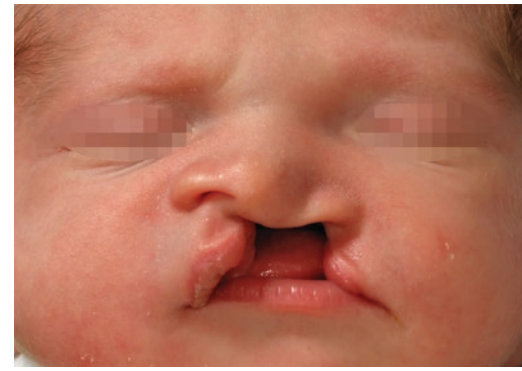

Fig. 27.2 Unilateral cleft lip

Anatomy of the Bilateral Cleft Lip

The bilateral cleft lip deformity presents some additional challenges in comparison with the unilateral cleft lip. In its complete form, the lack of constraint from either lateral maxillary segment or the orbicularis muscle allows the premaxilla to protrude, and may also be displaced and angulated superiorly. The central prolabium contains no muscle fibers, with the orbicularis terminating at the alar base on either side. As a result, there is complete absence of bilateral philtral columns and the cupids bow, with a blunted white roll, all of which require reconstruction at the time of lip repair. The columella is significantly shortened, with a flattened nasal tip, and the alar cartilages are flattened and stretched across the clefts. The alar bases may be quite wide, producing a horizontally oriented nostril, and there is a lack of bony support at the pyriform aperture (Fig. 27.3).

Presurgical Infant Orthopedics

The role of presurgical infant orthopedics (PSIO) remains somewhat controversial and is broadly split into two categories: active and passive. The

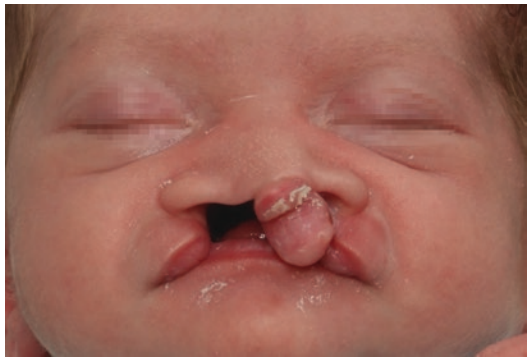

Fig. 27.3 Patient with bilateral cleft lip. Note the ectopic positioning of the premaxilla, which is often asymmetric

Latham appliance is an active device, comprising a screw-based orthodontic appliance attached to the maxillary segments by pins, typically around 2 months of age, and activated daily to maneuver the alveolar segments into position [20]. However, the long-term benefits of the device have not yet been proven, and in our opinion, the invasive nature of the procedure is not merited [21, 22]. Passive orthodontic appliances can also be used, and the technique known as presurgical nasoalveolar molding (PNAM) utilizes a removable acrylic appliance which is molded to the infant's palatal anatomy (Fig. 27.4a, b). The device is adjusted weekly or biweekly, shaving or adding to the acrylic in order to guide the growth and alignment of the palatal segments [23]. Extraoral tape traction is applied to the upper lip and cheeks, to effect narrowing of the alveolus and lip cleft. A nasal outrigger can be used, consisting of an acrylic bead which pushes anteriorly on the cleft side alar dome to improve the nostril form prior to surgical repair. Alternately, in patients for whom frequent visits to the orthodontist office are not feasible, external lip taping can be used without an intraoral device. This can effectively narrow the lip and alveolar clefts, facilitating surgical repair and optimizing the ability to achieve symmetry; no control over the position of the palatal segments is possible, and the device may not be appropriate for patients with lateral segment maxillary collapse [24]. An important consideration is the effect of PSIO on maxillary growth; the Latham device has been reported to adversely impact maxillary growth and potentially lead to poorer occlusal outcomes, particularly when combined with gingivoperiosteoplasty [21, 25]. The effects of passive orthopedic techniques on maxillary growth appear to be less unfavorable, though this continues to be debated and further study is required [26]. In our opinion, the benefits of PNAM are primarily in easing the primary nasal reconstruction; however, our experience is that many patients will still benefit from later revision despite PNAM. These findings were recently echoed in a report from Chang Gung hospital in Taiwan [27]. The argument for presurgical infant orthopedics is strongest for the bilateral cleft lip patient, where the foreshortened columella and displaced premaxilla can potentially derive the most benefit from presurgical correction [28]. In severe cases of premaxillary protrusion, a premaxillary setback can be achieved by osteotomizing the vomer at the time of surgery; however, this should be considered a last resort, as it has been shown to negatively impact maxillary growth [29]. Our preference is for passive presurgical orthopedics/nasoalveolar molding, avoiding the use of more invasive or aggressive modalities.

A simple and effective method of repositioning the protrusive premaxilla in bilateral cleft lip and palate patients was presented by our group in 1988, and further refined in 1996 [30, 31]. In this technique, a tissue-borne acrylic palatal plate is used, with an adjustable elastomeric orthodontic chain which encircles the premaxilla. As the premaxilla moves posteriorly, the elastomeric chain can be retightened to the palatal plate, maintaining constant force to effect repositioning. We have found the appliance to be noninvasive, easily adjustable, economic, and well tolerated (Fig. 27.4c).

Pearl

For unilateral cleft lip, our preference is to use PNAM in order to align the maxillary segments and improve nasal form, easing the primary nasal reconstruction. For bilateral cleft lip, our preference is to use a premaxillary repositioning appliance to bring the premaxilla into a more favorable position between the two lateral segments.

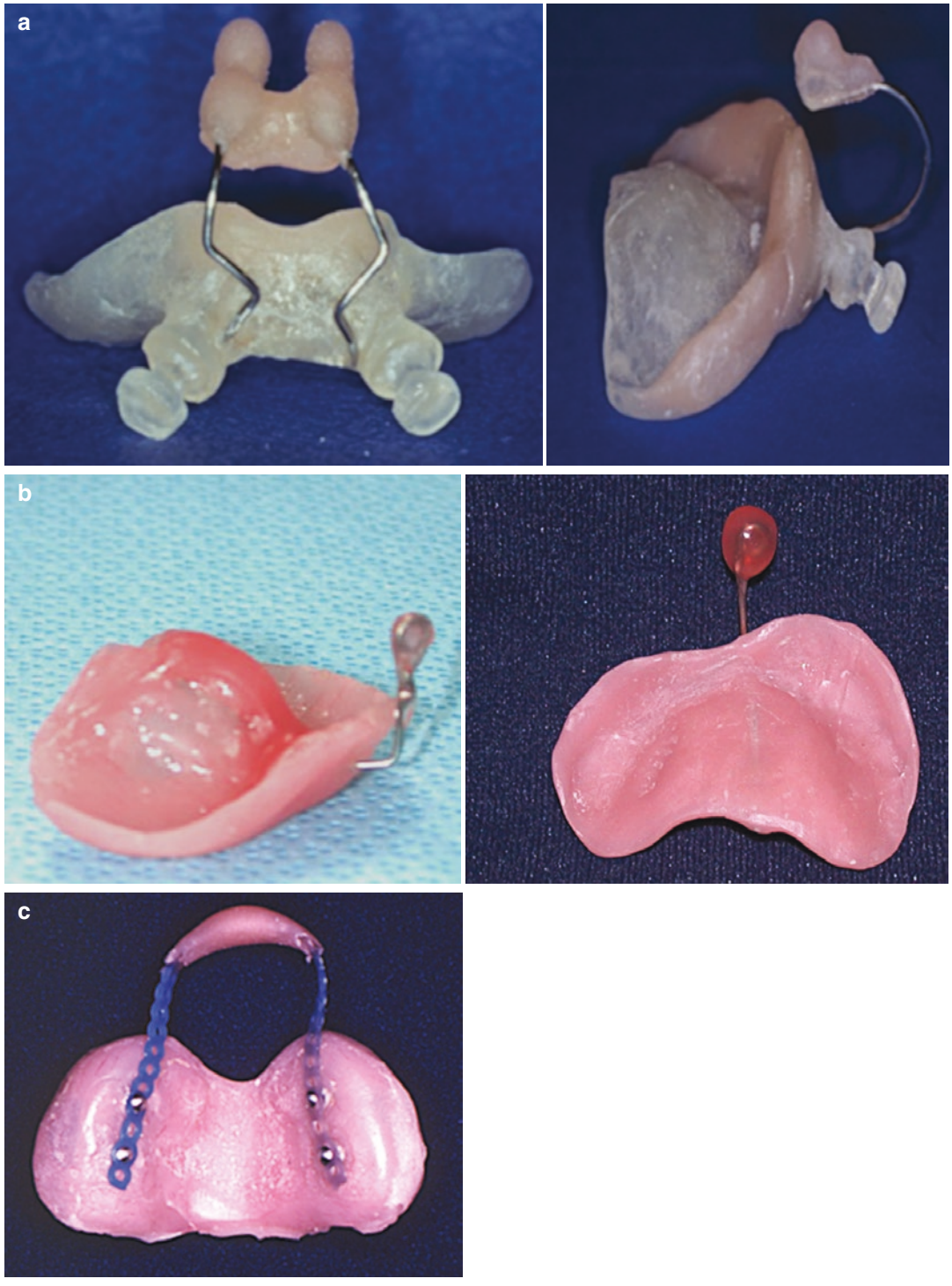

Fig. 27.4 Presurgical infant orthopedics. (**a**) Presurgical nasoalveolar molding. Photo courtesy of Dr. Lawrence Brecht. (**b**) University of Illinois, Chicago modified nasal molding appliance. The use of an orthodontic wire from the palatal prosthesis to the nasal outrigger allows easier adjustment of the position of the bulb during treatment. (Da Silveira et al. [73]). (**c**) Premaxillary repositioning device. A tissue-borne acrylic palatal plate is used with an adjustable elastomeric orthodontic chain which encircles the premaxilla. (Photos courtesy of Dr. David Reisberg)

Unilateral Cleft Lip Repair

- Several techniques for unilateral cleft lip repair have been described, but all are designed to achieve the same goals:
- Repair of the lip cleft, restoring lip competence
- Repair all layers, including the orbicularis muscle
- Restoration of a symmetrical cupids bow and philtrum
- Preservation of lip fullness and contour
- Repositioning of the displaced lower lateral cartilage
- Repair of nostril floor
- Establishment of a symmetric nostril sill
- Minimization of scar, as close as possible to the appearance of a normal philtral column

Pearl
Regardless of the technique chosen, meticulous tissue handling is essential to avoid unnecessary trauma to the tissues. Skin hooks often provide adequate manipulation without the potential for crushing the tissue with forceps, and where possible the muscle should be grasped rather than skin.

In order to achieve the abovementioned goals, it is necessary to borrow tissue from the lateral lip element to augment the height of the cleft-side philtral column and equalize the lip heights. The various techniques achieve this in different ways. Variations of the rotation-advancement repair described by Millard remain the most common technique in use today [32]. In this technique, the medial lip element is rotated downward to level the cupids bow. A backcut is employed in order to lengthen the cleft side philtrum, and the lateral lip skin is advanced into the resultant defect (Fig. 27.5a). This places the resultant suture line mostly along the new philtrum column, and the incision affords good access to the nasal tip if primary cleft rhinoplasty is planned. The nasal floor and lip vestibule are lined with mucosal flaps. This versatile operation allows the surgeon to vary the length of the lateral advancement flap as needed to account for the degree of required downward rotation of the medial lip element. This can be considered both a primary benefit of the technique as well as a disadvantage, as it requires experience and surgical judgment in order to obtain good results. The Tennison-Randall triangular flap repair, on the other hand, is more easily taught and relies on exact measurements prior to making incision, with a triangular flap from the lateral lip element inset into a backcut made lower on the medial lip element to obtain the necessary increase in medial lip height (Fig. 27.5b) [33]. Several other techniques incorporate the use of a smaller triangular flap from the lateral lip element in order to obtain medial lip height and improve symmetry of cupids bow, including Noordhoff's modification of the rotation-advancement technique, and Fisher's anatomical subunit repair (Fig. 27.5c) [34, 35].

Pearl
Regardless of the technique chosen for skin repair, the importance of repositioning and accurately repairing the orbicularis oris muscle cannot be overstated.

As described in the Functional lip repair [36], the abnormal insertions of the orbicularis at the base of the nose must be freed, and the muscle reoriented across the cleft in order to avoid abnormal contour, particularly with animation.

Primary Correction of Cleft Nasal Deformity at the Time of Lip Repair

Despite early concerns regarding the potential for growth disturbance following nasal dissection at the time of cleft lip repair, primary cleft lip nasal correction has gained increasing acceptance among cleft surgeons, with the majority now performing at least some nasal dissection, and there is increasing evidence that this can be safely performed without adversely impacting growth [37]. It has increasingly become accepted as an integral part of the primary cleft lip operation.

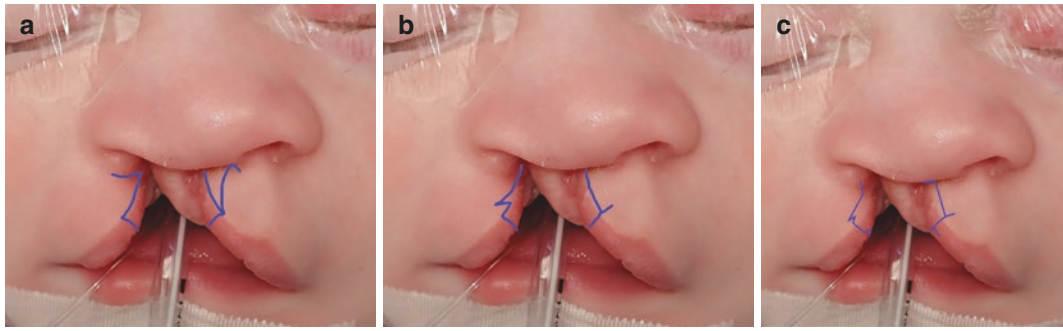

Fig. 27.5 Techniques of unilateral cleft lip repair. (**a**) Millard rotation-advancement; (**b**) Tennison-Randall triangular flap repair; (**c**) Fisher anatomical subunit repair

A variety of closed and open techniques have been described, but all involve undermining and separation of the nasal tip skin from the underlying malpositioned lower lateral cartilage, allowing it to redrape. Various external or internal suture techniques can then be used to resuspend the cartilages in a more appropriate position. Perhaps equally important is the management of the anterocaudal septum, which can be disinserted from the maxilla and repositioned in the midline at the time of cleft lip repair. This approach has been shown to have beneficial effects in terms of severity of septal deviation and inferior turbinate hypertrophy in adolescence, and effectively sets the foundation for later definitive correction [38].

Pearl
Disinsertion and repositioning of the malpositioned caudal septum can be performed at the time of primary lip repair, and potentially limits the extent of septal deviation with further growth.

Figure 27.6 demonstrates the operative sequence for repair of a complete unilateral cleft lip. Particular note should also be made of the incomplete unilateral cleft lip, as the technique for repair may differ depending on the extent of the cleft. For near-complete clefts, in which only a Simonart's band is present, the technique is similar to that used for a complete cleft. Similarly, for lesser clefts involving a large portion of the lip height, the best approach is often a complete repair since the underlying muscle is not intact despite the presence of a skin bridge. Nasal sill or tip asymmetry is often present, and necessitate the same care in treatment planning as for a complete cleft. For microform or *forme fruste* cleft lips, however, it may be feasible to achieve an aesthetic and functional repair with less extensive techniques [39].

Pearl
In patients with an incomplete cleft lip, the surgical plan must take into account the extent of abnormality of the orbicularis muscle, which is often more extensive than the skin cleft and necessitates a more extensive dissection and repair as for the complete cleft.

Bilateral Cleft Lip Repair

The goals of bilateral cleft lip repair are as follows:

- *Symmetry*. The achievement of symmetry is potentially easier in the case of a symmetrical bilateral cleft lip when compared with a unilateral cleft lip. However, an exception to this lies in the asymmetric bilateral cleft patient, where extreme care and skill are required to achieve a symmetric result

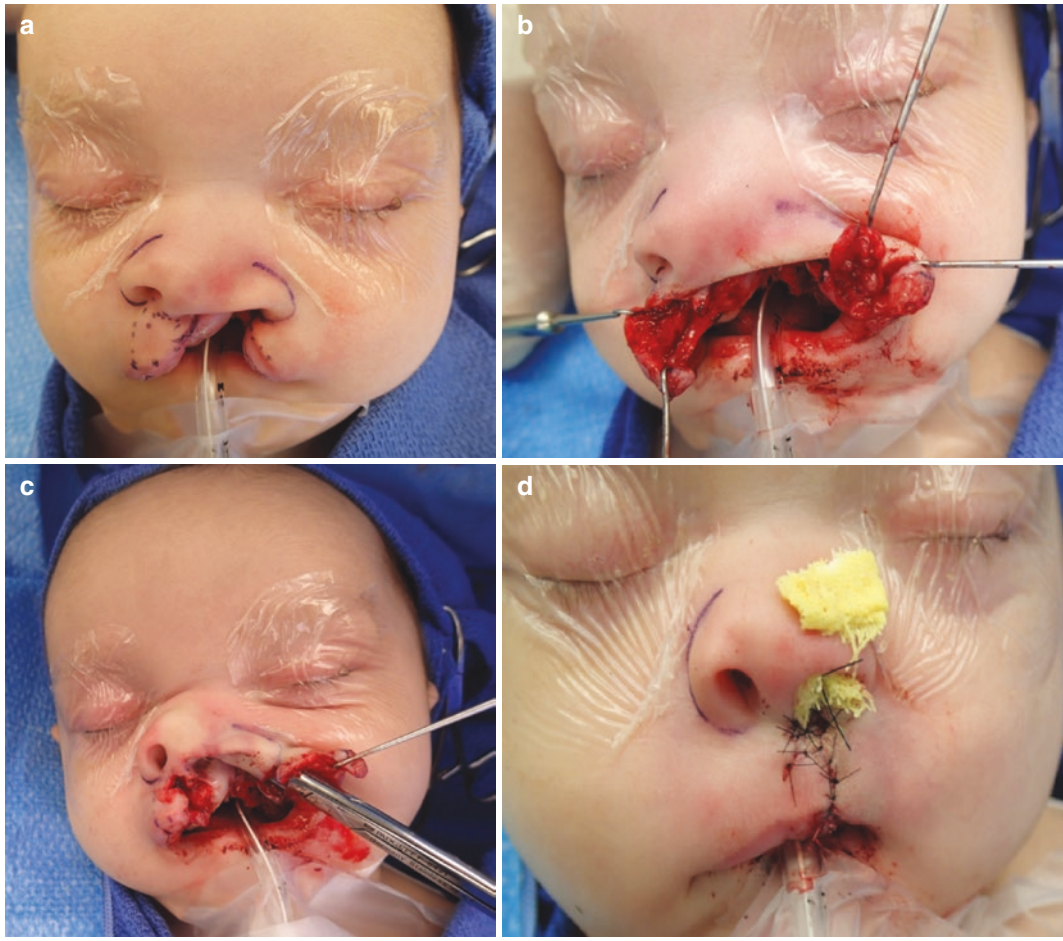

Fig. 27.6 Unilateral cleft lip repair using the rotation-advancement technique. (**a**) Operative markings. (**b**) Lip dissection complete. Note the orbicularis muscle has been freed from the skin, mucosa, and its abnormal attachments to the nose. (**c**) Scissor dissection onto the nasal tip. (**d**) Completion of the procedure, with bolster sutures placed

- *Muscle continuity*. It is of critical importance to establish continuity of the orbicularis across the clefts, as this establishes forces which act to further improve the position of the displaced premaxilla and alveolar segments [40].
- *Appropriate size and shape of the philtrum*. It is well accepted that the prolabium, and therefore the constructed philtrum, tend to be faster growing compared with the surrounding tissues, and are therefore designed smaller with this future growth in mind. The cupid's bow peaks should be 4–6 mm in width, and the columellar base should be 2–3 mm in width [41].
- *Construction of a median tubercle*. The construction of the median tubercle should be performed using the lateral lip elements, as techniques which retain central red lip elements from the prolabium tend to result in a conspicuous deficiency of the central red lip known as the whistle deformity.
- *Repositioning* of the displaced lower lateral cartilages [42].

While there is no universally accepted technique for bilateral repair of the cleft lip, the majority of techniques in use today follow these principles as outlined by Millard, and expanded upon by Noordhoff [43], Mulliken [41], and oth-

ers. The incisions on the prolabium are designed to simulate the philtral columns, while the prolabial vermilion is used to line the upper lip vestibule. The intervening tissue is discarded. After skin incisions are made, the muscle is dissected free of its abnormal attachments at the alar base bilaterally and advanced to meet in the midline. The cupids bow, central red lip, and tubercle are reconstructed using lateral lip elements to provide the necessary fullness, color, and contour. Stepped incisions are used on the lateral lip elements to facilitate this. Mucosal flaps are used to line the nasal floor (Fig. 27.7). The extent of nasal dissection is highly variable between surgeons. Figure 27.8 demonstrates the authors' operative sequence for repair of a complete bilateral cleft lip.

Pearl
As with the unilateral cleft lip, adequate release and repair of the orbicularis is critical to the outcome of bilateral cleft lip repair. Establishing orbicularis continuity in the midline minimizes the risk for animation deformity.

The management of the short columella remains a controversial topic. In Millard's original technique descriptions, bilateral "forked" flaps are recruited from the prolabial segment, either side of the designed philtrum, and banked at the nasal sill for later recruitment into the nose to lengthen the columella [44]. More recently, there has been a push to "keep nasal tissue within the nose" and recruit the additional length through incisions at the nasal tip or alar rim, with correction of the splayed and separated lower lateral cartilages [41, 45]. The use of presurgical orthopedics in this patient population does not negate the need for nasal tip correction at the time of cleft lip repair, since the achieved correction will quickly revert to the pre-orthopedic state without further treatment.

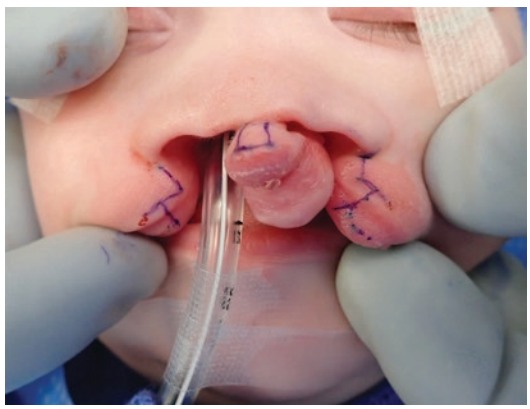

Fig. 27.7 Bilateral cleft lip repair markings

The choice of suture material for skin closure is variable between surgeons, with permanent suture placement and later removal under anesthesia a common practice. Absorbable suture such as 7-0 or 8-0 vicryl is an appropriate alternative for many patients; however, the higher risk of unfavorable scarring in patients with darker skin should be taken into consideration.

Postsurgical Management

Postsurgical management after cleft lip repair is also highly variable between surgeons and centers. Soft nasal stents can be used to maintain and optimize the nostril shape, though to gain maximal benefit they may require continuation for up to 6 months postoperatively [46]. The lip repair requires commonsense protection during the first 2 weeks after surgery, and straws and hard/sharp toys should be avoided during this time. We have previously demonstrated that bottle or breast feeding may be resumed immediately postoperatively with no adverse effects [47]. The incision can be cleaned with dilute hydrogen peroxide as needed to remove crusting, followed by antibiotic ointment. Scar massage with silicone ointment can begin at 3 weeks postoperatively.

Pearl
Infants can resume bottle or breast feeding immediately following cleft lip repair.

Pearl
Massage of the lip scar may begin at 3 weeks after surgery.

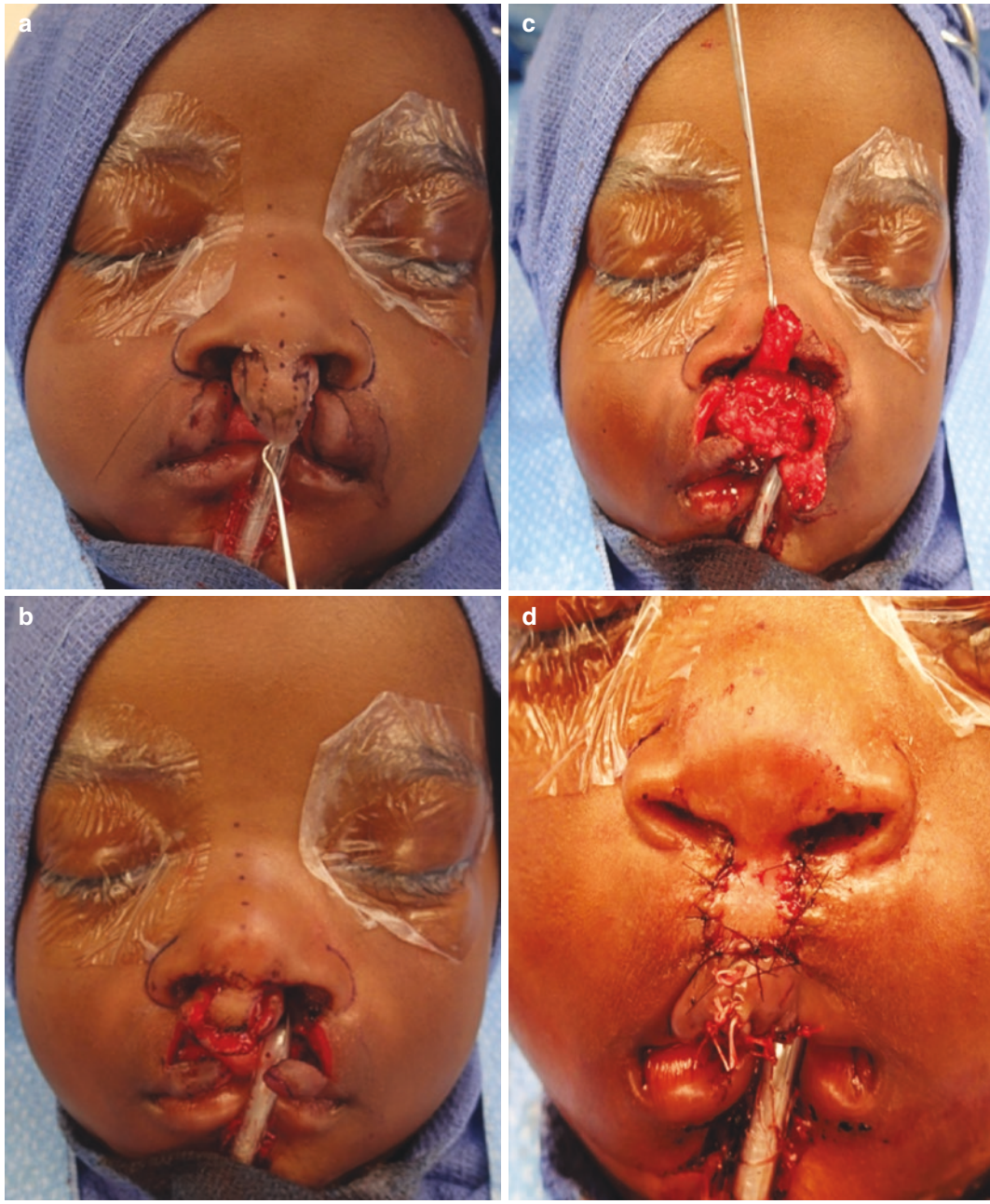

Fig. 27.8 Bilateral cleft lip repair with rotation-advancement technique. (**a**) Operative markings, (**b**) after incisions, (**c**) dissection complete. Note the bilateral orbicularis oris muscles are sutured together in the midline. (**d**) Completion of the repair

Unfavorable Outcomes of Cleft Lip Repair

Early complications of cleft lip repair include bleeding, dehiscence, and infection. Later adverse outcomes may include unfavorable scarring, scar contracture, muscle dehiscence or mismatch, mucocutaneous deformities, vermilion deformities, loss of sulcus, or any combination of these [48]. Dehiscence of the lip repair

can occur in the immediate postoperative period and may range from partial to complete breakdown of the repair. If there is inflammation and induration of the suture line, this should be allowed to settle completely before attempting re-repair.

Families should be counseled to expect some degree of scar thickening, erythema, and contracture as part of the normal healing process in the first few months. It is typical to develop some cupids bow asymmetry as this progresses, though in most cases the asymmetry resolves as the scar matures. Persistent hypertrophic scars may require treatment with steroid injection or later surgical revision.

Aside from these complications, the aesthetic outcomes of lip repair can also be suboptimal. These can include minor asymmetries, mismatch of the vermilion-cutaneous junction, contour irregularities, muscle diastasis or bunching, whistle deformity, and inadequate or excessive lip vertical height or transverse length. The techniques required for correction of these problems can range from minor revisions to complete recreation of the defect and re-repair. While a complete discussion of the techniques for revision of suboptimal cleft lip repairs is beyond the scope of this chapter, a comprehensive review of this topic is available [48].

Anatomy of Cleft Palate

The presence of a palatal cleft has important functional implications in terms of speech, swallowing, and hygiene. A patent palatal cleft allows free movement of food, liquid, and mucous between the oral and nasal cavities, which can also have adverse social ramifications. As with clefts of the lip, cleft palate may be unilateral or bilateral, complete or incomplete. Palatal clefts may involve the secondary palate only (posterior to the incisive foramen, involving the soft palate with or without the secondary hard palate), or the primary and secondary palate together. In the case of a complete unilateral cleft palate, the cleft involves the midline of the soft palate and secondary hard palate, and the mucosa overlying the vomer is continuous with the palatal mucosa on the non-cleft side. In bilateral cleft palate, the cleft of the hard palate extends anteriorly on either side of the vomer, which is a separate structure (Fig. 27.9). In addition, significant abnormalities are observed in the velar musculature. In the non-cleft individual, the muscles of the soft palate function as a muscular valve whose function is to lift and appose the velum to the posterior pharyngeal wall, effecting velopharyngeal closure during speech and swallowing. In the cleft patient, this muscular valve action is absent due to the aberrant attachments of the musculature, primarily levator palatini. The fibers of the levator are longitudinally oriented and insert onto the posterior edge of the hard palate, rather than crossing the midline to meet with the contralateral muscle as they should. Velopharyngeal insufficiency (VPI) is also contributed to by the impaired function of the palatoglossus, palatopharyngeus, and superior constrictor muscles, while impairment of the tensor palatini muscle can lead to incomplete opening of the eustachian tube and resultant middle ear infections [49].

The risk of velopharyngeal insufficiency is also present in patients with a submucous cleft palate (SMCP). SMCP is a condition where the palatal mucosa remains intact, but with underlying separation and abnormal orientation of the levator musculature. Clinical exam features suggestive of an SMCP include a bifid uvula, a palpable notch at the posterior edge of the hard palate, and a dark line (zona pellucida) running the length of the central soft palate as a result of the underlying diastasis. The question of whether to repair a submucous cleft palate in early infancy remains debated.

Pearl

Since the majority of patients with SMCP do not develop velopharyngeal insufficiency (VPI), it is our preference to wait for adequate speech development before determining the need for VPI surgery.

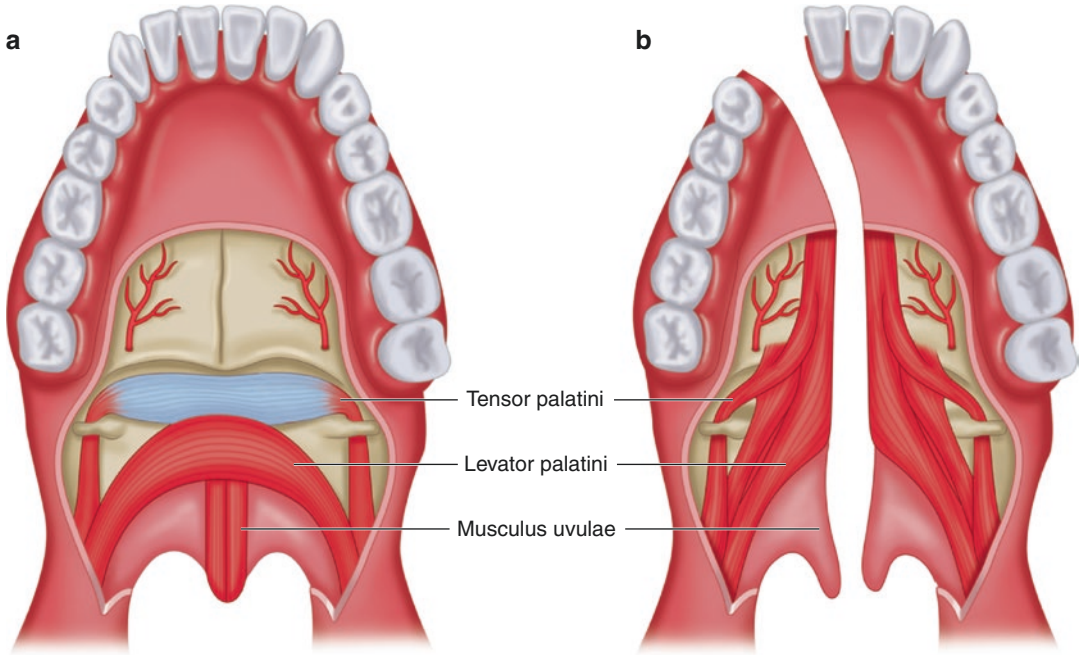

Fig. 27.9 Abnormal muscular anatomy of complete cleft palate. (**a**) Non-cleft anatomy; (**b**) cleft anatomy. The velar musculature, unable to cross the midline cleft, runs in an anteroposterior direction and inserts into the posterior edge of the hard palate

When required, if surgical repair is carried out in the first few years of life, it does not appear to result in poorer long-term speech outcomes [50].

Particular note should also be made of infants with Pierre-Robin sequence, in which the palatal cleft is invariably wider and is often U-shaped rather than the more typical V-shaped configuration. Palatal repair in these patients can be technically challenging, and this patient population is predisposed to the development or exacerbation of airway difficulties following palate repair.

Cleft Palate Repair

The principles of cleft palate repair are as follows:

- Anatomic approximation in layers
- Closure of the palatal opening
- Avoidance of tension
- Release the abnormal attachments to the posterior hard palate
- Reorient and repair the velar musculature, principally the levator palatini
- Maintain or extend the length of the palate
- Minimize the potential for growth disturbance by reducing the extent of residual raw surfaces

Pearl
Attention to the muscular anatomy, and appropriate repositioning of the levator palatini, is of critical importance to the speech outcomes following palate repair.

The repair of a complete cleft palate requires techniques to address both the hard palate and the soft palate. In our experience, the optimal timing involves hard and soft palate repair at the same setting. There are a variety of methods described for palatal repair, but all share the following basic tenets: the repair of the hard palate is carried out

in two layers, with the oral layer overlying the nasal lining repair. The soft palate repair is carried out in three layers, with the all-important muscle closure sandwiched between the nasal and oral lining repairs. Palatal closure should be accomplished under no tension, in order to prevent postoperative dehiscence and fistula.

Pearl
Tension-free closure is key to the avoidance of fistula formation. Palatal tissues closed under tension will dehisce.

Mucoperiosteal flaps can be completely elevated from the palatal bone on either side of the cleft and are based on the dominant greater palatine pedicle. The incisions, technique, and extent of elevation differ between techniques, but preservation of the blood supply is key (Fig. 27.10).

Pearl
Meticulous tissue handling is of equal importance during palatoplasty and for cleft lip repair. Rough handling of the tissues will increase the likelihood of dehiscence and fistula formation.

Our preference is to undertake a two-flap palatoplasty as popularized by Bardach and Salyer. This technique involves a unipedicle mucoperiosteal flap design, with the medial and lateral incisions carried anteriorly to meet just behind the alveolus. The mucoperiosteal flaps are then completely elevated on the greater palatine pedicle, medialized, and repaired as a two-layer closure throughout the length of the hard palate. Following approximation of the mucoperiosteal flaps in the midline, they are resecured to the alveolar margin to minimize the area of denuded bone and amount of secondary healing required [51]. The Von Langenbeck repair, by contrast, utilizes a bipedicled flap design, preserving the anterior sphenopalatine artery pedicle and relying on lateral relaxing incisions with or without infracture of the hamulus to achieve medialization of the hard palate flaps. The improved blood supply is thought to result in a lower rate of dehiscence, and it remains a viable technique for clefts of the secondary palate. The Veau, Wardill, and Killner technique, which is rarely used in current practice, divides the anterior pedicle in order to "push back" the mucoperiosteal flap in a V-to-Y pattern, achieving some lengthening but at the expense of leaving the repaired nasal layer exposed as a single-layer closure, and is associated with increased rates of anterior fistula as a result. The large areas of denuded bone have also been suggested as a cause of maxillary growth disturbance, both in this technique and others [52].

With all of these techniques, nasal lining flaps must also be raised in order to close the nasal layer and lower the risk of fistula formation. In the case of a unilateral cleft, the nasal lining flap is dissected superiorly along the surface of the attached vomer on the non-cleft side, allowing it to be reflected to meet the cleft-side nasal lining. In bilateral clefts, bilateral superiorly based vomer flaps are dissected to meet with the nasal lining flap on each lateral segment. Posteriorly, the nasal closure transitions to a direct closure of the bilateral nasal lining flaps near the junction of hard and soft palate.

Pearl
The area of highest tension in repair of a complete cleft palate is generally at the junction of the hard and soft palate. Adequate release of the lateral soft tissues via the relaxing incisions is frequently necessary to sufficiently medialize the tissue for tension-free closure.

The intra-velar veloplasty (IVVP), described by Braithwaite in 1968 [53], and subsequently named by Kriens [49], represented a large innovation in functional cleft palate repair. In this technique, the abnormal attachments of the levator palatini to the posterior edge of the hard pal-

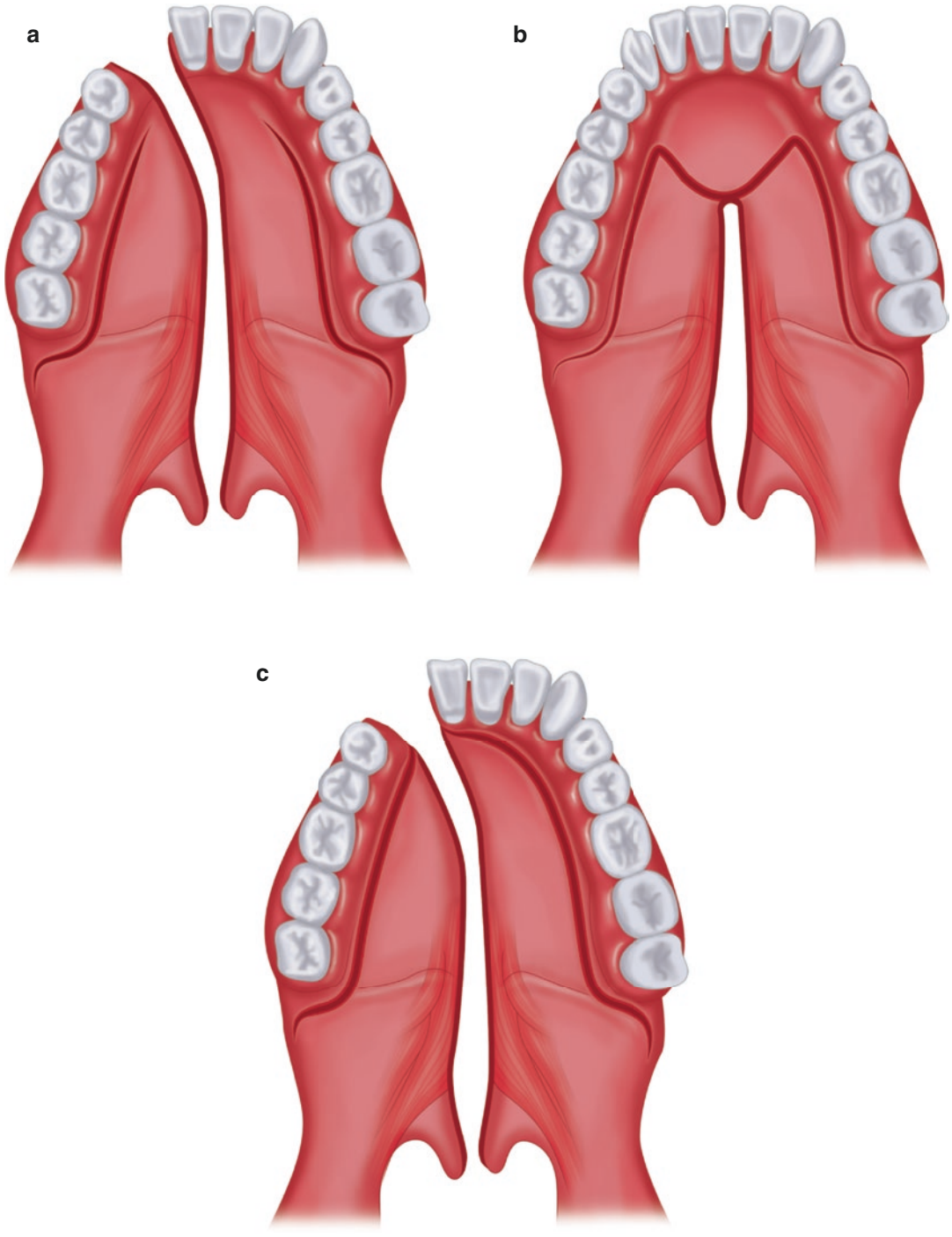

Fig. 27.10 Hard palate repair techniques. (**a**) Von Langenbeck repair; (**b**) Veau-Wardill-Killner repair; (**c**) two-flap palatoplasty

ate are disinserted, and further dissection of the muscle allows retro repositioning and creation of an intact muscular sling across the cleft in the posterior half of the soft palate (Fig. 27.11a). The extent of muscle dissection varies widely between authors, with some surgeons preferring the use of

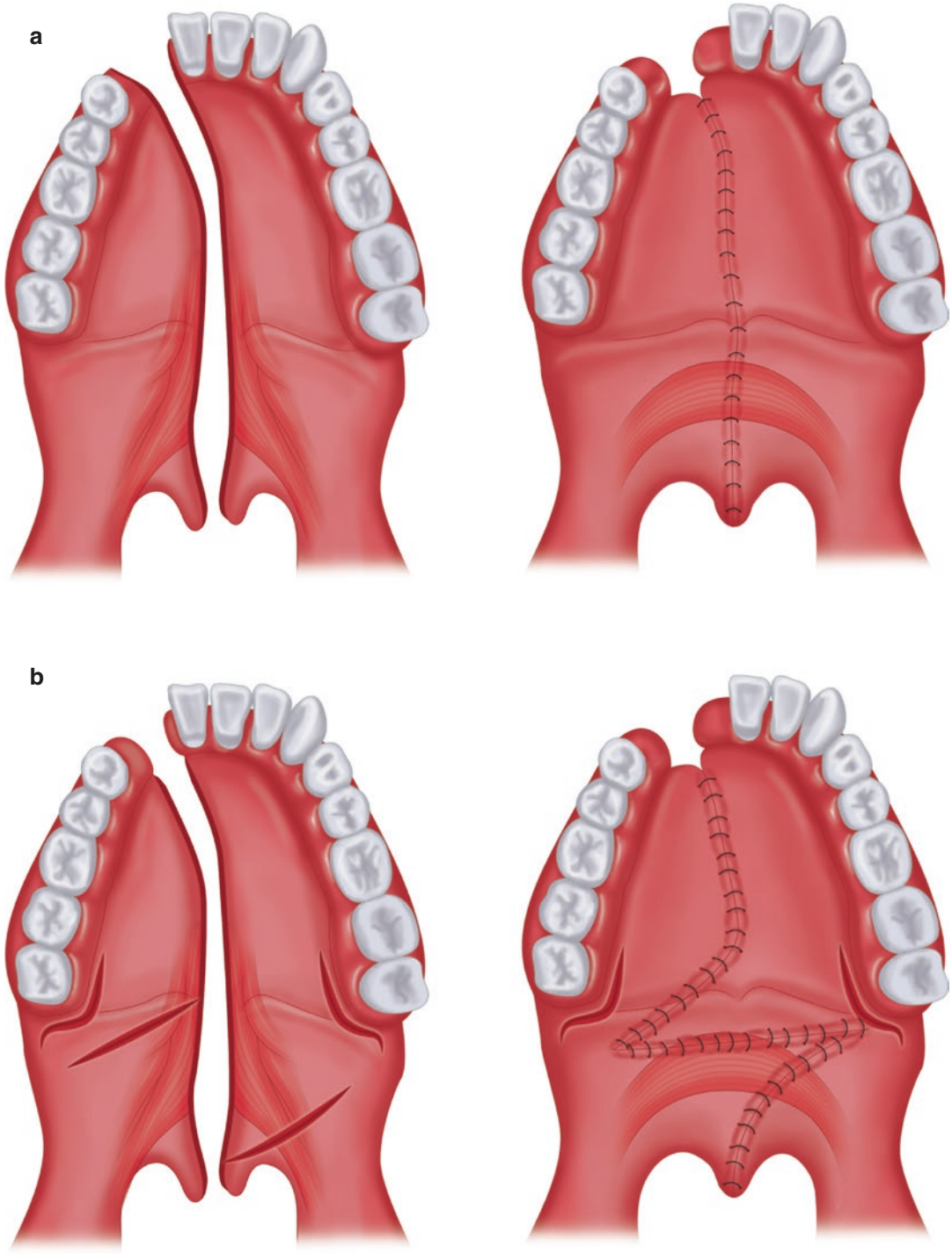

Fig. 27.11 Soft palate repair techniques. (**a**) Intra-velar veloplasty; (**b**) Furlow double-opposing Z-plasty

an operating microscope to facilitate more radical dissection, division of the tensor palatini tendon, and overlapping of the levator muscle to increase velar tone. Excellent speech outcomes have been reported with this technique [54]. Perhaps the most commonly used technique for soft palate

repair is the double-opposing Z-plasty described by Furlow [55] (Fig. 27.11b). This technique uses two overlapping Z-plasties based around the midline cleft. One of the Z-plasties contains a posteriorly based muscle and oral mucosa flap, while the other Z-plasty contains a posteriorly based muscle and nasal mucosa flap. When the flaps are transposed, the levator is reoriented transversely and recreates the muscular sling. This technique provides a robust repair and has the additional benefit of producing some palatal lengthening, but can be difficult to execute in wider clefts. Several studies have evaluated the speech outcomes for both techniques, and good results have been reported for each [56]. The decision of which technique to use is in large part surgeon-dependent, though may also be tailored to the individual patient's anatomy. For example, patients with very wide clefts may be better suited to treatment with IVVP rather than the Furlow technique.

Pearl
Excellent outcomes can be achieved with either IVVP or Furlow palatoplasty, and each technique may have a place in the armamentarium. The well-rounded surgeon should be familiar with both techniques.

Figure 27.12 demonstrates the steps involved in repair of a secondary palate cleft with the Furlow double-opposing Z-plasty technique

Unfavorable Outcomes of Palate Repair

Airway compromise is more common in patients with Pierre-Robin sequence, Treacher Collins syndrome, mandibular hypoplasia, and in premature infants. For these reasons, many surgeons prefer to postpone the palatoplasty until adequate growth has occurred or, in the case of mandible hypoplasia, to undertake mandibular distraction prior to palate repair [57]. Other complications include intraoperative or immediate postoperative bleeding, early dehiscence, unplanned fistula, velopharyngeal deficiencies, and skeletal deformities [48].

Pearl
Early dehiscence is generally a technical complication and should return to the operating room for repair.

The overall incidence of fistula formation at the site of prior repair is reported to be between 6.4 and 17.9% and is highest in bilateral cases [58]. Reported recurrence rates after attempted fistula repair are quite variable, and as a result some surgeons recommend conservative management for asymptomatic fistulae. If fistula repair is planned, we recommend waiting several months after the initial palatoplasty to allow inflammation and edema to resolve.

Maxillary growth restriction has been intensively studied in the cleft palate population. While some patients with cleft palate have intrinsically limited maxillary growth potential, it has been shown that the degree of maxillary growth restriction varies among surgical repair techniques. The Veau-Wardill-Kilner Pushback, for example, has been shown to result in higher rates of maxillary hypoplasia and class III malocclusion due to larger areas of denuded bone that heal by secondary intention. The timing of repair also appears to play a role, with earlier repairs associated with greater growth impairment [59]. Lastly, velopharyngeal insufficiency can be considered a late complication or adverse outcome following palatoplasty.

Velopharyngeal Insufficiency and Speech Surgery

Modern cleft palate reconstruction techniques focus on retropositioning and repair of the velar musculature, with the goal of allowing normal

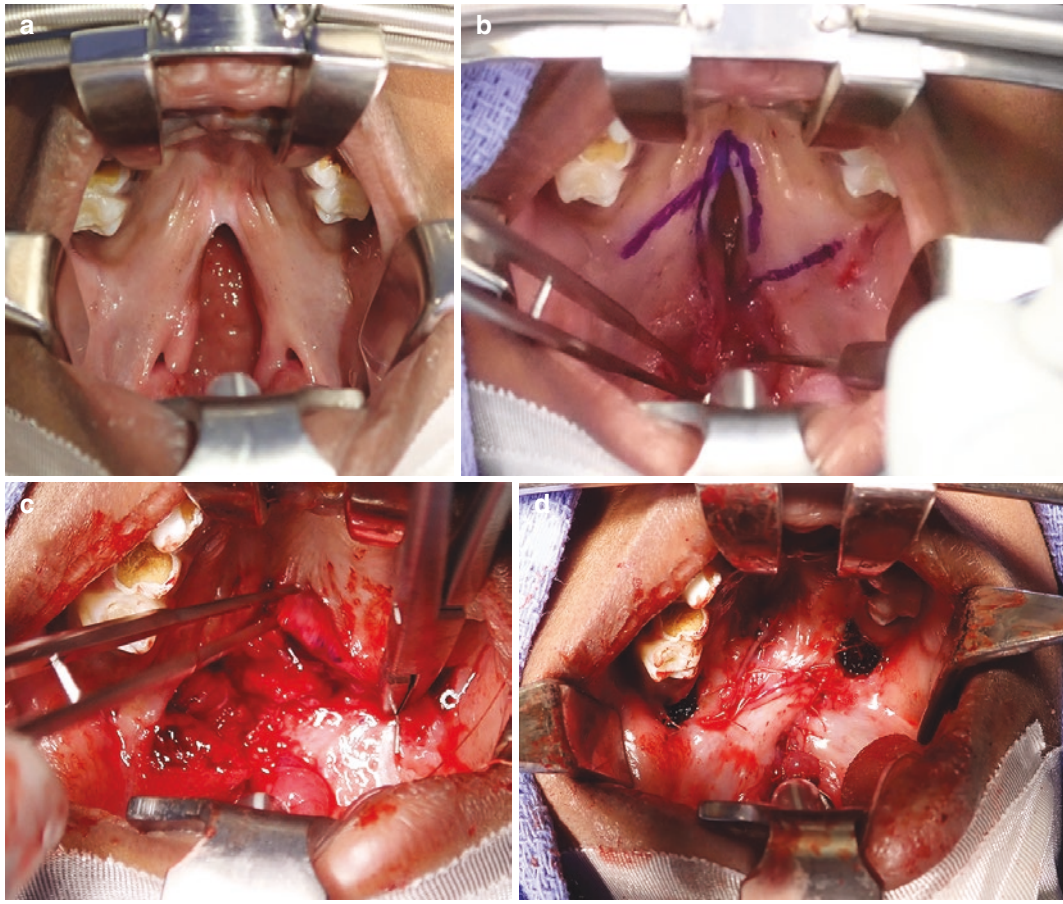

Fig. 27.12 Steps involved in Furlow double-opposing Z-plasty. (**a**) Cleft of the secondary palate. (**b**) Design of oral-side z-plasty. The nasal-side z-plasty will be a mirror image of the oral side. (**c**) Nasal repair completed, with transposition of the z-plasty flaps. (**d**) Oral repair complete

function of the velar mechanism during speech and swallowing. With regard to speech, closure of the velopharyngeal port separates the oral and nasal cavities and facilitates generation of the intraoral air pressure needed for pressure-sensitive sounds during speech (plosives, fricatives, and affricates). In the presence of a palatal cleft, oronasal fistula, or poorly functioning velum, air can escape from the nose, giving rise to velopharyngeal insufficiency (VPI) and a hypernasal quality to speech. If VPI is persistent, compensatory articulation patterns can develop, and these can be difficult to correct despite optimal speech therapy.

Pearl

Articulation problems can develop independent of VPI, but the goal of early palate repair is to limit those articulation problems that are directly related [17].

Velopharyngeal insufficiency following an otherwise successful palate repair can be attributed to insufficient palatal length, inadequate muscle repositioning/repair, excessive scarring, levator hypoplasia, ineffective oropharyngeal

sphincter closure, or any combination of these. The reported incidence of VPI ranges from 4% to 30% [60], and to date there has been no compelling evidence of superiority between the various soft palate repair techniques.

Speech assessment begins with a clinical examination by an experienced speech pathologist and, if indicated, proceeds to investigation with nasendoscopy. A small-diameter pediatric endoscope is inserted into the nose under local anesthesia, and the velar mechanism can be visualized during speech as directed by the examiner. The presence of any gaps in the closure, air bubbling, and the pattern of closure can be determined. While nasendoscopy provides the most information and is the preferred investigation for VPI, a small percentage of patients may not tolerate the procedure, and in these cases, videofluoroscopy can be undertaken instead. Anatomic testing with acoustic nasometry and functional testing with rhinomanometry can provide valuable additional diagnostic information.

Various surgical options are available for treatment of VPI, and the choice of which technique is in large part dependent on the closure pattern observed. For patients who have undergone prior straight-line closure of the soft palate, a secondary Furlow palatoplasty may be considered in order to provide additional length when indicated. Another option when very small gaps are present is autologous fat transfer to the posterior pharynx [61]. Patients with limited lateral wall motion may benefit from a *sphincter pharyngoplasty*, which brings bilateral superiorly based flaps of muscle and mucosa from the posterior tonsillar pillars to the posterior pharyngeal wall, augmenting the volume of the posterior wall and tightening the velopharyngeal port [62]. For patients with larger gaps, and those with limited posterior wall motion, a superiorly based *pharyngeal flap* can be raised and inset into the velum or hard/soft junction, occluding the majority of the velopharyngeal port and leaving a small dynamic port on each side. The risk of obstructive sleep apnea due to overclosure of the velopharyngeal port is highest with the pharyngeal flap, though can also occur with the sphincter pharyngoplasty [63]. Regardless of the severity of VPI, method of surgical correction, or the age of the patient, intensive speech therapy by a speech pathologist experienced in the treatment of patients with clefts is key to a successful outcome.

Pearl
Successful treatment of velopharyngeal insufficiency requires intensive speech therapy, combined with surgical intervention when appropriate. There are many surgical options available, and the decision of which to employ requires careful evaluation.

The Residual Cleft and Alveolar Bone Grafting

The timing of reconstruction for the alveolar cleft is another area of debate. The term "alveolar bone graft" understates the problem, as the residual deformity may be comprised of an oronasal fistula and anterior palatal cleft, nasolabial cleft, maxillary hypoplasia and a pyriform bony defect, as well as the alveolar cleft.

Pearl
The residual cleft is a three-dimensional defect involving much more than just the alveolar ridge, and the plan for treatment of this must take into account the associated hypoplasia of the maxilla and pyriform region.

One approach, which is designed to address the alveolar cleft alone, is the use of gingivoperiosteoplasty (GPP) in infancy [25]. An alternative approach, termed *primary bone grafting*, utilizes autologous rib bone graft as a bridge between the alveolar segments. While this approach was commonplace from the 1950s onward, it has since fallen out of favor at most centers. Both GPP and primary bone grafting require close attention to presurgical infant orthopedics in order to bring the alveolar segments in close apposition. Critics of primary bone grafting also note that rib grafts

tend not to grow commensurate with the child, and fail to form a true alveolar process, leaving a bony deficiency at the alveolus which may not support tooth eruption. Neither GPP nor primary bone grafting addresses the more extensive maxillary hypoplasia that is invariably present, and both techniques have also been implicated as contributors toward maxillary growth restriction [52]. With that in mind, in the authors' opinion, the main benefit of primary bone grafting is the ability to maintain good alignment between the alveolar segments as the child grows. This can potentially avoid the issue of severe lateral segment collapse, particularly for the bilateral complete cleft patient, in which a V-shaped maxillary arch is often seen. However, in most cases, it does not preclude the need for later bone grafting.

For the majority of patients and cleft centers, secondary bone grafting in the mixed dentition period (ages 7–11 years) has become the preferred treatment of choice for stabilization of the maxilla and bony support for tooth eruption [64].

Pearl
Preoperative maxillary expansion is necessary, improving access to the cleft and aligning the maxillary segments prior to grafting.

The gingiva overlying the facial aspect of the alveolus and anterior maxilla is elevated, providing access to the bony cleft. The palatal-nasal lining is elevated and divided to allow repair of the nasal lining (roof of the defect) and the palatal mucosa (floor of the defect). These repairs are each carried posteriorly to meet at the incisive foramen, producing a sealed pocket for the graft in the form of a three-dimensional cone (Fig. 27.13).

Pearl
If deciduous teeth are present adjacent to the cleft margins, it may be preferable to extract 6 weeks prior to the bone graft procedure in order to avoid gingival defects at the time of surgery.

The most commonly used material for grafting is cancellous autologous iliac crest, first described by Boyne [65]. The addition of cortical segments placed at the roof and/or the anterior aspect of the defect has also been described as a means of protecting the delicate mucosal repairs and resisting contractile forces during healing [66, 67]. Bilateral alveolar clefts can present additional difficulties, in terms of the premaxillary position, presence of bilateral oronasal fistulae, and lateral segment collapse. It is generally preferable to carry out repair of bilateral clefts simultaneously, where feasible. Following the bone graft procedure, the maxilla should be maintained in its expanded state by means of a wire retainer until phase II orthodontia begins. Any orthodontic movements may be resumed after 3–4 months.

Orthognathic Surgery in Cleft Patients

Orthognathic surgery in cleft patients presents some challenges over non-cleft orthognathic surgery [68]. Patients will have undergone multiple operations at the same site, resulting in a scarred field. The upper lip may also be short in length and tightly scarred, restricting access. The maxilla is often hypoplastic on the cleft side, and asymmetric Le Fort osteotomies may be required in order to balance this—particularly when rotational movements are planned for correction of the dental midline (Fig. 27.14). The nasal lining is often tightly adherent at the cleft site and is more prone to tearing with elevation for Le Fort osteotomy. This necessitates additional care in dissection. Care must be taken during the downfracture of the Le Fort segment, as any weakness at the alveolar cleft site can lead to unintentional fracture and a two-piece Le Fort results.

Pearl
Downfracture of the Le Fort segment should not require great force. If gentle digital pressure is insufficient, the osteotomies are likely incomplete and should be revisited.

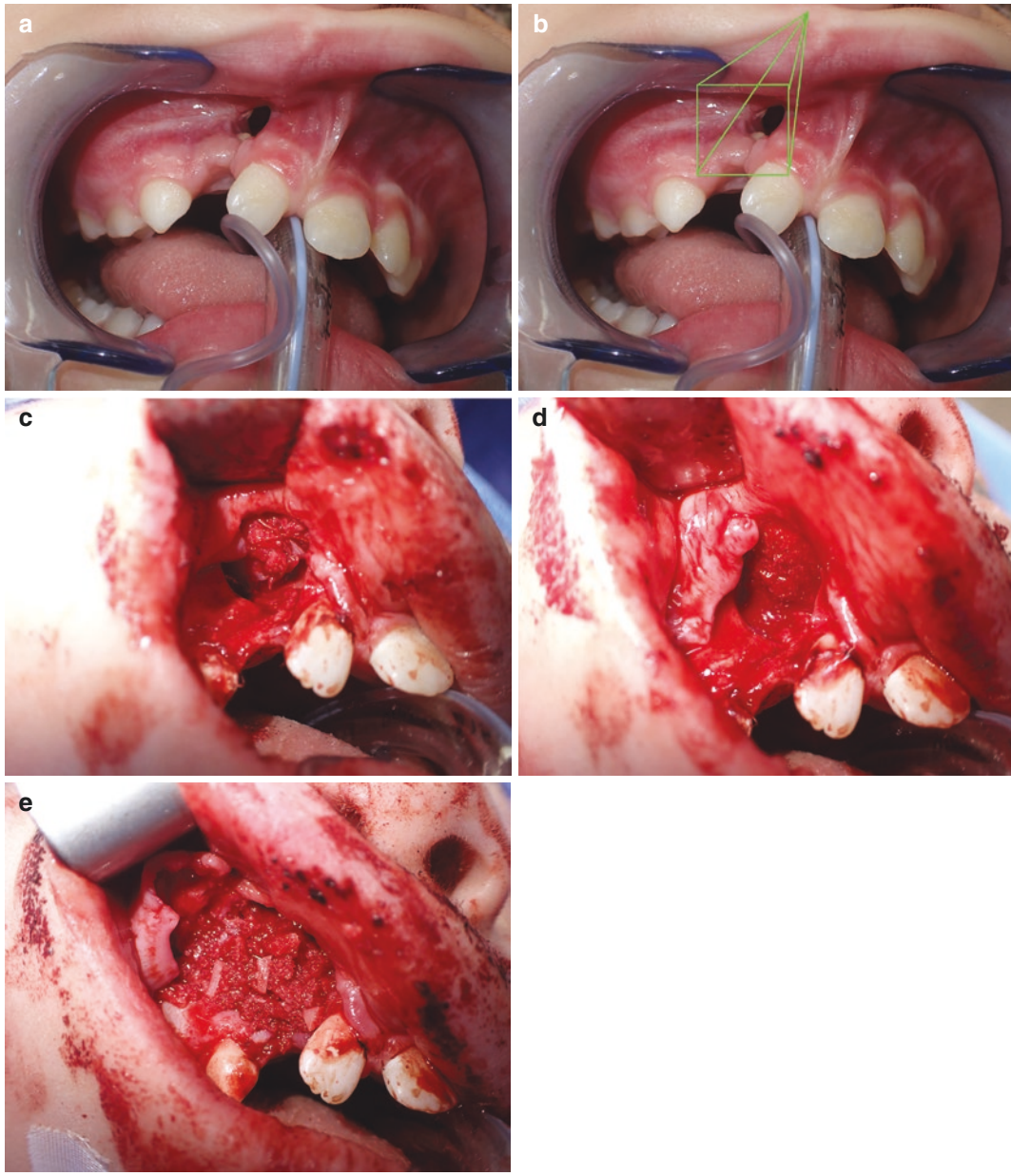

Fig. 27.13 Secondary alveolar bone graft. (**a**) Alveolar cleft anatomy; (**b**, **c**) gingival-mucosal repairs and three-dimensional pocket formation; (**d**) thin corticocancellous wedge placed superiorly; (**e**) particulate corticocancellous graft packed into the cleft

In patients presenting without prior reconstruction of the alveolar cleft, or those in whom alveolar grafting previously failed, the authors' preference is to (re)graft the alveolus and close any fistula as a preliminary surgery, followed by jaw surgery 6 months later. The palatal tissues can be densely scarred, and mobilization of the Le Fort segment may be more difficult. This can be particularly true when a pharyngeal flap is present, and in a minority of cases, the pharyngeal flap may require division in order to fully mobilize the Le Fort segment. Even in the

Fig. 27.14 The LeFort I osteotomy. (**a**) Preoperative class III malocclusion with anterior open bite; (**b**) intraoperative, two-piece LeFort I osteotomy with advancement; (**c**) postoperative result

absence of this maneuver, patients with cleft palate are at higher risk for velopharyngeal insufficiency following large maxillary advancements [69]. The severe maxillary hypoplasia seen in some cleft patients can result in very large negative overjets of 10 mm or more. Bone grafting the gap created by the advancement is often required for these larger movements, whereas it can frequently be avoided in less extensive cases. In patients with severe midface retrusion, a mandibular setback can be performed along with the Le Fort advancement, reducing the degree of maxillary advancement required. However, this is only appropriate if there is a degree of mandibular prognathism present. In patients in whom the mandible is already appropriately positioned, it may be more prudent to consider maxillary distraction as a means of achieving the required advancement while minimizing the risk of postoperative skeletal relapse.

Pearl
Maxillary distraction osteogenesis is a powerful tool which can facilitate larger orthognathic movements in an often scarred field.

In patients with Pierre-Robin sequence with cleft palate, there may be hypoplasia of both mandible and maxilla, requiring a bimaxillary advancement. Large maxillary advancements can also result in widening of the alar base, and this can be ameliorated by placement of a cinch suture from alar base to alar base, narrowing the base of the nose. Lastly, the upper lip is often incised and closed in a V-Y fashion, in order to correct any midline volume deficiency present [70]. In the authors' practice, orthognathic surgery is generally timed to coincide with the completion of facial growth in order to minimize potential for recurrence of malocclusion and facial disharmony. Any osseointegrated implant placement for prosthodontic rehabilitation is generally deferred until after the orthognathic movements have been completed.

Secondary Correction of the Cleft Nasal Deformity and Nasal Airway

With improved understanding of the safety of primary cleft nasal reconstruction, large improvements in nasal symmetry can be achieved at the time of primary cleft lip repair. In many cases, these improvements can be sufficient to allow the child to grow without the stigmata of cleft nasal deformity. In patients with more severe asymmetry, an intermediate cleft nasal reconstruction may be considered prior to school age, in order to improve nasal tip symmetry and/or correct any functional airway obstruction. When needed, this is often accomplished through a reverse-U incision with suture suspension of the repositioned lower lateral cartilage, as described by Tajima and Maruyama [71]. Definitive cleft nasal reconstruction is generally carried out in adolescence after orthodontic alignment of the maxillary segments and bone grafting of the maxillary cleft and hypoplastic region of the pyriform aperture [48]. Treatment must take into account not only the residual aesthetic deformity, but also any functional airway obstruction present. Preoperative evaluation includes a thorough clinical examination, functional rhinomanometry, and nasendoscopy. With this information, the surgeon can formulate a tailored plan for treatment. Airway obstruction can be related to septal deviation, collapse of the internal or external valve, intranasal swelling or scarring, or hypertrophy of the inferior turbinate, and the techniques required for correction vary accordingly.

Many standard rhinoplasty techniques are applicable; however, the patient with a cleft presents some additional challenges. An open approach is our preference. Columellar length can be deficient, necessitating a V-to-Y skin incision design. There can be severe asymmetries present in the unilateral patient, most commonly at the tip, but frequently also involving the middle and upper thirds. Correction of tip asymmetries usually requires mobilization and repositioning of the malpositioned lower lateral cartilage. In more severe cases, equalization of the domes may necessitate recruitment of the lateral crus more medially, with or without the

attached mucosa. In cases of severe lining deficiency, extensive scarring, or micronostril, a composite graft from the ear may be required for more complete correction. The septum is frequently deviated and may require separation from the maxillary crest in order to reposition it more centrally. In more severe cases, resection of the involved septum may be needed, leaving only a 1 cm L-strut for structural support. The septum can be a good source for cartilage grafts, though rib cartilage is also frequently required to augment or buttress the nasal cartilages. Any bony spurs or deviations contributing to airway obstruction can also be addressed at this point, and inferior turbinate reduction can be undertaken if indicated.

A variety of cartilage grafts may be placed, depending on the individual needs. These may include a columellar strut for tip support, onlay grafts for tip and/or dorsal projection, lateral crural extension grafts, alar rim or batten grafts, spreader grafts, and others. Osteotomies may be required for correction of bony pyramid asymmetry. Following closure, discrepancies of nostril size can be addressed with sill excisions or composite grafting from the ear [72].

The anatomy of the bilateral cleft lip nasal deformity is quite different, and the techniques for correction differ as a result. The tip is often relatively symmetric, but can be severely broad and flattened, lacking projection and with a significant deficiency in columellar length. A V-Y lengthening incision is designed as for the unilateral cleft lip, and excess fibrofatty tissue often needs to be excised from between the domes before medialization and suture fixation. Additional suture techniques can be used to further narrow and define the nasal tip. A columellar strut may be placed for support and projection, and tip projection can be further augmented with onlay grafts as needed. Following closure, nostril flaring may persist and require additional alar resections to be carried out for correction [48]. Correction of the cleft nasal deformity can be quite challenging and requires a thorough understanding of both normal anatomy and the differences encountered in patients with a cleft.

Conclusion

Cleft lip and palate are complex conditions that present a number of challenges for both the patient and surgeon. Several operative procedures are required, beginning in early infancy and continuing through early adulthood. As such, the importance of regular follow-up and integrated team care cannot be overstated for this patient population. Good communication between team members can help to streamline the care plan, minimizing the number of operations and time away from school. With careful planning and precise execution, excellent outcomes are achievable in even the most severe cases, restoring form and function while minimizing the stigmata associated with cleft lip and palate.

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28 Craniofacial Surgery: Craniosynostosis and Craniofacial Syndromes

Peter J. Taub and Paymon Sanati-Mehrizy

Introduction

Craniofacial surgery has a unique set of concerns and risks that should be well-understood. Careful planning and preparation prior to surgery is paramount. When excessive blood loss is expected, products to raise the patient's hematocrit in anticipation of surgery and hopefully avoid the need for blood transfusion may be prescribed [1]. For all cases, early infiltration of local anesthesia along the proposed incision lines and waiting an ample period of time can significantly enhance visibility and minimize blood loss [2–4]. Since craniofacial surgery involves osteotomies with power tools (saw, burrs, drills), irrigation of any bone subjected to power cutting or rasping is important [5, 6]. A malleable retractor should always be placed behind a cutting surface to protect inadvertent injury to the underlying soft tissue. When placing plates and screws across an osteotomy line, each screw should be placed after each drill hole. It is disheartening to make all of the drill holes first, only to find that the plate doesn't quite sit properly, and limited space for new holes has been wasted. This is especially true in areas of limited bone such as the inferior orbital rim. Any loose particulate matter should be irrigated away prior to closing. Finally, careful consideration should be given to whether the patient requires intensive care postoperatively.

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_28) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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Cranial Procedures (Craniectomy, Fronto-orbital Advancement, Monobloc)

Planning

Mobilization of large segments of bone, such as with a Monobloc osteotomy or even a maxilla alone, often requires Rowe disimpaction forceps to facilitate the down-fracture. These require placement of the prongs into the nasal cavity and into the oral cavity. On account of the pressure sometimes required to mobilize the bones, it is prudent to prefabricate an acrylic appliance for the palate and maxillary dentition. This lessens the chance of inadvertent palatal fracture or dental avulsion.

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Preparation

Access for a simple strip craniectomy may be through two small incisions at either end of the fusion. Access to the skull and fronto-orbital region is typically via a coronal incision, which may be zig-zagged to minimize visualization beneath the hair-bearing scalp. The apex of the incision is at the vertex of the skull and extends laterally roughly in line with the helical root. Minimizing the inferior extent of the incision on either side goes a long way to keeping the incision hidden. Specific areas to infiltrate in advance of a procedure for the skull in which a coronal flap is to be elevated for exposure are the supraorbital rim, where perforating vessels off the supraorbital and supra-trochlear vessels reside and cause bleeding. This is in addition to infiltration of the scalp incision. Separate infiltration of the upper gingivobuccal sulcus incision should be performed if access to the maxilla is planned.

Dissection

In younger patients, dissection over areas of exposure should be in a supra-periosteal plane to minimize blood loss. This should be limited to the working areas to minimize postoperative edema. This is especially important in pediatric patients, where a small amount of blood loss can be critical. Over the site of an osteotomy, the periosteum can be dissected free. When reflecting the forehead tissues, several maneuvers require mentioning. The frontal branch of the facial nerve resides on the undersurface of the temporoparietal fascia. Dissection of the lateral tissues should thus be deep to this, immediately over the anterior layer of the deep temporal fascia. This may be done by using the backside of a periosteal elevator to sweep any loose areolar tissue into the reflected flap. Areas of increased adherence exist at the nasion and the lateral orbital rim. Since it is necessary to completely reflect the forehead tissues to access the root of the nose and the lateral orbital wall, incising the periosteal tissues at the nasion and at the lateral orbital rim will facilitate release of the soft tissues and ease of flap turnover

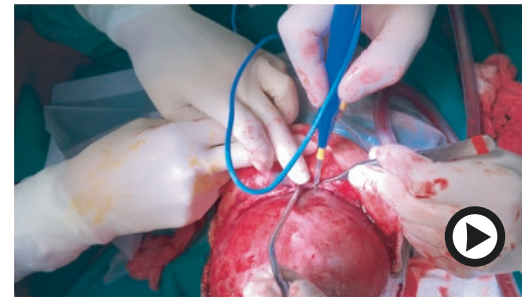

Fig. 28.1 Incising periosteal tissues at the nasion to aid in the release of soft tissues and flap turnover (▶ https://doi.org/10.1007/000-3v5)

(Fig. 28.1). Posterior dissection of the external orbit leaves the temporalis muscles largely intact to minimize postoperative hollowing.

Strip Craniectomy

Removal of a limited portion of cranial bone is performed by making small burr holes on each side of the synostosis at both ends. In younger infants, cutting the bone between the openings with a scissors will serve to complete the craniotomy. Careful dissection of the bone off the underlying dura allows safe removal of the stenotic suture with minimal risk of inadvertent dural injury.

Anterior Craniotomy

An anterior craniotomy (Fig. 28.2, blue) is used to gain exposure of the anterior cranial fossa to facilitate osteotomies of the orbital roof necessary to perform advancement at the orbital bandeau alone (Fig. 28.3a, b), or in concert with the midface as a Monobloc (Fig. 28.2, red). The anterior craniotomy is performed by making small burr holes in key areas that are then joined with an osteotome with a protected foot plate. Since there is often a thicker area of bone in the central inferior aspect of the frontal bone, it is difficult for the osteotome to traverse from one side to the other. This central, inferior portion of the anterior craniotomy may be scored superficially and then out-fractured once the remaining bone cuts have been completed. It

is safest to leave the transverse osteotomy across the sagittal sinus until last, in case of sinus injury and the need for rapid exposure to repair the defect. Any removed bone should be wrapped in moist gauze and labeled on a back table for later replacement at the end of the case.

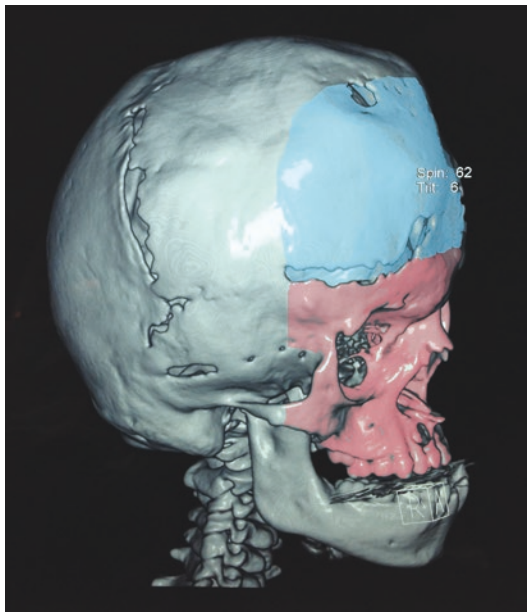

Fig. 28.2 Anterior craniotomy and midface advancement at the Monobloc level

Protection

Dissection and removal of the orbital bandeau area requires complete dissection of surrounding central nervous system structures, including the brain, meninges, and orbital contents. Care should be taken to avoid injury to the medial canthus. There are several components of the bandeau that need to be cut, although no specific order is required. Prior to this, the temporal fossa should be dissected to protect the temporal lobe of the brain, which lies beneath the sphenoid wing. Moving from lateral to medial, the dura should be carefully dissected and the spaced anterior to the lobe packed with a cotton pledget to minimize injury. When making the osteotomy in the orbital roof, the intracranial contents must be protected with wide malleable retractors from above, and the orbital contents must be protected with narrower malleable retractors from below within the orbit. An additional malleable retractor must be placed within the middle cranial fossa, retracting the underlying temporal lobe. With retraction on the globe, bradycardia may occur that does not require management by the anesthesiologist but will abate with release.

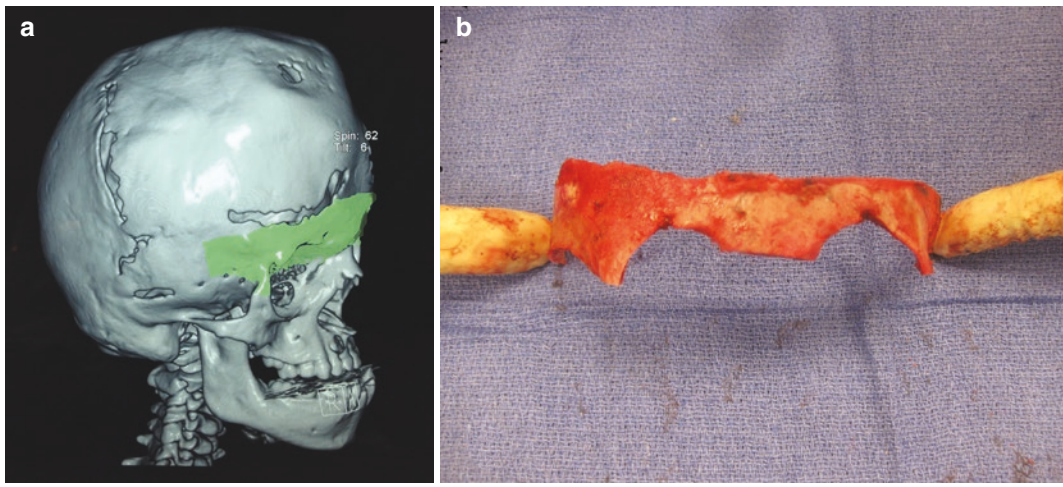

Fig. 28.3 (**a**, **b**) Orbital bandeau

Removal of the Orbital Bandeau

This must be done carefully, to avoid injury to the brain and to leave a stable segment of bone to advance. Extensive undermining of the dura is performed anteriorly over the roof of the orbits and continues laterally along the sphenoid wing to the temporal area. It is through this exposure that the concealed cranial portion of the bandeau may be visualized. Often in the presence of increased intracranial pressure, the bone is thin and the underlying dura is attenuated, and more firmly adherent to the overlying bone. Of particular risk is when the surgical blade is advanced from behind the lateral edge of the greater wing the sphenoid in an anterior direction and is lost from sight [7]. The orbital roof on either side is divided through the frontal craniotomy exposure anterior to the midline cribiform plate (Fig. 28.4). The blade is advanced from lateral to medial at a depth of roughly 1.5 cm. Care is taken to start the osteotomy behind the lateral edge of the greater wing of the sphenoid with the saw blade oriented inferiorly within the middle cranial fossa. The osteotomy is completed when it exits the medial orbit into the anterior cranial fossa. This is repeated on the contralateral side. An extension of the lateral osteotomy portion of the bandeau, or "tenon," allows for the bony segments to slide past each other yet maintain contact to maximize bony union (Fig. 28.5). They are created to facilitate bony healing and stabilization following advancement of the bandeau. Osteotomy in the midline must join the one from each medial orbital roof (Fig. 28.6). The saw blade will be held horizontally just superior to the frontonasal suture and directed posteriorly to complete the release. If the bandeau does not release easily, the cuts may need to be repeated with the saw blade, or redone with a hand osteotome, to ensure mobilization. The cause is usually incomplete connection in the region of the "triple point" [7].

Harvesting Bone Graft

If bone graft is needed and the calvarium is thick enough, it is often easiest to harvest a full-thickness portion of bone from an adjacent edge and split it on a back table. In this way, half the bone may be replaced to cover the donor defect. Splitting calvarial bone can be done with hand osteotomes (if they are sufficiently sharp) or with a saw (either reciprocating or oscillating). When using a saw, the overlying bone turns a whiter color as it is separated in half (Fig. 28.7).

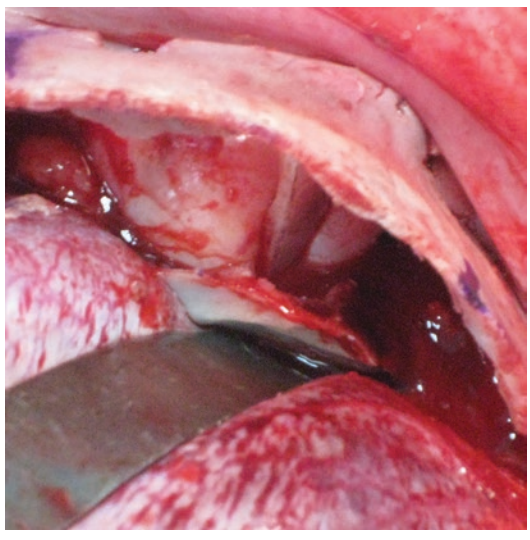

Fig. 28.4 Superior view of the orbital roof osteotomy

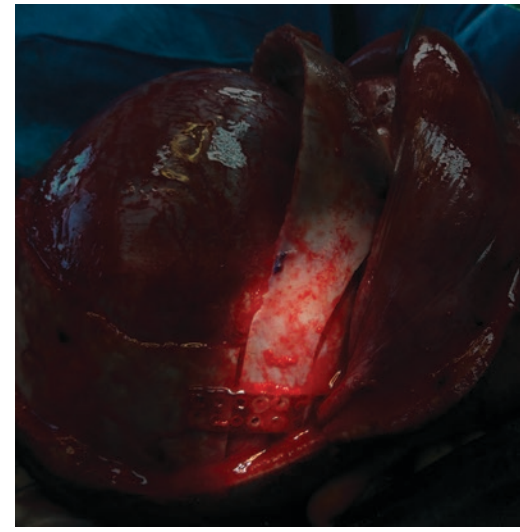

Fig. 28.5 Tenon extension of the orbital bandeau (highlighted) to maintain bone contact

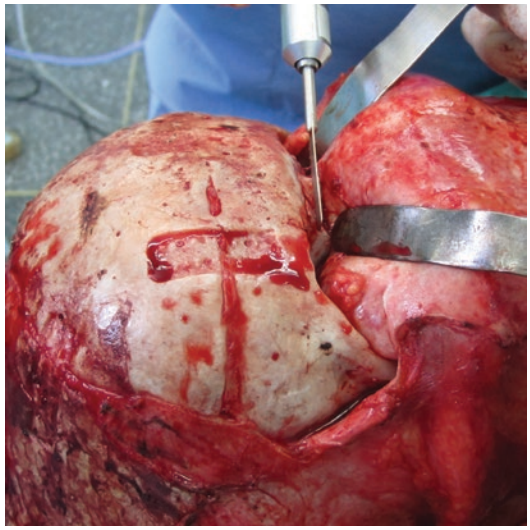

Fig. 28.6 Medial osteotomy of the bandeau

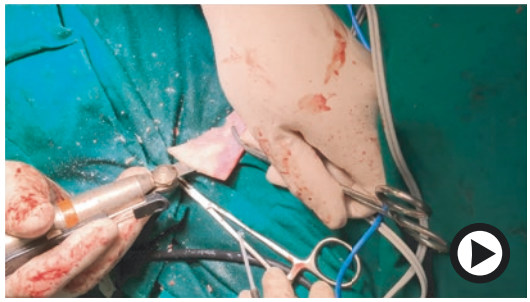

Fig. 28.7 Blanching of split calvarial bone when using a saw (▶ https://doi.org/10.1007/000-3v4)

Fixation

Anterior translocation of the orbital bandeau is held into place by fixation at the tenons and at the nasion. This is often done with resorbable material plates. The bandeau is further stabilized with replacement of the anterior craniotomy. Inverting the orientation of the craniotomy segment may provide a better contour to the forehead when it is replaced. This piece can also be sectioned in the midline if a more aesthetic result can be achieved. The location of the plates can be laterally along the bandeau and posteriorly to the parietal skull.

Closure

Wide dissection in a supra-periosteal plane may be necessary to obtain scalp closure following expansion of the cranial space by advancement of the orbital bandeau. Galeal scoring may also be used as a secondary maneuver, cognizant to minimize trauma to the subdermal vasculature (Fig. 28.8). This can be done with low-power electrocautery to preserve the underlying dermal vasculature. Complete galeal closure is necessary prior to closing the skin.

Orbital Procedures (Facial Bipartition, Box Osteotomy)

Planning

Preoperatively, CT scanning will document the degree of hypertelorism, and ophthalmology consultation is obtained for a baseline examination. If a facial bipartition is planned, the patient and family should be made aware that movement of the bony segments superiorly will likely result in separation of the central incisors inferiorly, creating a diastema. This will not occur with box osteotomies.

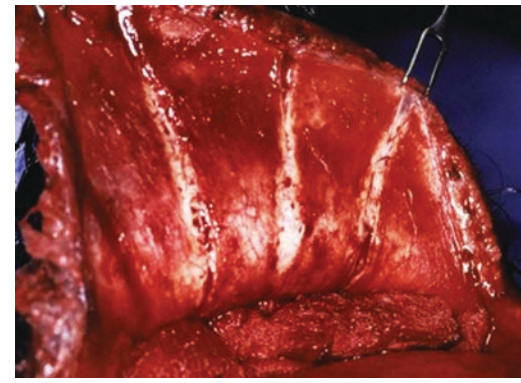

Fig. 28.8 Galeal scoring with preservation of the underlying dermal vasculature

Preparation

Any procedures involving the orbits should make every effort to protect the globes. Early lubrication with ointment will minimize trauma to the cornea from either inadvertent contact or from the prep solution. In addition, a temporary tarsorrhaphy can be performed at the beginning of the procedure and either removed at the conclusion or left for several days if chemosis is likely.

Dissection

To safely perform the internal osteotomies in the orbit, an extensive, subperiosteal dissection around the internal surface needs to be performed. This will include taking down the lateral canthus but should leave the medial canthus intact. More posterior dissection than needed should also be avoided, to minimize injury to the optic nerve and annular muscle ring.

Orbital Box Osteotomy

Complete osteotomy of the orbit is performed to allow re-positioning either closer to the midline or in a more superior or inferior position. As such, the components may be thought of as eight separate cuts around the orbit as concentric boxes—four externally and four internally. The latter consist of a superior cut, which is accomplished by the anterior craniotomy; a lateral cut, which is performed across the anterior zygoma; an inferior cut within the maxilla and below the foramen of the infraorbital nerve; and a medial cut lateral to the medial canthal tendon. The internal orbitotomies run around the inside of the globe from roof to lateral wall to floor to medial wall behind the lacrimal apparatus.

Facial Bipartition

Unlike the box osteotomy, the orbit is left connected to the maxilla, and the two sides are divided in the midline, with removal of a wedge of intervening bone. The tip of the wedge is oriented between the central incisors.

Positioning

Movement of the opposite sides of the face may be difficult despite completion of all of the osteotomies. To facilitate juxtaposition, a wire can be threaded between the two segments and twisted to provide sufficient force to gently approximate the segments.

Fixation

Plates are placed at the superior extent of the midline to minimize relapse. Once fixated, the wire may be removed. A cantilever bone graft is usually required for nasal dorsal support.

Maxillary Surgery (Le Fort Osteotomies)

Planning

Down-fracture and mobilization of the upper jaw is facilitated by using fixation on the teeth for leverage. Preoperative placement of orthodontic brackets and hooks (Fig. 28.9) avoids the need to place Erich arch bars at the beginning of the procedure, which can be

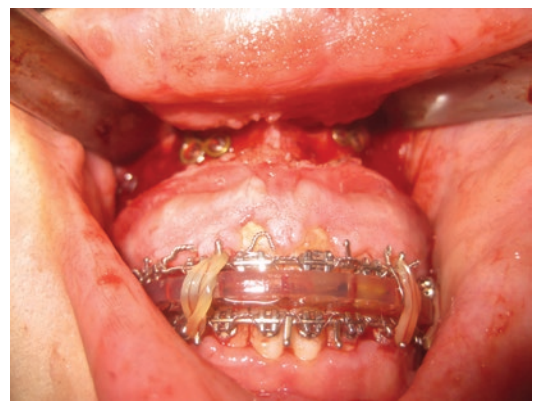

Fig. 28.9 Orthodontic brackets and hooks

time-consuming and more difficult to remove postoperatively.

Preparation

For procedures that require obtaining occlusion of the upper and lower jaws, a nasotracheal intubation is ideal. In this case, the tube should be sutured to the nasal septum and at the anterior hairline to minimize inadvertent extubation during the course of surgery. If this is not possible, the orotracheal tube can be pushed behind the retromolar trigone when the teeth are brought together or, more preferably, the tube can be brought out through a small incision in the submental crease. Early infiltration of the upper (and lower, if needed) gingivobuccal sulcus is important to minimize blood loss in orthognathic procedures. If the peri-orbital tissues are used for an approach, these should be infiltrated as well.

Dissection

Exposure of the anterior and lateral maxilla can be expeditious if the surgeon is cognizant of the key steps. The incision in the mucosa with a cutting cautery should be 5 mm above its reflection onto the alveolar ridge so that there is a sufficient cuff of tissue to utilize for closure at the end of the procedure. Dissection onto the bone can then be done with a coagulating cautery in the inferior aspect of the incision. With a periosteal elevator, it should continue around the lateral buttress to the pterygomaxillary plate, and within the medial aspect of the medial buttress inside the piriform aperture. This dissection should be careful not to injure the nasal mucosa but also be sufficient enough to allow placement of a reciprocating saw blade. The floor of the nasal cavity should similarly be dissected free of the overlying nasal mucosa to avoid injury by the saw and mobilization of the maxilla. This is best done with an extra-curved Freer-type elevator, since the floor of the nasal cavity travels inferiorly as it extends away from the piriform rim.

Osteotomy

Several specific cuts of the maxilla are required in order to down-fracture the inferior segment. The hemi-maxilla may be thought of as a square. An osteotomy needs to be made across the (1) anterior wall of the maxillary sinus, (2) the lateral buttress and lateral wall of the maxillary sinus, (3) the medial buttress and medial wall of the sinus, and (4) the pterygomaxillary plate posteriorly. A reciprocating saw is generally 10 mm in length and does not always reach the posterior wall of the maxilla. Completion of these medial and lateral buttress cuts can be completed with a straight-guarded nasal osteotome. The thinner posterior wall of the sinus can generally be separated with the down-fracture. For the anterior cut, care should be taken when passing the osteotome toward the nasotracheal tube on the side of the intubation. Each pterygoid plate is separated with a curved osteotome placed behind the molar teeth. Since this area is not well visualized, a gloved finger is placed on the lingual surface so that it can palpate the osteotomy *before* the mucosa is violated. Down-fracture should be performed by applying downward pressure on the bone just inferior to the osteotomy, *not* on the teeth or dental brackets. In many instances where the down-fracture is difficult, it is the area of the pterygoid plate that is not completely cut and should be redone.

Positioning

Although mobilized by down-fracture, it may be difficult to place the maxilla into its new position/occlusion. All bony encumbrances should be identified and removed with a rongeur. Some of these are able to be identified preoperatively with CAD-CAM planning and may be at any portion of the bony segments (Fig. 28.10). With all encumbrances removed, the use of looped elastic bands can be helpful to apply a continual force on the maxilla and loosen any soft tissue attachments that hinder ultimate desired occlusion.

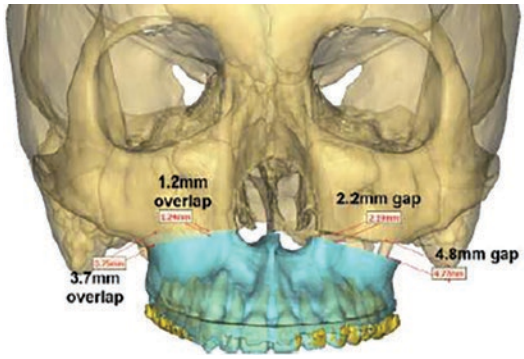

Fig. 28.10 CAD-CAM planning of the maxillary osteotomy

Fixation

Plates and screws should be placed in the region of the medial and lateral buttresses. A minimal amount of screws should be placed across the fracture line, and intermaxillary fixation released, to confirm proper occlusion. Once confirmed, the remainder of the screws should be placed for more stable fixation. In this way, space is not wasted on holes that might have been made improperly. The jaws should come into the desired occlusion without difficulty by simply ranging the mandible into the maxilla. If it does not, the fixation should be removed and redone.

Mandibular Surgery (Sagittal Split Osteotomies, Intraoral Vertical Ramus Osteotomies)

Planning

Similar to maxillary surgery, preoperative placement of orthodontic brackets and hooks (Fig. 28.10) for orthognathic surgery avoids the need to place Erich arch bars on the patient in order to achieve bony movement.

Preparation

Surgery on the mandible requires the ability to obtain occlusion, so nasotracheal intubation is required. The tube should be sutured to the nasal septum and anterior forehead. Early infiltration of the lower gingivobuccal sulcus is important to minimize blood loss.

Dissection

Portions of the medial and lateral ramus and lateral body of the mandible require dissection to perform a sagittal split osteotomy of the mandible. Again, an incision in the gingivobuccal sulcus is made 5 mm lateral to its reflection onto the bone from the mid-ramus to the region of the second molar. Subperiosteal dissection is performed using a periosteal elevator, exposing the lateral mandibular body. The mucosal incision can then be extended superiorly, exposing the external oblique ridge and the medial aspect of the mandibular ramus. During this portion of dissection, the mental nerve should be identified at its foramen. Additionally, a J-stripper can be used to release the attachments of the pterygo-masseteric sling from the inferior border of the mandible. While thorough subperiosteal dissection aids in visualization, periosteal attachments preserve blood supply, and thus dissection should be limited appropriately. Alternatively, a similar incision is required if performing a vertical ramus osteotomy, with subperiosteal dissection exposing the lateral ramus. During this dissection, the local of the antilingula should be noted, as this serves as an approximate location of the mandibular foramen.

Osteotomy of the Mandible

The sagittal split osteotomy will traverse from the medial ramus, down the anterior ramus, along the oblique ridge, and onto the lateral body of the mandible. The osteotomes should be directed laterally so as to minimize involvement of the cancellous bone and avoid traversing the canal of the alveolar nerve (Fig. 28.11). Bony separation is carried out with osteotomes directed superiorly to inferiorly. It can be helpful to leave osteotomes in place once they cut the inferior surface of the

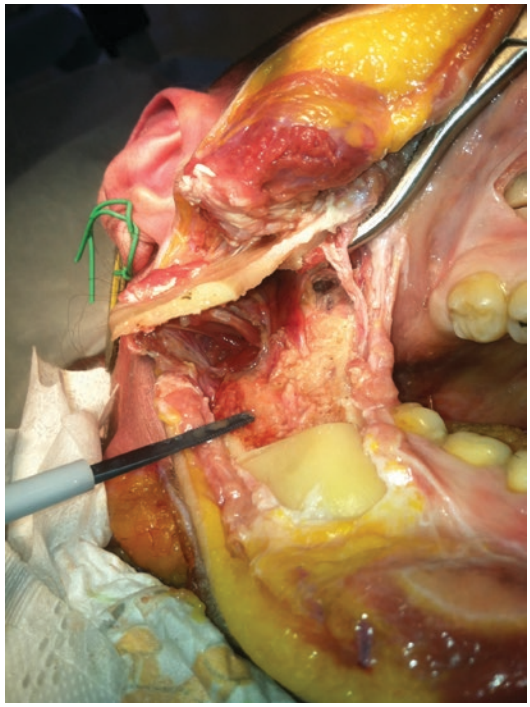

Fig. 28.11 Position of the alveolar nerve within the mandible

mandible while another is used in a subsequent segment of bone. For the vertical ramus osteotomy, careful attention must be paid to the location of the osteotomy, as the mandibular foramen is not directly visualized. As mentioned above, the antilingula on the lateral ramus serves as an approximate marker for the mandibular foramen. The osteotomy is performed posterior to the mandibular foramen with an oscillating saw, from the sigmoid notch to the inferior border of the mandible.

Fixation

Numerous fixation methods have been described for fixation of the segments for sagittal split of the mandible [8–10]. Three or more bicortical screws may be placed at the inferior and superior regions of bone. On account of the length of the screws, either an angled screwdriver or a transbuccal trocar will likely be needed. Plates across the lateral surface of the segments are usually monocortical to avoid injury to the alveolar nerve. These may be placed through the gingivobuccal incision with standard instruments. When performing an intraoral vertical ramus osteotomy, rigid fixation is not required. Rather, the patient remains in intermaxillary fixation for 6 weeks, allowing for bony union.

Conclusion

For each procedure within the specialty of craniofacial surgery, whether during infancy or childhood or even later in adulthood, there are surgical hurdles that must be recognized and overcome. The anatomy is unique but lends itself to successful manipulation if the surgeon has mastered the techniques of craniofacial surgery. And while the procedures are time-consuming and challenging, they can be completed expeditiously without unnecessary errors if there is meticulous attention to detail.

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Orthognathic Surgery

29

Alexis Tashima and Donald R. Mackay

Introduction

Orthognathic surgery requires a well-orchestrated combination of surgery and orthodontics in order to optimally treat dento-facial deformities. Dento-facial deformities result from growth modifications seen in either the maxilla or mandible, in a single dimension or multiple dimensions during development. The overall objective of treatment is to achieve proper, stable class I occlusion and to improve soft tissue aesthetics. In addition to aesthetic concerns, important functional considerations play a role in orthognathic surgical planning. Issues with mastication, lip incompetence, speech difficulties, spitting, oral hygiene, or TMJ function must all be considered. The psychosocial impact of dento-facial deformities is harder to define or quantify; however, the patient's confidence and satisfaction with appearance should be part of the discussion held with their surgeon. Recent advances in preoperative planning, including virtual surgical planning, can guide treatment and improve efficiency. The three osteotomies discussed in this chapter include the Le Fort I type osteotomy, the bilateral sagittal split osteotomy of the mandible, and the osseous genioplasty, which will address most dento-facial deformities.

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Patient Evaluation

Evaluation of a new patient should begin with general medical history in addition to dental history. The patient's psychosocial history, including social support system, plays a role in their ability to be compliant postoperatively and to cope with the stress of surgery.

The surgeon will work closely with the patient's orthodontist in defining the deformity and establishing a treatment plan. In examination of the patient, the surgeon can quickly establish whether the patient has an Angle class I, II, or III deformity. It is vital to evaluate not only the occlusion but also the facial skeleton. For example, differentiating between mandibular excess versus maxillary deficiency, or a combination of both, is necessary for treatment planning (Fig. 29.1). Paranasal flattening or malar flattening can indicate a deficient maxilla, for example. Additional evaluation of the tongue is necessary in the setting of mandibular excess. A large tongue with evidence of indentations from the teeth should serve as a warning sign that a bilateral sagittal split osteotomy with a mandibular setback may crowd the airway. In this setting, a Le Fort I osteotomy with maxillary advancement

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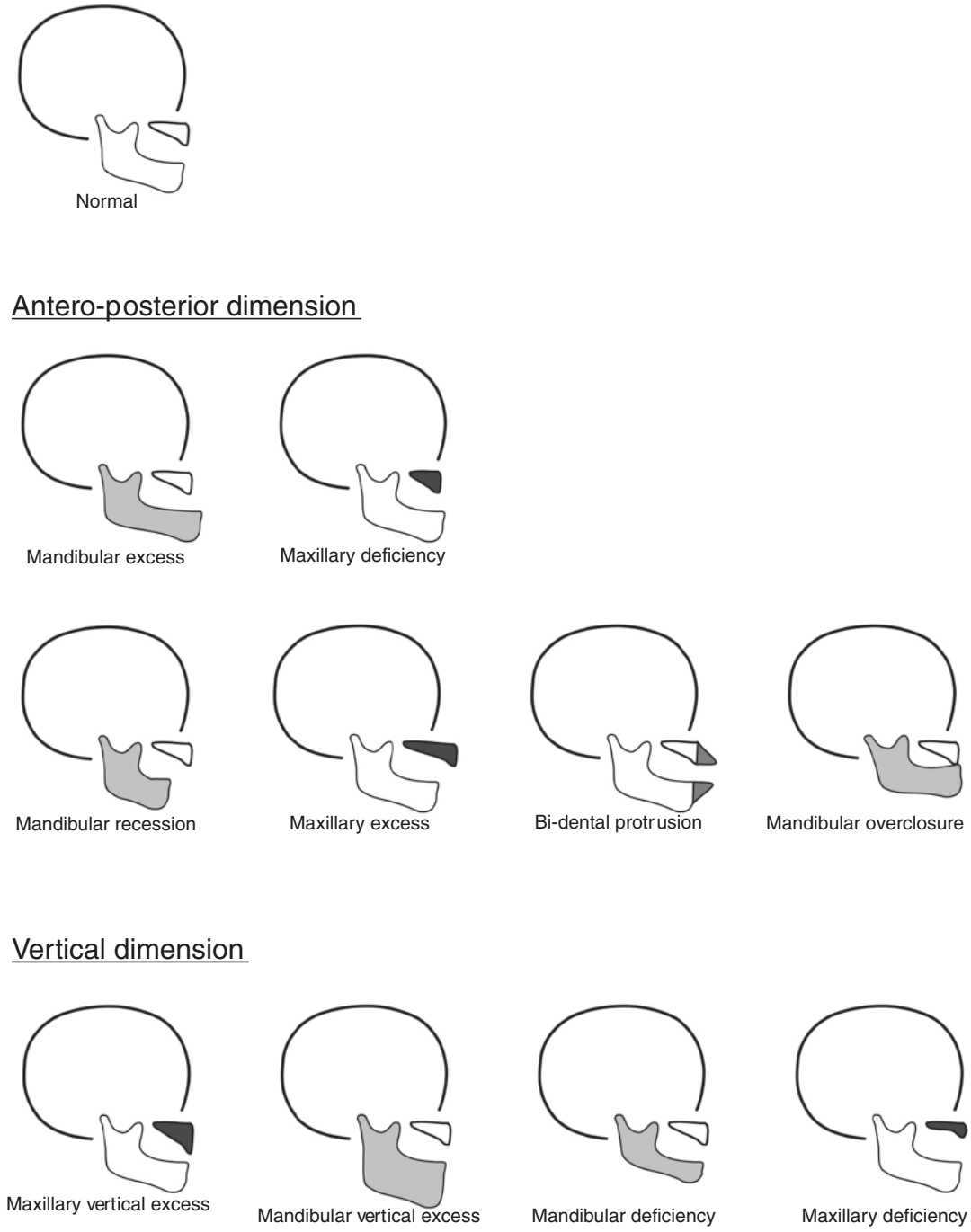

Fig. 29.1 Deformity of the facial skeleton in the anteroposterior dimension and vertical dimension

may be the better solution to correct the deformity.

Radiographic studies are integral to evaluating the patient and preoperative planning. Panorex and AP and lateral cephalometrics allow for evaluation of dentition and facial skeletal relationships.

The sagittal cephalometric analysis will give us vital information, including the following. The relationship of the maxilla to the skull base is identified by the angle between the sella, nasion, and point A (Fig. 29.2). The relationship of the mandible to the skull base is identified by the angle between the sella, nasion, and point B (Fig. 29.3). The relationship of the maxilla to the mandible or the angle between point A, nasion, and point B can then be determined (Fig. 29.4). The position of the maxillary incisors to the bony base of the maxilla, or the angle between axis of the maxillary central incisor to the point A, nasion perpendicular can also be defined (Fig. 29.5). The position of the mandibular incisors to the bony base of the mandible (angle between the axis of the mandibular central incisor to the mandibular plane angle) can also be identified (Fig. 29.6).

The vertical cephalometric analysis provides the upper facial height (UFH) nasion to anterior nasal spine (ANS), in addition to the lower facial height (LFH) (ANS to menton) allowing the ratio of the UFH to LFH to be identified (Fig. 29.7). The vertical cephalometric analysis also allows

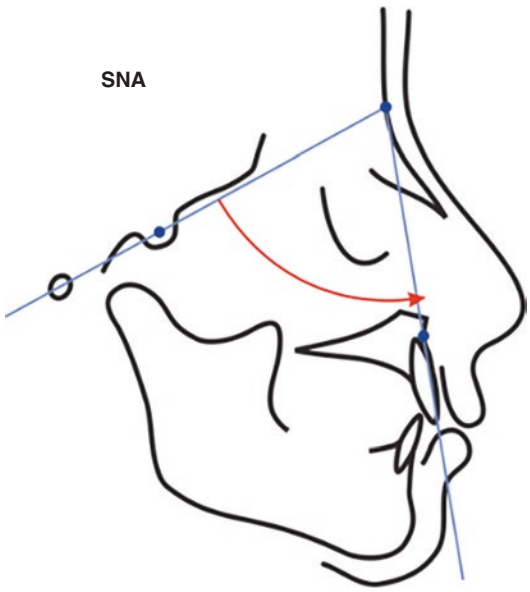

Fig. 29.2 The angle between Sella–Nasion–A point (SNA) indicates the horizontal position of the maxilla relative to the cranial base

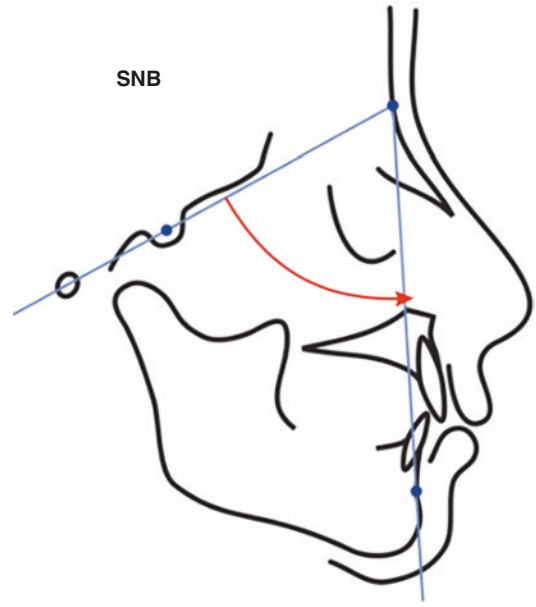

Fig. 29.3 The angle between Sella–Nasion–B point (SNB) indicates the horizontal position of the mandible relative to the cranial base

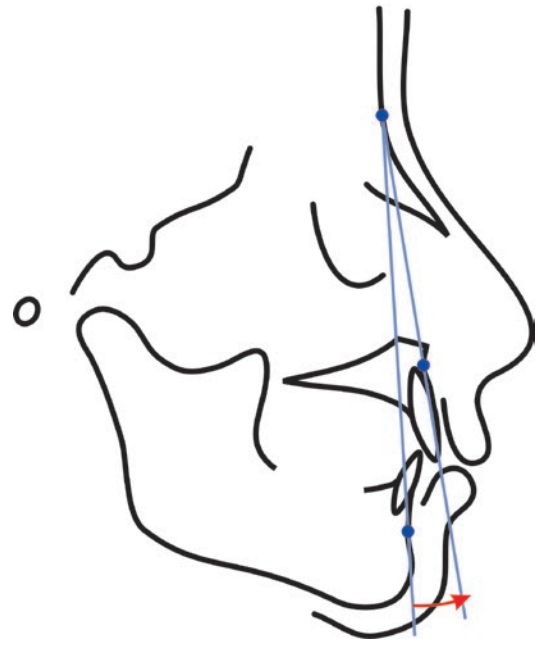

Fig. 29.4 The relative position of the maxilla to the mandible is measured by the angle between A point–Nasion–B point (ANB). An angle measuring >5° Class II, maxillary excess or retrognathic mandible. An angle measuring <1° Class III, deficient maxilla or prognathic mandible

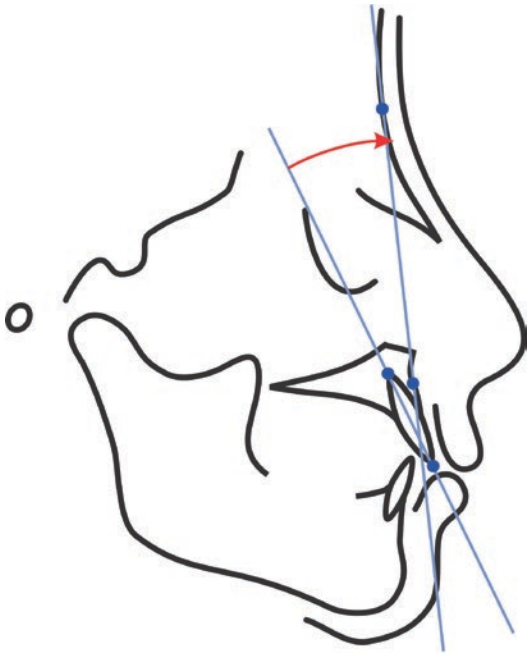

Fig. 29.5 The position of the maxillary incisors to the bony base of the maxilla (angle between axis of the maxillary central incisor to the point A, nasion perpendicular)

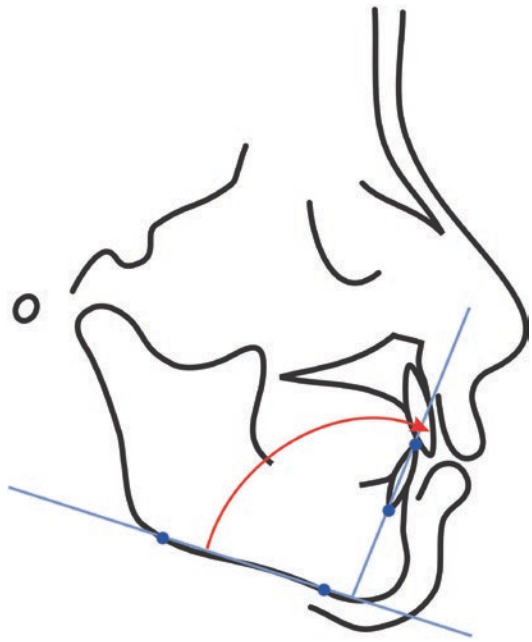

Fig. 29.6 The position of the mandibular incisors to the bony base of the mandible (angle between the axis of the mandibular central incisor to the mandibular plane angle)

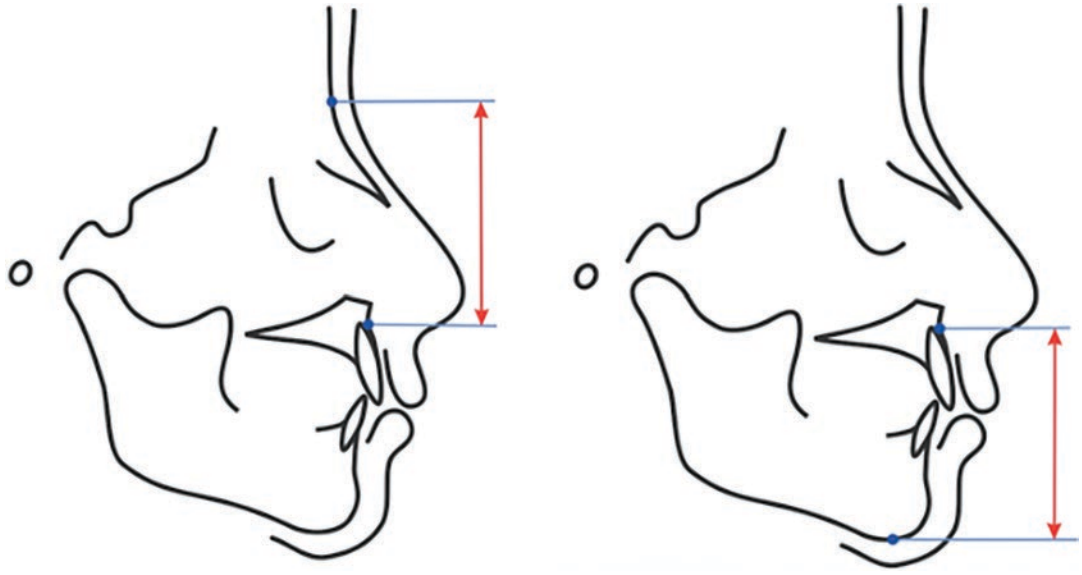

Fig. 29.7 Upper facial height, UFH (nasion to anterior nasal spine (ANS)), the lower facial height, LFH (ANS to menton) allows for comparing the ratio of UFH to LFH

for measurement of the symphysial height (mandible incisor tip to menton) (Fig. 29.8).

The above measurements are then compared to the normal range, as a picture of the abnormal dento-facial deformity emerges. For example, one can then decipher whether a class III abnormality is due to a maxillary deficiency or a mandibular excess.

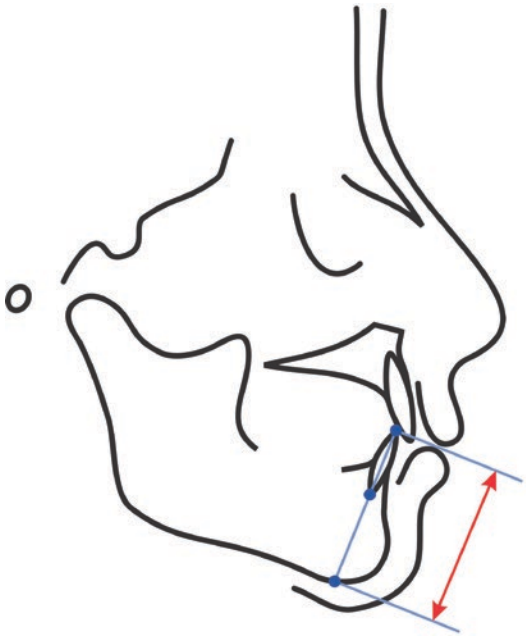

Fig. 29.8 Symphysial height (mandible incisor tip to menton)

Virtual Surgical Preoperative Planning

One of the most progressive areas of advancement in regard to orthognathic surgery has been the addition of virtual surgical planning. Using computer-aided design/computer-aided manufacturing (CAD/CAM) to formulate proposed osteotomies and bony movements, as well as to fabricate splints, has proven to save time and provide a less costly alternative to standard planning techniques [1, 2]. Additionally, differences in three-dimensional measurements between virtual surgical planning and postoperative results have been shown to have minimal significant deviation, proving that virtual surgical planning and CAD/CAM-fabricated splints produce accurate and reliable surgical outcomes [3–6]. The growing popularity of virtual surgical planning does shift the task of preoperative planning from the hands of the clinicians to the computer technicians, presenting an interesting paradigm shift. However, given the decrease in time for preoperative splint planning, fabrication time, and proven accuracy, virtual surgical planning has proven very useful in treating these patients [7] (Figs. 29.9, and 29.10).

Virtual surgical planning will take on an even greater role as the soft tissue predictions become more reliable. One can imagine planning to an ideal aesthetic soft tissue profile and then work-

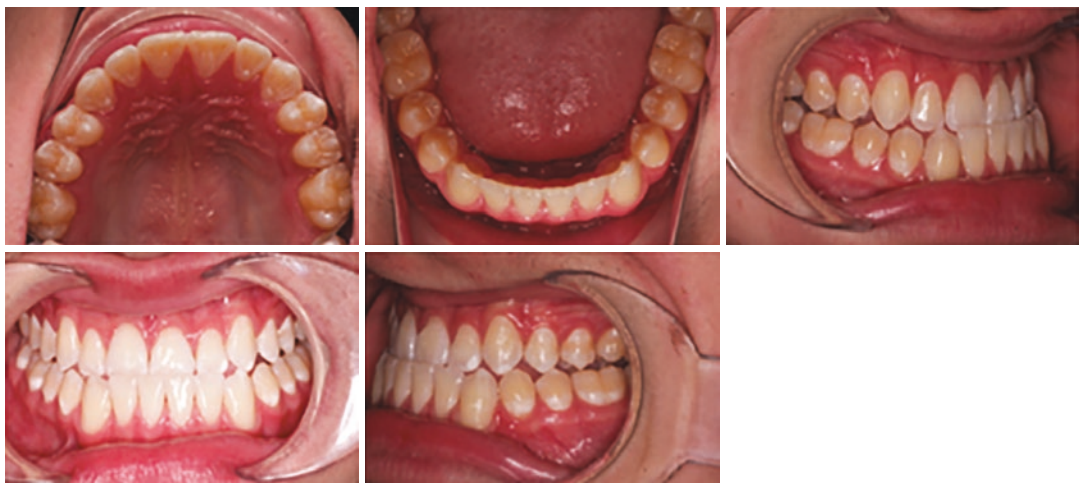

Fig. 29.9 Preoperative images of Class III malocclusion secondary to mandibular excess

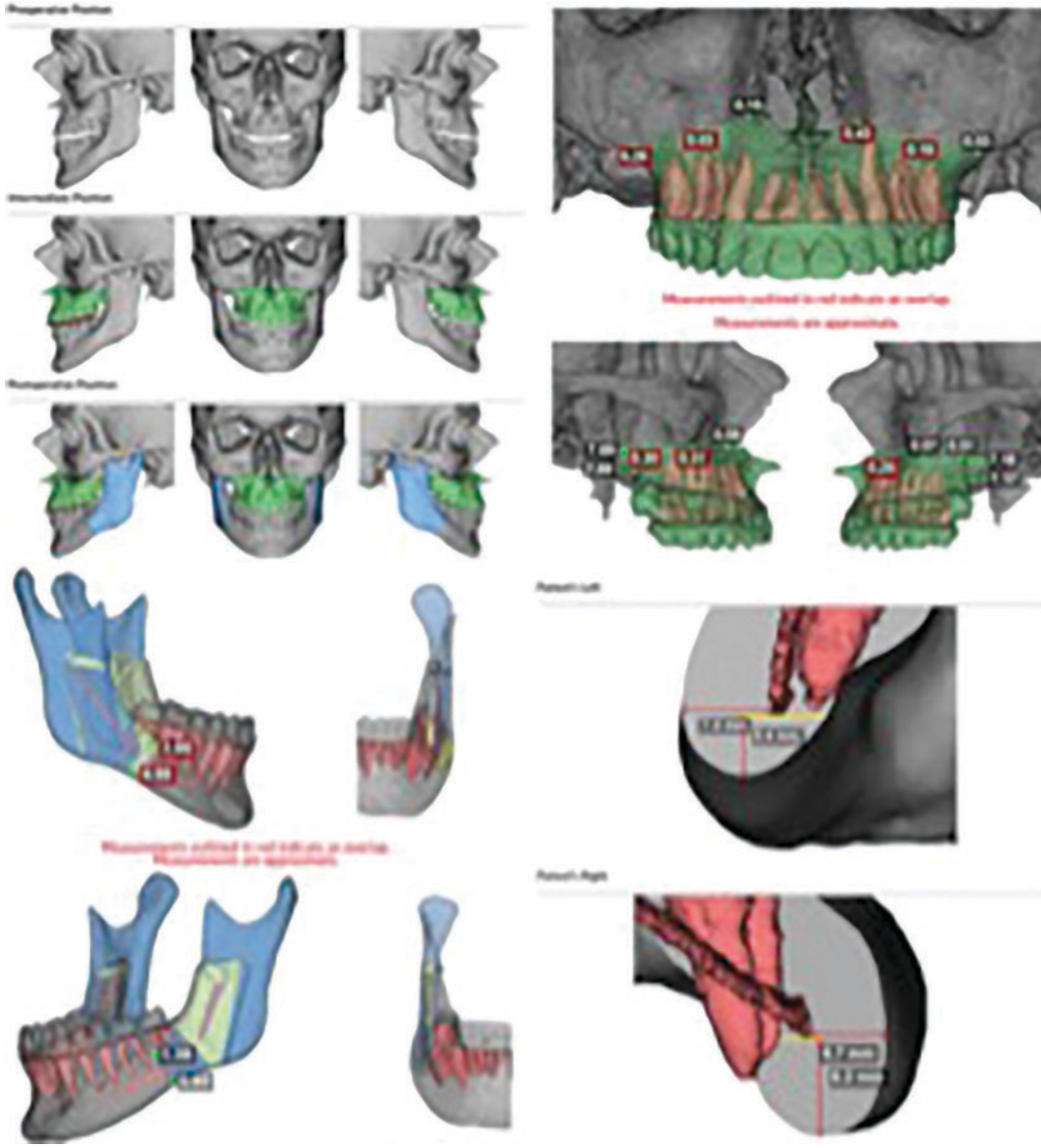

Fig. 29.10 CAD/CAM 3D imaging allows for planned osteotomies and movement. Note mapping of the tooth roots and course of inferior alveolar nerve to avoid injury

ing backwards to see what needs to be altered in the skeletal framework in order to achieve that profile.

Sequence and Timing

Appropriate timing of orthognathic surgery relies on accurate determination of skeletal maturity in the patient. Radiographic evaluation of the distal radius is a well-established method of determining skeletal maturity [8]. However, this requires additional imaging for this purpose. Alternatively, skeletal maturity and peak in mandibular growth can be detected based on the analysis of the second, third, and fourth cervical vertebrae visible in cephalogram typically obtained for preoperative planning [9]. This has been proven to be a reliable method for determining skeletal maturity, and does not require additional imaging for the patient [10].

Patients may undergo orthognathic surgical treatment either prior to their orthodontics or following orthodontic correction [11]. In majority of cases, it is preferred to correct any dental compensations prior to orthognathic surgery. However, teeth are more mobile after surgery, and therefore performing some postoperative orthodontic corrections is becoming more common. Timing of third molar extraction is also a consideration when planning surgery. Extraction prior to surgery should be performed to allow several months of bone healing. Concurrent extraction of third molars can be performed at the time of bilateral sagittal split osteotomy without any increased rate of complications [12].

Some controversy exists in regard to doing the maxilla or mandible first. Sequencing is based on preoperative planning and model surgery with creation of an intermediate splint. If only one jaw is being repositioned, a final splint can be fabricated to establish occlusion. In the case of both maxillary and mandibular repositioning, an intermediate splint is used and can be fashioned to allow for movement of the maxilla or the mandible first, depending on surgeon preference. Many surgeons perform the mandibular corticotomies first followed by the Le Fort I osteotomies and repositioning, before returning to convert the mandibular corticotomies to osteotomies and repositioning the mandible. This allows for easy exposure to visualize the mandible to perform the corticotomies without concern for altering the position of a previously plated maxilla during exposure. Returning to complete the osteotomies requires less wide mouth opening for exposure and less likelihood of unintentional malposition of the maxilla [13]. However, given the added time and lack of issues with malposition of the maxilla with mandibular exposure, the author prefers to complete the Le Fort I osteotomy and maxilla repositioning followed by the mandibular osteotomies and repositioning.

Soft Tissue Consideration

While the goal of orthognathic surgery is a harmony between stable occlusion and aesthetics, ultimately, aesthetics should not be sacrificed for occlusion [14]. However, understanding the expected affect that modifications to the bony skeleton will have on the soft tissue is vital. In the case of maxillary advancement, the nasal tip has been shown to advance 30% and the upper lip is expected to shorten 10–20%. With mandibular setback, the soft tissue of the chin is expected to move 90–100% of the setback, the lower lip moves only slightly, and an increase in neck fullness is expected. The accuracy of CAD/CAM soft tissue predictions in response to bony movements is improving, but it cannot be considered reliable in all cases [15].

Normative data for all orthognathic soft measurements is largely based on North American Caucasians and do not reflect ideal bony and soft tissue ideals of most population groups. Evaluating a patient's soft tissue profile and aesthetic goals should be the starting point for orthognathic surgical planning. Ultimately, we should be able to reliably predict an "ideal" soft tissue profile and work backwards to see what bony movement is needed to achieve this aesthetic goal.

Le Fort I Osteotomy

Tips

- Ensure that the occlusal splits fit before surgery.
- Ensure you have an adequate cuff of soft tissue above the teeth. This makes closure easier and improves perfusion of the maxilla.
- Make sure the pterygomaxillary disjunction osteotome is positioned just behind the maxillary tuberosity and not too high.
- Do not use any force greater that your thumb pressure to complete the osteotomy. Use Smith spreaders gently along the osteotomy lines to identify where the osteotomy needs to be completed. This is often posteriorly. Use the disjunction osteotome to protect the maxillary artery as you complete the osteotomy either with a fine osteotome

or a piezo saw, which is what the author prefers.
- Remember to trim the caudal septum and even the inferior turbinates, if needed, when performing a maxillary impaction.
- Always place an alar base cinch suture before closing the soft tissue.

Le Fort I osteotomy, performed either as a single piece or with segmental osteotomies, allows for a variety of adjustments to be made to the maxilla. In the anterior-posterior direction, the maxilla can be advanced as a single piece or in multiple pieces, depending on other needed adjustments. In order to set back the maxilla, segmental osteotomy is usually necessary. The height of the mid-face can be increased by down-grafting the maxilla [16], or decreased with intrusion of the maxillary segment. Width can also be adjusted with the use of segmental osteotomy to increase the width, and tooth extraction is often necessary to achieve a decrease in width. Additionally, the position of the upper lip, nasal tip, columella labial angle, and alar base can be altered with a Le Fort I osteotomy.

In the operating room the patient is placed in a supine position on the operating table. General anesthesia is induced and a nasotracheal tube is placed to secure the airway. The tube is sutured through the caudal nasal cartilaginous septum using a silk suture to ensure placement of the tube does not become disrupted during surgery. The tube is then taped to the forehead and operating table using flexible foam tape with foam padding to protect the skin of the forehead. Care must be taken to avoid pressure injury to the nasal ala (Fig. 29.11).

Measurements are then made to determine the vertical distance from the medial canthus to the maxillary arch wire on the central incisors, lateral incisors, and canines bilaterally. These measurements are referenced later when evaluating the vertical position of the maxilla.

Local anesthetic in the form of 1% lidocaine with epinephrine 1:100,000 is then infiltrated into the surgical area. The patient is then prepped and draped to include the forehead superiorly and clavicle inferiorly.

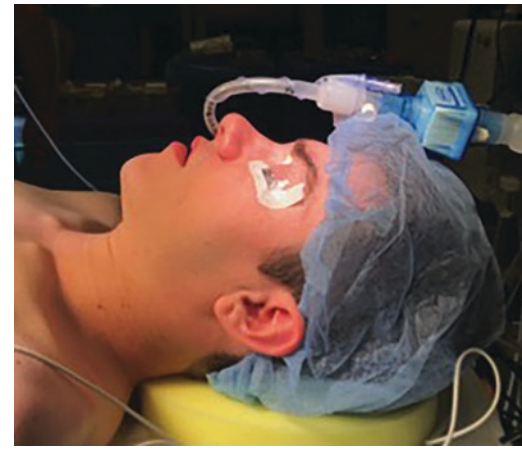

Fig. 29.11 Le Fort I: Nasotracheal intubation with airway secured through the cartilaginous septum and the scalp to avoid distortion or pressure on the nasal ala

Careful placement of the intra-oral upper buccal sulcus incision is vital to allow both adequate exposure and ease of closure. A cuff of detached mucosa at least 5 mm in length should be left when designing the incision. Special consideration in bilateral cleft patients is needed to protect the blood supply to the gingiva in the midline, and therefore the mucosa in the midline is left intact, effectively making two separate incisions lateral to the midline.

Dissection is then carried down to the periosteum with electrocautery. Adequate exposure of the maxilla can be achieved using a periosteal elevator, taking care to identify and avoid injury to the infraorbital nerve. A curved elevator allows for elevation of the nasal mucosa from the pyriform aperture and anterior nasal spine (Fig. 29.12).

The osteotomy is then designed by first marking with pencil the horizontal cut starting from the pyriform aperture and extending posteriorly above the teeth roots, posteriorly to the pterygomaxillary junction, and laterally just inferior to the infraorbital nerve. Where a maxillary advancement and simultaneous downgraft is planned, the horizontal osteotomy can be angled superiorly passing just under the infraorbital nerve. A vertical component then carries the osteotomy inferiorly before the posterior horizontal osteotomy is completed above the roots of the

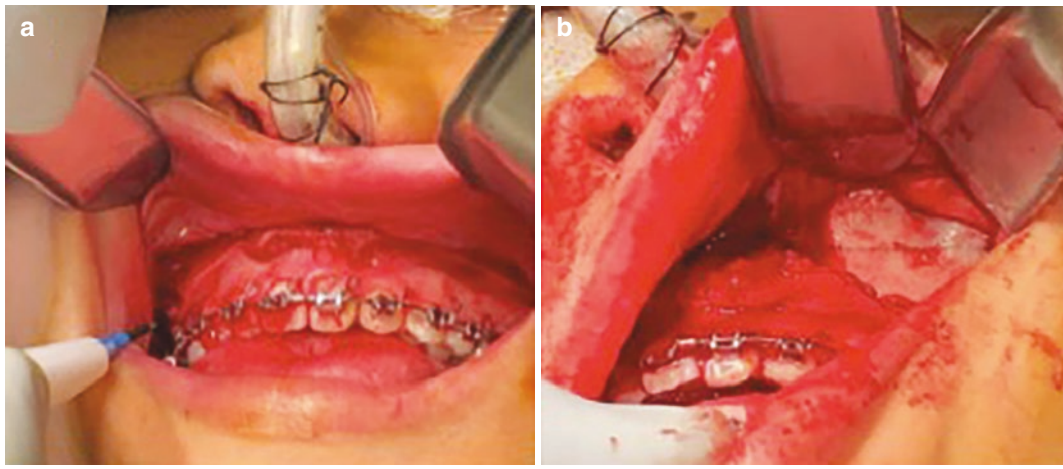

Fig. 29.12 Le Fort I. (**a**) The incisions is made above the attached gingiva, leaving a cuff of at least 5 mm of unattached gingiva for closure. (**b**) Subperiosteal dissection is completed to expose and protect the infraorbital nerve

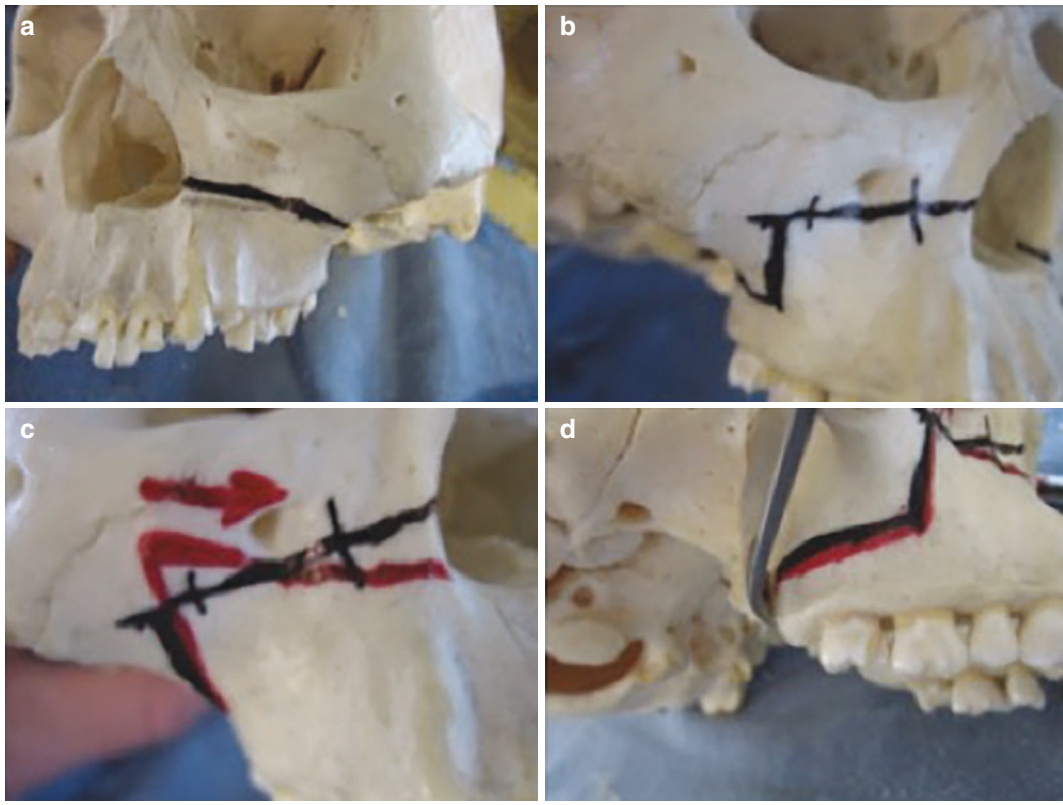

Fig. 29.13 Le Fort I. (**a**, **b**) Design of the osteotomy taking into account the tooth roots and infraorbital nerve. (**c**, **d**) Modification of the horizontal osteotomy angled to allow for advancement and down grafting of the maxilla without bone graft

posterior molars. This allows for advancement and down grafting of the maxilla without requiring bone graft to achieve bony contact after movement (Fig. 29.13).

Traditionally, osteotomies are performed using an oscillating saw. However, the author prefers using a piezoelectric saw which seems to be more precise, causes less severe nerve damage, and has less postoperative swelling and discomfort [17–20].

A curved osteotome is used to complete the osteotomy in the pterygomaxillary recess, separating the pterygoid plate from the maxillary tuberosity. Care must be taken to protect the area behind the maxillary tuberosity when completing the osteotomies to prevent damage to the maxillary artery and venous plexus in the area (Fig. 29.14). Palpating with a finger behind the maxillary tuberosity allows for confirmation of separation and control while performing the pterygomaxillary disjunction. A guarded osteotome is used to separate the septum and vomer from the maxilla. Straight osteotomes or a piezo saw are also used to complete osteotomies along the lateral nasal wall bilaterally (Fig. 29.15). Down fracture is completed with digital pressure only in a controlled manner, with minimal force applied to the base of the pyriform aperture. Maxillary disimpaction forceps are used for soft tissue mobilization only, and not for down fracture, to avoid skull base injury or unfavorable fractures. In the setting of intrusions, the septum and turbinates are trimmed to avoid buckling of the septum and deviation of the nose.

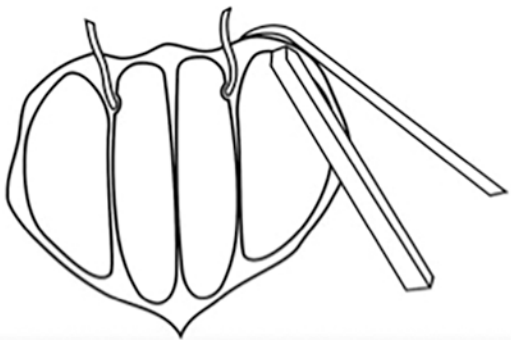

Fig. 29.14 Le Fort I. Curved osteotome used to complete the osteotomy in the pterygomaxillary recess, separating the pterygoid plate from the maxillary tuberosity while protecting blood supply

Once the maxilla is freely mobile and soft tissue has been adequately freed to allow for movement, the position of the maxilla is then adjusted according to preoperatively planned movements. At this point, interdental and palatal osteotomies can be performed if a multi-segmented adjustment is indicated.

The new occlusion is established using the prefabricated splint, which is held in place using elastic bands between the upper and lower surgical hooks. Once occlusion is confirmed in the splint, the maxillary–mandibular complex is adjusted as a unit. The complex rotates on an arc determined by the rotation the condyles in the glenoid fossa. The vertical measurements from the medial canthus to the maxillary arch wires obtained at the start of the operation are used to confirm the desired vertical height. This is crucial to achieving the ideal relationship or show of the upper incisors to the upper lip. The maxilla is then plated in the desired position using the appropriate plates to achieve stability (Fig. 29.16). Following plating, the maxillary-mandibular fixation is removed, and occlusion is verified by assuring that the condyle is in the fossa and that the mandibular teeth swing easily into the splint. If this is not the case, the plates should be removed and adjusted until the planned occlusion is achieved.

In the case of maxillary advancements and impactions, the base of the nasal ala widens, and an alar base cinch suture is placed to prevent this. The soft tissue is then closed with a running absorbable suture. A mucosal V-Y advancement of the upper lip in the midline will ensure adequate lip length.

Necrosis of the bony segment is a rare complication, but is most commonly seen in the central maxillary bony segment in patients with bilateral cleft lip and palate [21, 22]. Taking care to leave midline mucosa intact when performing the upper buccal sulcus incision is important in order to best preserve the blood supply to the central maxillary bony segment. In addition to the alar cinch suture, it is important to trim the inferior septum when impacting the maxilla. Failure to do so will distort the septum and nasal tip [23].

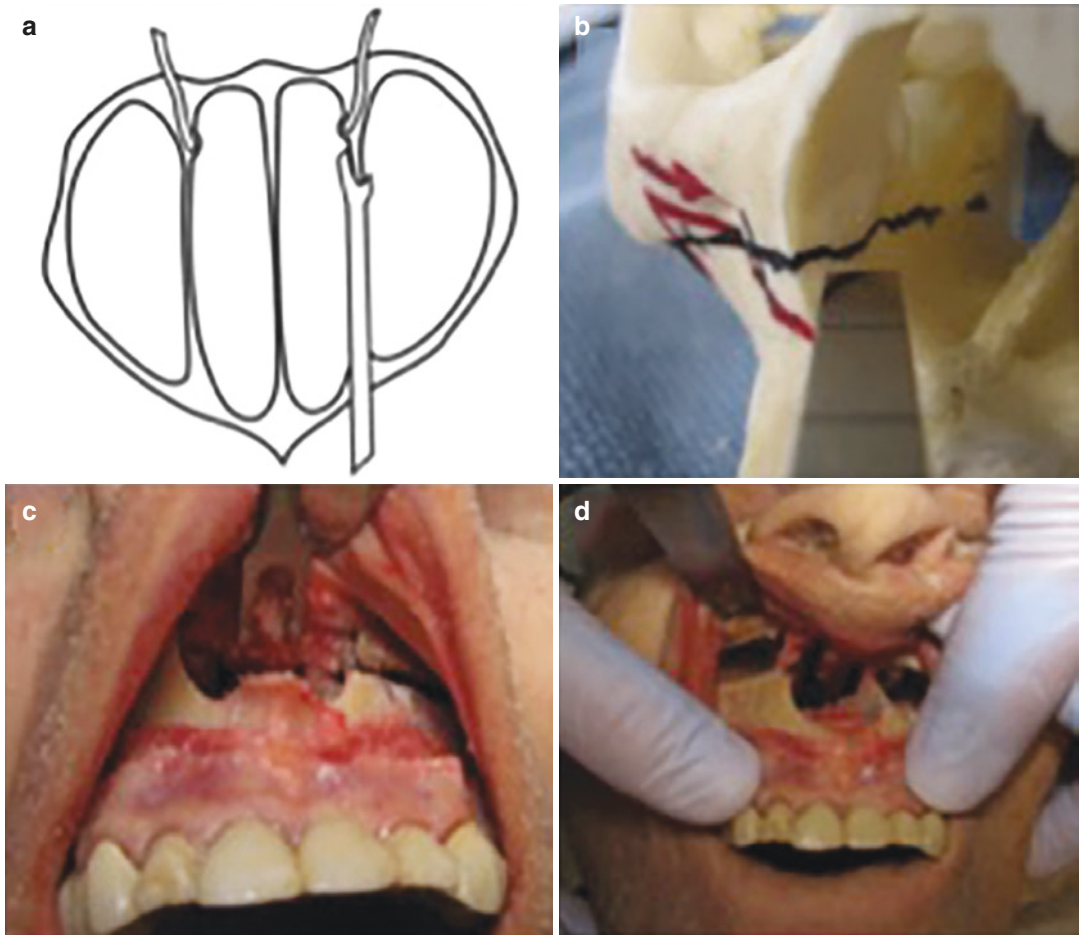

Fig. 29.15 Le Fort I. (**a**, **b**). Straight, guarded osteotome used to complete osteotomies along the lateral nasal wall bilaterally. (**c**) Guarded osteotome for separation of septum. (**d**) Down fracture with digital pressure only

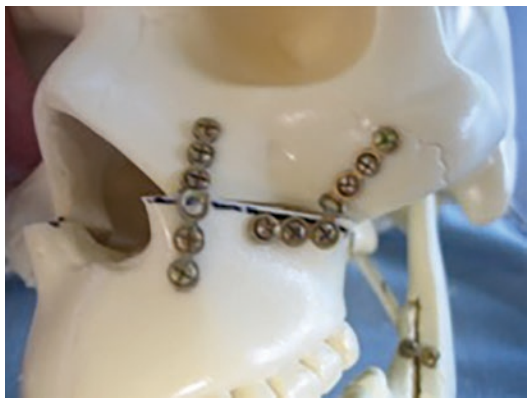

Fig. 29.16 Le Fort I: Plating of the maxilla along the nasomaxillary and zygomaticomaxillary buttress

Sagittal Split Ramus Osteotomy

Tips

- Placing the mucosal incision a little farther medially than conventional wisdom suggests makes the medal dissection easier.
- Make sure you are above the lingula by visualizing the inferior alveolar nerve before performing the medial osteotomy.
- Carry the medial corticotomy posteriorly to the depression posterior to the lingula.

- Make sure your osteotomies have gone through the full thickness of the cortex.
- Ensure that you have completed the osteotomy through the full thickness of the lower border of the mandible anteriorly. Use a channel retractor to protect the soft tissue when doing this.
- Place a large fiber handle osteotome in osteotomy cut along the external oblique ridge and give it one or two sharp blows with a mallet to commence the split. This is a very effective maneuver when all the initial osteotomies have been completed.
- Check that the inferior alveolar nerve is in the distal segment as you complete the split. It may be necessary to dissect the nerve free from the lateral wall of the proximal segment of the mandible with an osteotome to achieve this.
- Make sure the condyle is seated in the glenoid. Tell you assistant to "push the chin toward the occiput" while the rigid fixation is secured.
- Check the occlusion after fixation by removing the elastic bands. If the teeth do not fit into the splint with minimal pressure, remove fixation to correct the position.
- Pre-op planning and communication with your orthodontist is key.
- Additional changes to the nasal morphology can be observed in the case of inadequate reduction of the nasal septum, resulting in nasal deviation. Once again, care must be taken to reduce the septum in the setting of maxillary impaction to prevent deviation.

Sagittal split ramus osteotomy (SSRO) of the mandible allows for adjustments in the anterior-posterior dimension, including advancement and set-back of the mandible. The height and width cannot be adjusted as they can with a Le Fort I osteotomy. However, asymmetries affecting the occlusal cant can be adjusted to level the occlusal plane.

Local anesthetic in the form of 1% lidocaine with epinephrine 1:100,000 is infiltrated into the surgical field. The incision is made along the mandibular ramus from the level of the lingual, passing laterally along the extern al oblique ridge to the level of the first molar. The author makes the ramus incision more medial than is commonly described. It makes the medial dissection above the lingula easier and allows for better visualization of the inferior alveolar nerve. An adequate cuff of tissue must be left along the gingiva for closure. Dissection in a subperiosteal plane exposes the anterior ramus and lateral boarder of the mandible. Dissection of the ramus requires elevating the lower fibrous attachment of the temporalis upward toward the coronoid. The medial dissection in a subperiosteal plane is performed above the level of the occlusion. The lingula should be identified, and the inferior alveolar nerve must be visualized as in enters the foramen above the lingula (Fig. 29.17).

The horizontal osteotomy along the medial border of the ramus is made first above and posterior to the mandibular foramen. The nerve is visualized, and location confirmed prior to making the medial osteotomy. Piezo saw or Linderman burr is used to make this horizontal osteotomy through the cortex, approximately half the thickness of the bone. It is important to carry this osteotomy into depression behind the lingula. It is not necessary to carry the osteotomy all the way to the posterior edge of the ramus (Fig. 29.18).

The osteotomy then continues just medial to the external oblique ridge of the mandible downward and forward to the level of the first molar (Fig. 29.19). The lateral osteotomy is made vertically from the upper osteotomy down to the inferior border of the mandible through the cortical bone. The osteotomy must then be completed across the full thickness of the inferior border of the mandible to ensure a successful split of the mandible (Fig. 29.20). The author uses a piezo saw for all of these osteotomies. The split of the mandible is completed using osteotomes angled toward the lateral cortex to protect the nerve. The

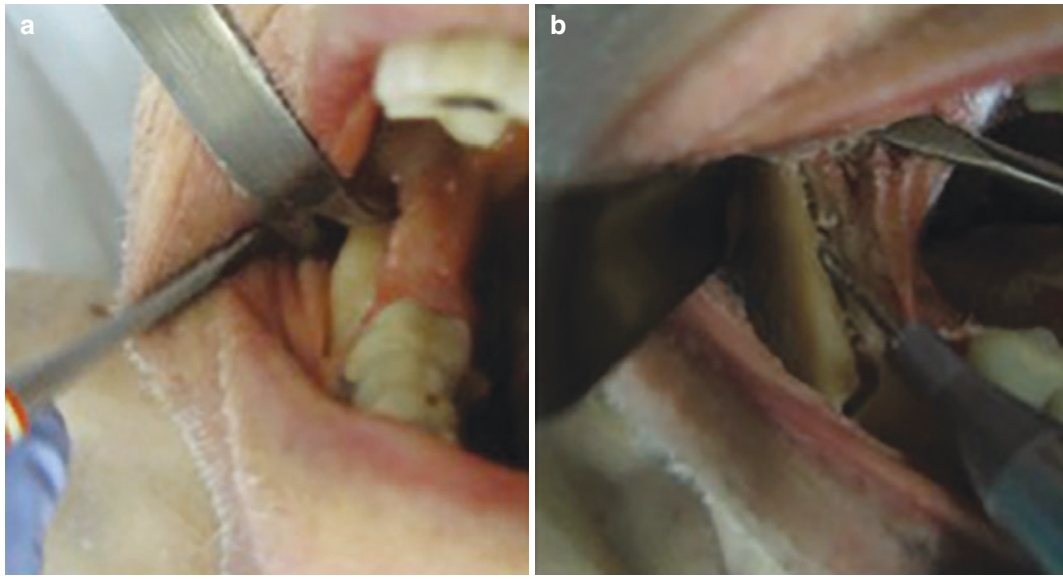

Fig. 29.17 Bilateral sagittal split osteotomy of the mandible. (**a**) Incision lateral to the attached gingiva. Exposure in the subperiosteal plane. (**b**) Osteotomy performed along the oblique ridge

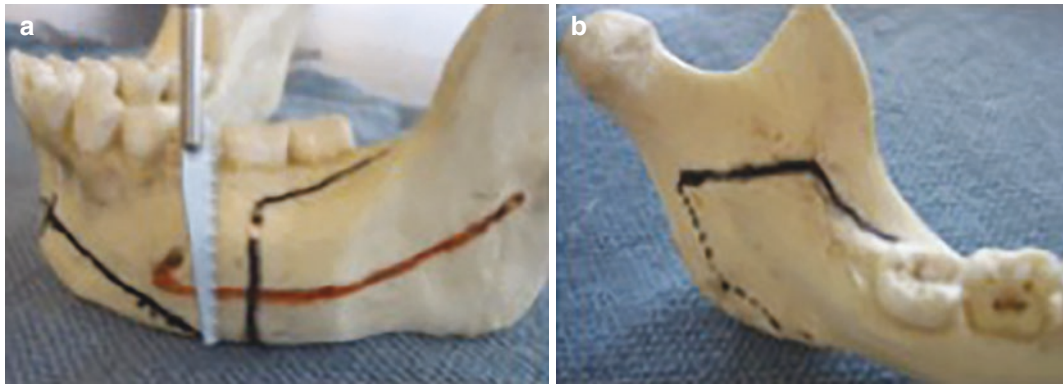

Fig. 29.18 Bilateral sagittal split osteotomy of the mandible. (**a**) Design of the osteotomy taking into account the location of the inferior alveolar nerve. (**b**) Horizontal osteotomy along medial ramus

nerve is visualized after the split, and care is taken to leave the nerve within the medial segment (Fig. 29.21). Some degree of decreased sensation in the lower lip is almost inevitable in these cases; visualizing and protecting the nerve minimizes the damage [24].

When the mandible is being set back, the medial pterygoid muscle and stylomandibular ligament must be released from their medial attachments. The correct occlusion and appropriate bony position is aided by placing the teeth in the prefabricated splint and placing elastic bands between the surgical hooks on the mandibular and maxillary orthodontic wires. Bony fixation is achieved with bicortical screws through transbuccal trocar access, or with lateral buccal plates and monocortical screws. The condyles must be seated during fixation. To ensure this, the elastic bands are removed and the occlusion checked before the elastic bands are replaced. If the occlusion is not correct, the rigid fixation is removed, and the process is repeated (Figs. 29.22, and 29.23).

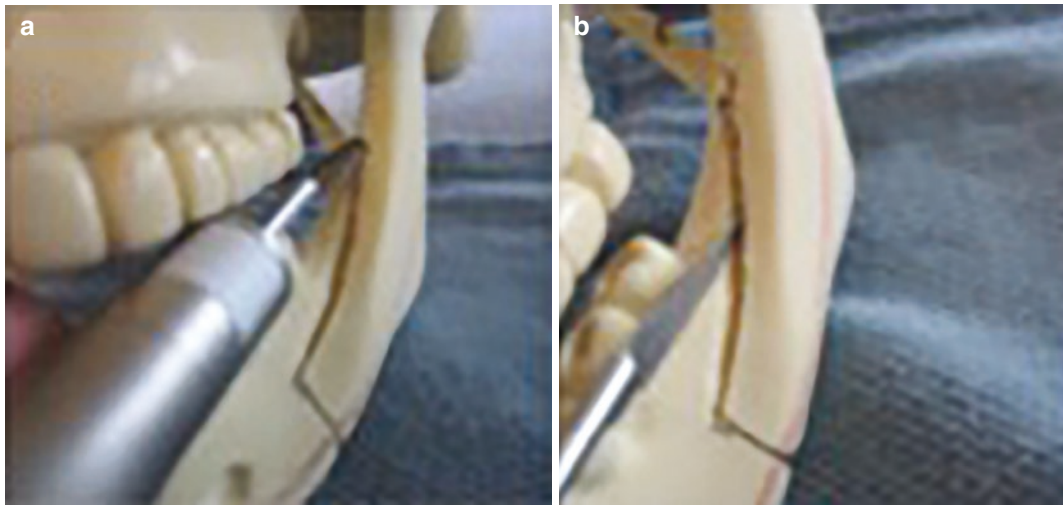

Fig. 29.19 Bilateral sagittal split osteotomy of the mandible. (**a**, **b**) Oscillating saw used to complete osteotomy allow oblique ridge

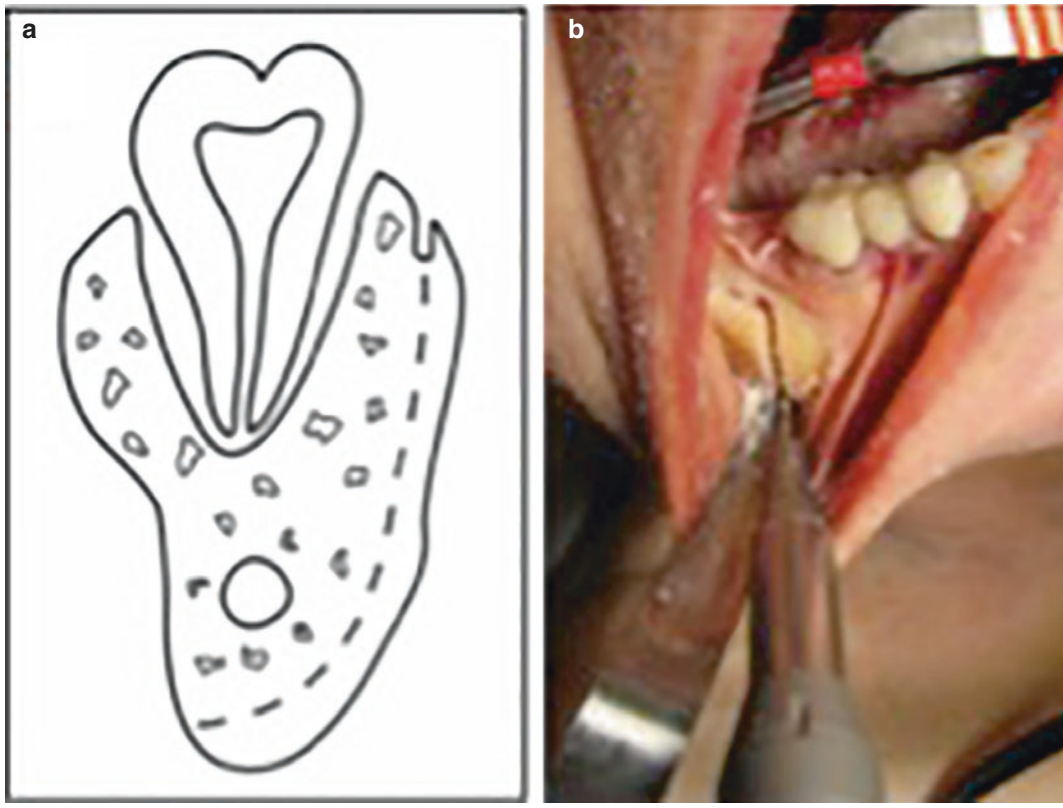

Fig. 29.20 Bilateral sagittal split osteotomy of the mandible. (**a**) Angle of osteotomy through cancellous bone to protect nerve. (**b**) Completion of vertical osteotomy along inferior border of mandible

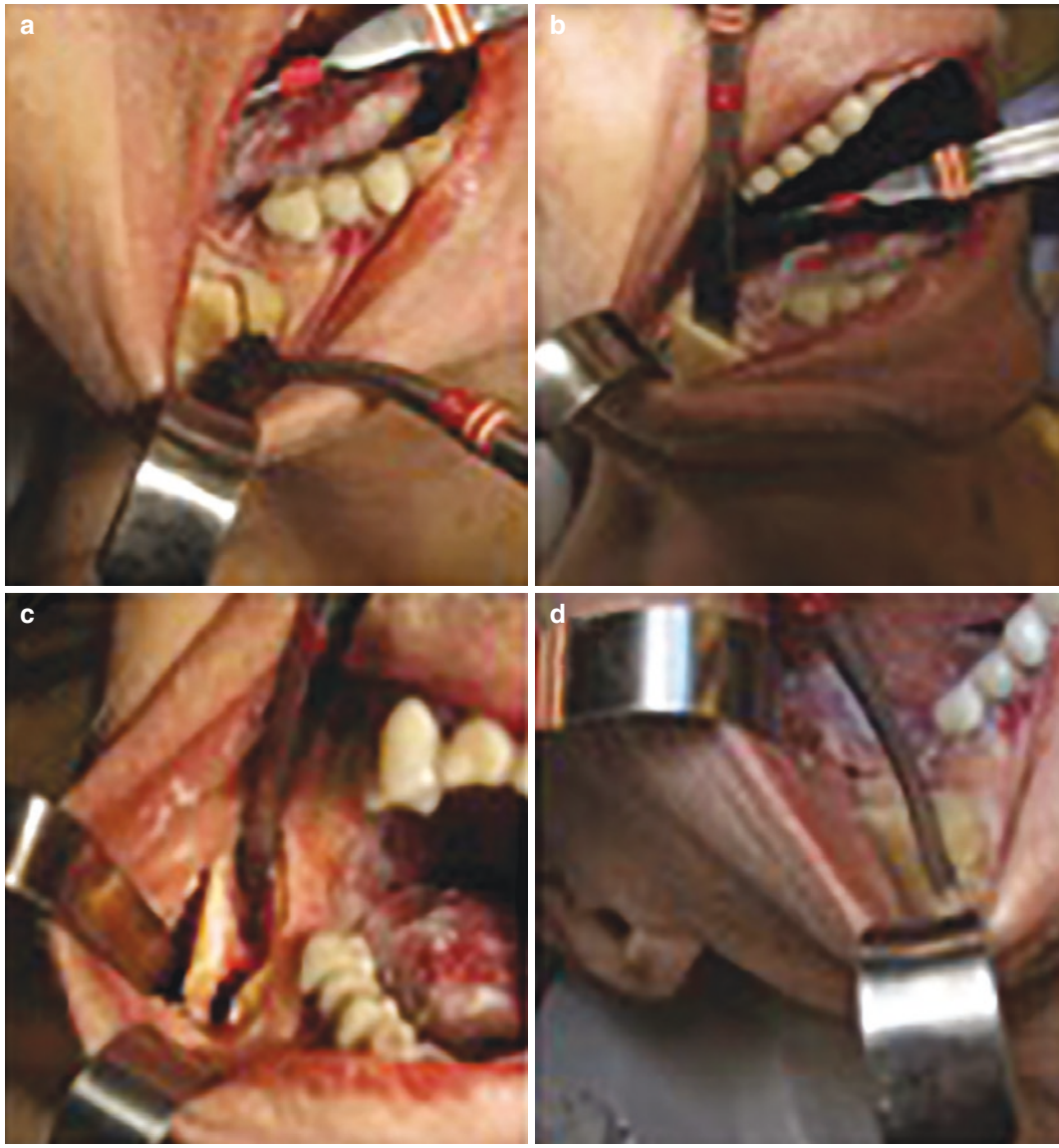

Fig. 29.21 Bilateral sagittal split osteotomy of the mandible. (**a**, **d**) Completion of osteotomy along inferior border with straight osteotome. (**b**) Straight osteotome used to complete osteotomy along body of mandible. (**c**) Visualization of the nerve during split

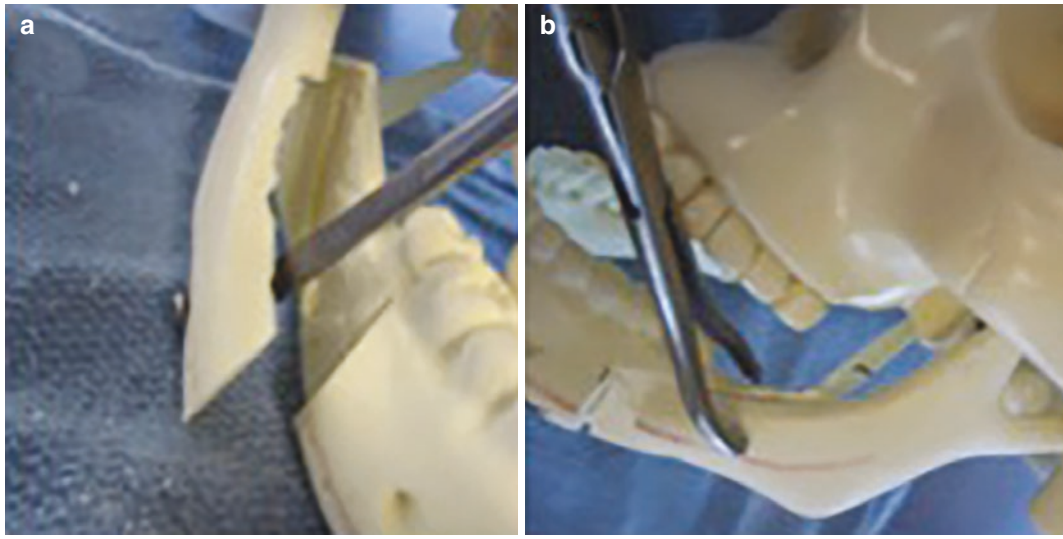

Fig. 29.22 Bilateral sagittal split osteotomy of the mandible. (**a**) Confirm mobility of proximal and distal segments of the split. (**b**) Secure movement for fixation

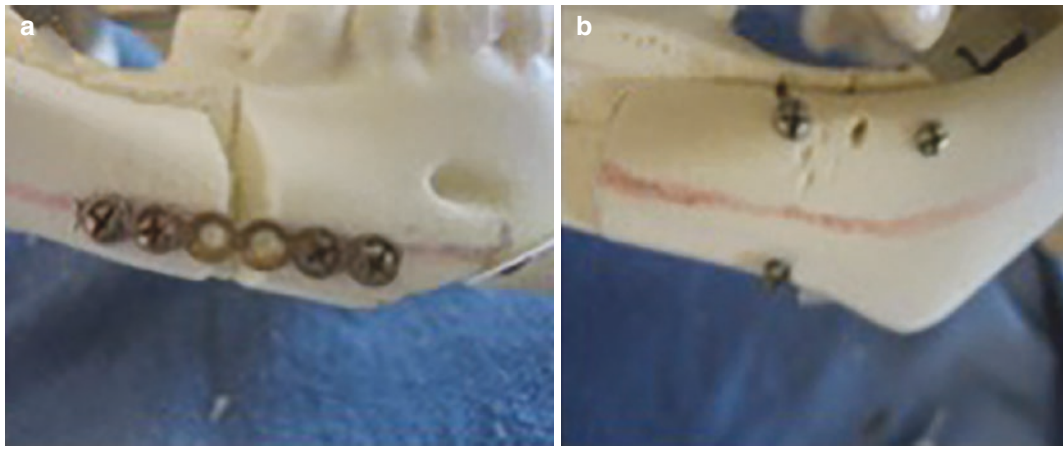

Fig. 29.23 Bilateral sagittal split osteotomy of the mandible. (**a**) Fixation of mandible with plates and monocortical screws. (**b**) Fixation with bicortical screws

Genioplasty

Tips

- Leave an adequate cuff of mucosa and muscle for closure.
- Do not "over-dissect" soft tissue and muscle over the chin.
- Visualize the mental nerve and protect it. Remember the nerve lies up to 5 mm below the mental foramen.
- Ensure your osteotomy line is below the tooth roots.
- Minimize a visual "step-off" on the inferior border of the mandible by carrying the osteotomy further posteriorly.

Evaluation of the chin position is important when considering overall facial appearance and harmony. Deformities of the chin can exist separately from deformities of the mandible. Genioplasty can be performed to address a need for advancement or setback in the anterior/posterior plane in addition to adjusting the height or width of the chin as needed. Asymmetries of the chin can also be addressed when performing a genioplasty by adjusting for sagittal or horizontal deformities.

An intra-oral incision in the buccal sulcus is made, leaving a generous cuff of mucosa and mentalis muscle to facilitate closure. A subperiosteal dissection allows sufficient exposure of the proposed osteotomy. An effort should be made to avoid over-dissecting the soft tissue and muscle over the chin, in order to prevent soft tissue descent and a "witches chin" deformity. The mental nerve should be visualized and protected before performing the osteotomy.

The osteotomy is then designed, taking into consideration the tooth roots with the canine length measuring 30 mm, as well as the course of the mental nerve as it travels inferior and distal to the foramen prior to exiting the bone (Fig. 29.24). The midline of the chin is then marked using a saw. The osteotomy is then performed using a piezo, an oscillating, or a sagittal saw.

Fixation of the bony segment can be achieved with prefabricated plates or using tricortical screws. Again, care must be taken to avoid damage to tooth roots when placing screws for fixation. The mentalis muscle should be re-approximated as a separate layer to avoid soft tissue ptosis, and the mucosal incision is then closed as a separate layer (Fig. 29.25).

Clinical Cases

Case 1

A 20-year-old male with a history of a bilateral cleft lip and palate underwent an 8 mm advancement and 4 mm downgraft to achieve this result (Figs. 29.26 and 29.27) with a stable class I occlusion.

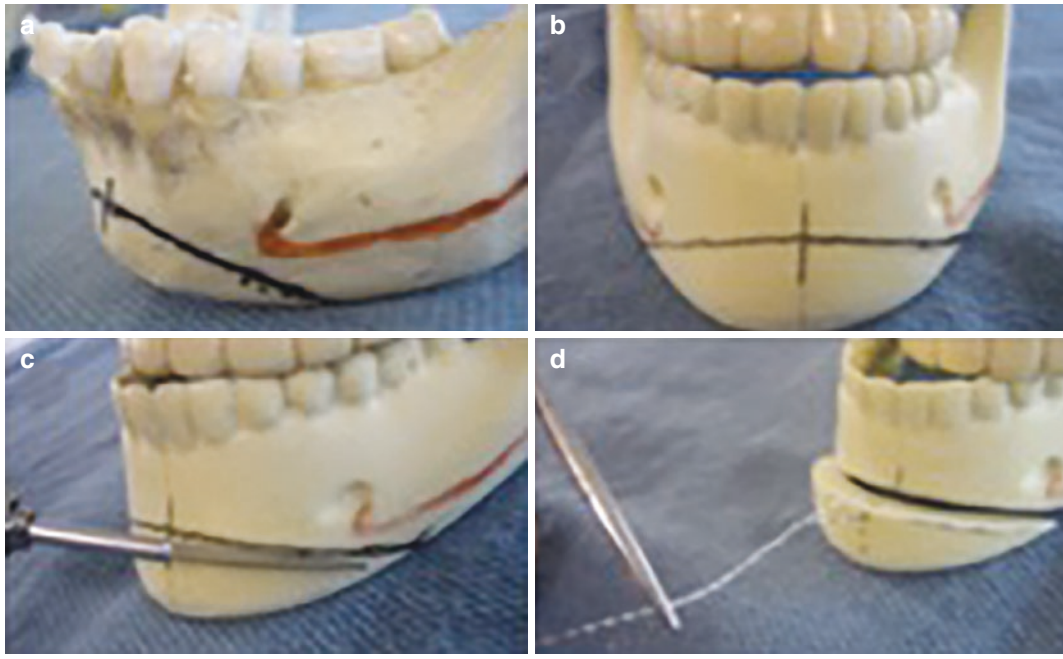

Fig. 29.24 Genioplasty. (**a**) Design of osteotomy taking into account the course of the mental nerve. (**b**) Osteotomy design, midline marked. (**c**) Oscillating saw used for osteotomy. (**d**) Wire placed following completion of osteotomy to assist with manipulation and fixation

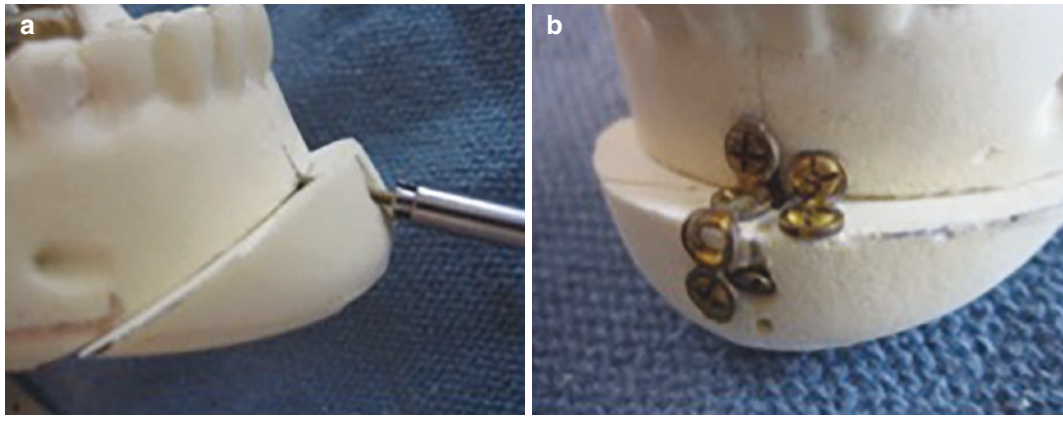

Fig. 29.25 Genioplasty. (**a**) Fixation after advancement with screw. (**b**) Fixation with customized bent plate

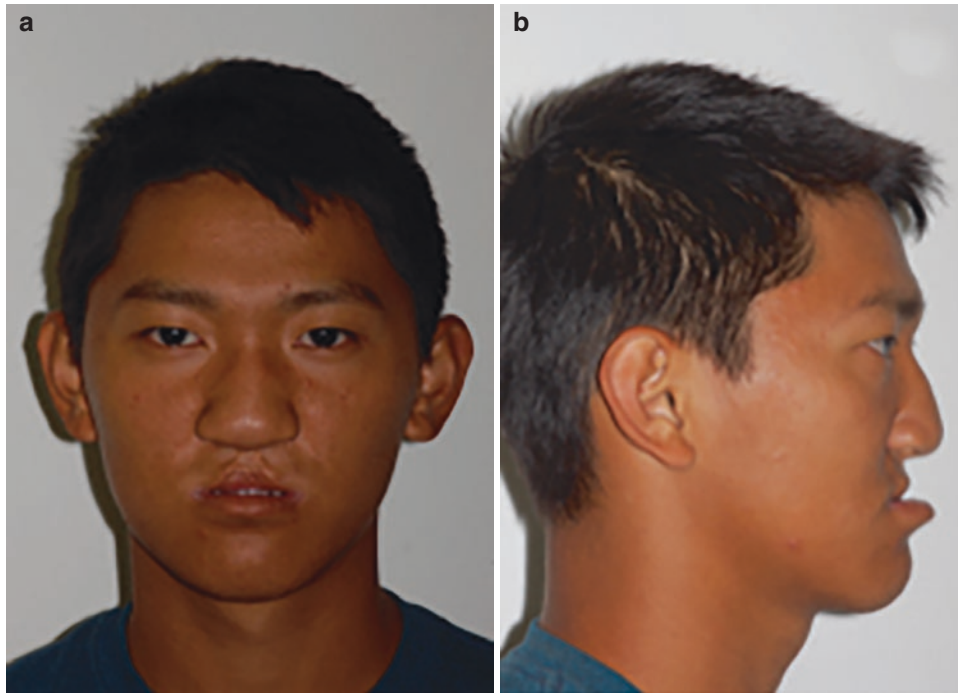

Fig. 29.26 Clinical case 1. (**a**, **b**) Patient with history of bilateral cleft lip and palate with Class III malocclusion and maxillary hypoplasia preoperatively. (C, D) Postoperative photos show status post Le Fort I osteotomy and maxillary advancement

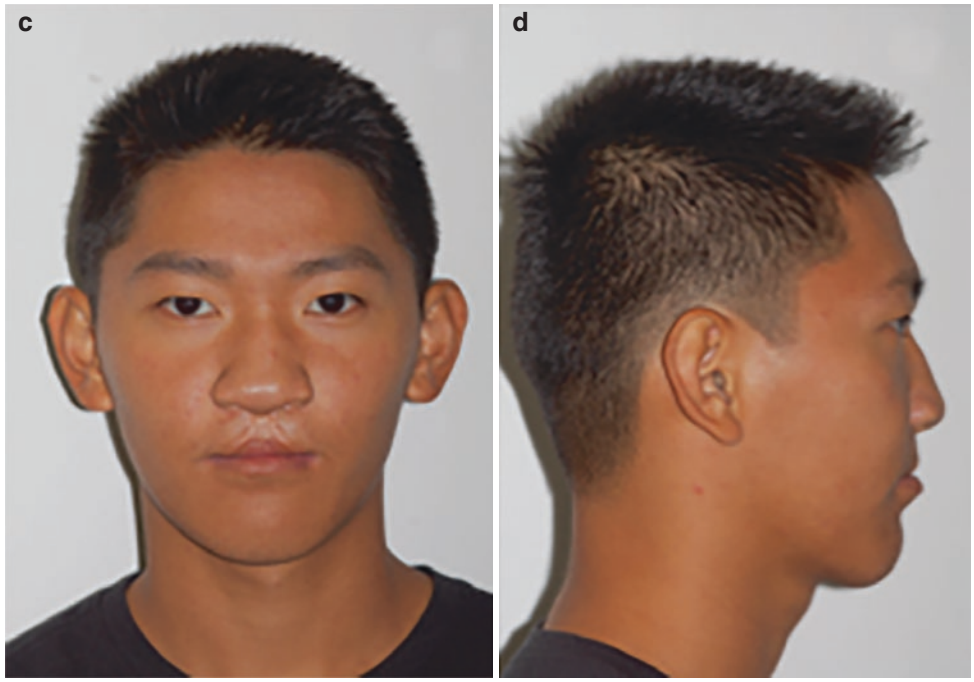

Fig. 29.26 (continued)

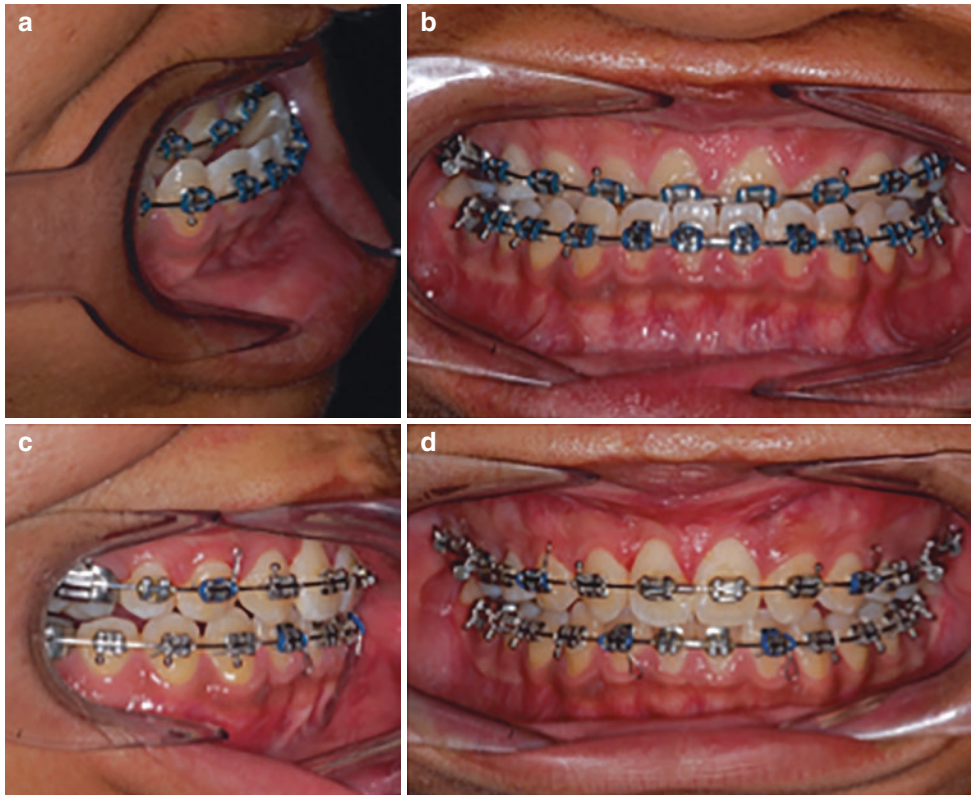

Fig. 29.27 (**a**, **b**) Same patient as Fig. 29.26 with history of bilateral cleft lip and palate with Class III malocclusion and maxillary hypoplasia pre-operatively. (**c**, **d**) Postoperative Class I occlusion status post Le Fort I osteotomy and maxillary advancement

Case 2

A 21-year-old male with a severe Class III dentofacial deformity due to a combination of maxillary deficiency and mandibular excess (Fig. 29.28). The surgical plan included a 10 mm Le Fort I advancement with a 4 mm downgraft and a 2.5 mm mandibular setback with a BSSO. Planning to get the maximal movement

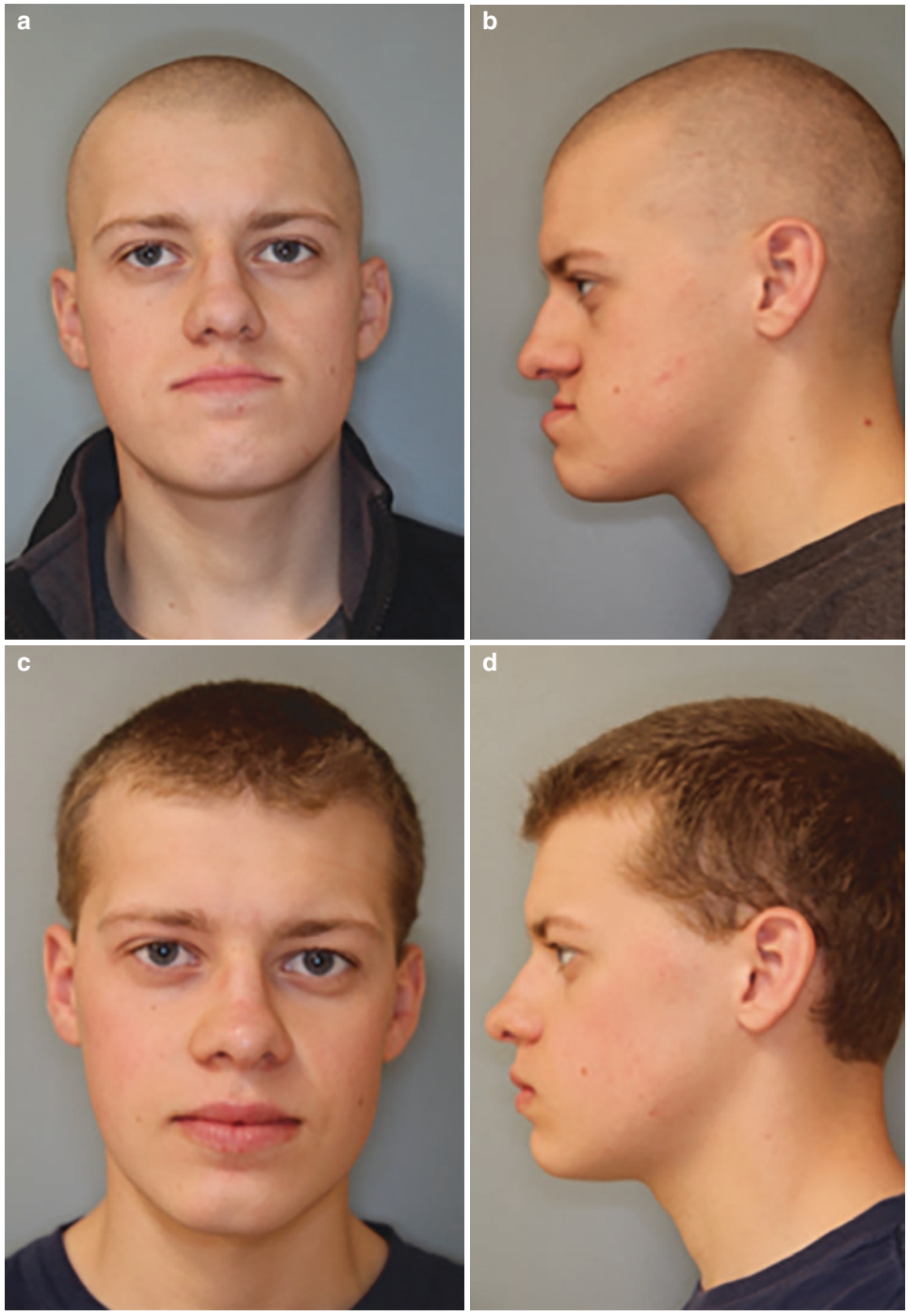

Fig. 29.28 Clinical case 2. (**a**, **b**) Patient with Class III malocclusion related to a combination of maxillary deficiency and mandibular excess, preoperative photos. (**c**, **d**) Postoperative photos following a Le Fort I osteotomy and maxillary advancement and bilateral sagittal split osteotomy with mandibular setback

with the maxilla gives a good aesthetic outcome by advancing the midfacial and paranasal soft tissue. The downgraft lengthens the foreshortened midface, and by autorotating the mandible, decreases prognathism. The extent of the mandibular setback is also reduced. In this case it only required a 2.5 mm setback.

This case illustrates an important principle. Where possible, you should expand the facial skeleton. Conventional wisdom would have suggested that a greater setback of the mandible with the BSSO would be appropriate. Doing so would have resulted in a fuller submental soft tissue profile, which is undesirable. He would also not have had the same improvement in the midface soft tissue profile.

Case 3

An 18-year-old male with another severe Class III dentofacial deformity due to a combination of maxillary deficiency and mandibular excess in both horizontal and vertical dimensions. The patient had a 9 mm Le Fort I advancement and 3 mm downgraft, together with a 6 mm BSSO setback. He also had a genioplasty with a 2 mm height reduction and 4 mm setback (Figs. 29.29 and 29.30).

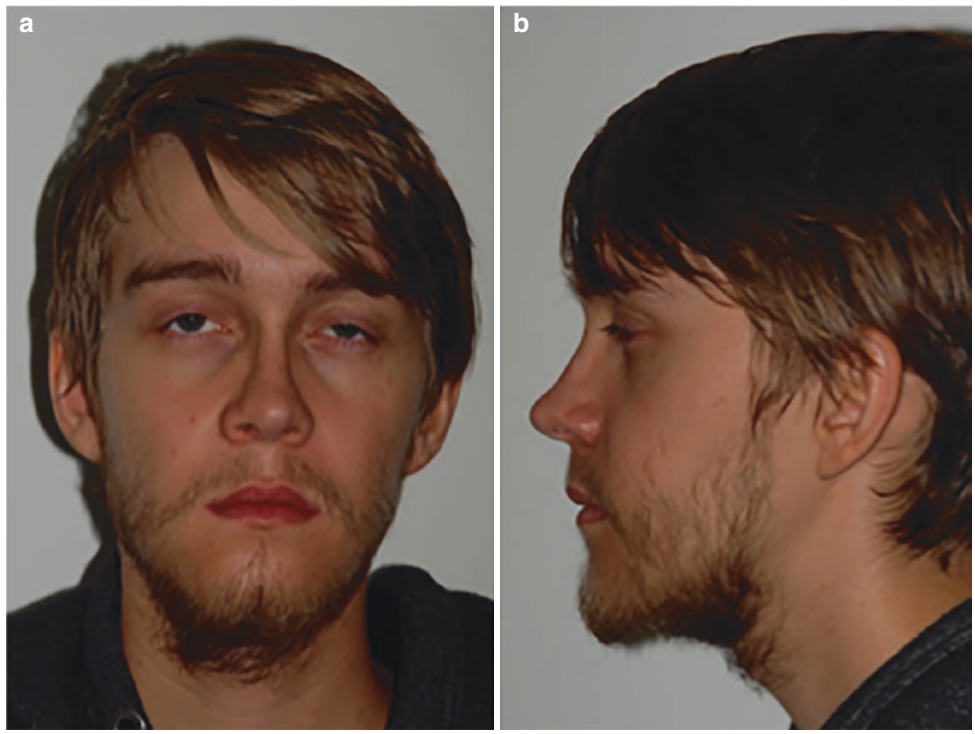

Fig. 29.29 Clinical case 3. (**a**, **b**) Patient with history of Class III malocclusion and both maxillary hypoplasia and prognathic mandible, preoperatively. (**c**, **d**) Postoperative photos status post Le Fort I osteotomy and maxillary advancement, bilateral sagittal split osteotomy and mandibular setback, and reduction genioplasty

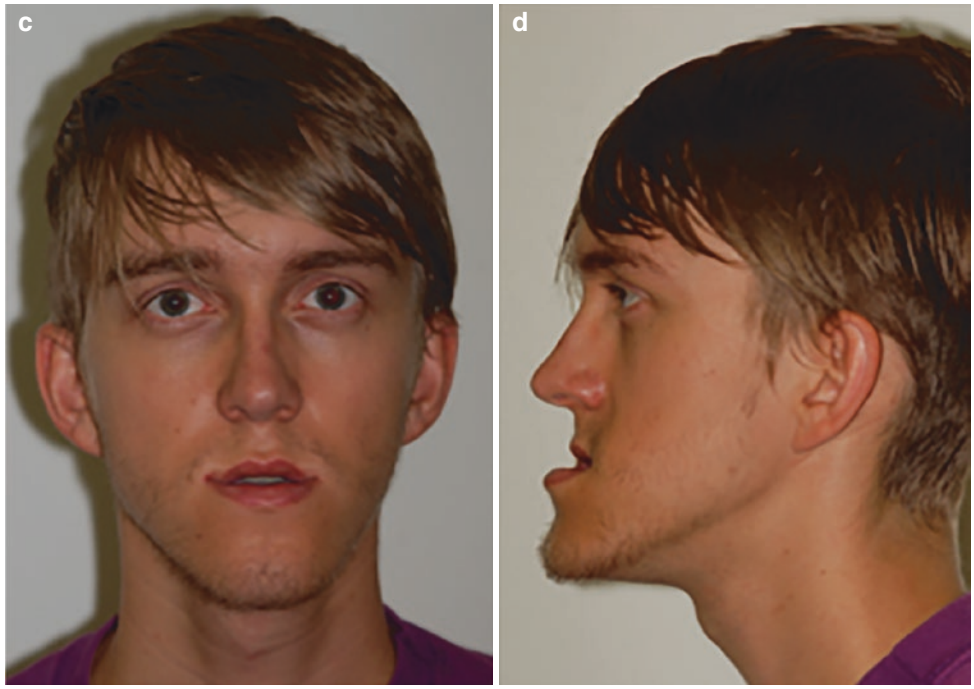

Fig. 29.29 (continued)

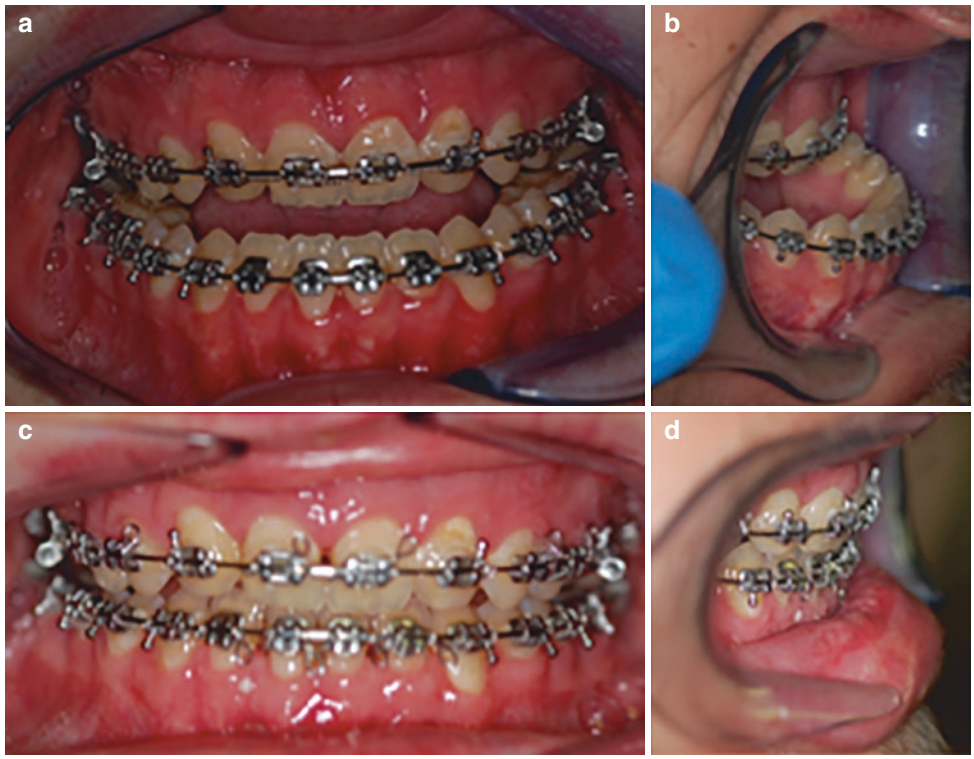

Fig. 29.30 (**a**, **b**) Occlusal views of patient in Fig. 29.29 with history of Class III malocclusion and both maxillary hypoplasia and prognathic mandible, preoperatively. (**c**, **d**) Postoperative photos status post Le Fort I osteotomy and maxillary advancement, bilateral sagittal split osteotomy and mandibular setback, and reduction genioplasty

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Facial Fat Grafting

30

Steven R. Cohen, Sierra Hewett Willens, and Hayley Womack

Ideology Behind ITR² Fat Grafting

Introduction to Fat Grafting

Despite the historic introduction of autologous fat grafting in 1893 [1], its incorporation into the aesthetic field largely took effect nearly a century later upon Coleman's inception of a standardized fat grafting technique [2, 3]. Noticing the variability in outcomes of his predecessors, Coleman refined and outlined a fat grafting technique that standardized the procedure to obtain more predictable results. In his reports, Coleman emphasized the importance of gentle negative-pressure harvesting, removal of cellular debris via centrifugation and decantation, and the deliberate placement of small aliquots of fat (microfat) to maximize surface area contact between harvested and recipient tissues [3]. The ideology behind Coleman's reports asserted that successful outcomes are dependent upon techniques that preserve the integrity of the graft while maximizing its potential to integrate into recipient tissues. Decades later, Coleman's standardized technique remains a paradigm of fat grafting today.

Understanding Facial Aging

Traditionally, aging was believed to be solely attributed to global gravitational descent of soft tissues, yet Lambros' findings on stabilized junctions, immobilized fibrous networks, and deflated facial compartments provoked greater investigation into causations of phenotypic facial aging and its effects on underlying tissue anatomy [4]. In response, Pessa and Rohrich isolated anatomically distinct facial fat pad regions through methyl-blue cadaver stainings, thus defining the superficial and deep facial fat pad compartments commonly known today [5]. In contrast to conventional beliefs that perceived aging as global phenomena, Lambros, Pessa, and Rohrich's studies indicated that deflation of specific fat pad compartments may not occur in unison, but rather in a more site-specific manner, later reflected in clinical trends [6, 7].

At 22 years of age, our physiology begins to shift from an anabolic-like stage of growth and

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development to a more catabolic-like stage of death and decay. Paralleling the bodies' underlying changes in gene regulation, phenotypic changes begin to surface in the skin, fat compartments, and underlying bone, as well as in the dynamic relationship that exists between them. Photo-damage, skin laxity, and tissue volume loss are the most prevalent outcomes of facial aging, yet underlying bone reabsorption has also been shown to play a significant role in amplifying these morphological changes. Through a series of observations, Mendelson reported that the superomedial and inferolateral rims, maxilla, pyriform, and pre-jowl area of the mandible are most susceptible facial regions to undergo bone reabsorption [8]. Although bone reabsorption and fat pad deflation may occur independently, their outcomes are interdependent. For example, bone reabsorption of the maxilla has been shown to provoke tear-trough deformities, which are further aggravated by simultaneous volume loss and descent of the malar fat pad, that in turn accentuate the nasolabial folds [8]. With these aspects in mind, aging should be modeled as a collective of interdependent anatomic and physiologic changes that work synergistically to exacerbate the appearance of facial aging. As one structural compartment begins to falter, the integrity of the facial infrastructure could be compromised, if not addressed with intervening methods.

New Applications

The introduction of millifat, microfat, and nanofat has transformed facial fat grafting by allowing the surgeon to dynamically treat the varying architectural infrastructure of the face. Fillers provide aesthetic enhancement while our tissues continue to age, whereas appropriately sized fat parcel can treat the same range of facial aging concerns presently addressed with cosmetic fillers, while remaining inexpensive, biocompatible, and offering regenerative effects. Previously, Rigotti and his team demonstrated signs of neo-angiogenesis and histologic changes of age reversal in elastin and collagen through mechanically obtained stromal vascular fraction [9]. Supporting this notion, our team found novel findings of regenerative, long-lasting effects of fat grafting that provided an in vivo extension of a molecular fat grafting theory [10]. Collectively, stem cells, regenerative cells, and growth factors found in adipose tissue may offset the rate of tissue decay. With this in mind, facial fat grafting can be designed to anatomically *replace* tissue and bone loss with "like tissues" while offering the patient longer lasting results through *regenerative* applications.

ITR²: Injectable Tissue Replacement and Regeneration

ITR² is a new standardized method of fat grafting which:

1. Diagnoses the anatomic components of volume loss by evaluating the surface topography of the face.
2. Addresses specific anatomic losses of these different tissues, including skin, facial fat in the deep and superficial compartments, and bone.
3. Replaces these anatomic losses of fat and bone with autogenous or allogeneic fat grafts (and allogeneic bone) that are sized for structural replacement of bone and deep fat losses, superficial fat replacement, and dermal and epithelial replacement and/or regeneration.

Given that morphological features of aging occur in a consortium, the underlying bone, fat compartments, and skin should be addressed collectively through an anatomically precise method that preserves the structural integrity of the varying facial compartments.

ITR² is a new concept of autologous fat grafting predicated on the works of Coleman, Pessa, Rohrich, Mendelson, and others who contributed to the field of facial aging, aesthetics, and surgery. ITR² modifies fat into three different parcel sizes—millifat, microfat, and nanofat—to more accurately replicate characteristics of fat cells lost with facial decay and provides increased blood supply and regenerative cells to the aging face.

Millifat is characterized as fat parcels of diameters of 2.4 mm or less. Millifat is more structural in nature and is therefore used to restore the structural integrity of the pre-skeletal regions and deep fat pad compartments. In ITR^2, millifat can be used to replace volume loss from underlying bone reabsorption affecting regions of the lateral eyebrow, pyriform, nasal bridge, columella, lips, chin, and mandibles. In addition, millifat can be used to augment deflated deep fat pad compartments such as the deep medial cheek, the buccal fat pad, the suborbicularis oculi fat (SOOF), as well as larger areas of volume loss seen in the temples, and volume loss along the periosteal in the orbit.

Microfat is characterized by fat parcel sizes of 1.2 mm or less in diameter. Microfat is used to treat the superficial fat pad compartments of the face and other superficial structures that appear to undergo morphological changes with age. These regions include the intraorbital fat pad, the medial cheek, nasolabial fat pad, and the superficial medial cheek fat pad, along with forehead, chin, deep on the periosteum of the tear troughs, and perioral skin. Microfat is also used for some types of acne scars as well as a carrier for SVF and/or PRP for alopecia and in wounds.

Nanofat is characterized by parcels of tissue of approximately 500 microns. In essence, nanofat is a liquid product composed of stromal vascular cells, free fatty acids, and extracellular matrix proteins that can treat pigmentation under the eyelids and fine rhytids in both perioral and periorbital regions. Nanofat can also be used to treat wounds, incisions, acne scars, and alopecia. Nanofat can be injected either through a blunt cannula, microneedling device, or mesotherapy techniques. Additionally, nanofat can be centrifuged to eliminate free fatty acids and be applied to the skin as a topical agent with transdermal delivery via laser resurfacing. In most patients undergoing facial aesthetic surgery, or full facial fat grafting, a combination of all three types of fat grafts are utilized.

Herein, we discuss injectable tissue replacement and regeneration, a new standardized technique of facial fat grafting designed to restore the natural infrastructure of the face, while acting as an interventional treatment modality as a means to offset the rate of facial aging. ITR^2 represents a new concept of proactive, dynamic aesthetic management built upon modern knowledge of aging processes and backed by scientifically designed treatments to address age-related changes.

Application of ITR^2 Fat Grafting

Preoperative Evaluation

In contrast to fillers, ITR^2 fat grafting provides biologic effects such as neo-angiogenesis and improvement in microarchitecture of the skin. As such, we often recommend ITR^2 to most patients seeking facial rejuvenation, or patients who request more than one filler. At the same time, harvested cells consist of the same genetic makeup of the host, and therefore should be expected to behave in a similar manner once engraftment begins. Given that some individuals age more rapidly than others, their tissues and cells will likely be less effective when used for regenerative effects. As with any autologous and allogeneic tissues, patients will need to understand that realistically, several treatments may need to be repeated as a means to impede the phenotypic effects of aging; however, ongoing stimulation of tissue via serial resurfacing, such as fractional lasers in combination with platelet-rich plasma (PRP) and/or nanofat, may delay a patient's individual rate of tissue decay. Naturally, sun protection, anti-inflammatory nutrition, and exercise will no doubt promote healthy tissues and thus offset certain parameters contributing to aging. In addition, the use of neurotoxins reduce facial motion to preserve muscular stability and reduce sheering, providing other means to delay deterioration.

Preoperative Markings

Through facial analysis, the surgeon can correlate particular anatomic losses of the face with topographical changes on the surface, ultimately

allowing for enhanced treatment planning. With ITR^2 the patient is marked with a white makeup pen while sitting in an upright position. Prior to evaluating specific regions of the face, the skin is first assessed for signs of photodamage. The epidermal, dermal, and subcutaneous tissue thickness are then evaluated, and scalp hair quality and/or loss is noted to determine if a restorative application may be beneficial.

The upper third of the face is analyzed and the degree of bone recession along the glabella and supraorbital rims are noted. The temples are then assessed for either deep or superficial fat loss. Deep fat loss of the temples is often associated with temporal depression, whereas superficial fat loss is often associated with an increase in appearance of the temporal veins. Often both are present. Next, deeper rhytids are assessed for possible sharp-needle intradermal fat (SNIF) grafting technique [11]. Loss of fullness of the lateral brow and loss of convexity of the skin caudal to the eyebrow and supratarsal fold depth are noted.

Next, the middle third of the face is evaluated. The upper and lower eyelids, in addition to the periorbital region, are inspected. In the inferior orbit, the rim is evaluated, as is the prominence of the intraorbital fat. Next, the tear trough and lid cheek junction are evaluated. The position of the globe is noted from the vertex and submental view to determine the degree of proptosis. The lid-to-pupil position is noted, and the degree of senile enophthalmos is evaluated. The zygomatic arch and body are outlined in white. The superior arch corresponds with the inferior temporal region. The deep lateral and medial SOOF are noted, as is the deep medial fat compartment of the cheek. The degree of buccal hollowing is evaluated. The nose is assessed for any aesthetic deformity and/or aging, and the degree of pyriform recession is noted.

Lastly, the lower third of the face is assessed, and the lips are evaluated, along with the perioral tissues and degree of thinning and rhytids. The marionette basin is evaluated, as is the chin and labiomental fold. Chin texture may be improved with nanofat microneedling and fractional laser with topical delivery of nanofat bio crème. The pre-jowl area just lateral to the mandibular retaining ligaments, if scalloped, is addressed, as is the inferior border of the mandible and the gonial angle. Chin projection is evaluated, and the neck is inspected for degree of subcutaneous loss, deep and fine rhytids, and severity of sun damage.

Preoperative Preparation and Anesthesia

Depending on patient preference and aesthetically desired outcomes, ITR^2 can be carried out nonsurgically or surgically when combined with other rejuvenating procedures. If the prior, patients are given oral prophylactic antibiotics 1 day before the procedure. If the latter, patients are intravenously provided prophylactic antibiotics at the time of surgery. Additionally, our clinic offers patients the opportunity to undergo a fixed focused ultrasound treatment, ranging from 1 week to a couple of days prior to the procedure. In this methodology, the patient's host tissues are stimulated to promote endogenous angiogenic growth factors and regenerative agents that will be grafted into the recipient's facial tissues [12].

Adipose Tissue Harvest

ITR^2 fat grafting requires approximately 45 minutes to an hour, if performed alone and without additional procedures. Fat is harvested from any area of excess subcutaneous fat and/or areas of patient preference if sufficient adipose tissue is available. Previous reports have shown no statistical difference in adipocyte viability between abdominal fat, thigh fat, flank fat, or knee fat donor sites [13]. The patient is prepped and draped under sterile conditions. Harvest begins with a 14-gauge needle puncture, followed by infiltration of tumescent fluid (500 ml of Ringers lactate with 25 mg Lidocaine and one vial of epinephrine, 1:1000).

To obtain millifat, a 12-holed cannula, with openings measuring 2.5 mm diameter (Marina Medical, Inc. Davies, FL), is inserted into a

slightly dilated 14 G needle hole. Using a 60 mL syringe with a lock, the fat is aspirated. At this point, the surgeon can decide to either isolate microfat and nanofat mechanically via in vivo harvesting using 1 mm and 500 micron 12-holed cannulas (Millineum Medical, Carlsbad, CA, or Marina Medical, Stuart, FL), or through a mechanical processing device (Lipocube, Inc., London, UK) used to emulsify and downsize the harvested millifat into the appropriate microfat and nanofat parcel sizes. Generally, 120 mL of fat is removed, and the punctures are closed by secondary intention or by Dermabond (Ethicon, US) wound adhesive.

Fat Processing (See Fig. 30.1)

If millifat, microfat, and nanofat were harvested in vivo with 2.5 mm, 1 mm, and 500 micron 12-holed cannulas, respectively, the tumescent fluid is decanted, and each fat graft is rinsed with Ringer's lactate to reduce blood contamination.

If only millifat was harvested in vivo with a 2.5 mm diameter cannula, the tumescent fluid is decanted and the fat graft is rinsed with Ringer's lactate. Upon cleaning the millifat, a portion of the harvested fat is set aside for delivery. The remaining fat is transferred into 20 cc syringes and processed through a mechanical emulsifier device. Our clinic uses Lipocube's Nanocube kit, a mechanical device that uses four ports to re-size the harvested and processed millifat fat into microfat and nanofat parcels. Our clinic prefers the Nanocube mechanical device over other systems, given its disposable use and its cellularly optimized nanofat; however, a variety of other systems can be used for ITR[2].

Recent findings indicate that centrifugation and filtration systems may provide little benefit-cost ratio [14]. As such, we consider simple washing, gravity separation, and decantation to be sufficient in eluting the tumescent solution and processing the adipose tissue. However, the surgeon may decide to incorporate centrifugation or other filtration systems upon preference.

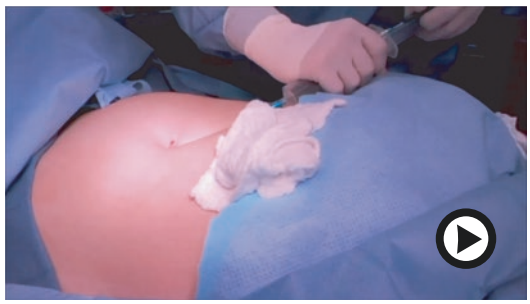

Fig. 30.1 Injectable tissue replacement and regeneration procedure including patient marking, fat harvesting, fat processing with Lipocube Nanocube, and fat graft delivery (▶ https://doi.org/10.1007/000-3v6)

Delivery Placement (See Fig. 30.1)

According to topographical evaluation, fat grafts are assigned to anatomic locations in the face relative to the natural fat parcel size: millifat (2–2.5 mm), microfat (1 mm), and nanofat (500 microns and less) (Fig. 30.2). Placement of the millifat starts in areas of deep fat pad compartment loss and areas renowned for bone reabsorption. Microfat is then used to treat the superficial fat pad compartments and other superficial areas of volume loss. Nanofat is used last through a variety of methods such as microneedling, Mesotherapy, or transdermal delivery via laser (Table 30.1).

Up to 12 puncture sites are made with an 18-gauge needle and are re-used whenever applicable in delivering the three appropriately sized fat grafts. A schematic denoting graft placement and injection site can be seen in Fig. 30.2.

Millifat ≥2.4 mm Parcel

Millifat is placed below the muscle. Using an 18-gauge needle, a puncture site is made along the nasolabial fold, lateral and superior to the oral commissure. This puncture site allows the surgeon to address areas of bone recession in the pyriform region. The cannula is then directed cephalad to graft the deep medial fat compartment and the medial then lateral SOOF. A second puncture site is made in the anterior hairline at

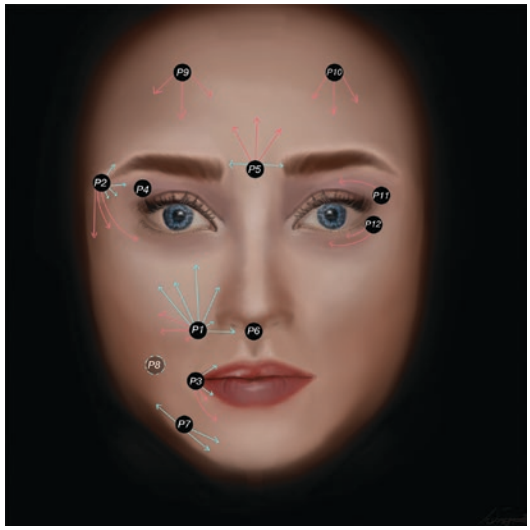

Fig. 30.2 Puncture site chronology and injection vectors used in ITR[2] fat grafting. Blue arrows represent injection placement of millifat *below the muscle*; pink arrows represent injection placement of microfat *above the muscle*. *P1*: Injection site denotes millifat placement along the pyriform, medial and lateral soof, deep medial cheek, pre-skeletal zygoma, and maxilla. Additionally, this placement site may be used to inject microfat along the perioral regions, the superior lip skin, and cheek region. *P2*: Millfat can be injected here to address volume loss in the temporal region. The same injection site can be used for microfat to address the infraorbital compartment and temporoparietal fascia. *P3*: Millifat injection site for lips; microfat injection site for marionette basin, lower perioral region, and chin. *P4*: Millifat injection site to address deep fat loss and bone absorption around the orbital rims and superior orbital sulcus. *P5*: Millifat injection site for medial supraorbital rim, glabella, and nasal radix. *P6*: Millifat injection site for columella, dorsum, and nasal tip. *P7*: Millifat injection site for mandibular border, gonial angle, chin, and pre-jowl sulcus. This injection site may also be reused to address gonial angle and chin volume loss with microfat. *P8*: Intra-oral injection site to address buccal fat pad volume loss with millifat. *P9/P10*: Microfat injection site for lateral forehead. *P11*: Microfat injection site for lower brow. *P12*: Microfat injection site to address the lower eyelid and orbital retaining ligaments

Table 30.1 Fat graft parcel sizes and their respective anatomic placement

Type of fat graft	Parcel size of graft	Anatomic placement
Millifat	2.4 mm	Skeletal regions and deep fat pad compartments
Microfat	1.2 mm or smaller	Superficial fat pad compartments
Nanafat[a]	400–600 microns	Superficial placement either through intradermal injection or through a topical agent and transdermal delivery

[a]Nanofat may be mixed with microfat to include additional growth factors
[b]SVF or PRP may be used together or serially with any fat graft

the level of the lateral eyebrow to address the deep temporal region and lateral eyebrow. The fat is grafted along the pre-periosteal lateral supraorbital brow. A third puncture site is made at the commissure, and the upper and lower hemi-lips are injected. The glabella, medial supraorbital rims, and the nasal radix are injected through a needle puncture in the central glabella, approximately 1.5–2 cm above the nasofrontal junction. The nasal dorsum, tip, and columella are then grafted through an entry point between the domes of the nasal tip. Attention is directed to the chin, mandibular border, and gonial angle. Modest retrogenia can be improved with millifat grafting. The area just lateral to the mandibular ligament and along the mandibular border is grafted in the pre-skeletal level through the same puncture site. Millifat is placed along the inferior mandibular border and into the gonial angle to define the jawline, camouflage mild jowls, or lower an obtuse mandibular angle. If the buccal fat compartment shows volume loss, it is injected using an intraoral approach. The patient is given intravenous clindamycin, and the mouth just below Stensen's duct is prepped with betadine and punctured with an 18-gauge needle. It is important to place only small amounts of fat into the deep buccal compartment and re-inspect the area frequently to determine if the proper amount has been injected. It is important not to overfill this lowlight area.

Microfat ~1 mm Parcel

Microfat is placed above the muscle. To treat the perioral skin, superior lip skin, and cheek region, microfat is grafted using the previous puncture site along the nasolabial folds. To address the marionette basin, lower perioral region, and chin, the microfat is grafted using the previous oral com-

missure incision. The SNIF technique is used for the philtral columns (cupids bow) and rhytids perpendicular to the white roll of the upper and lower lips. The superficial temporal fat compartment is grafted with microfat using the same temporal puncture site as the deep temporal compartment. For the forehead, the glabellar needle puncture site is used to inject superiorly and laterally into the medial brows. Two more needle incisions are then placed along the hairline on each side at the mid-pupillary line as a means to address the central, inferior, and lateral forehead subcutaneous (superficial) fat compartment volume loss. The incision for the upper lid sulcus and lower brow fat pad is located on the lateral superior orbital rim about 3 mm inferior to the tail of the eyebrow. For the lower eyelid, two access points are used: the tear trough point and a second point just lateral to the nasojugal groove. Microfat placement is in the supra-periosteal, preseptal space. Lastly, the same puncture site along the jawline is used to restore a uniform silhouette of the lower face by injecting microfat along the lateral and superior gonial angle, the submental crease, as well as other areas of the chin that were not addressed earlier.

Nanofat ≤500 Micron Parcels

Our clinic prefers to prepare nanofat with the Lipocube Nano™ (London, UK) system, since it allows for a more matrix-rich product with less traumatized regenerative cells (unpublished data). Nanofat is placed using either the SNIF approach, intradermally with microneedling, or with a topical biocrème. When delivered through a SNIF technique for dermal rhytids, this cellularly optimized nanofat is injected intradermally using a 25–27 G cannula attached to a finger activated grafting device, or with a 3 mL Cellbrush (Cytori, San Diego, CA) or an automatic grafting device, Lipopen (Juvapen, Neuchâtel, Switzerland). Finally, nanofat is delivered with a mechanical microneedling device into the face, neck, and décolletage. A 5 cc–20 ml aliquot of nanofat is kept to combine with a transdermal liposomal carrier to form a topical nanofat biocrème (neo-U). Patients having nanofat microneedling and/or nanofat biocreme (neo-U) in conjunction with fractional lasers of different wavelengths have experienced significant improvement in aesthetic outcomes, with faster healing compared to historical controls. In patients having facelifts with ITR^2, facial volume improves by about 45% at 1 month, drops to about 25–30% from 7 to 12 months, and then improves to 74% at 18–24 months [15]. These findings suggest that there may be a reversal of tissue decay using ITR^2 in conjunction with facelift surgery.

Case Demonstrations

Patient 1

Here presents a 65-year-old woman seeking facial rejuvenation surgery (Fig. 30.3a). To address the varying degrees of facial aging, the patient was treated with ITR^2 and received the following additional procedures at the time of service: mini facelift, cheek lift, and platysmaplasty. Millifat was harvested from the abdomen. The lipoaspirate was decanted and a portion was set aside for structural and deep fat compartment fat grafting. An aliquot of the millifat was emulsified with Lipocube Nanocube to obtain microfat and millifat. Millifat was used to restore structure along the nasal bridge, the lips, manibles, the pyriform, and brow (Fig. 30.3b). To address volume loss in the deep fat compartments, millfat was transferred to the temples, deep malar fat pads, and buccal fats (Fig. 30.3c). To address superficial volume loss, microfat was used to treat the infraorbital orbital region, the nasolabial folds, the marionette lines, and the lips (Fig. 30.3d). To treat fine lines, nanofat was injected into the tear troughs, nasolabial folds, and along the perioral region. Given that this patient did not receive laser treatment, nanofat was injected into the skin via microneedling (Fig. 30.3e). The patient can be seen postopertatively at 3 months (Fig. 30.3f) and 8 months (Fig. 30.3g).

Patient 2

Clinical trends have suggested that deflation of the periorbital and malar fat pads are one of the first facial regions to succumb to underlying morphological changes, as presented in this 28-year-old male bothered by lower eyelid hollowing (Fig. 30.4, left). A total of 30ccs of millifat, microfat, and nanofat were used along with microneedling of the nanofat and postoperative nanofat biocreme to address his initial symptoms of facial aging. The patient can be seen postoperatively 6 months (Fig. 30.4, right).

Postoperative Care

Postoperative care consists of analgesia, nonsteroidal anti-inflammatory medications, and arnica for bruising. Direct application of ice is not permitted. Instead, excessive swelling is treated as needed with a tapering oral steroid regimen. In patients undergoing facelift surgery or laser resurfacing, preoperative skin care is maintained with products containing matrikine (tripeptides and hexapeptides), ingredients that exhibit biologic functions to modulate extracellular matrix repair and neo-collagenases. In patients with a

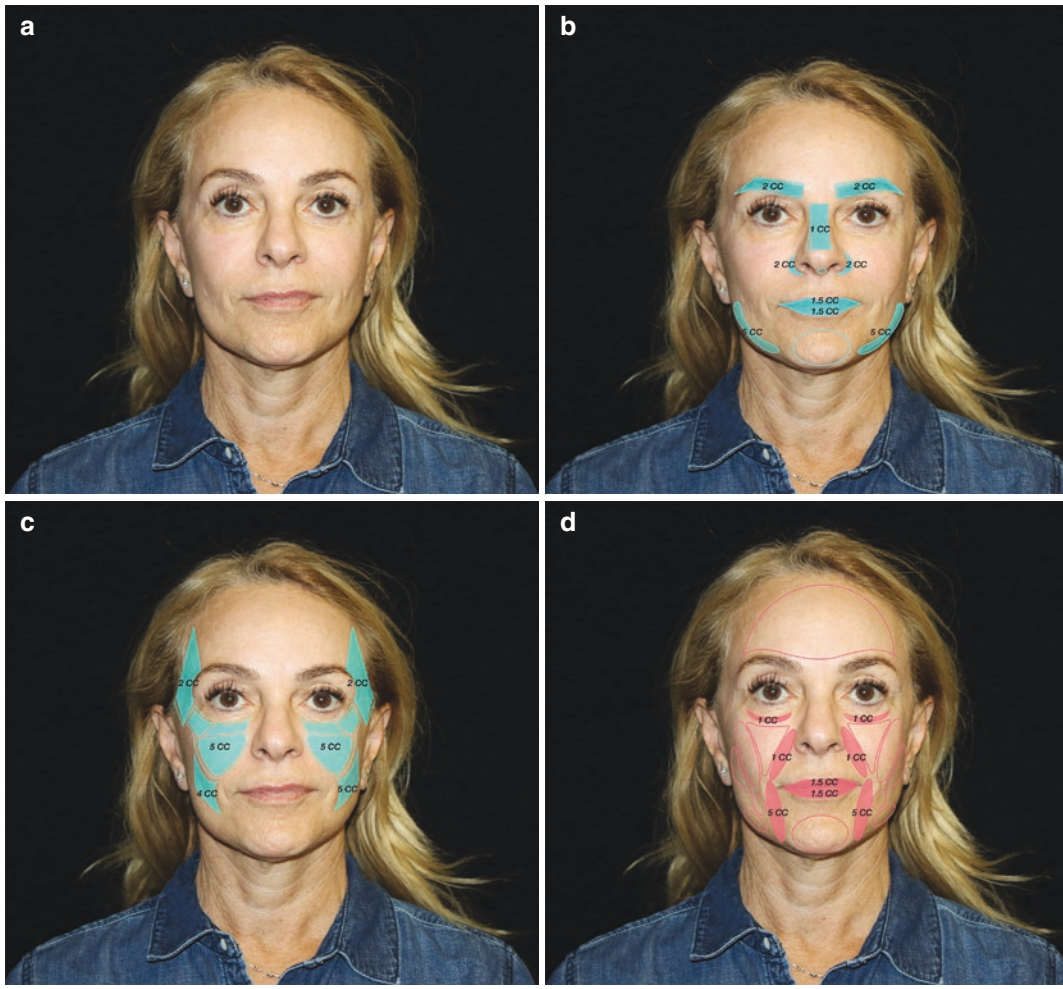

Fig. 30.3 (**a**–**g**) Patient example of ITR^2 fat grafting technique in combination with other facial rejuvenation procedures. (**a**) Preoperative photo. (**b**) Millifat used to restore structural compartments of the face. (**c**) Millifat used to replace volume loss in deep fat pad compartments. (**d**) Microfat used to replace superficial volume loss. (**e**) Nanofat used to treat fine lines. (**f**) Postoperative photo at 3 months. (**g**) Postoperative photo at 8 months

Fig. 30.3 (continued)

history of herpes simplex virus, perioperative prophylactic antivirals treatment is prescribed.

Down Time, Recovery, and Management of Complications

Patients can expect some bruising, facial swelling, and mild ecchymosis, which generally dissipates by day three to five, with the exception of the lips, which usually dissociate about 5–10 days. For a small portion of patients, approximately 15%, recovery can extend to a few weeks.

Complications from ITR^2 have been very rare, and only related to excessive fat grafts in the lower eyelids. Although very rare, transconjunctival or transcutaneous lower blepharoplasty with fat removal has taken care of the problem. We no longer use microfat above the orbital retaining ligament, only matrix-rich nanofat. Since adopting ITR^2, we have not experienced any overgrowth with patient weight gain. Additional procedures are recommended based on the patient's physical findings and individual aging patterns.

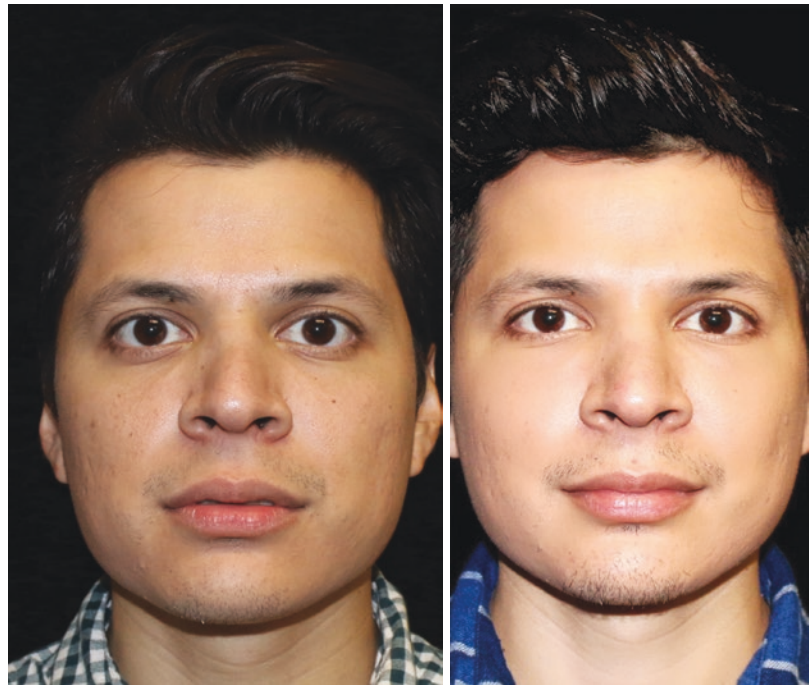

Fig. 30.4 Patient example of ITR^2 fat grafting in young adults. Left: Preoperative photo. Right: Postoperative photo at 6 months

Conclusion

ITR^2 is an umbrella concept that incorporates knowledge of anatomic and histologic findings of facial aging with our ability to diagnose the areas of anatomic changes from the skin's surface to underlying bone. Although this approach may seem at first complex, it is simple, standardized, and routine to perform. ITR^2 is based on being able to observe the anatomic changes of facial aging in different fat compartments, skin, and bone. Treatment is directed at all tissues that have decayed from epithelium to bone, using three sizes of fat grafts to address structural changes, superficial fat losses, and skin thinning. Treatment using ITR^2 can be combined with other aesthetic procedures on the eyelids and face. New ideas such as injectable cartilage gel and injectable decellularized bone are actively being explored.

It is possible to model the facial tissues as they progress from the period of growth and development to decay. Our concept involves stimulating the tissue with platelet-rich plasma and/or cellularly optimized nanofat at the earliest signs of decay to prevent the rapidity of these changes. Sun damage is treated with skin care and energy-based devices and lasers as needed. Skin care products with matrikines, extracellular matrix-derived peptides that regulate cell activity, are used to clear the extracellular matrix of debris [15]. Aesthetic products, such as fillers, are used for beauty enhancement, but have little to no effect on tissue health. Patients requiring more than one filler are excellent candidates for their first ITR^2 treatment for facial volume loss.

New innovations such as nanofat biocrème, nanofat microneedling, treatment of nasal aging with fat grafting and/or cartilage gel injections, buccal fat pad fat grafting, chin and jaw augmentation with decellularized, allogeneic bone, and intra-orbital fat grafting to correct senile enophthalmos are presented as new concepts under the umbrella of Injectable Tissue Replacement and Regeneration, and may play important roles in the future of facial reconstruction and rejuvenation.

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Facial Trauma

31

Amjed Abu-Ghname, Angela S. Volk, and Larry H. Hollier Jr.

Introduction

Facial trauma accounts for a significant number of emergent plastic surgery admissions. While the incidence and severity of facial fractures have decreased substantially following the widespread implementation of airbags and seatbelts, injuries to the head, face, and cervical spine still occur in almost 50% of automobile accidents [1–3]. Additionally, an increase in interpersonal violence and assault has resulted in facial injuries with unique features and complications [4].

Over the past 30 years, remarkable advancements in facial trauma management have been achieved. The evolution of diagnostic imaging and novel bone-fixation technology, combined with the use of microvascular reconstructive techniques, has revolutionized the treatment of facial injuries. Despite these advancements, the traditional principles of assessment, access, reduction, and fixation still remain. This chapter discusses the preferred approach for facial fractures based on the senior author's clinical experience. Additionally, it provides a multitude of practical tips and tricks for the preoperative evaluation, operative planning, and decision-making associated with these fractures.

Tips and Tricks of Facial Fractures

Zygomaticomaxillary Complex (ZMC) Fractures

Displacement is an absolute indication for operative reduction and fixation due to the potential of enlarged orbital volume with secondary enophthalmos and malar recession [5, 6]. Adequate visualization can be achieved in most patients using incisions in the upper gingivobuccal sulcus and the lower eyelid.

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_31) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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Tip
Color desaturation should always be tested during examination, as color perception, particularly red, may be the first sign of optic nerve compromise [7]. While diminished visual acuity is a concern, it is a late manifestation of traumatic optic neuropathy [8].

Trick
The easiest way to test color desaturation in the emergency department is to dim the lights and hold a penlight up to the finger, simulating the color red. The patient should be asked to close one eye and then the other. Any difference in the perceived color between the two eyes is worrisome and mandates a formal ophthalmologic consult and deferral of immediate surgical intervention.

Tip
An afferent pupillary defect is also indicative of optic nerve injury, and can be elicited by the swinging flashlight test. The affected pupil fails to constrict with direct light stimulation, but constricts in a consensual response when light is directed in the contralateral eye [9].

Tip
When reviewing the computed tomography (CT) scan, it is most useful to evaluate the lateral orbital wall in the axial plane. Due to its broad articulation, axial cuts reveal any displacement or malposition and help determine the degree of deformity (Fig. 31.1) [5].

Tip
An intraoral approach through an incision in the upper gingivobuccal sulcus should be performed first, as it allows broad exposure of the fracture and allows reduction.

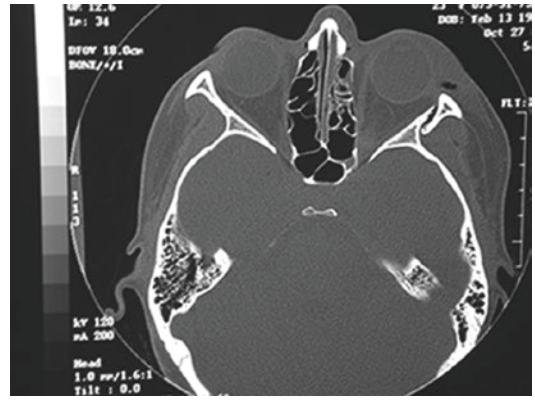


Fig. 31.1 Axial computed tomographic scan demonstrating fracture and displacement of the right lateral orbital wall. (Reprinted with permission from Hollier et al. [5]. Available at: https://journals.lww.com/plasreconsurg/pages/default.aspx)

Trick
Sustained, upward traction can be performed using a blunt elevator inserted laterally beneath the zygomatic arch via the intraoral incision. This mobilizes the fractured fragment into a more anatomic position. In rare cases, the zygomatic complex "snaps" into a reduced position and, if the orbital floor is intact, the operation is complete. If anatomic reduction cannot be achieved, one should proceed to the lower eyelid incision. This component of the surgery is facilitated by the former approach, as the orbital rim is in a more anatomic position.

Trick
To facilitate reduction, a Carol-Gerard screw may be placed through the lower-eyelid incision or transcutaneously in the prominence of the cheek into the body of the zygoma (Fig. 31.2a–c). The screw acts like a joystick to disimpact the fragment and maintain proper alignment with its articulations.

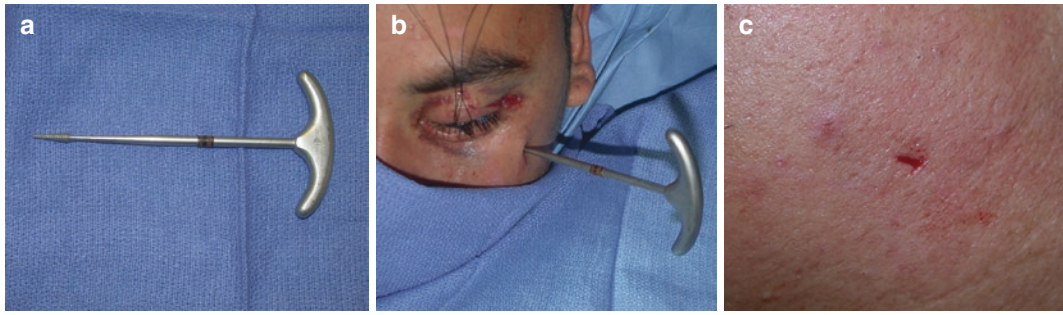


Fig. 31.2 (**a**–**c**) Carol-Gerard screw. (**a**) This bone screw can be used to gain control of the zygoma in orbitozygomatic fractures. (**b**) A No. 11 blade is used to make an approximately 2 mm incision over the prominence of the cheek. (**c**) The screw is then placed into the malar prominence and is used as a handle to disimpact the fragment

Tip
A transconjunctival approach is always preferred. Subciliary incisions are best avoided, due to a higher risk of lower-lid retraction, especially in older patients [10, 11].

Tip
Upper-eyelid incisions are typically not necessary unless zygomaticofrontal suture displacement is visualized preoperatively on a coronal CT scan. Given its relative strength, this buttress is the last to be displaced, and thus remains largely intact in most ZMC fractures [7]. In addition, upper-eyelid incisions offer limited visualization with the narrow buttress really only helping to assess vertical position of the ZMC.

Tip
At the end of the operation, given the anatomical reconstitution of the defect, the operated eye should exhibit more anteroposterior projection compared to the contralateral side secondary to intraoperative swelling. Should the globes be symmetrical, there should be concern for residual malposition and enlargement of the orbital cone.

Trick
Plate removal and fragment mobilization should be attempted if reduction is deemed inadequate. If appropriate globe position is still not achieved, one should assume the need for additional orbital volume correction. Placing a carved wedge of high-density porous polyethylene posterolaterally within the orbital cone projects the globe further without elevating the vertical position of the eye.

Orbital Fractures

Orbital fractures are frequently a component of ZMC injuries and should follow the same general assessment, with a few notable considerations [12]. Indication for surgical intervention of orbital fractures remains an area of controversy, with defect size the most disputed parameter. Defects greater than 1 cm^2 or greater than 50% of the orbital floor are frequently cited as indications for surgery [12, 13]. Early enophthalmos and extraocular muscle entrapment, whether demonstrated on clinical or radiologic exam, are also indications for surgery [14].

Tip
Visual acuity may be difficult to accurately evaluate in the acute setting due to profound eyelid edema, absence of contact

lenses or glasses, or presence of ointments or medications in the eye. However, prior to surgery, formal ophthalmologic consultation with detailed acuity assessment is mandatory in every case.

Tip
The sagittal planes of CT scans are helpful to fully visualize the shape of the orbital floor, while coronal views are critical for complete assessment. In contrast to many other facial fractures, soft-tissue windows are helpful in orbital fractures for full appreciation of periorbital soft tissue, particularly the extraocular muscles.

Tip
Given the initial posttraumatic swelling, any enophthalmos that manifests early in the post-injury phase indicates significant enlargement in the orbital volume.

Tip
Given no extraocular muscle entrapment, short delays of 7–10 days can facilitate surgery by allowing swelling to subside. However, prolonged delays should be avoided, due to soft tissue contracture.

Tip
Exposure through a transconjunctival incision is currently the preferred approach. When combined with a lateral canthotomy, excellent fracture visualization may be achieved.

Tip
A subtarsal lower-eyelid incision is a viable option in older patients with prominent wrinkling that conceals the incision. This approach provides direct access to the infraorbital rim with minimal risk of lid retraction [15].

Tip
Dissection within the orbital cone should be carried posteriorly and cephalically, rather than just posteriorly, to avoid inadvertently placing the implant low and into the maxillary sinus (Fig. 31.3). Due to the upward inclination of the orbital floor, the implant must be placed superiorly in order to accurately reconstruct the defect. Failure to do so maintains orbital volume expansion and results in enophthalmos.

Tip
It is important to remember that the optic nerve is located posteromedially approximately 45 mm from the orbital rim, and is thus very difficult to injure with careful cephalic dissection.

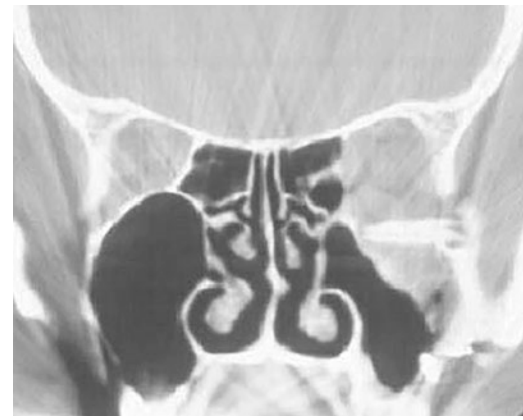


Fig. 31.3 Incorrectly placed orbital floor prosthesis. Orbital floor implant inadvertently placed posteriorly into the maxillary sinus. (Reprinted with permission from Hollier and Koshy [8])

Trick

To identify the posterior ledge, an elevator can be placed posteriorly into the maxillary sinus and gradually moved superiorly until the underside of the posterior ledge is encountered. By sliding the elevator anteriorly, a stepoff can be felt once the ledge is found (Fig. 31.4). This technique allows better appreciation of the defect margins, especially when faced with a large defect and challenging visualization.

Tip

Floor implants made of a combination of titanium mesh and porous polyethylene offer reconstructive advantages that supersede the use of either material separately. The titanium in the implant is malleable, allowing shaping and recontouring, while the polyethylene coating allows the implant to be inserted more easily. This is in contrast to pure titanium, which often tends to get caught in the periorbita.

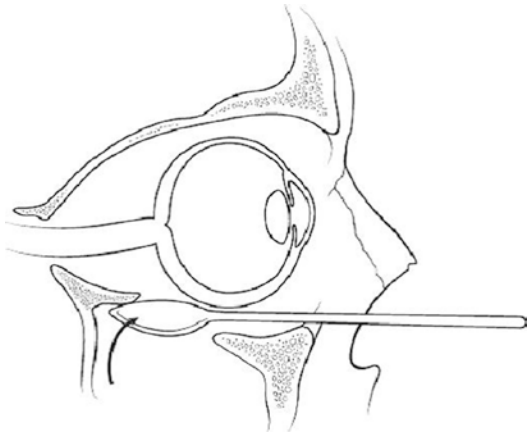


Fig. 31.4 Identification of posterior ledge in orbital floor fractures. The elevator is placed into maxillary sinus and gently moved superiorly and anteriorly to identify the posterior ledge. (Reprinted with permission from Hollier and Koshy [8])

Nasal Fractures

Diagnosis of nasal fractures is primarily clinical. CT scans may be helpful in particularly severe injuries, especially in defining the septal component of the injury [8]. Timing of the injury is the main determining factor in the management of nasal fractures [16]. In patients who present immediately following the injury, closed reduction can be performed under local anesthesia with intranasal vasoconstriction. In patients presenting several hours after the injury, closed reduction is often delayed 5–7 days due to swelling. These patients can be discharged home on a course of oral steroids to allow resolution of edema prior to surgical management.

Tip

Old photographs are particularly beneficial in managing nasal fractures, as they help the surgeon appreciate the patient's preoperative appearance as well as postoperative expectations.

Tip

It is extremely important that patients adjust expectations and understand that the treatment goal is to minimize the nasal deformity. It is unlikely that the deformity will be completely corrected with closed reduction alone. Patients should be counseled regarding the possibility that a rhinoplasty may be required in the future.

Tip

Any nasal drainage should raise concern for cerebrospinal fluid (CSF) rhinorrhea. Postnasal drip may often be the only complaint associated with a CSF leak, as it preferentially drains posteriorly down the throat [16].

Tip
Although most leaks resolve spontaneously, minimizing the pressure at the dural tear site is the key to resolution. Patients should be advised to avoid the supine position whenever possible. Continued leaks beyond 1–2 weeks may warrant lumbar drainage.

Trick
If local anesthesia is selected for the closed reduction, cocaine can be used on pledgets to pack the nose, as it provides topical anesthetic and vasoconstrictive properties. An alternative is 4% lidocaine and oxymetazoline (Afrin).

Trick
Anesthetizing the underside of the nasal bone should be kept in mind, as the elevator is typically placed in that region. An easy way to access this area is by directing the needle transseptally and injecting the mucosal surface of the contralateral side.

Mandibular Fracture

Physical examination in mandibular fractures should focus on signs of malocclusion, anesthesia in the mental nerve distribution, and the state of dentition. The pattern and intrinsic stability of the fracture generally dictates the type of fixation required [17, 18]. Rigid fixation via an extraoral approach using large plates with a 2.4 mm screw diameter is typically required for complex fractures. Complex fractures include those that are severely displaced, comminuted, infected, atrophic, or involve multiple sites. Fractures without these characteristics are considered simple, and can be addressed via an intraoral approach using smaller plates with screws 2 mm in diameter.

Tip
CT scans are the most sensitive radiographic modality for diagnosing mandibular injuries; however, they provide very little useful information about dental trauma [19]. This is crucial when assessing third molar involvement in mandibular angle fractures [20].

Tip
Although moderate delays in the management of mandibular fractures have shown no increase in the incidence of infections, excessively delaying the management offers no advantage [21].

Tip
Even with a planned intraoral approach, patients should always be consented for the possibility of an extraoral incision.

Trick
In all cases of open reduction and internal fixation of mandible fractures, it is best to first expose, reduce the fracture, and place epinephrine-soaked cottonoids at the fracture site (1 cc of 1:1000 epinephrine in 1 l of saline; 1:1,000,000 diluted solution) (Fig. 31.5). Applying arch bars without initial reduction can lock the arch in malocclusion. Should this happen, the easiest solution is to cut the bars at the fracture site to facilitate reduction. By applying cottonoids before placing the intermaxillary fixation (IMF), the operative field is relatively hemostatic during plating, which is particularly useful in mandibular angle fractures.

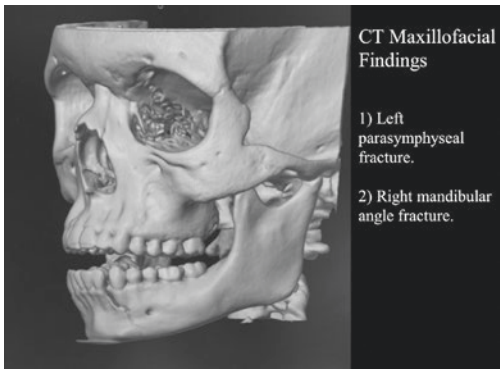


Fig. 31.5 Mandibular fracture (▶ https://doi.org/10.1007/000-3v8)

Trick
An easy and popular procedure for isolated angle fractures involves placing a single miniplate along the external oblique ridge of the mandible, also known as the Champy technique. Despite having the lowest number of serious complications, local complications such as plate exposure are not uncommon [22, 23]. To avoid this, it is best to place the intraoral incision lateral to the planned plate site, leaving enough of a mucosal cuff to cover the plate and avoid having it directly beneath the incision.

Tip
Stripping the periosteum and exposing the buccal aspect of isolated angle fractures offers little value, and only serves to prolong bone healing. Establishing the occlusion and aligning the fracture along the oblique ridge is sufficient.

Tip
The occlusion should be carefully checked following the placement of each plate by removing intermaxillary wires or elastics and gently tapping the mandible into occlusion. Forcing the occlusion may lead the surgeon to mistakenly believe that the bite has been corrected.

Maxillary Fracture

Maxillary fractures are classically described as LeFort I, II, and III patterns. These fractures rarely occur in isolation, and are often part of a more extensive fracture pattern.

Tip
By definition, these fractures must extend through the pterygoid plates, detaching the maxilla from the base of the skull. If the CT scan fails to reveal a fracture in the pterygoid plates, a true LeFort fracture is not present (Fig. 31.6a, b).

Tip
In the setting of panfacial trauma, maxillary fractures should be plated last, given that the occlusion has been corrected. This is particularly true for LeFort I fractures, as they can tolerate malalignment the most.

Frontal Sinus Fracture

Frontal sinus fractures are often associated with injuries to the central nervous system and the globes, making neurological and ophthalmologic evaluation crucial [24]. These fractures are becoming increasingly uncommon due to the installment of airbags and safety measures in vehicles. The management of these injuries is determined by the degree of involvement of the anterior and posterior tables and the nasofrontal outflow tract (NFOT) [25].

Tip
All frontal sinus fractures should undergo coronal and axial CT scanning. A great deal of attention should focus on the area of the draining pathway of the sinus (NFOT) in the medial region of the sinus floor.

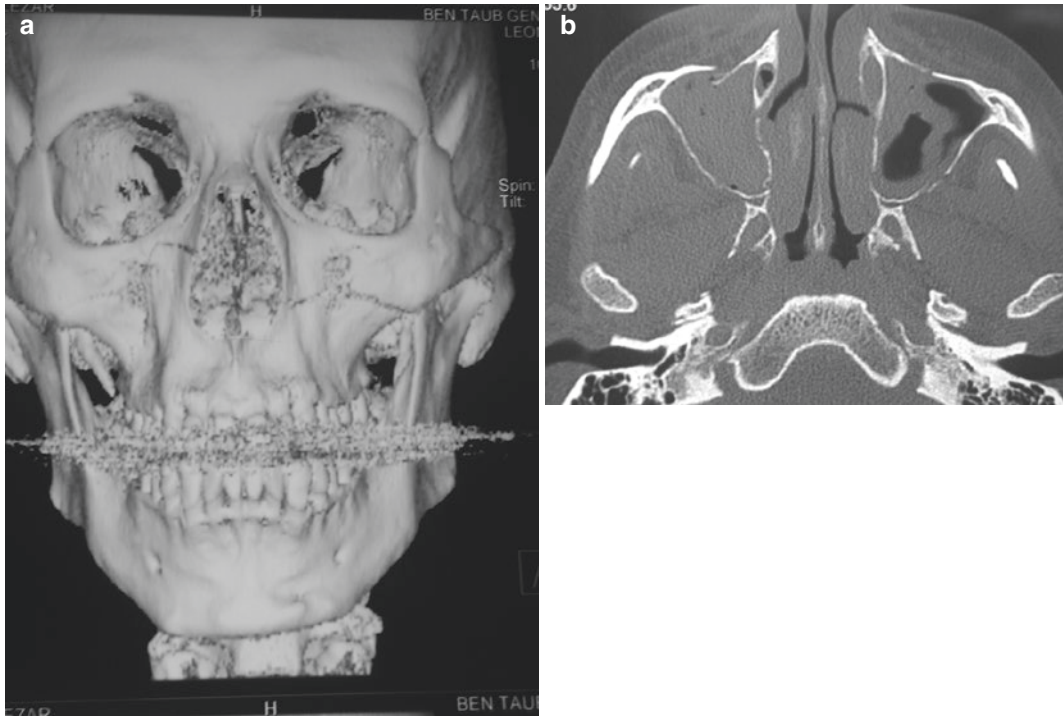


Fig. 31.6 (**a**, **b**) Incomplete Le Fort I fracture. (**a**) Three-dimensional computed tomography showing a midface fracture at the Le Fort I level. (**b**) Axial CT scan of the same fracture revealing intact pterygoid plates. The fracture was stable on examination under anesthesia and did not require stabilization. (Reprinted with permission from Hollier and Koshy [8])

Tip
Isolated and significantly displaced fractures of the anterior table are treated with open reduction and internal fixation to prevent contour deformities.

Tip
Cranialization should be considered in displaced posterior table fractures to prevent intracranial infections. This is mandatory for fractures associated with an ongoing cerebrospinal fluid leak.

Tip
The threshold for harvesting split calvarial bone grafts should be low, especially in the setting of extensive comminution with missing fragments in the anterior table. Providing fresh bone grafts significantly decreases the risk of bone resorption when compared to plating comminuted and devascularized fragments.

Tip
Concern for NFOT involvement in the fracture should prompt the surgeon to obliterate the sinus. There is no current data regarding sensitivity or specificity of the maneuver in which dye is placed in the sinus to evaluate transnasal drainage [24, 26]. In most cases, the decision can be made preoperatively based on CT imaging.

Tip
In the setting of multiple facial injuries, some surgeons advocate obliterating the sinus through one of the skin lacerations; however, exposure in such cases is almost always insufficient. Frontal sinus obliteration should be performed through a coronal incision.

Trick
When planning the coronal incision (Fig. 31.7a, b), one must consider the need to harvest a pericranial or galeal flap.

Trick
Defining the limits of the sinus under direct examination may be difficult, particularly in small fractures. Dimming the operating room lights and placing an endoscopic light into the sinus can facilitate delineation of the margins of the sinus (Fig. 31.8). Additionally, simply placing one arm of a bayonet forceps into the sinus until its limit is reached can help define the extent of the cavity.

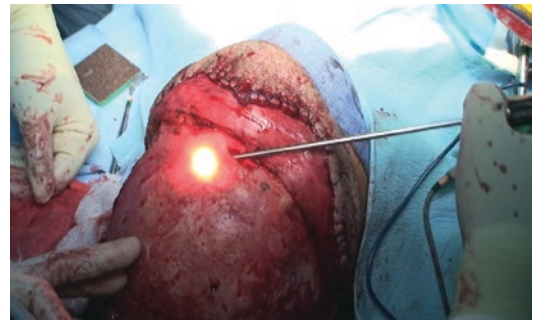
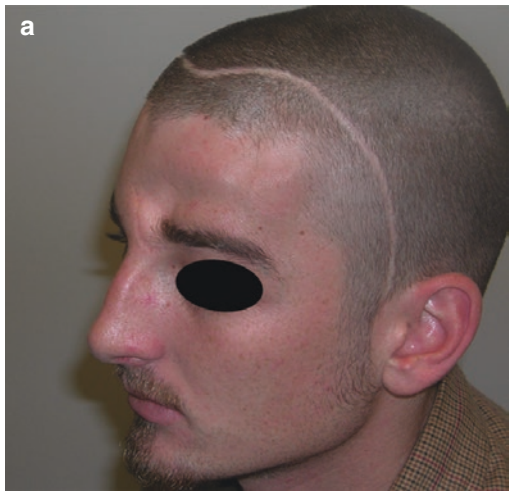


Fig. 31.8 Delineating the limits of the frontal sinus can be facilitated by dimming down the operating room lights and placing a light source within the sinus. (Reprinted with permission from Hollier and Koshy [8])



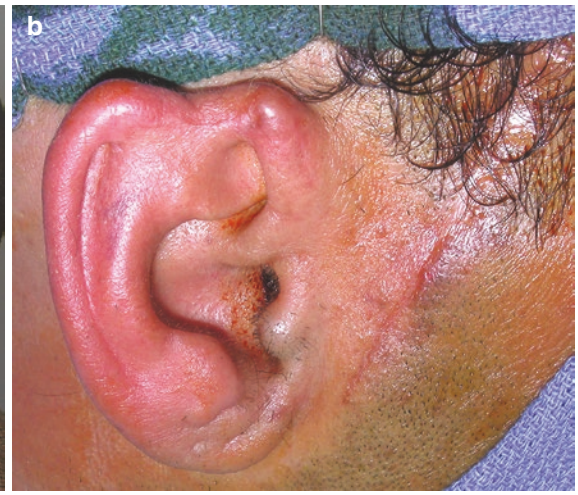


Fig. 31.7 (**a**, **b**) Coronal incision is a popular and versatile approach to the anterior cranial vault and upper and middle third of the facial skeleton. (**a**) The traditional straight-line incision may leave a noticeable straight-line scar that may be obvious with the hair parted away from the incision. To help alleviate this problem, the stealth incision was introduced. The stealth incision is a zigzag incision line that helps camouflage the coronal scar. (**b**) While preauricular extension has been recommended by many authors to improve access and exposure to the facial skeleton, such incision may produce a noticeable scar

Tip
When removing the anterior table, one should bevel the edges in anticipation of bone replacement.

Trick
When destroying the mucosa, special attention should be made to the complete removal of the *vascular crypts of Breschet* within the sinus's bone structure. These invaginations contain mucosal remnants, necessitating a burr to ensure complete removal. A carbon dioxide laser is also a potential option.

Tip
Leaving the frontal sinus empty following sinus obliteration is a perfectly safe and effective approach with the potential for "spontaneous osteogenesis" [24, 27]. One should not expect revascularization of a nonvascularized graft material such as fat in the sinus cavity. In reality, small sinuses may be completely filled by the same pericranial or galeal flap used to obliterate the nasofrontal communication.

Tip
It is extremely important for patients to be closely followed in the long term. Complications may manifest very late in the postoperative period. A follow-up CT scan should be performed 3–6 months after the procedure. Complaints of frontal headache or nasal drainage warrant a shorter interval.

Nasoorbitoethmoid Fractures

Signs of nasoorbitoethmoid (NOE) fractures include loss of dorsal nasal support and telecanthus with rounding of the medial canthal angle. Axial and coronal CT scans are the most helpful in determining the location and the degree of injury [8]. To restore a normal appearance, intercanthal distance and nasal projection must be restored. This requires both lower eyelid and coronal incision [28].

Tip
Injuries to the nasolacrimal duct can be associated with NOE fractures; however, primary exploration is not indicated unless a clear laceration is present.

Trick
Understanding the anatomy of the medial canthal tendon (MCT) is integral for the assessment and management of these fractures. Evaluating the bone segment to which the MCT is attached is key for diagnosing a true NOE fracture [29]. The easiest way to visualize this structure is to follow the lacrimal canal as it ascends into the lacrimal fossa on the CT scan. The MCT attaches to the bone surrounding this fossa.

Trick
Definitive diagnosis based on the CT scan can occasionally be difficult. In such cases, the diagnosis can be made under anesthesia by placing a blunt elevator intranasally at the level of the medial canthus. The degree of mobility can be determined by digital palpation of the medial canthus externally and applying pressure against the internally positioned elevator.

Tip
Delaying the treatment for more than 2–3 weeks can make the reduction difficult and yield suboptimal results. It is best to be performed soon after the initial swelling has resolved.

Tip
When dissecting the fracture, great care must be taken not to strip the insertion the MCT from the bone fragment (Fig. 31.9)

Tip
If a transnasal canthopexy is required, the most crucial aspect is achieving the correct vector of pull on the canthal tendon, which is oriented posteriorly and superiorly. Reattaching the tendon too anteriorly can result in persistent telecanthus.

Trick
The best way to achieve the correct direction of pull on the canthal tendon is by drilling from the contralateral side to a point at the level of the superior posterior aspect of the lacrimal fossa. The MCT is best secured through an anterior 3 mm incision just into the dermis 2 mm medial to the medial canthus and then grasped with a double-armed permanent suture or wire. The suture or wire can then be secured to a screw placed on the contralateral side (Fig. 31.10).

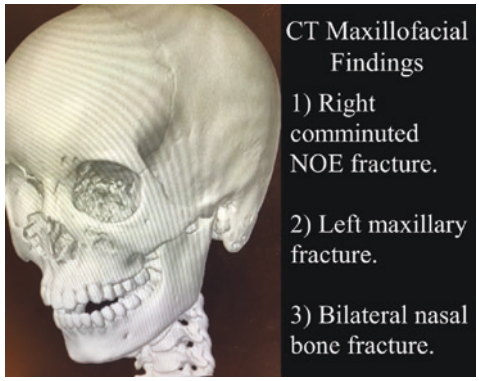


Fig. 31.9 Nasoorbitoethmoid fracture (▶ https://doi.org/10.1007/000-3v7)

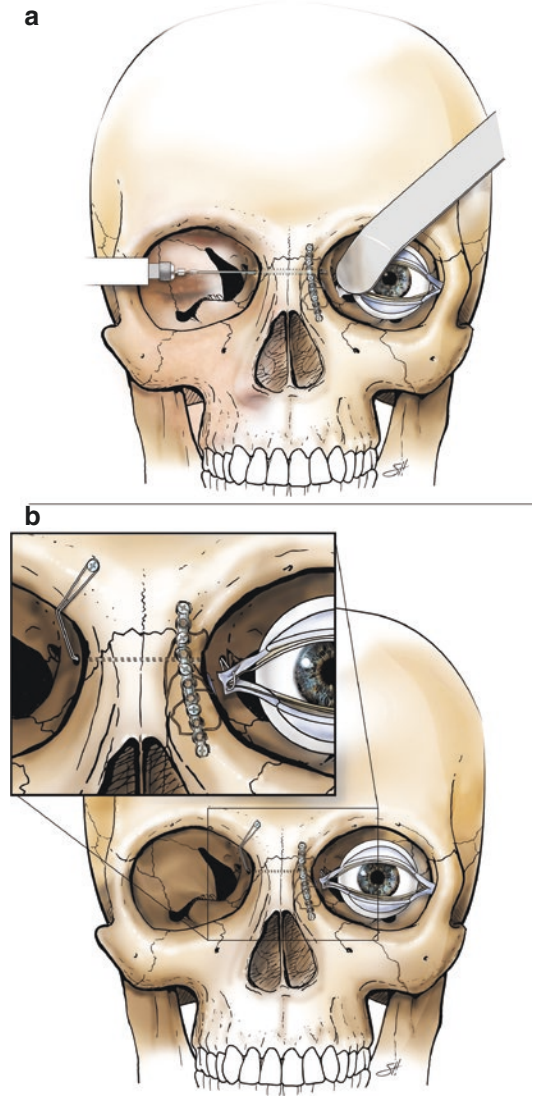


Fig. 31.10 Placement of transnasal canthopexy wire. (**a**) A drill is used to drill a hole from the contralateral side. Caution must be used to make sure that instrument does not advance too far, injuring the globe. (**b**) The medial canthal tendon is grasped with a double-armed permanent suture or a wire. The suture or wire is then passed through the hole and secured to a screw placed on the contralateral side. (Reprinted with permission from Baylor College of Medicine)

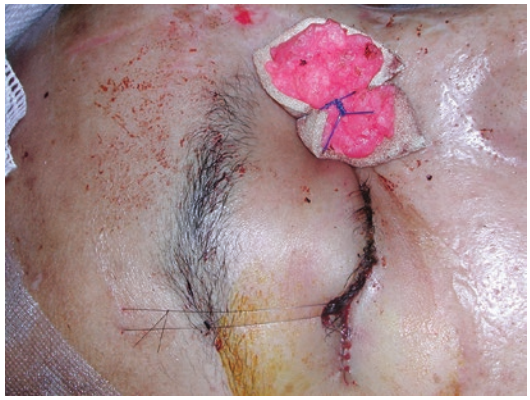


Fig. 31.11 Patient with a nasoorbitoethmoid fracture fixed using a soft-tissue bolster. The suture is placed through and through the skin and bone transnasally, and used to tie a bolster of felt to provide pressure over the skin of the region for 1–2 weeks

Tip
During the healing phase of the thin medial canthal region, it is critical for pressure to be applied externally on the soft tissue in order to restore the normal contour of the medial canthal valley. Failure to provide this external pressure allows the accumulation of blood and serum, precluding the tight adherence of the skin with the underlying bone.

Trick
External pressure can be applied by placing a soft tissue bolster for 1–2 weeks. One approach in securing this is to pass a large suture from one medial canthal region transnasally (Fig. 31.11).

Gunshot Wounds and Panfacial Trauma

Facial gunshot wounds typically require extensive operative interventions and postoperative care due to a combination of soft tissue loss and bone fractures. The extent of the injury is related to properties within the projectile and firearm, along with tissue characteristics and anatomic relationships. Regardless of the class of firearm and the velocity of the projectile, the reconstructive approach should involve three stages: initial stabilization, definitive reconstruction, and potential secondary refinement [30]. Short delays of 5–7 days in operative management allow the surgical team time to adequately plan the operative approach and discuss expectations with the patient and family. However, lengthy delays are not recommended, due to fracture consolidation and soft tissue contracture.

Tip
Restoration of the anteroposterior projection and width of the face is the first goal of skeletal reconstruction. Although the order in which the craniofacial skeleton is addressed is somewhat controversial, reconstructing the zygomatic arch early establishes the facial width and projection, and provides a frame for subsequent reconstructions [31].

Tip
Bone defects greater than 5 mm should be bone grafted [30–32]. Due to similarities in height and thickness, iliac crest bone is preferred for reconstructing the mandible. Rib or calvarial grafts are more suitable for reconstructing the orbit and midface, due to their abundance and contour. Defects larger than 6 cm require vascularized bone for the reconstruction. In such defects, the fibula osteocutaneous free flap is a preferred option.

Tip
Soft tissue injuries can often be re-approximated or closed with local rotational or advancement flaps. Extensive soft tissue

loss may require free tissue transfer. It is important to not only consider the defect of the skin envelope but also the need for lining components. Failure to recreate the lining may result in fistula formation, and significant soft tissue contracture.

Trick
Preferred options to reconstruct soft tissue loss are the anterolateral thigh flap and the radial forearm flap. Both are thin with a long vascular pedicle, providing an adequate skin paddle. Additionally, a two-team harvest can be performed with low donor site morbidity.

Complications and Secondary Deformities

Enophthalmos

Clinically, enophthalmos is noticeable when the displacement is 2 mm or greater. Failure to restore the correct orbital volume is the most common mistake when repairing orbitozygomatic fractures, resulting in late enophthalmos (Fig. 31.12). Correction of enophthalmos should be directed toward correction of the orbital volume.

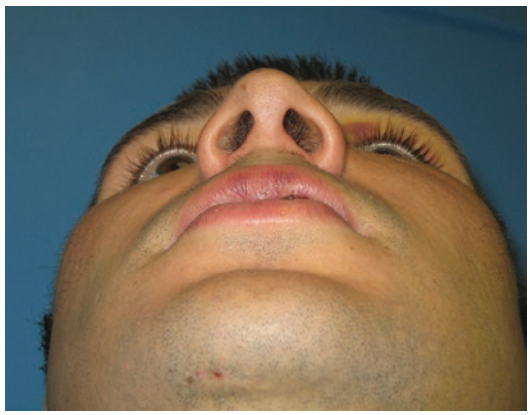


Fig. 31.12 Patient with left enophthalmos despite repair of an orbital floor fracture

Tip
Delayed enophthalmos is evaluated with a maxillofacial CT scan with 1.0 mm cuts.

Tip
In fractures of the orbital floor or medial wall, alloplastic implants or bone grafts in the deficient areas can help correct the orbital volume.

Entropion and Lid Retraction

Lid retraction in the early postoperative period can be successfully managed, in most cases, via aggressive lower-eyelid massage and forced eye closure exercises.

Tip
Early operative intervention should be avoided unless the patient suffers from significant corneal exposure and irritation.

Tip
After 4–6 months of conservative therapy, unresponsive lid retraction can be treated operatively via a transconjunctival approach. Release of the middle lamella must be followed by filling the defect with a hard palate mucosal graft and a lateral canthoplasty (Fig. 31.13a–d).

Telecanthus

Secondary telecanthus is very challenging to adequately correct, and results are often disappointing when compared to the acute repair. If one does approach this deformity, the entire soft tissue envelope must be mobilized and scar tissue resected or released.

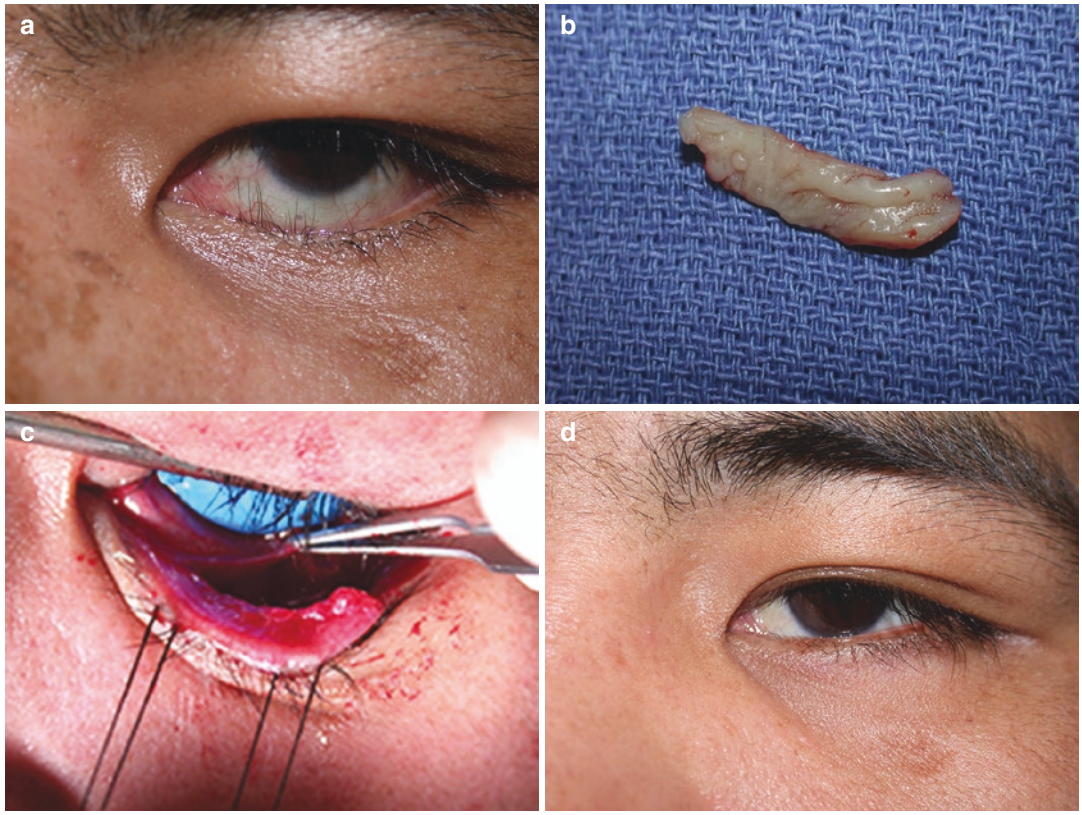


Fig. 31.13 (**a**–**d**) Lower-lid entropion. (**a**) Retraction in the early postoperative period should be managed with aggressive lower-eyelid massage and forced eye closure exercises. (**b**, **c**) Unresponsive retractions can be managed operatively via a transconjunctival approach and hard palate mucosal graft. (**d**) Correction of the deformity at 3-month follow-up

Tip

The correct position of the MCT insertion is at the posterosuperior aspect of the lacrimal fossae. If this region has been distorted, it should be reconstructed back to the normal contour, guided by the uninjured side. The surgeon should also remember that it is impossible to overcorrect the medial canthus in this deformity.

Malocclusion

The majority of secondary malocclusions noted early postoperatively will require operative exploration, hardware removal, appropriate reduction, and stabilization (Fig. 31.14). Once bone consolidation has occurred, recreating the fracture or orthognathic surgery is necessary.

Tip

Orthodontics is a tool to address only very mild degrees of malocclusion.

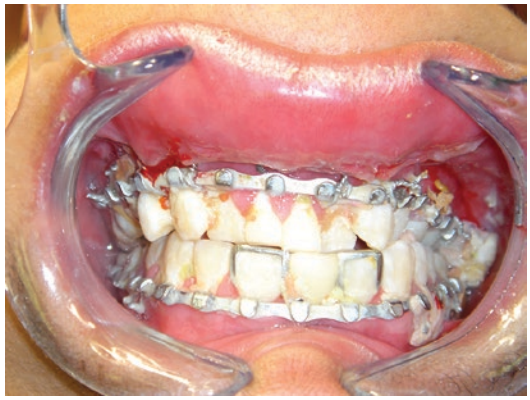


Fig. 31.14 Patient with postoperative malocclusion due to inaccurate reduction of a mandibular fracture. (Reprinted with permission from Sharabi and Koshy [6]. Available at: https://journals.lww.com/plasreconsurg / pages/default.aspx)

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Part IV

Adjunctive Procedures

32 Lasers and Aesthetic Devices: Skin Resurfacing, Tattoo Removal, and Body Contouring

Mark S. Nestor, Daniel Fischer, David Arnold, Taraneh Matin, and Jessica L. Jones

Laser Resurfacing

Laser resurfacing serves as a great nonsurgical option for facial rejuvenation. By tackling signs of aging and photodamage such as rhytides, lentigines, and dyschromia, laser resurfacing helps to restore a healthy and youthful appearance with minimal risk and rapid recovery. Laser skin resurfacing has come a long way. The continuous wave carbon dioxide (CO_2) laser was introduced in the 1980s but was associated with substantial side effects, including scarring, and significant recovery time [1]. Shortly after, advancements in laser therapy led to the development of the short-pulsed, high-peak power, and rapidly scanned, focused-beam CO_2 laser and the normal-mode erbium-doped yttrium aluminum garnet (Er:YAG) laser [1]. These lasers allowed for greater precision control but still required a major 2-week recovery period. Finally, this led to the development of the fractionated lasers which allow for minimal risk and shorter downtimes [1].

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Laser Selection

Nonablative lasers are specifically designed to target the dermal tissue while sparing the epidermis, therefore allowing for notably less down time and a higher safety profile, but with less impressive results [2–5]. The *ablative* lasers, on the other hand, vaporize the epidermal layer while also stimulating the dermis—this allows for enhanced cosmetic results, but with greater down time and procedural risk. A more intermediate approach would be with a *fractionated* laser. Fractionated lasers target alternative sections of tissue, creating discrete and separated columns of ablated tissue. This interweaving method allows for faster recov-

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ery by stimulating the surrounding untreated tissue to contribute to the healing process [2–5]. Although ablative laser skin resurfacing produces the greatest degree of cosmetic improvement, fractional resurfacing can be a more practical option, allowing for minimized risk and recovery time while producing adequate improvement [2].

For laser skin resurfacing to be effective and safe, precise and isolated thermal destruction is required. The CO_2 laser emits a wavelength of 10,600 nm, which is strongly absorbed by tissue water. This allows for the CO_2 laser to target the appropriate tissue depth, causing immediate contraction of the ablated tissue by denaturing existing old collagen [3, 6]. Subsequently, new collagen formation is stimulated, and in conjunction with ablation of the epidermis, cosmetic enhancement is achieved through controlled wound healing. Compared with the CO_2 laser, the Er: YAG laser emits light at the 2940-nm wavelength. At this frequency, the peak absorption range of water is more closely approximated, making the Er: YAG laser's water absorption coefficient 16 times greater than the CO_2 laser [2–4]. Because of this, the Er: YAG laser causes far fewer side effects than the CO_2 laser and requires less recovery time [2, 3, 7, 8].

Avoiding Unfavorable Results and Complications

Preoperative Planning

In order to achieve successful treatment outcomes, proper patient selection is paramount. It is important that patients have realistic expectations and a thorough understanding of the procedure and its associated risks [2]. Furthermore, patients need to be able to understand and maintain adequate postoperative care, including ultraviolet protection [8].

Patients with medical conditions involving poor wound healing, a history of collagen vascular disorders, conditions with a propensity for koebnerization, or past facial keloids or hypertrophic scarring are not candidates for laser resurfacing [2, 3]. Furthermore, patients with recent isotretinoin therapy within 6 months or a history of radiation within the treatment area have a higher risk for complications for this procedure [3, 9]. When treating Fitzpatrick skin types IV to VI, the high risk of post-inflammatory hyperpigmentation needs to be addressed. This is extremely important when treating ethnic patient populations [1, 2, 10–15].

Intraoperative Considerations

The *laser fluence*, the energy per unit area of tissue, is the most important property of laser resurfacing. Cosmetic outcomes and the rate of complications are significantly related to the laser fluence and the number of passes [3]. The higher the fluence, the greater the depth of tissue penetration, and thus the more drastic the results and the recovery time.

When treating deeper rhytides, increased energy fluence and ablation is advised, in order to have greater dermal contraction and stimulation for enhanced results. Higher fluence is also advised for the perioral area, glabella, and cheeks. In contrast, the periauricular, forehead, and lateral aspects of the cheek are more sensitive and require less fluence in order to avoid hyperpigmentation and erythema. Similarly, areas with less vasculature require less fluence for treatment. Examples include the infraorbital area, jaw, neck, and chest. For these areas, it is advised to minimize the amount of pulse energy, stacking, density, and passes performed [12].

Hypopigmentation 6–12 months postoperatively is a potentially significant and permanent side effect from treating deeply into the reticular dermis. Susceptible facial areas include the mandible and skin adjacent to photodamaged skin [15].

For enhanced results, a feathering technique should also be utilized to avoid sharp transition lines at the neck and hairline area [3].

The "snap test" is a useful method to assess the risk of ectropion formation in the lower eyelid. It entails pulling the lower eyelid and evaluating for return to resting position within 3 minutes. If it does not, laser resurfacing is not recommended in this area [11].

Postoperative Complications

In general, complications arising from laser resurfacing are uncommon and mild. However,

potential risks must be considered and discussed with the patient, as with any procedure.

Applying excess energy results in an increased risk of hypertrophic scarring. The first indicators of scar formation postoperatively are focal areas of induration and intense erythema. Immediate recognition is vital to prevent permanent scar development [15]. For mild hypertrophic scars, steroid-impregnated tape, low-potency steroid creams or lotions, or topical silicone or silicone sheeting is advised. For moderate to severe scarring, an intralesional steroid injection may be performed at 3- to 4- week intervals [16]. In addition, the treatment of hypertrophic burn scars with the pulsed-dye laser is effective when administered at 6- to 8-week intervals [17].

Persistent erythema may indicate extensive thermal necrosis and can last more than 6 months or lead to scarring if not treated early on with strong topical steroids. Other topical therapies that may help include vitamin C, hydroquinone, retinoic acid, azelaic acid, or glycolic acid [12].

While the risk for postoperative infection is very small, it must be considered in those undergoing laser resurfacing. Viral prophylaxis against herpes simplex virus (HSV) may be indicated, as reactivation can lead to improper wound healing and increased risk of secondary bacterial infection [15]. The classic vesicular appearance of HSV may not present due to an incomplete epithelial barrier; instead, patients often have painful, erythematous erosions with accompanying fever and malaise [18]. Valacyclovir or acyclovir dosed 1 day prior to the procedure and continued for 7–10 days provides adequate prophylaxis [18].

Laser Tattoo Removal

Tattoos have existed for many thousands of years, dating back to 3370 BC, and the oldest evidence of a human tattoo was found on the mummified skin of an Otzi Iceman discovered in 1991 [19]. Since then, tattoos have played a large part in many cultures and societies. According to a survey conducted in 2015, it was found that 29 percent of US adults have at least one tattoo [20]. Similar to the increasing popularity of tattoos, more people are also seeking to have them removed. According to one study, it is expected that at least five to ten million individuals will seek tattoo removal over the upcoming years [21–23]. Throughout the mid-to-late twentieth century there were various attempted techniques for tattoo removal, ranging from salt abrasion to surgical removal. These methods all invoked a high risk of damage to the surrounding skin and often resulted in scarring and incomplete removal [22]. In 1983 Rox Anderson began exploring laser tattoo removal, describing it as "precise microsurgery by selective absorption of pulsed radiation" [24, 25]. Since then there have been many advances, and it is currently the gold standard for tattoo removal. Although laser tattoo removal offers great efficacy and minimal side effects, it is not without risk and requires expert management.

Tattoos are applied by injecting organometallic dyes into the skin's dermal layer, with handheld tattoo guns or other means of micro-needling and dermal penetration. Once the pigment is inserted into the dermal layer, it is absorbed and stored within fibroblasts and macrophages in the dermis as pigment melanosomes (tattoo particles) [26]. Over time, some pigment migrates into the deeper dermis and finally into regional lymph nodes, resulting in discoloration and fading [26].

The atoms or molecules that give a compound its color are called chromophores, and each chromophore absorbs a certain wavelength of light in relation to its absorption coefficient. Laser tattoo removal is thus based on the concept of selective photothermolysis, wherein specific wavelengths of laser light are used to target the chromophores of tattoo pigment, allowing for destruction while leaving surrounding tissue intact [24]. It is theorized there are two synergistic mechanisms working in concert to achieve this targeted destruction, called thermal lock-in (thermal relaxation theory) and stress lock-in (stress relaxation theory) [27].

Thermal relaxation time (TRT) is the time it takes for a heated structure to lose its absorbed energy by diffusion of heat into surrounding materials. In other words, it is a measure of how quickly it cools. If an object is heated slower than

its TRT, heat escapes by diffusion, thus limiting the rise in temperature achieved and causing collateral damage to nearby structures. Conversely, an object heated faster than its TRT reaches the target temperature before heat can escape into the surrounding materials and achieves what is called thermal lock-in. This allows destruction of the cells storing tattoo particles while minimizing damage to nearby tissue [27].

In addition to being damaged by the sharp rise in temperature itself, the heating of targeted cells causes damage via vibration (photoacoustic waves). This vibratory energy dissipates into surrounding tissues similar to the diffusion of heat. Analogous to TRT, stress relaxation time (SRT) is the time it takes for the vibratory energy to spread from the target to nearby structures. Heating a cell faster than its SRT achieves stress lock-in resulting in disintegration, with minimal collateral damage [23, 27].

Since tattoo particles are very small, they have short TRTs and SRTs and require very rapid heating to minimize surrounding damage. This is achieved by using lasers with high fluence and short pulse widths. For the past three decades, the quality-switched lasers (QS lasers) have been the standard of care for laser tattoo removal. QS lasers deliver pulses in the nanosecond range, which is shorter than the TRTs of tattoo particles. However, it is believed that tattoo particle SRTs are in the picosecond range, so further development of lasers with even shorter pulse widths has been sought for the past 15 years. Recent advances have led to the development and commercialization of picosecond lasers. These are believed to induce both photoacoustic and thermal effects within the pigment particles, leading to better results and fewer adverse effects [23, 26, 28–30].

Laser Selection

A key component for successful laser tattoo removal is the correct laser selection. Different Fitzpatrick skin types, as well as different color tattoo ink, dictate which laser will be most effective (Table 32.1). When treating patients of ethnic background or Fitzpatrick skin type IV or higher, lasers with longer wavelengths, such as the 1064-nm Nd: YAG laser, should be used in order to avoid hypopigmentation [31, 32]. Blue-black is one of the easiest tattoo pigments to remove, and this can be done using the QS 694 nm ruby, 755 nm alexandrite, or the 1064 Nd:YAG [33, 34]. For orange, red, and yellow ink, the 532 nm wavelength using the Nd: YAG laser is recommended. Purple ink requires treatment with the QS 694-nm ruby laser, and green ink is best removed with the QS 755-nm alexandrite laser [35]. For white, tan, or brown pigmentation a different approach needs to be taken. These tattoo inks are typically composed of iron oxide and titanium dioxide, and when exposed to pulsed laser treatments they carry a high risk of darkening. For these colors, ablative lasers such as the CO_2 or Er: YAG laser are recommended [36–38]. In a large cohort trial of patients treated with QS lasers, about 47% of tattoos were cleared after 10 treatment sessions, while 75% were cleared after 15. Predictors of poor response to treatment include the presence of non-black or non-red ink, tattoo size (larger than 30 cm^2), localization to the lower extremities, treatment intervals of 8 weeks or less, and smoking [39]. Common adverse events include erythema, burning, blistering, hypo- or hyperpigmentation, and scarring [39].

In recent years, the picosecond laser has become a new gold standard in laser tattoo

Table 32.1 Optimal lasers used for tattoo removal based on pigment

Pigment	Q-Switch laser
Red, orange, yellow	Nd:YAG 532 nm
Green	Ruby 694 nm Alexandrite 755 nm Picosecond
Blue	Ruby 694 nm Alexandrite 755 nm Nd:YAG 1064 nm Picosecond
Brown, black	Ruby 694 nm Alexandrite 755 nm Nd:YAG 1064 nm
Purple/violet	Nd:YAG 532 nm Ruby 694 nm
White, tan, light brown	Nd:YAG 532 nm CO_2 laser

removal. Brand names include PICO, PicoSure, PicoWay, and enlighten. The advantage is in its name, delivering high-frequency energies in trillionths of a second, or in the range of 300–750 picoseconds (ps), thus working much faster than its QS counterparts. Since most tattoo pigments have a thermal relaxation time (TRT) within the picosecond range, the laser delivers the most specified delivery of thermal radiation to tattoo particles. In effect, the laser more effectively targets pigments and minimizes the collateral damage to surrounding dermal tissue, making the efficacy and side effect profile generally superior to QS lasers [40]. Picosecond lasers have been shown to be useful in treating tattoos refractory to other forms of laser therapy, in addition to a reduced amount of scarring and hypopigmentation [41]. Widespread use of these lasers is still restricted, due to additional cost and availability compared with QS lasers [42].

Preoperative Planning

Similar to other cosmetic procedures, proper patient selection is paramount in achieving desired results. The procedure and all its potential side effects must be thoroughly explained to patients in order to set realistic expectations regarding their treatment outcome. For patients with darker skin, it is important that they understand that they are at greater risk of acquiring procedural complications such as hypopigmentation, tissue texture changes, and potentially scarring [43]. Furthermore, a thorough and adequate medical history needs to be obtained. Patients with active infection or inflammatory disorders such as eczema or psoriasis do not qualify for laser tattoo removal. Furthermore, patients with a history of sarcoidosis should not be treated [26]. Patients need to be counseled on strict sun protection before and after laser tattoo removal.

For optimal treatment results, it is important to know the age of the tattoo and how it was acquired. Due to the partial absorption and breakdown of older tattoos by the body, they often require fewer treatments. Similarly, the method by which the tattoo was acquired will also affect the treatment. Whereas professional tattoos are applied using handheld guns that deliver uniform dermal injections of ink, amateur tattoos are applied using handheld needles, which deliver the ink at variable depths, are more superficial, and have fewer ink particles.

Intraoperative Planning

Patient comfort is an important consideration during laser tattoo removal. Subcutaneous lidocaine or topical anesthetic ointment should be administered prior to the treatment [26].

When performing laser tattoo removal, the goal is to achieve immediate skin whitening while using the lowest energy fluence. This allows for decreased risk while achieving the desired results. When applying the laser there should be about a 10 percent overlap of spots [44]. For optimal results, several laser passes should be done at each treatment session, with enough time in between to allow for the white tissue response to resolve. In order for this to occur, about 20 minutes is required between passes, and an average of four passes should be completed [45]. To expedite the process, perfluorodecalin can be applied between passes to resolve the ash-white tissue response faster [46]. Multiple sessions are typically required for complete tattoo removal. Laser sessions should be scheduled roughly 1 month apart to allow for adequate skin healing and ink clearance. For subsequent laser treatments, increased energy fluence will be required due to increased ink density.

The Kirby–Desai scale can be utilized as a tool to help estimate a patient's required number of laser sessions. The scale takes into account six key factors: patient Fitzpatrick skin type, tattoo location, tattoo color, amount of tattoo ink, inherent scarring or tissue change, and ink layering [27]. While this scale is helpful, patients should be advised that the number of required treatments is not definite and that the scale is limited and does not account for factors such as laser type.

Postoperative Consideration

Sun protection plays a key role in obtaining successful results. The importance of sun protection must be emphasized to patients. Slight blistering and crusting are expected side effects of the treatment. It is important for the treatment area to stay clean and covered with ointment for 7–10 days post-treatment.

Body-Contouring Devices

A number of different treatment modalities have been designed for fat reduction and body contouring, including laser, cryolipolysis, radiofrequency, high-intensity focused electromagnetic field (HIFEM), and high-intensity focused ultrasound (HIFU). Cryolipolysis is a moderately effective and well-tolerated treatment option for discrete bulges of fat in easily localized and isolated areas [47]. Laser therapy, on the other hand, is particularly effective for areas such as the outer thighs or abdomen, where adipose tissue is more evenly distributed and not as discrete or "pinchable" [48].

Cryolipolysis

Cryolipolysis is a moderately effective and well-tolerated treatment option for discrete bulges of fat in easily localized and isolated areas. In 2010 the FDA approved the first cryolipolysis device for the specific treatment of flank fat. Since then, cryolipolysis has been approved for use on the abdomen, thighs, buttocks, flank, back, submental area, and upper arms. Cryolipolysis utilizes the technology of controlled cooling to cause targeted adipocyte apoptosis while preserving the surrounding tissue, muscle, and nerve structures [47, 49].

Panniculitis occurs as adipocytes are selectively targeted via apoptosis due to the cooling effect, without damaging nearby tissues. This inherently causes apoptosis and inflammation, which peak at about 2 weeks but last about 3 months, during which time fat stores significantly diminish [50].

Patients uniquely benefit from this therapy as long-term follow-up data show that results are permanent. However, it is important to inform patients that this technique is yet not as effective as liposuction [50].

Preoperative Considerations

As with any cosmetic procedure, patient selection and proper counseling is crucial for setting realistic expectations and achieving the best results. The optimal patient has soft, discrete collections of fat that can be pulled away from the body via suction into the device for freezing. The mechanics of performing the procedure prevent its use on amorphous and panicular fat and make using it on the arms challenging. Thus, obese patients are not good candidates [50].

Multiple sessions are often required to optimize aesthetic results. The overall duration of treatment is tailored to the needs of each patient and depends on the number of areas treated per visit and total number of visits. In patients with an ideal body weight, one to three treatment sessions are typically performed at 2-month intervals [51].

Consideration of a multimodal treatment approach can be given to maximize efficacy in patients willing to undergo multiple procedures. The combination of cryolipolysis with noninvasive fat-reduction treatments, such as ultrasound or radiofrequency, can improve outcomes by destroying a greater number of adipocytes [50]. Contraindications would include patients with diseases such as cryoglobulinemia, paroxysmal cold hemoglobinuria, and cold agglutinin disease.

Intraoperative Planning

The cryolipolysis machine utilizes a vacuum cup to pull collections of fat away from the body for freezing between two cooling panels. This cools the tissue to 4–10 °C for 35–60 minutes and must be performed at each site of treatment. Patients generally have minimal side effects but may report unpleasant sensations of stinging, tingling,

tugging, or pinching during the procedure that usually lessen as the area becomes numb [51].

Postoperative Considerations

Although most patients experience results at 3 weeks post-treatment, improvement may continue to progress for up to 6 months. It is common for patients to experience a minimal amount of edema, ecchymoses, numbness, and tingling for the following days to weeks after cryolipolysis. Any pain reported after treatment, however, has been mild to moderate, lasting a few days maximum, and reported only in a small population of patients. There has been no evidence of permanent damage or side effects after treatment. There have been rare reports of paradoxical adipose hyperplasia consisting of tender and hardened tissue at the treatment site that may develop 2–3 months post-treatment. These tend to resolve spontaneously, rarely requiring liposuction. There has been a concern for elevated triglycerides and liver damage due to destruction and leakage from adipocytes; however, to date, there has been no laboratory evidence to support this [51].

Laser Therapy

Laser fat reduction is a relatively new and safe option for patients seeking overall fat reduction in areas such as the outer thighs or abdomen. Currently, there are two main devices for laser fat reduction: low-level laser therapy (LLLT) using 635 nm and 532 nm wavelength, and the new 1060 nm diode laser.

LLLT is the therapeutic application of low-irradiancy laser light (1–5 mW/cm^2) insufficient to cause photothermal or photoacoustic effects [52, 53]. It has been used for over 40 years to promote healing and reduce tissue inflammation, edema, and pain in a variety of musculoskeletal pathologies [53, 54]. In the last two decades, LLLT has been explored for use in multiple fat-reduction techniques, beginning with LLLT-assisted lipoplasty. This involves applying a 635 nm light to the skin surface prior to liposuction, with the intent of emulsifying fat in order to soften the area prior to aspiration of adipose tissue [48]. LLLT devices have been cleared by the FDA for use in noninvasive dermatological aesthetic treatment for reducing hip, waist, thigh, and upper arm circumference [53, 55].

The mechanism of action has not been elucidated, but there are several theories. These include the creation of transitory micropores in adipocyte cell membranes allowing lipids to "spill" out, induced triglyceride mobilization from unharmed cells, conversion of brown fat to yellow fat, and, more recently, increased systemic lipid metabolism via an unknown autocrine/paracrine intermediate [48, 52, 56, 57].

LLLT devices such as the Meridian LAPEX 2000 and LipoLaser are used for body contouring. The results of their use in clinical trials have been mostly positive; the majority of studies have shown a statistically significant, albeit mild, benefit, while a few others have shown no benefit [52, 58]. One study performed on the waist, hips, and thighs showed a total circumferential reduction of 8.91 cm, with the greatest reduction across the waist (2.66 cm). Another study showed a 13.13 cm total circumferential reduction across seven body sites [48, 55, 57, 59]. Due to low levels of emitted light in LLLT devices, side effects are minimal, recovery times are shorter, and the technique is considered safe with regard to exposure of unprotected skin and eyes [57, 60].

More recently, the 1060 nm diode laser was developed for fat reduction. This device triggers adipocyte apoptosis through thermal destruction by heating adipose tissue to temperatures between 42 and 47 °C. The 1060 nm wavelength targets adipocytes with minimal to no absorption in the dermis, allowing for preservation of the overlying skin and adnexae. Additionally, minimal absorption of this wavelength by melanin allows for its use in all skin tones, and the device's contact cooling plates prevent significant discomfort and side effects. Adipocyte apoptosis leads to improved and lasting results [48, 61].

Preoperative Considerations

As discussed previously, appropriate patient selection and setting of expectations is key with any cosmetic procedure. Ideal patients are nonobese, with discrete areas of fat that can be targeted with the rectangular applicators of the 1060, such as on the flanks, abdomen, thighs, back, or arms, although it has only been FDA-approved for the first two. The majority of patients are pleased to see positive results, but they are subtle in comparison to liposuction. Contraindications to consider include pregnant women, as well as those with a tattoo, abdominal hernia, or implanted metal in the treatment area.

Intraoperative Considerations

For the 1060, four rectangular, non-suction applicators are placed on the patient and cover 35 cm2 of space, each allowing for the treatment of up to four sites simultaneously. The total treatment length is 25 minutes. Approximately 4 minutes are required to reach the target temperature, followed by 21 minutes of treatment time, including multiple heating and cooling cycles. Patients will feel some discomfort from the heating process, but pain reported is generally mild to moderate and counteracted by the cooling plates [52].

Postoperative Consideration

Mild to moderate tenderness is the most common side effect of treatment, but no downtime post-procedure is required before patients may resume normal daily activities. Rarely, swelling or induration can occur, but these typically resolve spontaneously within 1–3 weeks. No cases of elevated serum lipid levels have been documented thus far, despite the theoretical possibility of such with the leakage of fats from the procedures. Appreciable changes often occur with a single session, but results are best seen at the 3-month mark after treatment [50–52].

Magnetic Resonance Contouring

The FDA approved the use of magnetic resonance imaging with high-intensity focused electromagnetic technology (HIFEM) in 2018 for contouring of the buttocks and abdomen. Although this is the most recent method in noninvasive body contouring, it has been previously used in treating musculoskeletal, urologic, gynecologic, and neuropsychiatric disorders. One advantage in this technique over other noninvasive fat-reduction therapies is that it has been shown to increase overall muscle strength, tone, and thickness [62, 63].

This method works by administering about 20,000 pulses to muscle tissue in a half-hour session in order to stimulate muscle contractions. The suggested mechanism of action is that these rapid contractions stimulate lipolysis in adipose tissue, which then releases free fatty acids that further break down surrounding tissue, leaving behind a larger muscle-to-fat ratio. The evidence for this has been supported by increases in the apoptotic index of 120 histological slides by 91.7%, which is a cosmetically desirable reduction in fatty tissue. This increase in the muscle-to-fat ratio can also be explained by studies supporting an increase in muscle density and strength over a 6-month period, likely due to repetitive nerve stimulation of muscle fibers; however, further research is needed to support this theory. About 91% of patients have shown a decrease in the distance between the abdominal muscles in response to HIFEM, another cosmetic advantage unique to this therapy [62, 63].

The Emsculpt (BTL Industries, Inc., New York, NY, USA) is one such HIFEM device used for contour sculpting that allows for adjustment of stimulation intensity, ideally to levels of 90–100% which are typically tolerated by most patients. This allows for the optimization of the strength of muscle contractions for best results. Patients are typically treated initially four times for about 30 minutes over a period of 2 weeks, followed by a maintenance treatment every 3–6 months. During treatment, a minority of patients describe feelings of tugging and minimally painful muscle contractions

or electric shocks. The only side effect reported in this minority was temporary muscle soreness, without long-term complications.

The high satisfaction rates among patients that have undergone HIFEM therapy correlate with the success of treatment among clinical trials of which significant reduction in fat deposition, waist circumference, and diastasis recti were reported. Results can typically be seen as early as 1 month post-treatment. One study reported that 92% of patients were cosmetically satisfied with results at 3 months post-treatment. Another study has shown success in treating the cosmetic appearance of gluteal muscles as well, both from investigators' and patients' perspectives. Additional research is still necessary to investigate long-term outcomes, as studies so far have only included a 6-month maximum follow-up phase [62, 63].

There are currently no universal guidelines for selecting an ideal candidate for HIFEM non-invasive body contouring. While one study has rejected a positive correlation between high BMI and efficacy of treatment, another study has suggested the opposite, hypothesizing that inferior muscle contraction occurs due to weaker delivery of electrical impulses across a larger span of fatty tissue. While patients with high BMI are likely to experience significant results, based on these findings, it may be preferable to select patients with lower BMI or those that measure less than 2.5 cm of superficial adipose tissue with the pinch of two fingers. The only contraindications to HIFEM thus far include those with metallic or electronic implants and pregnant patients.

Radiofrequency Skin Tightening and Body Contouring

Radiofrequency is another cosmetic technique used in fat reduction and skin tightening. It can be applied to multiple areas of the body, including the face, abdomen, thighs, and buttocks. This method works by selectively heating tissue rich in collagen, immediately molding and degrading fibers for rapid skin tightening. The effects are long-lasting due to fibroblast production, which in turn generates new collagen and elastin. Body contouring and fat reduction are also achieved, as the heat stimulates apoptosis of adipocytes [61, 64, 65].

These radiofrequency devices have a unipolar, monopolar, and bipolar setting, each with its own advantages and disadvantages. Unipolar is best for causing deep-tissue damage, but is the most difficult mode to adjust and manage. Multipolar mode is the most effective in skin tightening, and most often preferred, as it penetrates in a more uniform manner.

FDA-approved in 2002, Thermage (Solta Medical, Pleasanton, CA, USA) is the earliest and most frequently used radiofrequency device for skin tightening and fat reduction. Vanquish (BTL Industries, Boston, MA, USA) is a more recent device specialized for abdominal, back, and flank fat reduction. The advantage of this device is that it includes extendable paddles for spanning larger areas of treatment. The device truSculpt (Cutera, Brisbane, CA, USA) treats the midsection as well, using a monopolar technique with flexible handpieces that have the capability of targeting small, hard-to-reach locations in addition to larger areas. As in HIFEM, the ideal candidates for radiofrequency contouring are suggested to have a low-to-medium BMI and visibly obvious skin laxity.

Finally, the Venus Legacy (Venus Concept, Toronto, ON, Canada) is unique in that it uses non-thermal energy for skin tightening. This device contains electrodes that generate a pulsed electromagnetic field to stimulate growth factor release, angiogenesis, and rapid production of new collagen. Adipose tissue, however, is heated at 43–45 °C for 20–30 minutes, but in order to preserve the epidermis from damage and avoid placing patients at risk for burns, scarring, pigmentary changes, and infection, the skin is subsequently cooled with a cryogen spray. This method has shown desirable results and only minimal pain from heat during the actual treatment, with mild erythema and swelling, typical for the first 24 hours post-treatment. There have been few reports of transient facial tenderness and numbness, and the formation of subcutaneous nodules. It is important to monitor the skin during treatment in order to identify any signs of

epidermal injury. This can often be done with the aid of temperature sensors included in select devices in order to prevent burns. Bipolar and high-pass treatment techniques are often preferred, in order to avoid or minimize many of these post-treatment side effects.

Radiofrequency as a body-sculpting technique has shown efficacy and high satisfaction rates among patients, 71–97% of which reported subjective improvements. Research is still needed to evaluate long-term effects of this technique, but what is clear is that skin tightening is observed with just a single session, and significant improvement has been demonstrated after 2–6 months of treatment [61, 64, 65].

Ultrasound Skin Tightening and Body Contouring

The idea of using high-intensity focused ultrasound (HIFU) therapeutically was initially introduced in 1942, and since then it has been used for a variety of purposes such as treating tumors, uterine fibroids, and kidney stones. While new technologies have replaced ultrasound as a treatment modality for many applications, in recent years attention has turned to its use for body contouring and skin tightening.

Focused ultrasound energy causes rapid heating via molecular vibrations and shear forces and induces coagulative necrosis of adipocytes when surpassing 56 °C. The convergence achieved at high frequencies allows for targeted destruction of adipose tissue with no damage to surrounding nerves or vasculature. Additionally, the elevated heat stimulates collagen contraction and thickening. Low-frequency focused-pulse ultrasound is an alternative modality that causes mechanical disruption of adipocytes without the thermal destruction that HIFU creates [66–68].

Patients are usually treated at 4-week intervals for 2–6 months, and gradual improvements in adiposity occur over time. Multiple clinical trials have demonstrated moderate reductions in waist circumference measured 12 weeks after treatments with HIFU, averaging between 1 and 4.6 cm. No effect on BMI or weight has been documented [66–68].

HIFU therapy is typically well tolerated, with only mild adverse effects such as tenderness, erythema, or bruising that self-resolve in hours to days. Rarely, patients may experience temporary numbness, tingling, or muscle weakness if nerves are accidentally targeted during the procedure. No changes in blood lipid levels or inflammatory markers have been reported.

Patient satisfaction post-treatment has been reported at 47–86%, independent of diet and exercise regimens. Thus, body contouring with HIFU is a safe and viable option for nonobese patients seeking moderate, targeted fat reduction and skin tightening with minimal downtime [66–68].

Conclusion

Noninvasive body-contouring devices are a viable alternative for patients seeking targeted fat reduction without undergoing surgery. The various options can be matched to patient and physician preference, and combination therapy with multiple modalities can be undertaken for enhanced results. Other advantages include a generally mild to minimal side effect profile and zero down-time, in nearly all cases. However, the results are far less dramatic than liposuction, so realistic expectations must be set prior to initiating treatment. As more data is gathered and technology advances, these techniques will play a growing and valuable role in the clinician's aesthetic toolbox.

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Pediatric Tissue Expansion

33

Laura S. Humphries and Bruce S. Bauer

Reconstruction with Tissue Expansion: Principles and Pearls

- *Careful patient selection is imperative*. Parents and patients (when old enough) must have a thorough understanding of expansion process and potential complications.
- *Surgeons must have an understanding of potential problems with tissue expansion and their avoidance*. Always consider whether other reconstructive techniques are more suitable in the specific situation.
- *Rotation/advancement and transposition flaps are "better" than advancement flaps alone* [1]**.** Advancement flaps are more difficult to advance with each expansion. In a growing child, tissue expanders placed especially in the trunk/back can result in skeletal growth problems and scoliosis.
- *Never excise nevus completely until you know that you can close it*.
- Evaluate the site and tissue to be expanded based on the lesion to be excised or defect corrected. *Then, aim to place the largest tissue expander possible to allow for the greatest amount of expansion of normal tissue*. This may mean that part of the nevus will be expanded to the edge of the flap.
- *Fixate the expanded flap to deep tissue during inset so it is less likely to retract*.
- *Expansion of an extremity is limited by movement in axial direction*. Expansion works much better around an extremity.
- *Rectangular expanders are used throughout*, ideally with the thin, firm base allowing for low profile with minimal risk of raised pressure points.

Tissue Expander Case Materials

Tissue Expanders

- Tissue expander (TE) specifications (Fig. 33.1) [2]
- Design
- Material: silicone, smooth outer shell

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_33) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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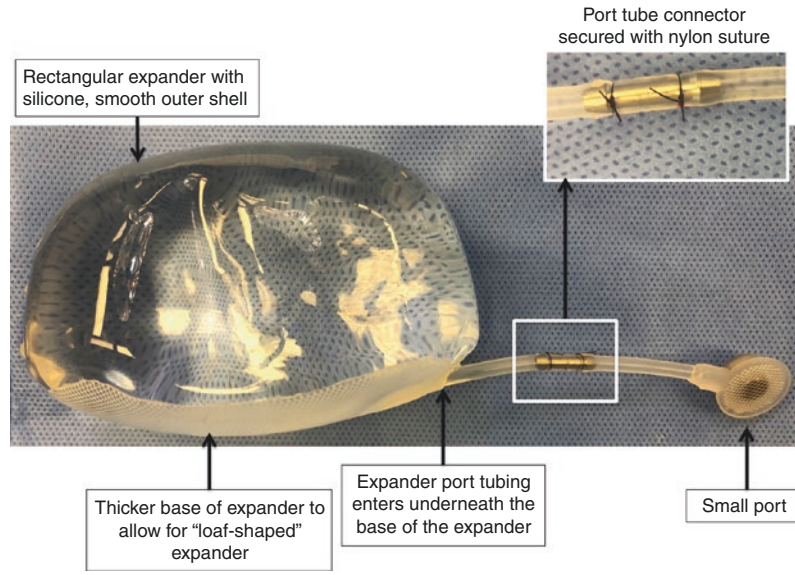

Fig. 33.1 Tissue expander specifications

Tip
Capsule formation is helpful to maintain vascularity to the flap, which is why a smooth outer shell is preferred over textured.

- Expander port tubing enters the expander underneath the base of the expander.

Tip
In earlier models, the port tubing entered along the edge of the expander, which could cause a pressure point on the overlying skin and lead to expander exposure.

Shapes

- Rectangular-shaped expanders are used in our practice to allow for the maximum amount of expansion.
- The base of the expander is a little thicker than the shell, resulting in more of a "loaf" shape. The tissue expander base lies against the base of the expander pocket.

Tip
Crescent- and croissant-shaped expanders aim to minimize dog-ear formation when the expander is removed. The dog-ear formed using the rectangular-shaped expanders shrinks away with time.

Sizes (Table 33.1)

Parts

- Each expander is attached to a remote port by silicone tubing. The port is either small or large in size.
- The length of the port tubing can be customized (shortened or lengthened) depending on the location of the port relative to the expander when they are placed.
- The tubing can be re-connected using metal connectors. This allows for customization of port tubing length as needed.

Table 33.1 Tissue expander[a] specifications, low rectangle shape

Fill volume (cc)	Length (cm)	Width (cm)	Projection/Height (cm)	Size of port
70–90	6.0	4.0	3.5–4.6	Small
250–300	10.0	6.0	5.0–6.3	Small
350–420	12.0	6.0	5.0–7.0	Small
500–600	12.0	7.0	6.0–7.8	Large
750–900	15.0	7.5	7.0–9.0	Large
1000–1200	17.0	8.0	8.0–10.2	Large

[a]Expanders made by Softspan™ Specialty Surgical Products, Inc. (SSP, Victor, MT, USA), Bauer Design

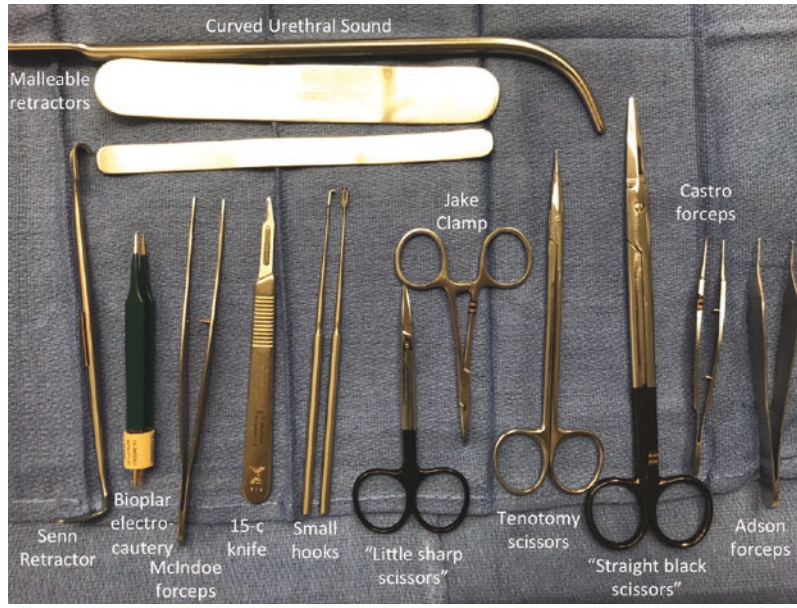

Fig. 33.2 Surgical instruments

Connector

- The connector is metal and connects each end of the silicone tubing.
- Two connectors and extra port tubing are provided in each tissue expander packet.

Port

- Specifications: Each expander comes with either a small or large port. 70–350 mL tissue expanders come with a small port, and the larger expanders come with large port. Both port sizes are also available separately.

Tip
Whenever the 250–350 mL expanders are used on the trunk, we replace the small port with a large port.

Surgical Instruments (Fig. 33.2)

- Senn retractor
- McIndoe forceps
- 15-c knife
- Small skin hooks

- Bovie electrocautery (Settings: 20–20, blend)
- Bipolar electrocautery (Settings: 20)
- "Little sharp scissors" (similar to an iris scissor)
- "Straight black scissors" (facelift-like scissors)
- Castro forceps
- Adson forceps
- Malleables (assorted sizes)
- Curved urethral sounds (assorted sizes)

Tip
May allow dissecting for expander placement and also port placement.

Sutures (Table 33.2)

- Types
- Needle tips: P-3 or PS-2 needle tip

Table 33.2 Suture type selection

Suture	Tissue expander placement	Tissue expander removal/flap
Deep sutures: deep stitches to secure skin flaps to fascia/ periosteum		4-0 clear nylon, P-3 or PS-2 needle; interrupted 3-0 Monocryl, PS-2 (on occasion)
Deep dermal sutures: layered skin closure	4-0 clear nylon, PS-2 and P-3; interrupted	4-0 clear nylon, PS-2 and P-3; interrupted 4-0 (PS-2 needle) or 5–0 Monocryl (P-3 needle); interrupted
Skin sutures	4-0 blue Prolene, P-3 needle; running	6-0 Chromic, P-3 needle; running 7-0 Vicryl (Ethicon, Inc., Somerville, NJ) (SE-140-B needle); running

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Suture Technique

- Avoid picking up the skin with forceps to prevent tissue injury.

Epidermal Suture Technique

- Needle must enter the skin perpendicularly on the entry side.
- Follow the curve of the needle.
- Bite should be full-thickness.

Running Subcuticular Suture Technique

- Hold the needle driver like a pencil.
- "Run" the suture toward yourself.
- When running toward yourself, "flip" the needle in the needle driver when taking a bite on the left side. This allows for the biggest bite of the dermis.

Drains (Fig. 33.3)

- Preparation
- Create holes at the distal end of the tubing attached to a 19-gauge butterfly needle drain.
- Place one drain into each expander pocket when placing expander and under each flap during the TE removal and flap closure.
- Insert butterfly needle into red-top tube for fluid evacuation.

Tissue Expander Placement [2, 3]

Principles

- The expander must be placed to minimize contour problems at the edges and the injection ports placed for ease of access during injection.
- Suction drainage is used in all cases.
- Layered closure is used in all cases with sutures left in place throughout expansion.

Fig. 33.3 Drains

19-gauge butterfly needle drain with holes at the distal end

Red-top vacutainer tubefor drain

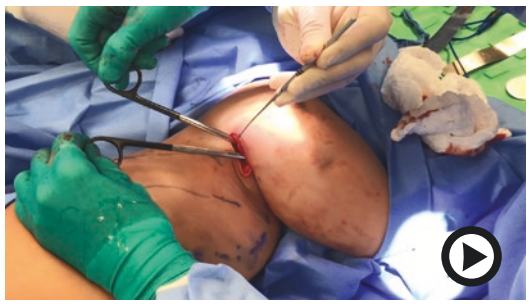

Fig. 33.4 Tissue expander placement in the pediatric patient (▶ https://doi.org/10.1007/000-3va)

General Instructions

Markings (Fig. 33.4)

- Measure base of the flap to estimate the expander size.
- Outline the maximum extent of the anticipated expander on the surface of the skin.
- Expander size depends on the size of the patient and the planned location of the expander.

Incision (Fig. 33.4)

- Incise the skin on the inside of the nevus or within a previous scar.

Tip

Some of the patients with a congenital melanocytic nevus (CMN) have villous hair that get more irritated with sutures, so the incision is made outside of the nevus, on its edge instead of within the nevus. For others (e.g., vascular malformations), make the incision outside of the lesion.

Tip
The old dogma is to place the incision for the tissue expander insertion perpendicular to the leading edge of the flap to prevent tension on the incision and allow for early expansion. Wound issues and incision placement in cases of serial expansion may arise with this practice. We have had success with placing the incision parallel to the leading edge of the flap.

Tissue Expander Pocket Preparation (Fig. 33.4)

- Retract the skin edges with small skin hooks.
- Use electrocautery to dissect down to fascia (electrocautery setting: 20–20 blend).

Dissection Technique

- Use "straight black scissors" to cut/spread the tissue to identify the correct plane in the subcutaneous space. Look at the surface of the skin when dissecting the expander pocket with scissors and/or malleable to determine the depth of dissection.
- Insert the scissors closed, spread perpendicular to the flap, and remove the scissors. Do this in a radial direction. Cut the intervening tissue.
- When approaching a curve, aim the scissor tips down toward the floor to maintain the same depth of dissection.
- Sweep the pocket with scissors, a finger, or a medium/large malleable to define the extent of the pocket. Stay within the skin markings so as not to make the pocket too large.
- May use malleables and/or urethral sounds to aid in the development and definition of the pocket.
- Dissect about 1 cm beyond border of the expander size. Minimize trauma to the skin with retractors.

Tip
If expander pocket is too big, the expander is likely to drift away from where you want it to be.

Port Placement (Fig. 33.4)

- Remote, buried ports are used for expansion.
- Position the port on a bony surface to facilitate needle insertion for expansion postoperatively.
- To develop the port pocket: dissect with large black scissors from inside of the expander pocket. Spread wide at the end where port pocket will be. The spread of the scissor should be beyond how far your fingers in the scissor can spread.
- Spread wide on the way back out.
- Insert small malleable to redefine the tunnel.
- Tunnel the port to the port pocket with a malleable or fingers.
- If the port pocket is difficult to develop from inside of the expander pocket, then make a small incision close to the planned location of the port pocket.

Tip
Always have enough port tubing length that if you are overexpanding, it does not draw the port back toward the expander, particularly on the trunk.

Tissue Expander Preparation (Fig. 33.4)

- Evacuate air from tissue expander.
- Instill just enough injectable saline into the expander to allow the expander to spread out.
- Hold the expander upright, folding over the top part of the expander while aspirating the air out.

- Fold the tissue expander edges underneath the expander base.

Connect Expander to Port Via Connector

- If the port tubing is too long, cut out a segment of the tube.
- Connect the two ends of the tubing with the metal connector.
- Tie a 2–0 black nylon (surgeon's knot, followed by two throws, lay down square) on either side of the connector to secure the tubing.

Drains

- Drain preparation as described previously.

Drain Placement (Fig. 33.4)

- Make a tiny hole through the skin from inside of TE pocket with "little sharp scissors" at desired drain exit.
- Insert Hartmann clamp through the hole from inside TE pocket.
- Drain pulled from outside-in.
- Secure drain to skin with 4-0 black nylon suture.
- Suture to skin close to drain exit.
- Wrap/tie nylon around the drain twice.
- Insert butterfly needle into red-top tube for fluid evacuation.

Closure (Fig. 33.4)

- Close deep tissue with interrupted 4-0 clear nylon suture.
- Close dermis with interrupted 4-0 clear nylon suture.
- Close skin with running 4-0 Prolene suture or 5-0 Prolene on the face.

Initial Expander Fill (Fig. 33.4)

- Expanders are filled intraoperatively via the remote port to a "comfortable" fill, ensuring smooth contour to the expander surface, and minimizing dead space in the pocket.
- Make sure the expander does not have any sharp points that may cause pressure on the overlying skin during expansion.

Anatomic-Specific Instructions

Head and Neck: Scalp and Forehead

Scalp (Table 33.3; Figs. 33.5a–e, 33.6a–e, and 33.7a–e)

Principles

- Tissue expansion on the scalp can begin safely at 6 months of age.
- Computer tomography scans have shown no evidence of suture distortion.
- Cranial molding with scalp expansion is fairly common. Remodeling usually occurs within 1–2 months. No persistent head deformities have been noted. The "washtub" deformity or soft tissue ridge at the edge of the capsule also resorbs, the initial presence of which seems to be more common in older patients.

Forehead (Table 33.4; Figs. 33.5a–e, 33.6a–e, and 33.7a–e) [4]

Principles

- Many large nevi of the forehead involve the adjacent scalp. Combined expansion of both

Table 33.3 Tissue expander placement: Scalp

Location of expander placement	Under the normal skin, expanding the greatest amount of normal skin possible to allow for advancement of the forehead. May need to place more than one expander (e.g., occipital and frontal/temporal), depending on lesion location and size
Size/shape of expander used	Rectangular Size ~250–500 cc
Incision location	Within the lesion
Plane of expander placement	Sub-galeal plane
Port placement	Small port over cranium in temporal region or mastoid
Closure	Galeal suture: 4-0 clear nylon, interrupted Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

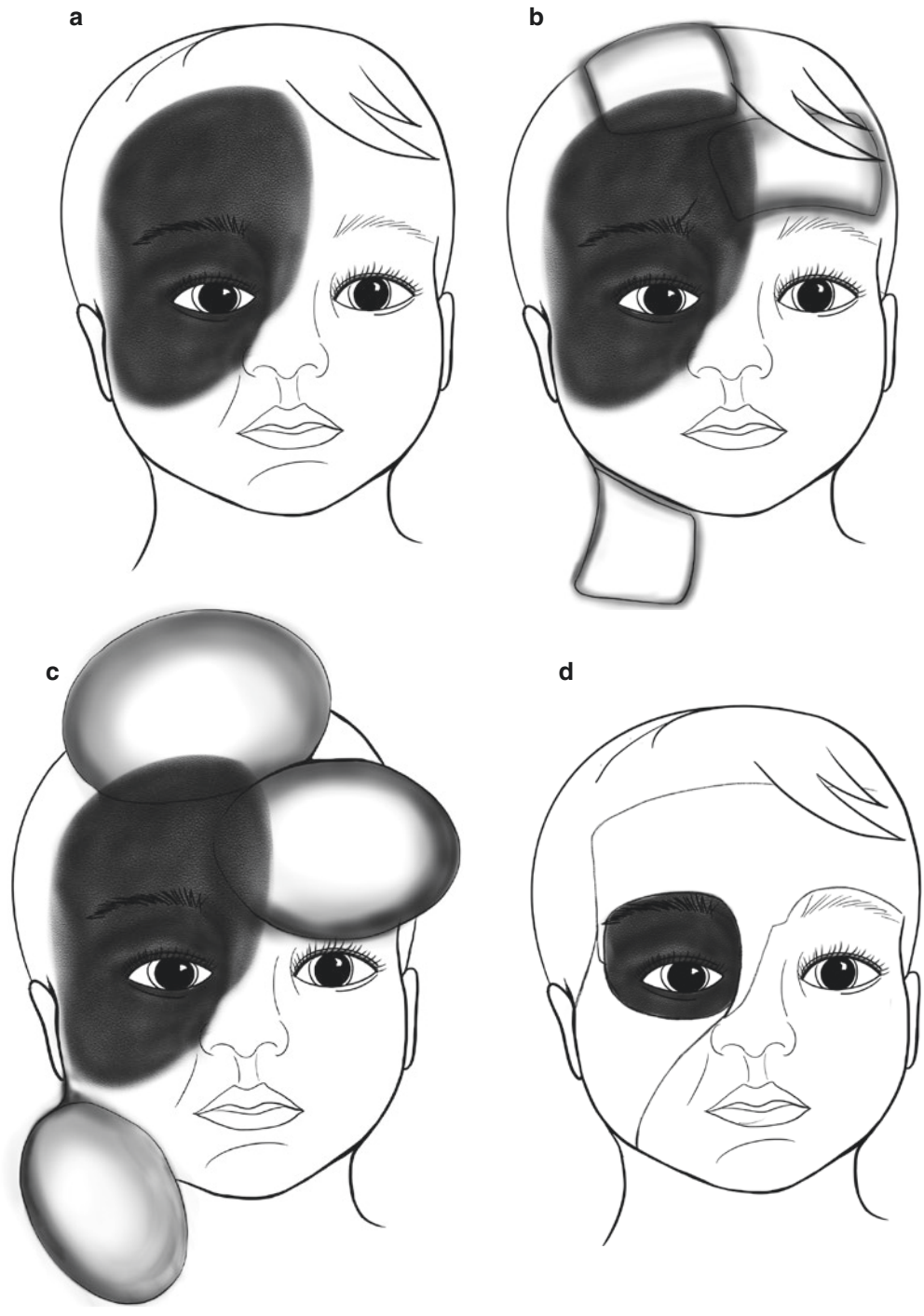

Fig. 33.5 (**a**–**e**) Pre-expanded flap reconstruction: Scalp, forehead, cheek, frontal view. (**a**) Congenital melanocytic nevus of the scalp, forehead, periorbital, nose, and cheek region; (**b**) location of tissue expanders of the scalp, forehead, and neck; (**c**) Expanded tissue expanders of the scalp, forehead, and neck; (**d**) Partial nevus excision and first-stage pre-expanded flap reconstruction of the scalp, forehead, cheek; (**e**) Remainder of nevus excision with second-stage reconstruction of the periorbital region with split-thickness skin grafts

Fig. 33.5 (continued)

the forehead and scalp in these situations will often maximize the available tissue and minimize the number of surgeries needed to complete the excision and reconstruction.

Head and Neck: Midface and Lower Face

Principles

- The lower eyelid, lips, and oral commissure and alar base are structures that can readily be distorted in the course of excision and reconstruction, when even limited tissue shortages exist.
- Tissue expansion provides the means of "creating" ample tissue to reconstruct both large and small defects where relatively small tissue shortages can result in persistent distortion of key facial features (i.e., lower eyelid, alar base, lips, and commissure).
- Understanding long-term effects of expanded flap movement may avoid long-term problems.

Cheek (Table 33.5; Figs. 33.5a–e, 33.6a–e, and 33.7a–e)

Principles

- Direct upward advancement of an expanded flap without additional elongation may create permanent tissue shortage with long-term distortion of the lower lid and canthus.
- Transverse movement of the expanded cheek flap minimizes the risk of canthal lid distortion.
- Expanded transposition flaps have been the mainstay of treatment for large nevi, scars, and vascular lesions of the midface. But a combined advancement with medial and lateral release and additional medial transposition appears to result in greater tissue movement as well as preservation of natural cheek contour.
- Judicious partial excision of the nevus may be done when the expander is placed.

Nose

- The nose can be reconstructed with direct tissue expansion of the nasal sidewalls (Table 33.6, Fig. 33.8a–c).
- When integrating the forehead reconstruction with treatment of all or part of the nasal nevus, the staging of the expanded flap to the nose is critical (Table 33.7, Fig. 33.9a).
- Nasal coverage, derived as a bonus of expanded forehead reconstruction, was first noticed in an early forehead reconstruction. The forehead flap for nasal coverage is designed with donor scar along the border of the aesthetic forehead unit.
- Movement of expanded contralateral forehead creates relative excess of skin above the ipsilateral brow as it advances across above the brow and down toward the zygomatic area.

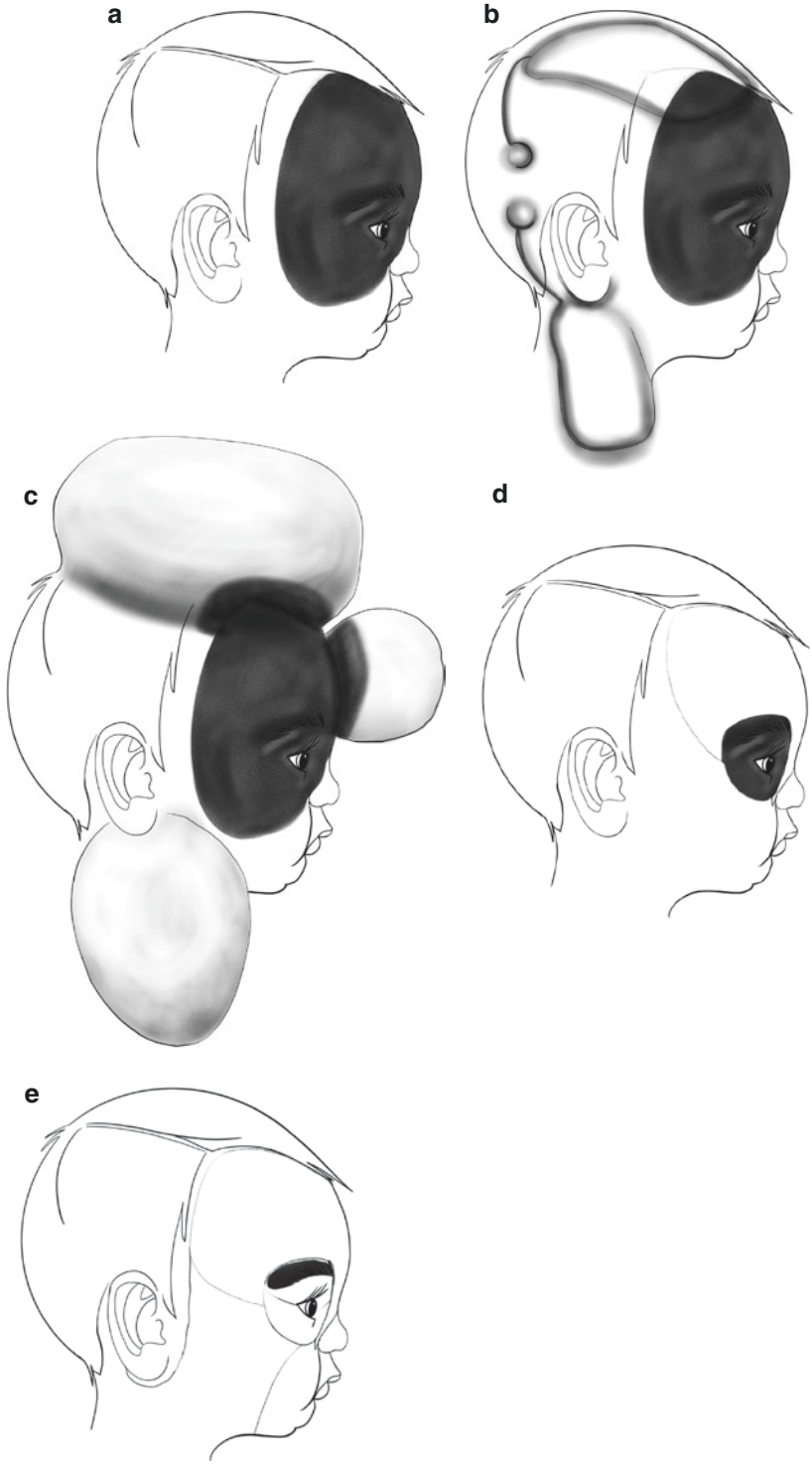

Fig. 33.6 (**a**–**e**) Pre-expanded flap reconstruction: Scalp, forehead, cheek, lateral view. (**a**) Congenital melanocytic nevus of the scalp, forehead, periorbital, nose, and cheek region; (**b**) location of tissue expanders of the scalp, forehead, and neck; (**c**) expanded tissue expanders of the scalp, forehead, and neck; (**d**) partial nevus excision with first-stage pre-expanded flap reconstruction of the scalp, forehead, cheek; (**e**) remainder of nevus excision with second-stage reconstruction of the periorbital region with split-thickness skin grafts

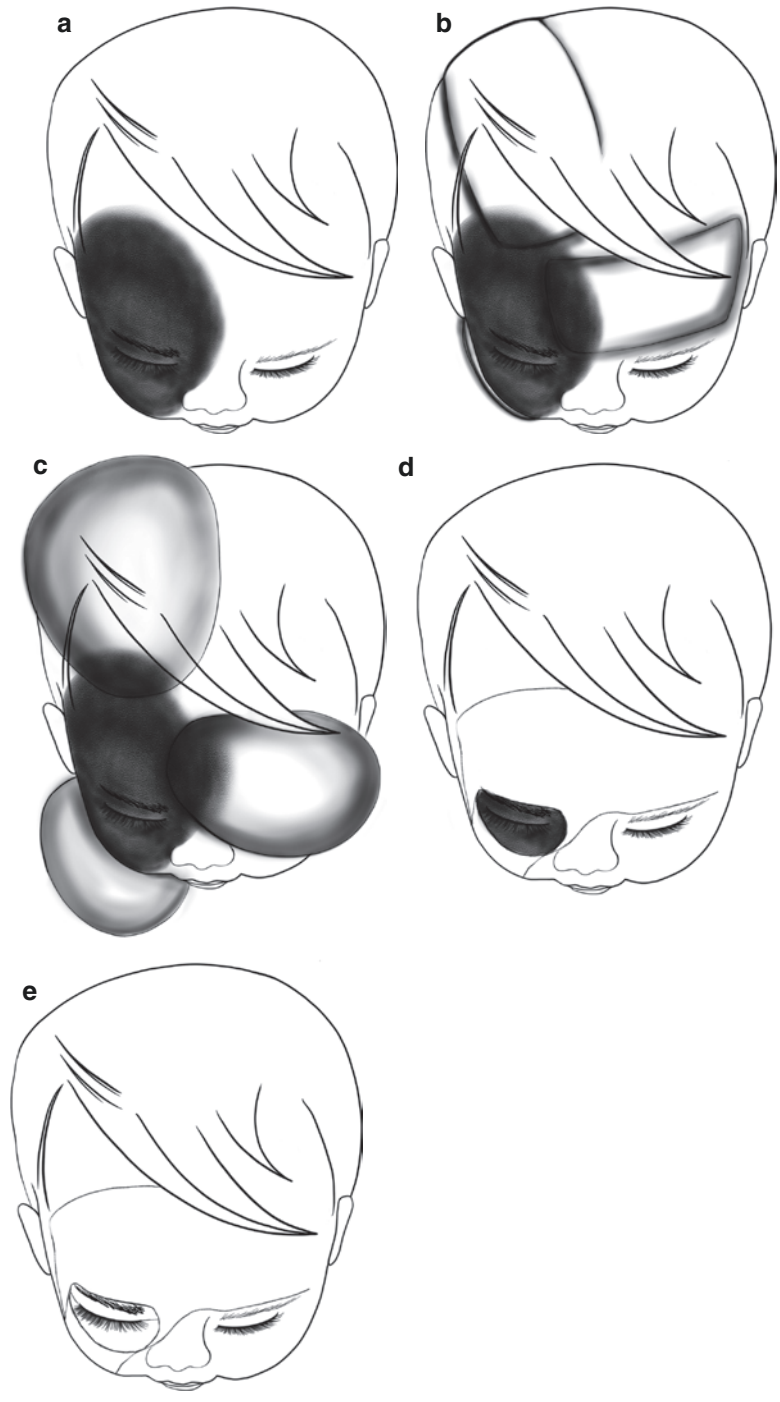

Fig. 33.7 (**a**–**e**) Pre-expanded flap reconstruction: Scalp, forehead, cheek, vertex view. (**a**) Congenital melanocytic nevus of the scalp, forehead, periorbital, nose, and cheek region; (**b**) location of tissue expanders of the scalp, forehead, and neck; (**c**) expanded tissue expanders of the scalp, forehead, and neck; (**d**) partial nevus excision with first-stage pre-expanded flap reconstruction of the scalp, forehead, cheek; (**e**) remainder of nevus excision with second-stage reconstruction of the periorbital region with split-thickness skin grafts

Table 33.4 Tissue expander placement: Forehead

Location of expander placement	Forehead or temporal region under normal skin and soft tissue. Expanding the scalp is acceptable, in order to expand the largest flap as possible
Size/shape of expander used	Rectangular Size 250 cc (small children) or 350 cc
Incision location	Within or posterior to border of nevus in the mid-forehead If there is not a portion of normal skin that goes under the nevus (i.e., between nevus and brow), then the incision should be placed to allow *all* normal forehead tissue to be expanded, even if it means some of the expander will lay well within the border of the nevus and result in nevus expansion
Plane of expander placement	Sub-galeal and sub-frontalis muscle plane
Port placement	Small port over cranium in temporal region or mastoid
Closure	Galeal suture: 4-0 clear nylon, interrupted Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Table 33.5 Tissue expander placement: Cheek

Location of expander placement	Inferolateral face and neck to allow for advancement–transposition flap
Size/shape of expander used	Rectangular Size ~70 cc
Incision location	Along the leading edge of the flap, within the line of the lesion (if nevus)
Plane of expander placement	Subcutaneous plane (superficial to the superficial musculoaponeurotic system, SMAS)
Port placement	Small port over mastoid
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

The portion of flap based on the supratrochlear pedicle provides nasal coverage. The remaining expanded forehead provides the tissue needed to fill the defect and complete forehead coverage (Fig. 33.9b–d).

- While the forehead flap has been the gold standard procedure for nasal reconstruction, tissue expansion has provided a means of doing this type of reconstruction without central forehead scars (Fig. 33.9d).

Table 33.6 Tissue expander placement: Nose, bilateral

Location of expander placement	Bilateral nasal sidewall
Size/shape of expander used	Rectangular Size 70 cc
Incision location	Along the leading edge of the flap, within the line of the lesion (if nevus) on the nasal dorsum
Plane of expander placement	Subcutaneous plane (superficial to the superficial musculoaponeurotic system, SMAS)
Port placement	Small port over frontal cranial bone in the scalp
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 5-0 Chromic, running

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Periorbital

- The periorbital region may be reconstructed with full-thickness skin grafts; however, they may result in a "flat" and low-volume appearance.
- Similar to the combined forehead/nasal reconstruction, the flap portion based on the supratrochlear pedicle may provide supraorbital eyelid reconstruction (between upper eyelid crease and brow) (Fig. 33.10).
- Pretarsal and preseptal upper and lower eyelids may be reconstructed with full-thickness skin grafts.

Trunk

Principles

- In general, the chest and anterior and poster trunk may be reconstructed with expanded transposition–advancement flaps from areas

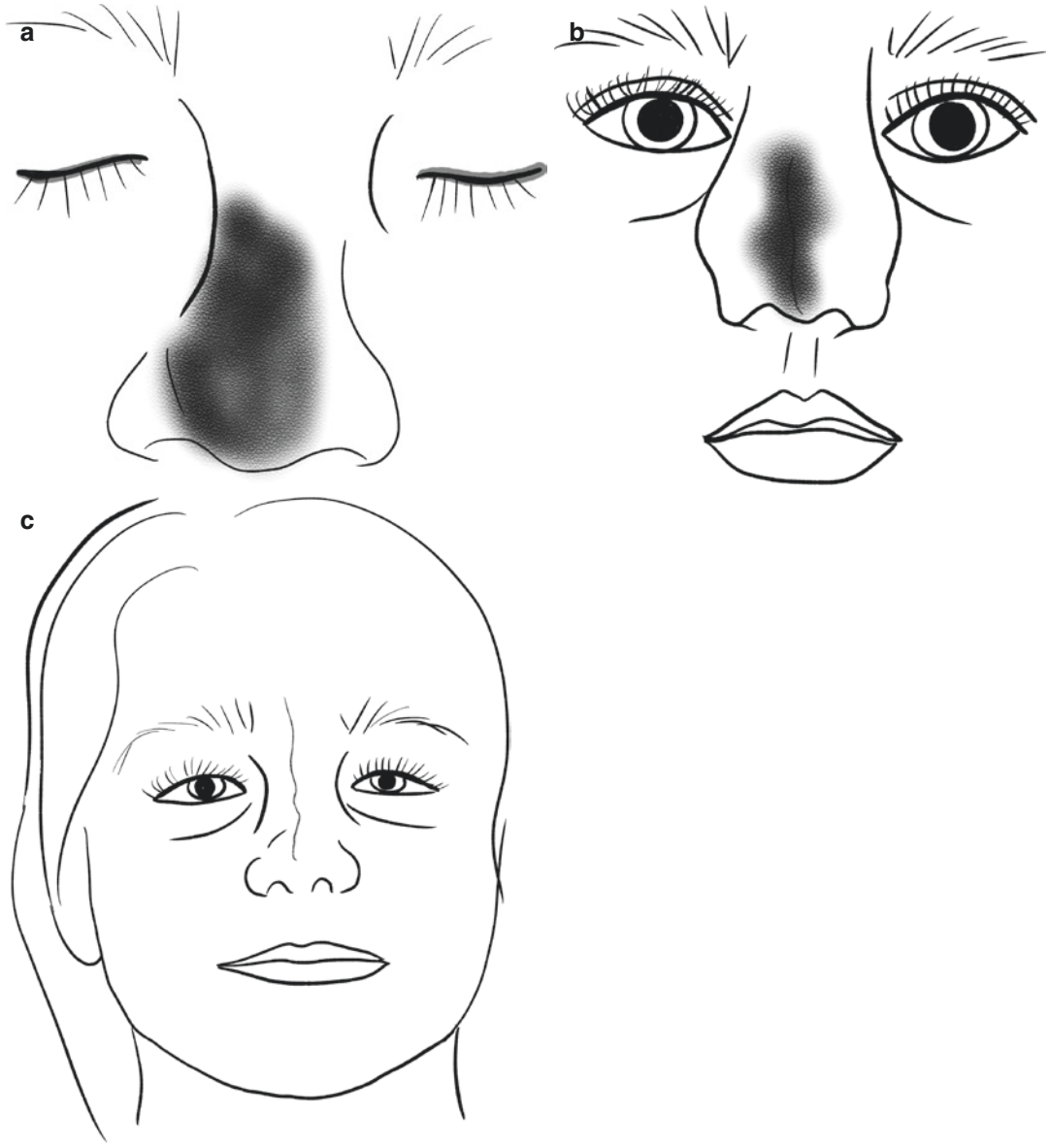

Fig. 33.8 (**a**–**c**) Pre-expanded flap reconstruction: Nose, bilateral tissue expander. (**a**) Congenital melanocytic nevus involving the nasal tip, ala, dorsum; (**b**) first-stage serial excision with bilateral tissue expander placement on the nasal dorsum with subsequent expansion; (**c**) remainder of nevus excision with pre-expanded bilateral nasal flap inset

Table 33.7 Tissue expander placement: Nose, expanded forehead flap

Location of expander placement	Forehead (centrally or paramedian)
Size/shape of expander used	Rectangular Size 250 cc
Incision location	Lateral aspect of the forehead
Plane of expander placement	Sub-galeal/sub-frontalis
Port placement	Small port over cranium in temporal region or mastoid
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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of normal tissue on the abdomen and upper and lower back.

Chest (Table 33.8 and Fig. 33.11a–i)

Principles

- The approach to the chest and breast area depends on the lesion treated, the available normal tissue, and the gender of the child.
- Female: Expansion on the anterior trunk must be planned to avoid potential distortion of the breast.
- Advancement of the expanded flaps should aim to diminish scars of the chest and must stop at the inframammary fold to minimize the risk of late distortion of the breast.
- Expanded full-thickness skin graft may also be used to resurface the breast after lesion excision.

Anterior Trunk (Table 33.9 and Fig. 33.11a–i)

Posterior Trunk (Table 33.10 and Fig. 33.11a–i)

Tip
May reconstruct the neck from expanded flap from upper back or shoulder.

Tip
May reconstruct buttock from expanded flap from mid-back.

Extremities

Principles

- Movement of expanded flaps is limited by the geometry of the limb.
- It is easier to move a flap transversely than axially: "Think 'transposition' where possible."
- Transfer of distant flaps may be preferable to flaps on the extremity.
- Expansion adjacent to a lesion on the extremity will narrow the extremity circumference. Transposition avoids distortion.

Upper Extremity [5]

Shoulder/Upper Arm (Table 33.11, Figs. 33.12a, b and 33.13a–d)

Principles

- For proximal shoulder, noncircumferential upper arm lesion, transposition flaps from the back work well.
- For proximal circumferential arm lesions, expanded free flaps work best.

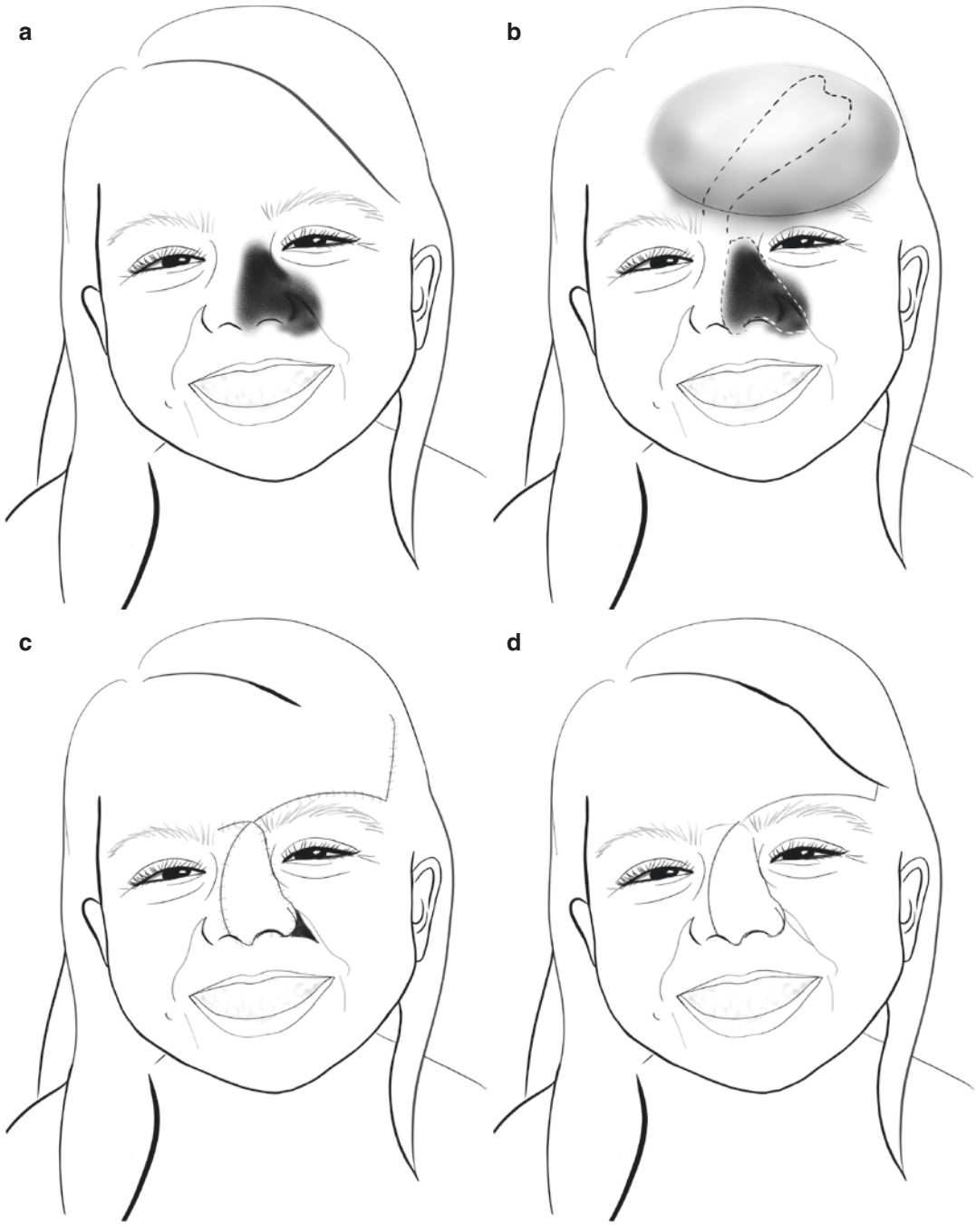

Fig. 33.9 (**a**–**d**) Pre-expanded flap reconstruction: Nose, forehead flap. (**a**) Congenital melanocytic nevus involving the nasal tip, ala, dorsum, columella; (**b**) first-stage forehead expansion, and subsequent forehead flap design; (**c**) partial nevus excision and pre-expanded, pedicled forehead flap inset; (**d**) remainder of nevus excision at alar–cheek junction, and division of forehead flap

Fig. 33.10 Pre-expanded flap reconstruction: Periorbital region. The flap portion based on the supratrochlear pedicle may provide supraorbital eyelid reconstruction (between upper eyelid crease and brow)

Table 33.8 Tissue expander placement: Chest

Location of expander placement	Normal tissue of the upper abdomen (males and females) or the contralateral chest (males). May place more than one expander (e.g., one on each side of the upper abdomen) at a time to allow for greater volume of expansion
Size/shape of expander used	Rectangular Size 500–1000 cc
Incision location	Along the edge of the lesion
Plane of expander placement	Subcutaneous. Consider placing the TE in an oblique orientation to allow for advancement/transposition to the chest
Port placement	Large port over anterior thigh or rib
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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- Rest of the arm to the wrist, the flaps will come from the trunk.
- For smaller lesions on the upper extremity, it works much better to expand around than in a proximal–distal direction.

Forearm (Table 33.12 and Fig. 33.13e–j)

Principles

- For circumferential mid-forearm and lower forearm lesions, expanded flank flaps allow for the creation of a large pedicled flap through which the forearm can be placed during vascularization of the flap.

Lower Extremity [6]

Principles

- Effective use of tissue expansion in the lower extremity is limited by the geometry of the limb and the limitation of flap movement. The flap generally moves better around a circumference of an extremity than in an axial direction.

Proximal Lower Extremity (Table 33.13 and Fig. 33.14a–e)

Distal Lower Extremity (Table 33.14 and Fig. 33.15a–g)

Principles

- In some cases, expansion for lower extremity axial-oriented defects may be feasible.
- One can resurface lower leg defects through pedicled, expanded flaps from the expanded posterior thigh/buttock.

Hand/Foot

Principles

- An expanded full-thickness skin graft provides excellent aesthetic and functional recon-

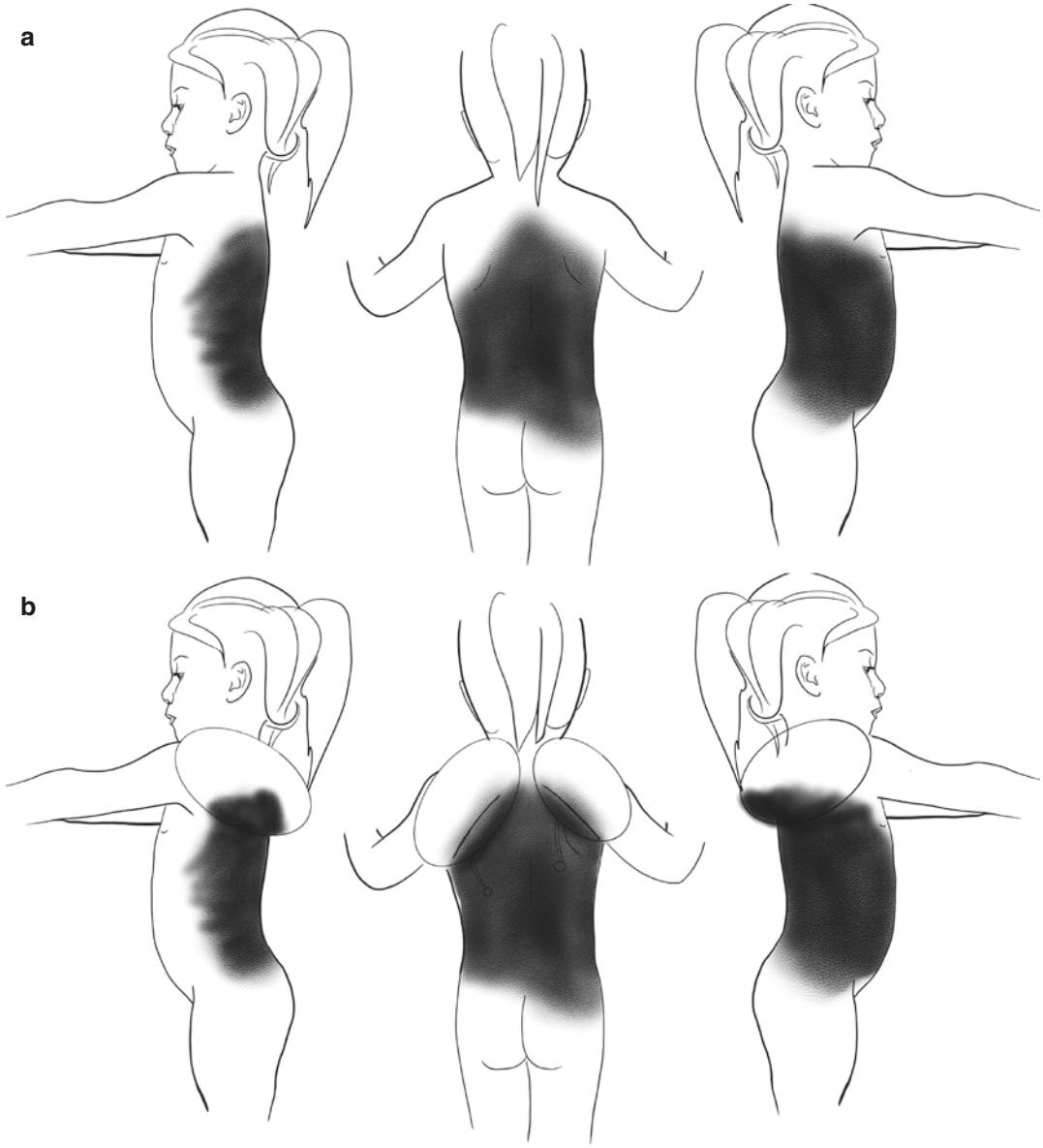

Fig. 33.11 (**a**–**i**) Pre-expanded flap reconstruction: Chest, abdomen, back. (**a**) Congenital melanocytic nevus involving chest, abdomen, and back; (**b**) first-stage tissue expander placement and expansion of the bilateral upper back; (**c**) subsequent partial nevus excision and pre-expanded flap reconstruction of the upper back, and serial excision of the lower back; (**d**) second-stage tissue expander placement and expansion of the bilateral upper back, and lower back; (**e**) subsequent partial nevus excision and pre-expanded flap reconstruction of the back, flank; (**f**) third-stage tissue expander placement and expansion of the bilateral upper back and abdomen; (**g**) subsequent partial nevus excision and pre-expanded flap reconstruction of the back, flank, abdomen, and chest; (**h**) fourth-stage tissue expander placement and expansion of the right upper back and abdomen; (**i**) final nevus excision and pre-expanded flap reconstruction of the abdomen and chest

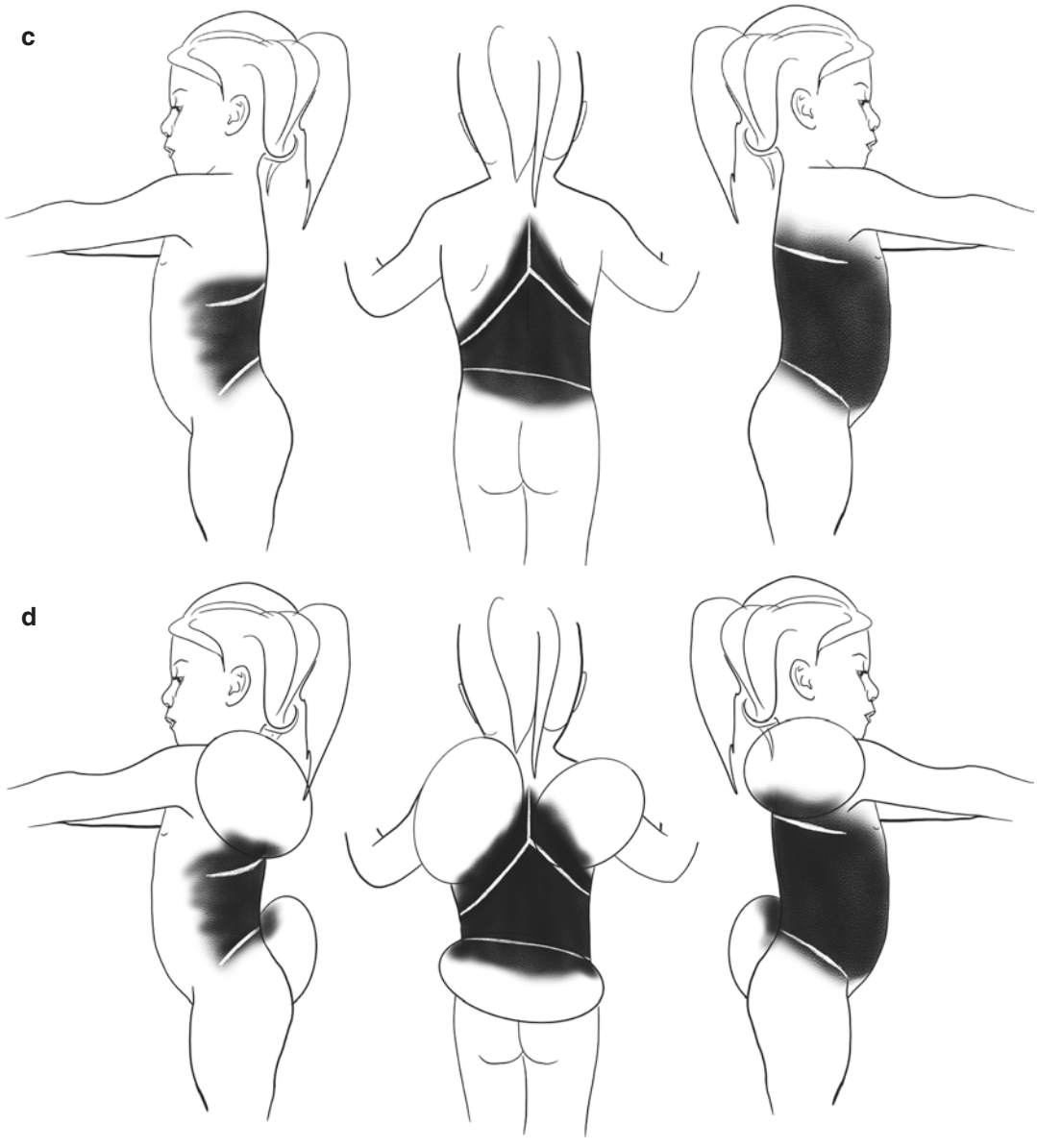

Fig. 33.11 (continued)

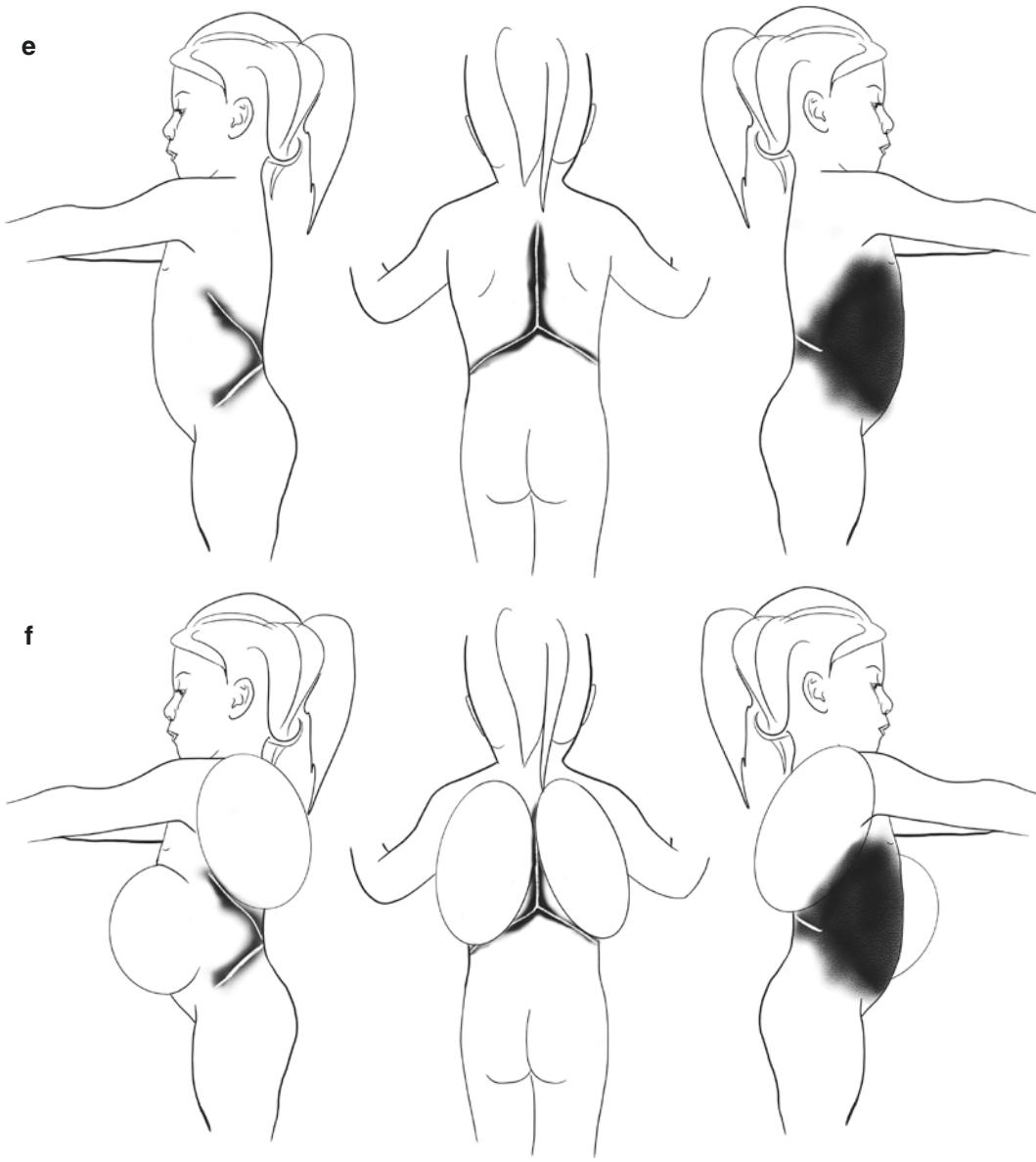

Fig. 33.11 (continued)

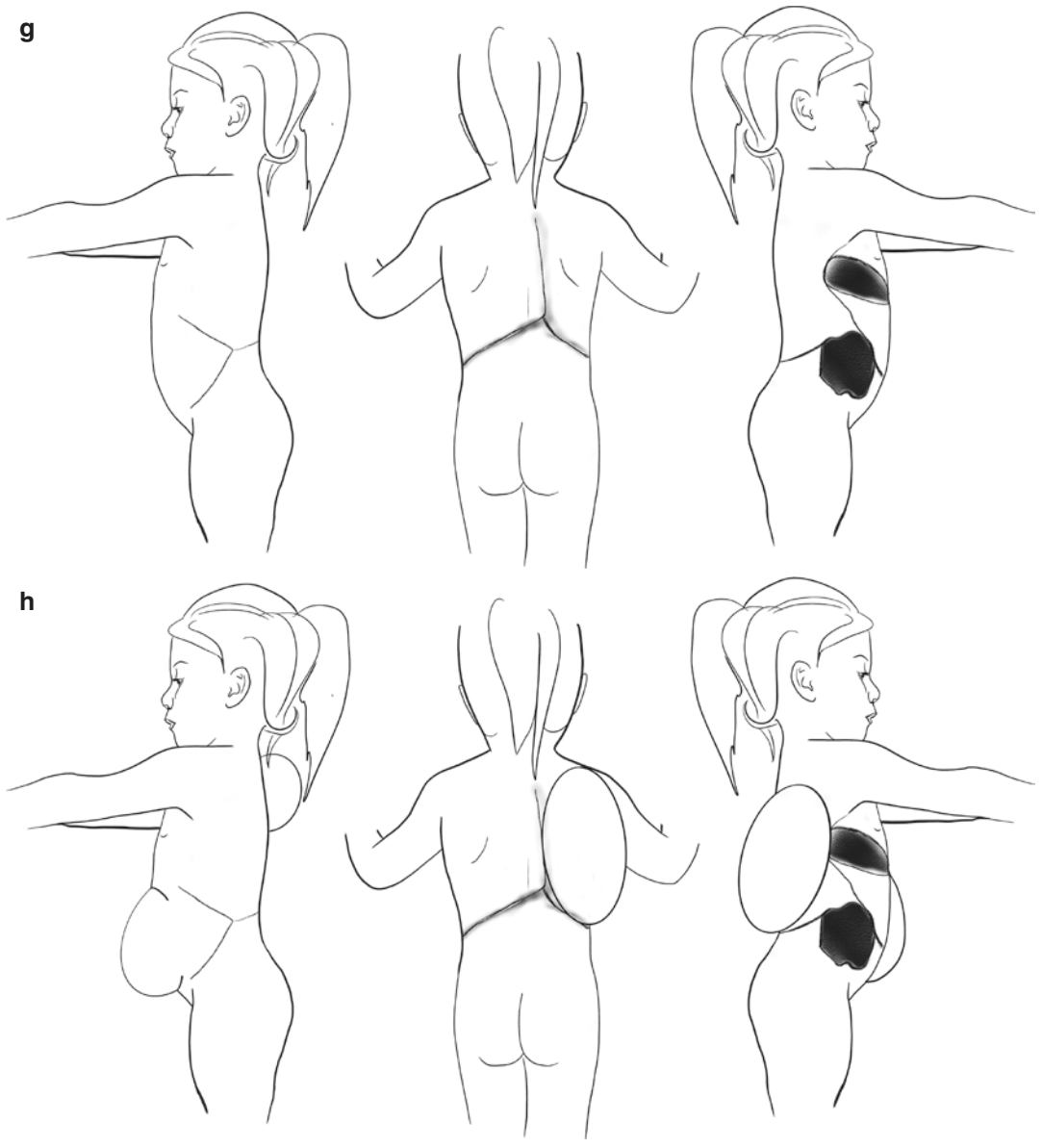

Fig. 33.11 (continued)

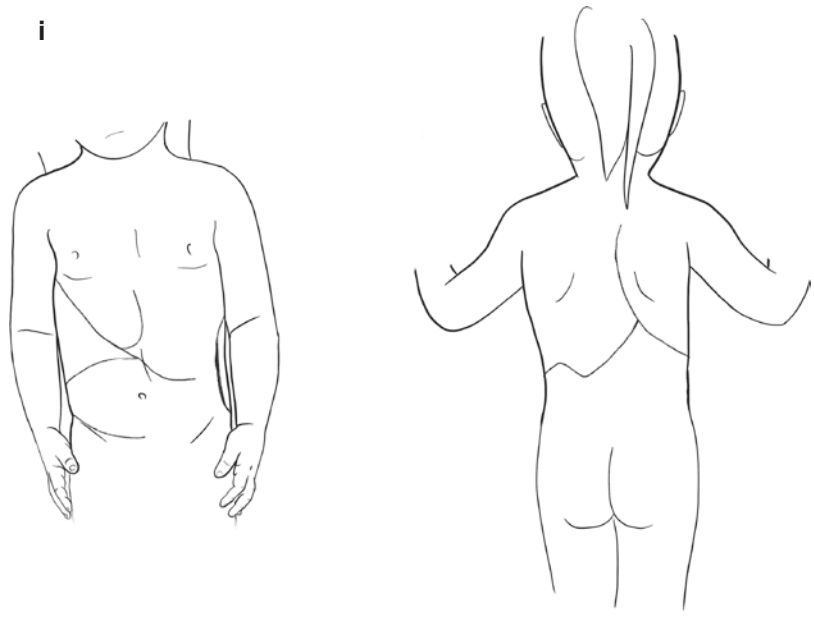

Fig. 33.11 (continued)

Table 33.9 Tissue expander placement: Anterior trunk

Location of expander placement	Normal tissue of the upper abdomen. Place more than one expander if possible
Size/shape of expander used	Rectangular Size 500–1000 cc
Incision location	Along the edge of the lesion
Plane of expander placement	Subcutaneous. Consider placing the TE in an oblique orientation to allow for advancement/transposition to the lower abdomen
Port placement	Large port over anterior thigh or rib
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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Table 33.10 Tissue expander placement: Posterior trunk

Location of expander placement	Normal tissue of the shoulder region or the lower back (depending on the location of the lesion). Place more than one expander if possible
Size/shape of expander used	Rectangular Size 500–1000 cc
Incision location	Along the edge of the lesion
Plane of expander placement	Subcutaneous. Consider placing the TE in an oblique orientation to allow for advancement/transposition to the lower abdomen
Port placement	Large port over iliac crest
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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Table 33.11 Tissue expander placement: Shoulder/Upper arm

Location of expander placement	Normal tissue of the shoulder region Design the flap as a transposition flap from the upper shoulder/back
Size/shape of expander used	Rectangular Size 250–500 cc
Incision location	Along the edge of the lesion
Plane of expander placement	Subcutaneous
Port placement	Large port over scapula
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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struction for dorsum of the hand, proximal fingers, and dorsum of the foot.

Tissue Expander Removal, Lesion Excision, Flap Reconstruction [2, 3]

Principles

- The augmented blood supply of the expanded flap allows for greater latitude in flap design.
- The larger the tissue expander, the more the tissue that is made available and the greater the freedom of flap design.

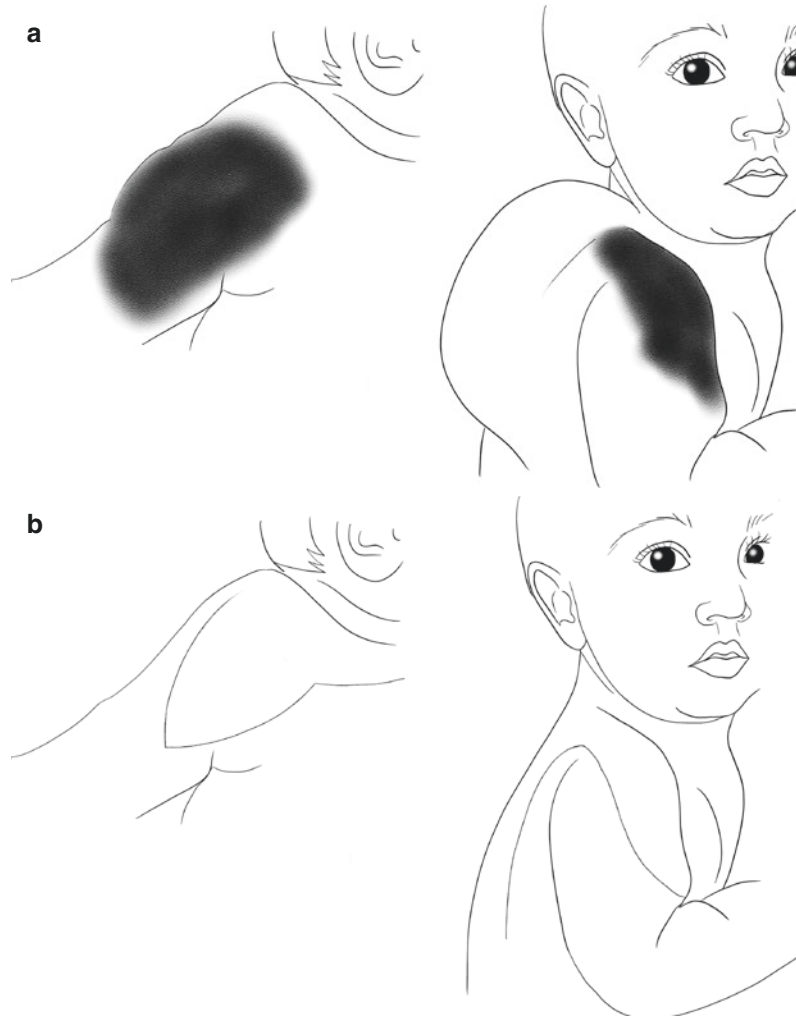

Fig. 33.12 (**a**, **b**) Pre-expanded flap reconstruction of the shoulder and upper arm. (**a**) Congenital melanocytic nevus of the right shoulder and upper arm with tissue expander placement on the right upper back. (**b**) Nevus excision and pre-expanded flap transposition from the back to the shoulder region

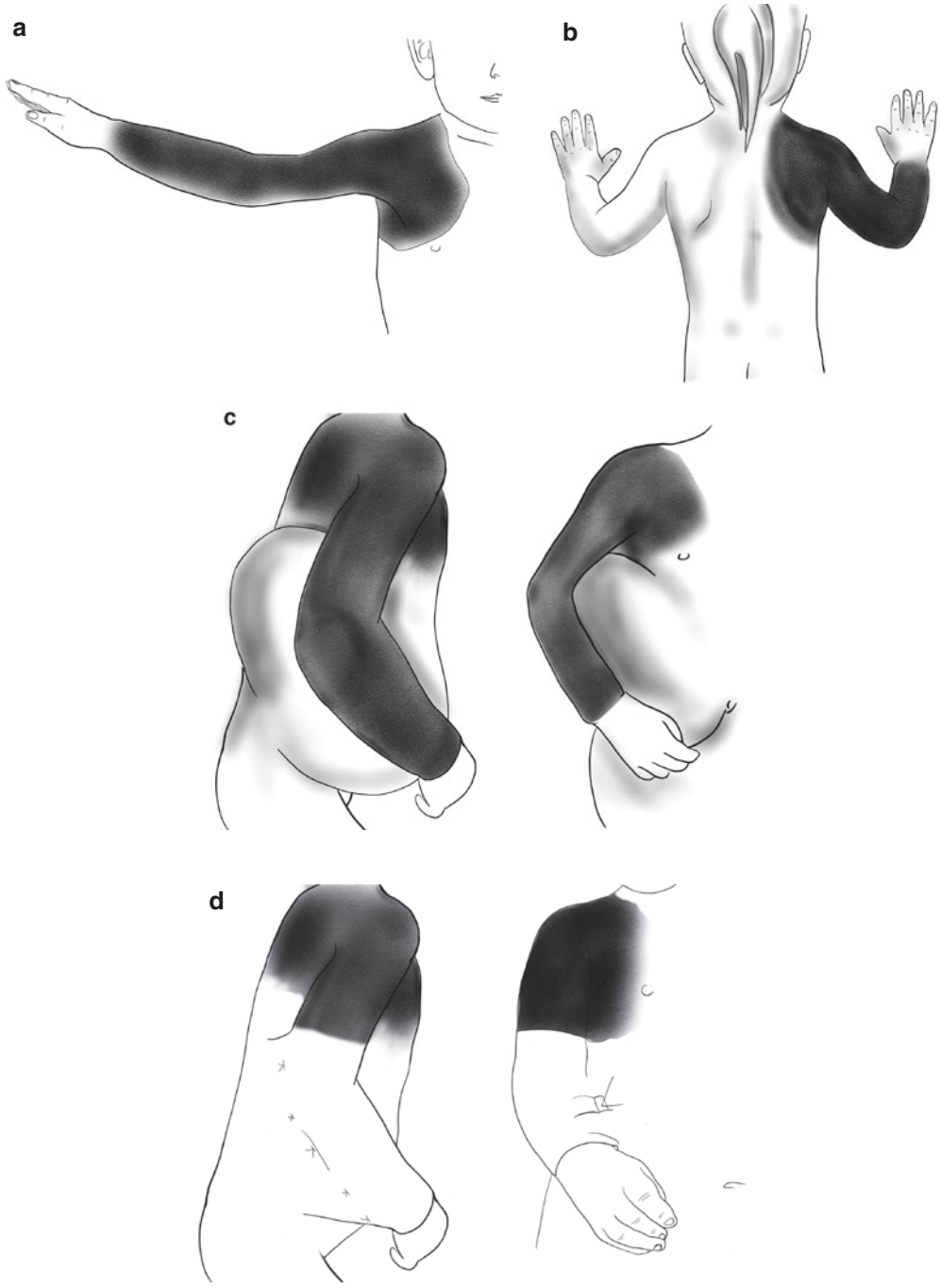

Fig. 33.13 (**a**–**j**) Pre-expanded flap reconstruction of the forearm, mid-arm, upper arm, and shoulder. (**a**) Congenital melanocytic nevus of the right shoulder, upper arm, and forearm, anterior view; (**b**) congenital melanocytic nevus of the right shoulder, upper arm, and forearm, posterior view; (**c**) first-stage tissue expander placement in the flank/abdominal region; (**d**) nevus excision of the forearm with near-circumferential inset of the forearm into the pre-expanded flank flap; (**e**) subsequent flank flap division and subsequent tissue expander placement of the back for shoulder/chest reconstruction; (**f**) partial shoulder nevus excision with pre-expanded flap transposition/advancement; (**g**) subsequent placement and tissue expansion of the upper back and (h) chest; (**i**, **j**) excision of remaining shoulder and chest nevus with pre-expanded upper back and chest flap reconstruction

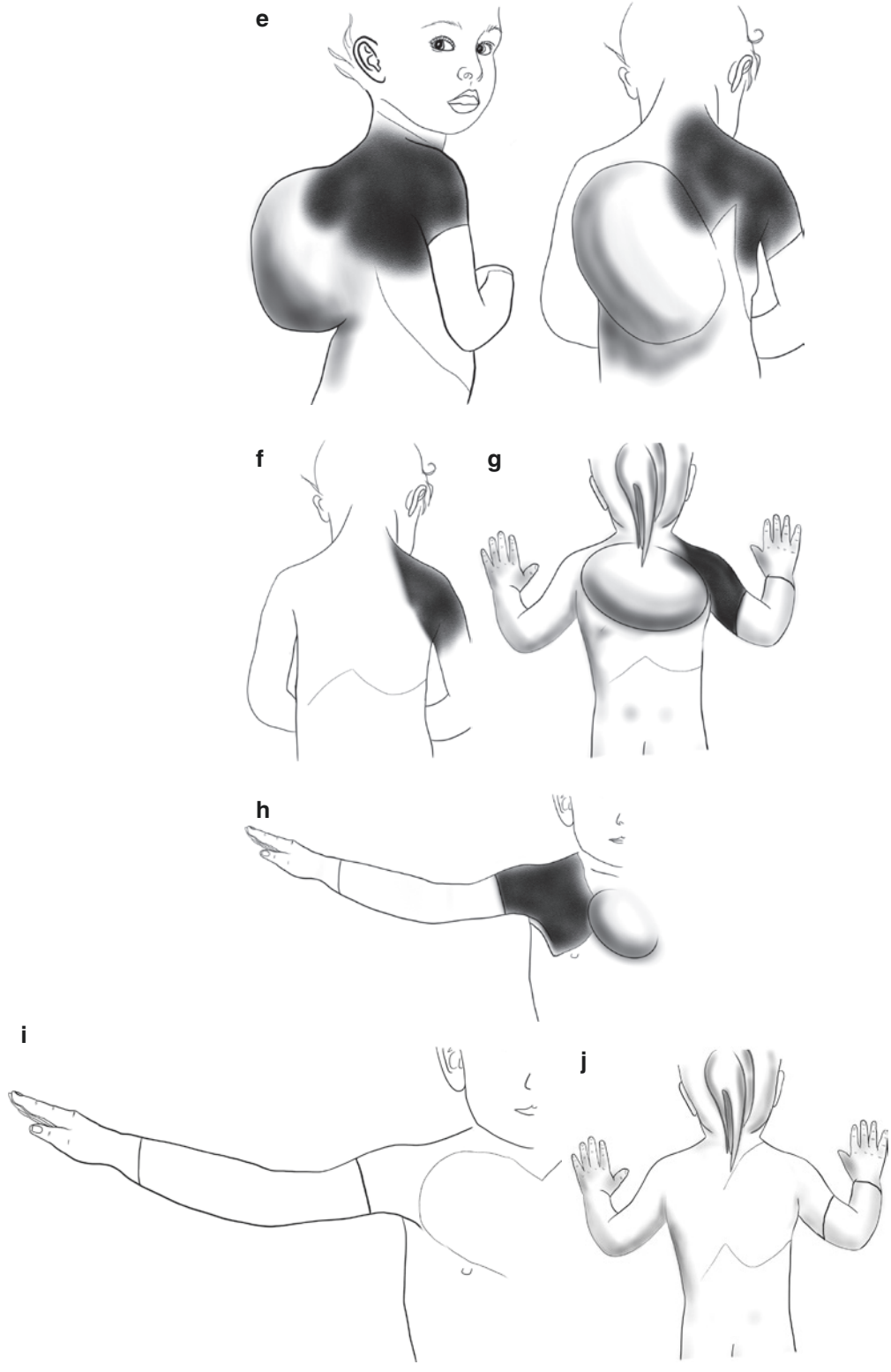

Fig. 33.13 (continued)

Table 33.12 Tissue expander placement: Forearm and mid-arm

Location of expander placement	Tissue expander placement in the abdomen/flank/back region, oriented obliquely and above the iliac crest
Size/shape of expander used	Rectangular Size 750 cc
Incision location	Obliquely along the upper chest
Plane of expander placement	Subcutaneous
Port placement	Large port over humerus
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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Table 33.13 Tissue expander placement: Proximal lower extremity

Location of expander placement	Tissue expander placement to allow for circumferential reconstruction (e.g., medial or lateral to a lesion)
Size/shape of expander used	Rectangular Size 250–750 cc
Incision location	Along the lesion
Plane of expander placement	Subcutaneous
Port placement	Large port over iliac crest
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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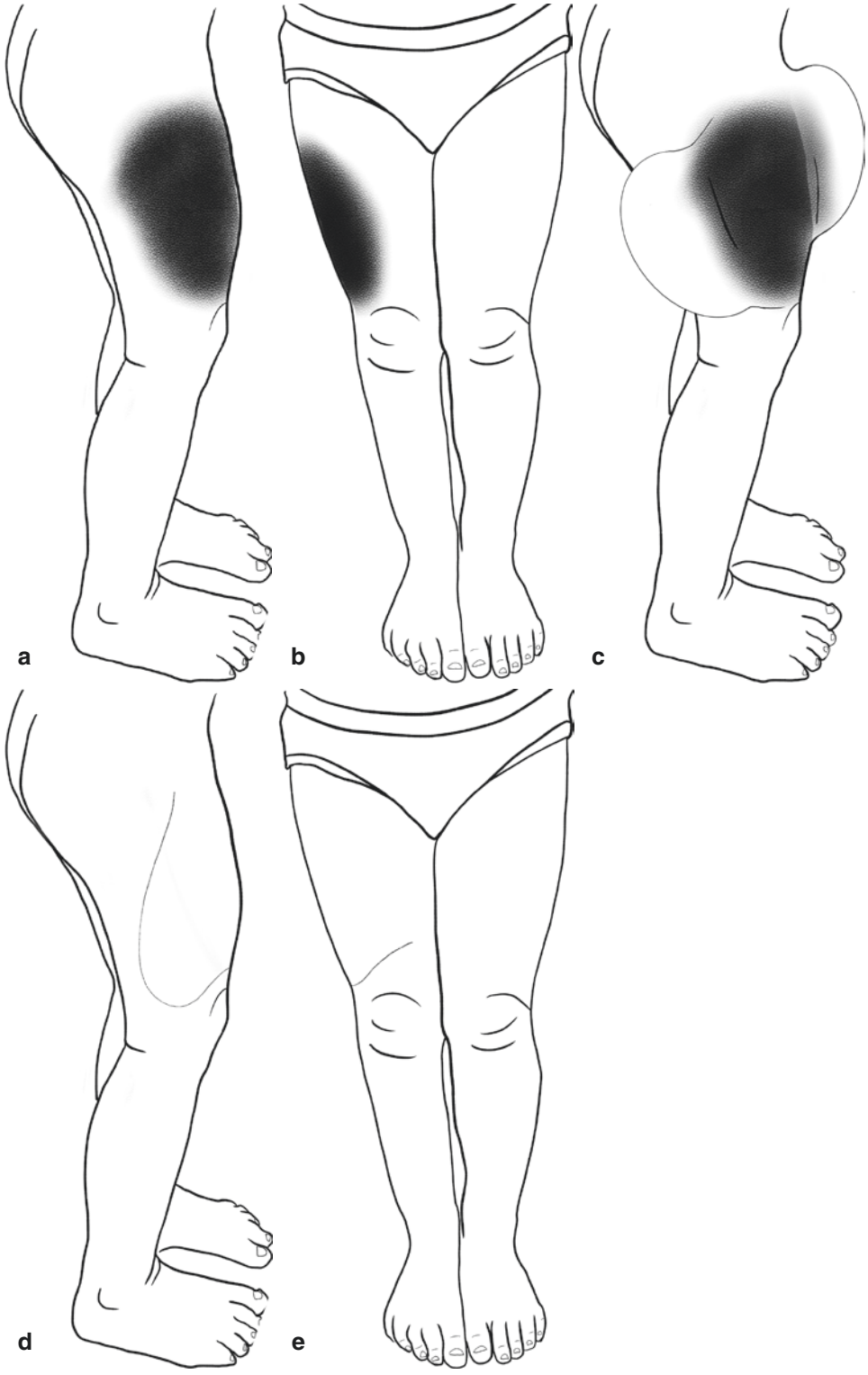

Fig. 33.14 (**a**–**e**) Pre-expanded flap reconstruction of the proximal lower extremity. (**a**) Anterolateral thigh congenital melanocytic nevus, lateral view; (**b**) anterior view; (**c**) posterior and anterior thigh tissue expansion; (**d**) nevus excision with pre-expanded flap transposition–advancement for reconstruction, lateral view; (**e**) anterior view

Table 33.14 Tissue expander placement: Distal lower extremity

Location of expander placement	Tissue expander may be placed in the posterior thigh/buttock region
Size/shape of expander used	Rectangular Size 350 cc
Incision location	Superior gluteal depression
Plane of expander placement	Subcutaneous
Port placement	Large port over iliac crest
Closure	Deep dermal suture: 4-0 clear nylon, interrupted Skin suture: 4-0 Prolene, running

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General Instructions

Markings (Fig. 33.16)
- Mark anticipated incision and rotation–advancement flap design. See anatomic-specific section for details.

Incision (Fig. 33.16)
- Make incision along planned markings of flap.
- Make incision into the lesion, along the leading edge of the flap.
- Retract the skin edges with small skin hooks.
- Use electrocautery to dissect down through the subcutaneous tissue to the tissue expander capsule.
- Enter the capsule at the deepest layer to allow for the planned flap to have an edge of capsule along the entire edge of the flap. Release the capsule along the leading and lateral edges of the flap, but ***do not*** disrupt the capsule at the flap base/pedicle/proximal end of the flap.
- Remove the tissue expander from the pocket.
- "Cut-as-you-go" flap design: Gauging how far the flap will release and will inset into place with the transposition, the flap cuts are made sequentially.

> **Tip**
> One typically cannot pre-design the inset and shape of the pre-expanded flap until it is inset sequentially.

Flap Inset (Fig. 33.16) See anatomic-specific section for details.

Drains (Fig. 33.16)
- Place one drain under each flap.
- Insert and secure drain as previously described.

Closure (Fig. 33.16) See anatomic-specific section for details.

Anatomic-Specific Instructions

Head and Neck

Scalp (Table 33.15 and Figs. 33.5a–e, 33.6a–e, and 33.7a–e)

Principles
- The expanded occipital scalp flaps both transposes and advances allowing significant movement and optimal orientation of hair follicles along the hairline.

Forehead (Table 33.16 and Figs. 33.5a–e, 33.6a–e, and 33.7a–e) [4]

Cheek (Table 33.17 and Figs. 33.5a–e, 33.6a–e, and 33.7a–e)

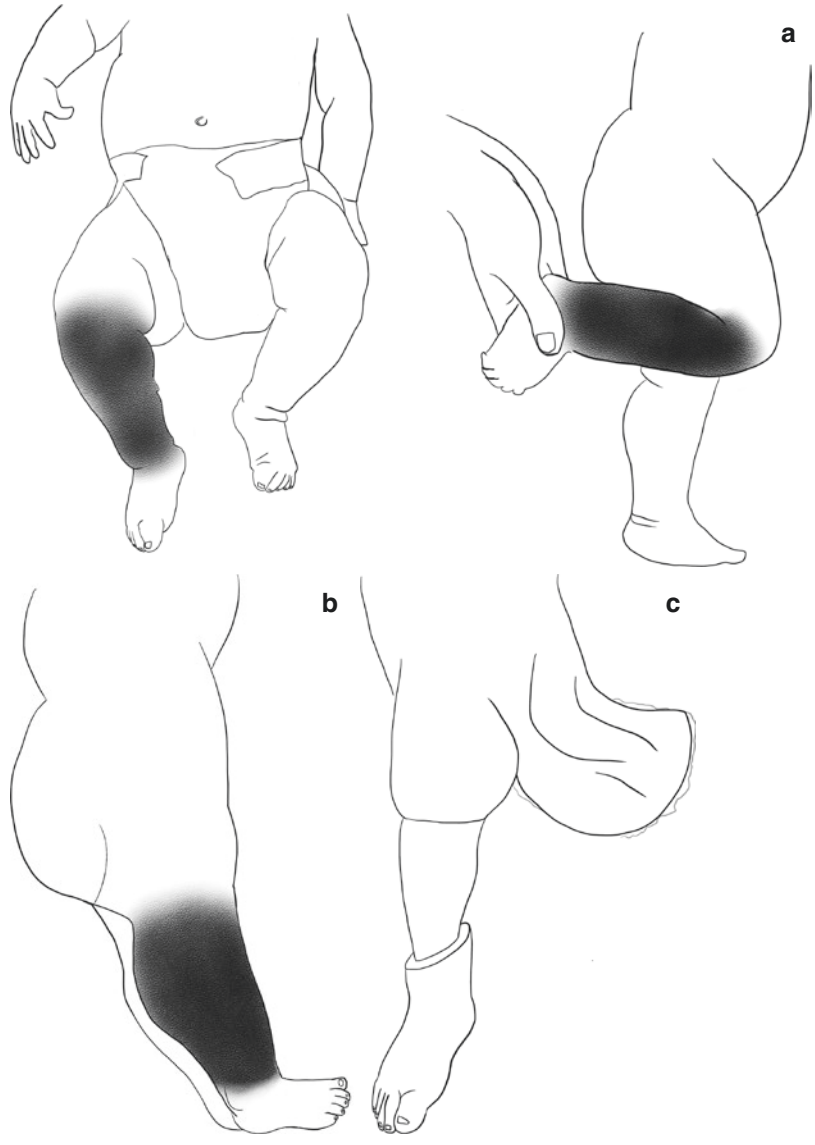

Fig. 33.15 (**a**–**g**) Pre-expanded flap reconstruction of the distal lower extremity. (**a**) Circumferential lower leg congenital melanocytic nevus; (**b**) tissue expansion of the posterior thigh; (**c**) circumferential nevus excision, elevation of the pre-expanded posterior thigh flap; (**d**) initial inset of the pre-expanded posterior thigh flap anteriorly over the lower leg defect. Note the bi-pedicled pre-expanded flap segment left intact at the proximal-most portion, near the buttock; (**e**) further inset of the pre-expanded posterior thigh flap anteriorly over the lower leg defect, and insertion of the ankle portion through the bi-pedicled pre-expanded flap as an "internal splint"; (**f**) final extremity position after the first-stage flap reconstruction; (**g**) pedicled flap division and inset with final reconstruction

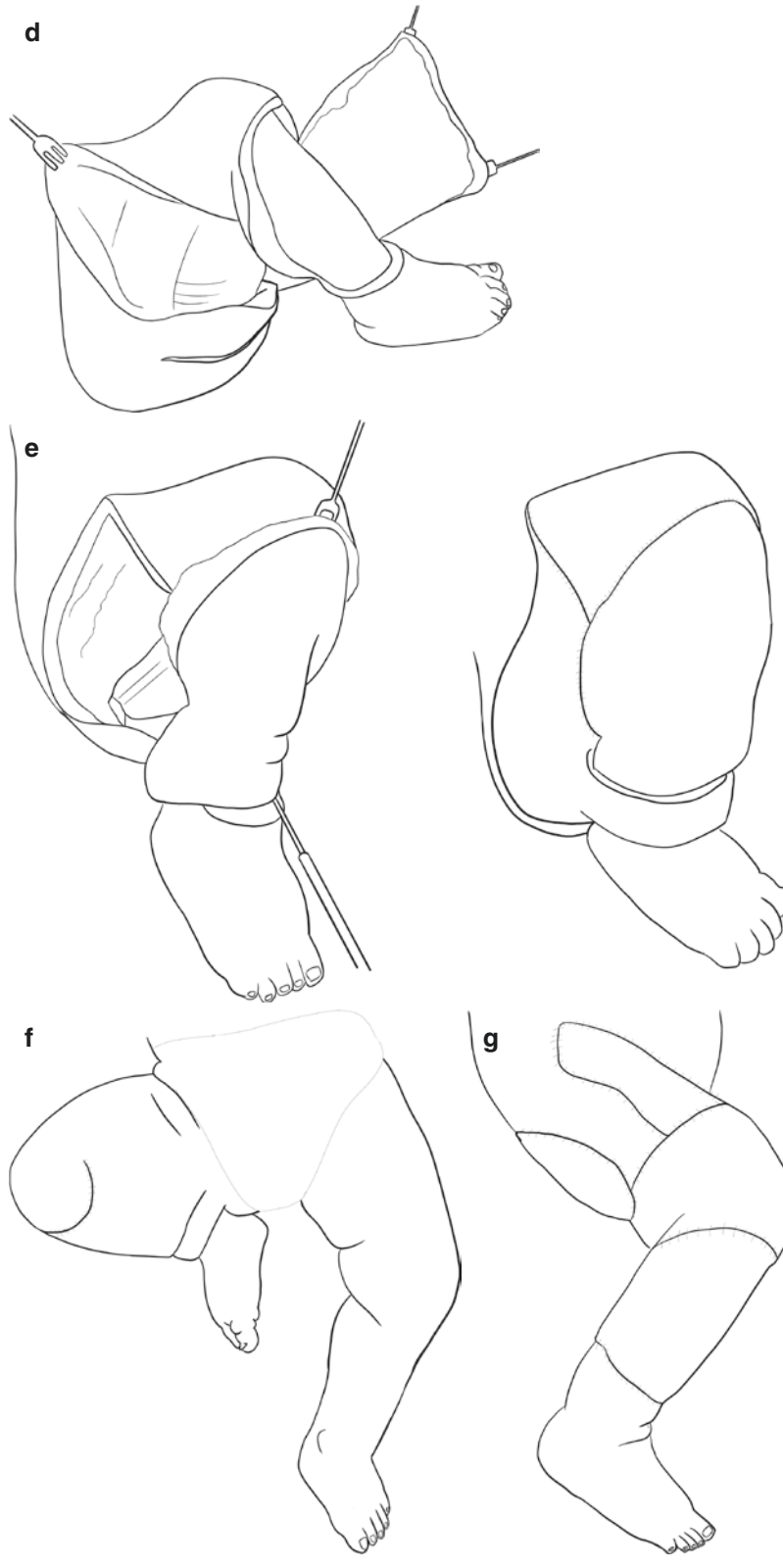

Fig. 33.15 (continued)

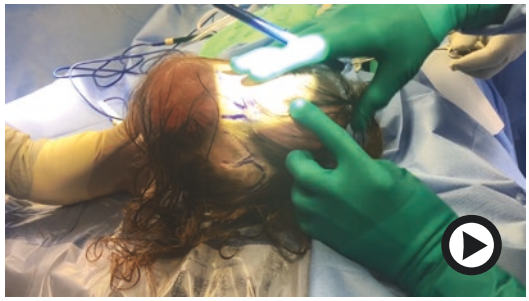

Fig. 33.16 Tissue expander removal and expanded flap reconstruction in the pediatric patient (▶ https://doi.org/10.1007/000-3v9)

Table 33.15 Tissue expander removal, lesion excision, flap reconstruction: Scalp

Markings/ Flap design	Mark along the border of the lesion as the leading edge of the expanded flap Design the rotation/advancement of the flap while aiming to maintain the proper orientation of hair growth
Incision/ Flap elevation	Make incision along the marked lesion Enter capsule and remove expander as described previously
Flap inset	The flap should be transposed and advanced to the furthest extent possible. May employ Z-plasties as needed in areas of relative excess to aid with flap inset. Do not excise "dog-ears," as they will flatten out with time
Lesion excision	Excise the lesion with flap advancement and inset
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 4-0 clear nylon, 5-0 Monocryl, interrupted Skin suture: 4-0 Prolene

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Principles

- Combined advancement–transposition flap design helps prevent lower lid malposition and lateral oral commissure distortion.
- Distortion of the lower lid and upper lip is further minimized by insetting the flap so as to push up slightly on the eyelid and down slightly on the upper lip. When tissues have settled, the final rim of nevus is excised, and the lid and lip positioned symmetrically without distortion.

Table 33.16 Tissue expander removal, lesion excision, flap reconstruction: Forehead

Markings/ Flap design	Mark line just above the eyebrows, out laterally, and across the glabella medially. Take care not to remove any brow skin
Incision/ Flap elevation	Make incision along the marked brow Flap usually across the forehead, and there will be an incision across the normal brow and as far across the affected brow Make incision into the nevus, along the leading edge of the forehead flap Enter capsule, and remove expander as described previously
Set the brow	Suspend the upper brow to the periosteal tissue using 4-0 clear nylon at (1) middle/medial brow; (2) lateral brow, so that when the flap is advanced the ipsilateral brow does not move Go straight down with the needle. As soon as you hit the bone, go back up superficially with the needle tip. Otherwise, the bite is too big and you can lose the needle Take a deep-to-superficial bite on the brow muscle tissue, then superficial-to-deep bite on the brow muscle. Tie to the periosteal suture tail Lateral brow suture is the most important suture on this side of the flap. If this is not secured, as the base of the flap is advanced, the lateral brow can be pulled superiorly
Flap inset	Start on the normal side at the base of the flap. Start insetting the base of the flap at the lateral brow: Make a back-cut into the base at the lateral brow incision, which allows the flap to move. Secure the flap to the brow (4-0 clear nylon triple suture to the periosteum, as above). These sutures should remain deep to the dermis Continue to advance the flap, and trim the flap edge to the level of the set brow. Secure as above As the edge is trimmed, make sure to keep the capsule attached underneath the excess flap. This flap remnant may be inset into other regions (temporal, cheek, upper eyelid, nose) On the superior, scalp side of the flap, an incision is made along the border of the expanded flap As the flap is being moved across the forehead, make sure that you can close the scalp part. The incision is in the scalp, parallel to the hairline, not at the hairline

Table 33.16 (continued)

Lesion excision	Excise the lesion as you advance and inset the flap. Once flap is secured at level of the brow, and flap is maximally advanced, measure the amount of lesion to be resected and excise it
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 5-0 Monocryl, interrupted Skin suture: 4-0 or 5-0 Prolene in the scalp, running Skin suture: 6-0 Chromic on the forehead, running Skin suture: 7-0 Vicryl on eyelid or nose, running

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Table 33.17 Tissue expander removal, lesion excision, flap reconstruction: Cheek

Markings/ Flap design	Mark along the inferolateral border of the lesion as the leading edge of the expanded flap Depending on lesion size and location, mark along the nasolabial fold, the lower lid-cheek junction, up to the temporal region just above the lateral canthus, the pre-auricular region, around the earlobe and post-auricular sulcus
Incision/ Flap elevation	Make incision along the marked lesion Enter capsule, and remove expander as described previously Depending on the size/location of the lesion and flap, will need to make incisions along the pre-marked areas above (nasolabial fold, lower lid-cheek junction, lateral canthal region, preauricular region, post-auricular sulcus)
Flap inset	The flap should be transposed and advanced to the furthest extent possible without distorting the lower eyelid, nasal ala, and oral commissure
Lesion excision	Excise the lesion with flap advancement and inset. The flap should be secured and suspended, when possible, to bone to prevent critical structure distortion (e.g., medially to the nasal sidewall, laterally to the lateral orbital rim) (4-0 clear nylon to periosteum)
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 5-0 Monocryl, interrupted Skin suture: 6-0 Chromic on the face, running Skin suture: 7-0 Vicryl on eyelid or nose, running

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- Skeletal fixation placed in a sequential fashion will allow the flap to be inset to optimal dimension and avoid secondary distortions.

Nose (Table 33.18 and Fig. 33.9)

Trunk

- *Chest* (Table 33.19 and Fig. 33.11a–i)
- *Anterior trunk* (Table 33.20 and Fig. 33.11a–i)
- *Posterior trunk* (Table 33.21 and Fig. 33.11a–i)

Extremities

- Upper extremity [5]
- Shoulder/Upper arm (Table 33.22; Fig. 33.12a, b and Fig. 33.13e-j)
- Forearm (Table 33.23 and Fig. 33.13a–d)
- Lower extremity [6]

Table 33.18 Tissue expander removal, lesion excision, flap reconstruction: Nose, forehead flap

Markings/ Flap design	Design the forehead flap with the TE still in place
Lesion excision	Excise the nasal lesion Create a three-dimensional template of the nasal defect from the paramedian expanded forehead skin
Incision/Flap elevation	Make incisions along the marked forehead flap Enter capsule, and remove expander as described previously
Flap inset	The flap should be transposed and inset into place on the nose
Donor site closure	Remaining expanded forehead skin flap can be used to close the forehead flap donor site Consider placing incision line along the superior edge of eyebrow and into temporal region to avoid paramedian vertical scar
Drain	One underneath the donor site in the forehead, secure as previously described
Closure	Forehead: Deep dermal suture: 5-0 Monocryl, interrupted Skin suture: 6-0 Chromic on the forehead, running; Nose: 6-0 Chromic suture

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Table 33.19 Tissue expander removal, lesion excision, flap reconstruction: Chest

Markings/ Flap design	Design flaps as a transposition–advancement flaps Females: Do not violate the inframammary fold with the incision so as not to distort the breast or affect breast growth
Incision/Flap elevation	Make incision along the marked lesion Enter capsule, and remove expander as described previously
Flap inset	The flaps should be transposed and advanced to the furthest extent possible without distorting the breast in females
Lesion excision	Excise the lesion with flap advancement and inset
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 4-0 Monocryl Skin suture: 4-0 Prolene

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Table 33.20 Tissue expander removal, lesion excision, flap reconstruction: Anterior trunk

Markings/Flap design	Design flaps as a transposition–advancement flaps
Incision/Flap elevation	Make incision along the marked lesion Enter capsule, and remove expanders as described previously
Flap inset	The flaps should be transposed and advanced to the furthest extent possible
Lesion excision	Excise the lesion with flap advancement and inset
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 4-0 Monocryl Skin suture: 4-0 Prolene

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- Proximal lower extremity (Table 33.24 and Fig. 33.14a–e)
- Distal lower extremity (Table 33.25 and Fig. 33.15a–g)
  - For reconstructions using expanded pedicled flaps from the posterior thigh, an intermediate delay of poster thigh flap is completed after 10 weeks of expansion. The incisions are placed along the distal, proximal, and most anterior aspects of the expanded flap down to, but not through, the capsule, and re-closed.
  - One week following the intermediate delay, the lesion may be excised and the posterior thigh flap elevated.

Table 33.21 Tissue expander removal, lesion excision, flap reconstruction: Anterior trunk

Markings/Flap design	Design flaps as a transposition–advancement flaps
Incision/Flap elevation	Make incision along the marked lesion Enter capsule, and remove expanders as described previously
Flap inset	The flaps should be transposed and advanced to the furthest extent possible
Lesion excision	Excise the lesion with flap advancement and inset
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 4-0 Monocryl Skin suture: 4-0 Prolene

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Table 33.22 Tissue expander removal, lesion excision, flap reconstruction: Shoulder and upper arm

Markings/Flap design	Design flaps as a transposition flap from the upper back/shoulder
Incision/Flap elevation	Make incision along the marked lesion Enter capsule, and remove expanders as described previously
Flap inset	The flaps should be transposed from the upper back into the defect
Lesion excision	Excise the lesion with flap transposition and inset
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 4-0 Monocryl Skin suture: 4-0 Prolene

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Table 33.23 Tissue expander removal, lesion excision, flap reconstruction: Forearm and mid-arm

Markings/ Flap design	Proximal marking on the abdomen along scar from previous surgery proximally
Incision/ Flap elevation	Make incision along the old abdominal scar Enter capsule, and remove expanders as described previously Incise at the distal end of the expanded tissue toward the hip to allow for insertion of the arm into the pre-expanded pocket
Lesion excision	Remove the arm from the pocket. Excise the lesion to the fullest extent possible that the expanded flap will cover
Flap inset	At time of expander removal: Re-insert the forearm into the tissue expander pocket Inset the edges of the flap to the extremity skin Place bolstered sutures (sometimes with the aid of a chest tube), to narrow the pedicle at the base. This will ensure that the expanded skin will wrap around the arm completely at the time of division In 3 weeks, at the time of flap division: Divide the bi-pedicled expanded flap, and close circumferentially on the arm Close the donor site on the lower abdomen in an oblique fashion
Drain	One underneath the flap, secure as previously described
Closure	At the time of expander removal Deep dermal suture: 4-0 Monocryl Skin suture: 4-0 Prolene At time of flap division: Deep dermal suture: 4-0 Monocryl Skin suture: 5-0 Chromic

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Table 33.24 Tissue expander removal, lesion excision, flap reconstruction: Proximal lower extremity

Markings/Flap design	Design flaps as transposition flaps moving in a transverse direction (versus axially)
Incision/Flap elevation	Make incision along the marked lesion Enter capsule, and remove expanders as described previously
Flap inset	The flaps should be transposed from the adjacent pre-expanded flaps
Lesion excision	Excise the lesion with flap transposition and inset
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 4-0 Monocryl Skin suture: 4-0 Prolene

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Table 33.25 Tissue expander removal, lesion excision, flap reconstruction: Distal lower extremity

Markings/ Flap design	Re-mark the previously made scar during the intermediate delay procedure
Incision/ Flap elevation	Make incision along the marked scar on the posterior thigh Enter capsule, and remove expanders as described previously
Lesion excision	Excise the lesion on the lower leg
Flap inset	Initial flap inset Preserve a bi-pedicled section of pre-expanded flap most proximally to assist with leg immobilization, inset at the level of the ankle Inset the remaining expanded flap around the anterior aspect of the leg, and suture the flap back to the cut edge of the posterior thigh skin At pedicled flap division, 3 weeks later Divide the pedicled flap, and inset the flap circumferentially around the lower leg Close the donor site
Drain	One underneath the flap, secure as previously described
Closure	Deep dermal suture: 4-0 Monocryl Skin suture: 4-0 Prolene

Nylon, Monocryl, Chromic, and Prolene sutures manufactured by Ethicon, Inc., Somerville, NJ

Perioperative Care

Disposition

Patients are transported to the postoperative anesthesia care unit (PACU) from the operating room after surgery. They are subsequently either admitted to the general pediatric floor for 23-hour observation or are discharged home, depending on patient pain control and parent comfort level.

Pain Medications

- Patients receive one weight-based dose of ketorolac (0.5 mg/kg) in the PACU and may receive an additional dose every 6 hours during the admission if pain remains significant. Scheduled acetaminophen is administered every 6 hours.
- Oral liquid acetaminophen and ibuprofen are scheduled every 3 hours on an alternating basis upon discharge. Liquid acetaminophen–hydrocodone may also be administered for patients older than 1 year, being careful not to exceed the maximum weight-based limit of acetaminophen in a 24-hour period.

Drains

- Red-top tubes changed to new tubes every 4 hours.
- Removal: Drains are removed when there is no fluid egress. Most are removed within 4–5 days after surgery. However, if they continue to drain, then at the time of the first expansion the drain is removed (expansion is at around 9–10 cc).

Dressings

- Bacitracin-coated Xeroform in the operating room. No antibiotic ointment is used after the initial intraoperative application. Aquaphor is subsequently used to avoid reaction to bacitracin.
- Covered with fluff gauze.
- Secured with Flexinet.
- Dressing change is completed the day after surgery in the outpatient office. A light dressing is applied until the drains are removed.
- Aquaphor is applied to the incision and flap except on scalp.

Suture Removal

- Tissue expander placement: Permanent sutures remain in place until tissue expander removal, unless there is significant peri-suture inflammation, the sutures loosen, or get irritated.
- Tissue expander removal: Sutures are removed in two to two-and-a-half weeks. Many of the sutures can be removed sequentially, with assistance of topical anesthetic cream.

Antibiotics

All patients receive a weight-based dose of intravenous antibiotics before the surgery. They continue to receive intravenous antibiotics on a scheduled basis while admitted to the hospital.

Discharge

Tissue expander placement: Oral antibiotics are continued until drains are removed.

Tissue expander removal: No antibiotics are prescribed.

Tissue Expansion Protocol

- Home expansion.
- Initial intraoperative fill with “comfortable” volume.
- Drain removal 2–10 days post-op.
- Start: Begin expansion 8–10 days post-op.
- Frequency/Duration: Weekly expansion over 8–12 weeks.
- Activity unrestricted 3 weeks after expander placement.

Injection Protocol and Technique

- Preoperative teaching sessions are completed with nurse clinicians, parents, and children. Effective injection of the expander in infant and child begins long before expander placement.
- Families are instructed on junction protocol, and the person who will be doing the injections must be present at the teaching session.
- Following the application of topical anesthetic cream and cleansing of the injection site, the amount of injection is determined by
  - Area expanded
  - Size of expander
  - Capillary refill of the overlying skin flap
  - Palpation over the expander

Amount of saline injected into the expander varies by site. Expansion at all sites is dependent on the underlying problem requiring expansion. The most important is that we never fix on injecting a specific amount at a specific time. Typically once per week, but may increase frequency to every fourth or fifth day. Typical injection amounts are as follows:

- Scalp 20–30 mL
- Face 5–15 mL
- Trunk 50–100 mL
- Extremities: varies by location
  - Final expansion volume: As long as the flap looks good in terms of vascular supply, there is no specific target number for expansion volume.
  - Expansion may continue even up to the day before scheduled surgery. However, rapid expansion may be associated with significant flap shrinkage.

Tissue Expander Teaching, Surgery, and Web-Based Follow-Up

- Families of patients send photographic documentation throughout the expansion process to the surgical and nursing team, which allows for preoperative review of the expansion progress.
- Surgical plans can be discussed in detail before the patient returns for the expander removal.
- Candid photographs demonstrate the "business as usual" adaptability of the pediatric tissue expander patient.

Additional Rounds of Expansion

- Timing: We will wait about 4 months after the tissue expansion removal/flap inset and the subsequent tissue expansion stage.
- Sequence: Each round of expansion is approached independently, and the sequence of each stage of the expansion is the same. During subsequent rounds of expansion, we are more cognizant of expander placement so that the scars that are there are not compromised by the position of the expander.
- The expansion protocol remains the same with additional rounds of expansion.

Complications and Their Management

Infections [7]

- Parents of patients are counseled to identify signs and symptoms of early infection or development of other infections, and to communicate these with the surgical team.
- Local signs and symptoms of infection include skin or incisional erythema or low-grade fever, and/or change in behavior. Other risk factors include bacterial infection in family members, or the presence of upper respiratory infection or ear infection.
- A low threshold is maintained to prescribe oral antibiotics to treat the infection or prevent its development.
- If the patient is febrile, we will suspend the expansion until they are afebrile. If obvious signs of redness develop on the flap, and they

develop high fever, then usually the patients will receive a dose of intramuscular antibiotic from their pediatrician for 1–2 days.
- If they do not have any sign of infection, then the parents are directed to examine over the port. If there is any semblance of fluid over the port, then parents are instructed to aspirate the fluid. Usually, this procedure helps enough to allow for antibiotics to help address the infection. Expander removal is rare.
- The patient must be at least 48 hours without a fever before re-starting expansion, and usually we wait around 1 week.
- Some patients may be kept on oral antibiotics throughout expansion. Specifically, children who have had more than a few ear infections may be placed on oral antibiotics during expansion. Children who have had more than five ear infections may have myringotomy tubes placed.

Tissue Expander Exposure

Tissue expanders may have threatened exposure or actual exposure, the situations of which are managed differently.

Threatened Exposure

Causes of threatened expander exposure include incisional breakdown, too rapid of an expansion, and pressure point of the expander on the overlying skin flap.

In the case of a pressure point, we initially place a square of microfoam tape (3M) to distribute force over a wide area until the point smooths out. It looks like skin is especially stressed, then put a Tegaderm on the area to keep surface moist and minimize stress on the area.

Actual Exposure

If an expander is exposed, the decision of whether to keep or remove the expander depends upon where the location of the exposure is in relation to the effect of gravity on the expander. If the tissue expander is in a location where gravity affects it, then the exposure site may get bigger with time (e.g., back), and the expander will likely need to be removed.

Conclusion

Tissue expansion may be used successfully and safely to reconstruct complex defects in children, particularly in patients with congenital melanocytic nevi. The principles of tissue expansion as outlined in this chapter may be successfully applied to reconstruct different areas of the body, each of which has specific considerations to optimize reconstructive success.

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Supermicrosurgical Lymphaticovenular Anastomosis

34

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Introduction

The lymphatic system is the third secretory system. In comparison to the arterial and venous systems, it is one that is often neglected. Problems with the lymphatic system can be congenital (primary), acquired (secondary), or iatrogenic in origin. Lymphedema is a result of an inability of the lymphatic system to adequately transport lymph fluid out of the regional area [1]. Secondary lymphedema is commonly due to infection with filarial nematodes in developing nations, whereas in developed nations, secondary lymphedema is predominantly due to cancer therapy [1]. The incidence of breast-cancer lymphedema has been reported to be as high as 70% after modified radical mastectomy with regional lymph node radiation [2]. Lymphedema tremendously impacts a patient's quality of life. It can lead to pain in the affected area, diminished function, and a decrease in self-confidence due to its disfiguring presentation in the affected regions [3].

Lymphedema is traditionally treated with complex decongestive therapy (CDT). CDT is therapist-directed and focuses on manual lymphatic drainage through bandaging, skin care, and exercise [4]. Since CDT manages and does not cure the condition, it requires lifelong adherence. The requirement of lifelong adherence is likely the cause of high failure rate of CDT observed in the senior author's (WFC) practice. Several microsurgical and supermicrosurgical interventions are currently available in the management of lymphedema. Lymphedema surgery is categorized as either reconstructive or debulking procedures [5]. The goal of reconstructive procedures is to restore lymphatic drainage in the affected area, whereas the goal of debulking procedures is to remove the pathologic tissue. The established reconstructive procedures include lymphaticovenular anastomosis (LVA) [6–9], vascularized lymph node transfer (VLNT) [10–17], and more recently, vascularized lymph vessel transfer (VLVT) [18, 19]. The primary debulking procedures include suction-assisted

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lipectomy (SAL) [20–22] and the Charles procedure [23, 24]. Procedures are patient- and disease-specific, with reconstructive procedures appropriate for fluid-predominant disease and debulking procedures more appropriate for solid-predominant stage.

The modern lymphatic reconstruction initially began with Dr. Hung-Chi Chen with the creation of lymph node transfer in the 1990s [10, 25–30]. There were attempts to perform lymphatic reconstruction through lymph node transfer prior to this, but all the attempts for lymphatic reconstruction were unsuccessful [10]. Supermicrosurgery, a technique of microvascular anastomosis for vessels of 0.3–0.8 mm, was first introduced 20 years ago by Koshima et al. [31]. This technique has allowed for the creation of lymphaticovenular anastomosis (LVA) to bypass the obstructed lymphatic drainage pathways [6, 8, 9]. The concept of LVA was not new. Lymphovenous bypass (LVB) was reported prior to Koshima's supermicrosurgical LVA [32, 33]. The differences were that the LVBs were microsurgical (frequently involving vessels >0.8 mm) and were usually strategically performed in the proximal limb segments [34]. The reported outcomes of LVBs were at best inconsistent, and therefore the technique was mostly abandoned [35, 36].

In recent years, lymphatic reconstruction has caught the attention of plastic surgeons, particularly among the reconstructive microsurgeons. However, given the technical complexity and difficulty of these procedures, these procedures as of today are still not widely practiced. Even among the few highly trained microsurgeons, the practice is not standardized. The purpose of this book chapter is to share the experience of the senior author who has developed some tips and tricks in lymphatic reconstruction over the years of treating extremity lymphedema.

At the University of Iowa, we perform the full spectrum of lymphatic reconstruction procedures. The choice of procedure is tailored to a patient's individual condition. We first categorize patients into solid-predominant or fluid-predominant disease. The distinction between solid and fluid predominance is frequently obvious during physical examination. In equivocal cases, magnetic resonance imaging (MRI) and bioimpedance spectroscopy can help delineate the composition of the observed limb bulk [22, 37, 38]. Patients with solid predominance are treated with debulking procedure, through either liposuction [22, 39, 40] or the Charles procedure [23, 24]. The choice of liposuction or Charles procedure depends on the severity of the subcutaneous fibrosis. Severe subcutaneous tissue fibrosis cannot be effectively removed by liposuction, and therefore indicates direct surgical excision [23, 24]. The skin should ideally be preserved whenever possible. Radical resection with perforator preservation (RRPP) [24] can be performed to preserve the skin if it is not excessively fibrotic. If rigid cutaneous fibrosis is already present, the Charles procedure becomes the treatment of choice. Patients with solid predominance following the debulking procedure may still undergo reconstructive procedures, whereas patients with fluid predominance can directly undergo reconstructive procedures such as LVA and lymph vessel/node transfer.

In our center, VLVT has mostly replaced VLNT, due to its similar efficacy and decreased risk of causing lymphedema at the donor sites [19, 41]. We perform liposuction with simultaneous contouring skin reduction, or the so-called flying squirrel technique [22, 39]. The VLVT and the "flying squirrel" liposuction are outside the scope of this book chapter. Since the senior author gets asked most frequently about his LVA technical approach, we will focus on LVA.

Preoperative Preparation

A thorough history of the patient that focuses on etiology, symptoms, functional impairment, progression of disease, prior treatments, and response to prior treatment, should first be assessed. Since surgery is not the first-line treatment for lymphedema, it is important to note all prior interventions and the patient's responses to those therapies [4]. The nature of the disease should be classified as either primary or secondary lymphedema [42]. Primary lymphedema lacks an initiating event [43–46], whereas if a

patient presents with persistent limb edema following radiation or surgical treatment, this is suggestive of secondary disease [47, 48]. It is important to note that duration of disease does not always correlate with severity. Occasionally patients with years of symptomatic disease may have only mild lymphatic injury, whereas patients with severe lymphatic injury could have a recent onset of disease [49, 50]. It is important to note a patient's disease progression when formulating a treatment plan. The threshold to surgical intervention is lowered in the pediatric population, due to the high likelihood of disease progression during their lifetimes [51]. Patients with rapid disease progression are also preferentially considered for surgery before their worsened disease states contraindicate them from receiving the appropriate surgery.

Physical examination should begin with a visual inspection of the affected limb and the extent of the swelling. It is important to note whether the swelling is fluid-predominant, solid-predominant, or a mixture of both. Early lymphedema is generally a fluid-predominant disease, and on exam would present with pitting upon digital pressure. Late lymphedema is characterized by solid-predominant disease, lipodystrophy, and fibrosis, and will not pit on exam. Limb volume should also be determined. The limb volume can be either derived from circumference measurement or direct measurement. Three-dimensional optoelectronic perometry and water displacement technique both provide direct volume measurement. 3D perometry is superior, due to its relative ease of use. Contrary to popular belief, 3D volume scanning lacks reliable reproducibility. Slight changes in patient posture during measurement can significantly affect the measurement. We recommend 3D scanning as a patient-tracking modality, as it effectively demonstrates limb volume progression over time. In our experience, 3D scanning has unacceptably high false negative rates, and its use as a diagnostic modality is not recommended.

The formal diagnosis of lymphedema is traditionally a clinical diagnosis. However, confirmatory studies should be obtained when surgical treatment is considered. Several conditions, such as lipedema and extremity venous insufficiency, can mimic lymphedema. A definitive diagnosis can be made through imaging modalities such as lymphoscintigraphy and indocyanine green lymphography [1, 52–54]. Lymphoscintigraphy has been the gold standard in diagnosing extremity lymphedema. Technetium-99m-sulfur colloid is injected at the digital web spaces of the targeted extremity. The colloid is taken up by the lymphatic system. The rates of transit and flow patterns are diagnostic for various lymphatic disorders. Drawbacks of lymphoscintigraphy include poor spatial resolution and obligatory radiation exposure. Indocyanine green lymphography (ICG) involves peripheral injection of a contrast agent that is subsequently taken up by the lymphatic system. ICG is nonradioactive through its use of a fluorophore that fluoresces when optically excited at 800 nm. The presence and locations of backflow patterns correspond to disease severity. Dermal backflow patterns "linear," "splash," "stardust," and "diffuse" help to stage disease severity [55]. ICG lymphography has shown to have a higher sensitivity and specificity than lymphoscintigraphy. In the senior author's practice, ICG lymphography has predominantly replaced lymphoscintigraphy as the imaging modality of choice for diagnosis, preoperative planning, and postoperative tracking [56, 57].

When staging lymphedema, there is no universally agreed-upon staging system. Commonly used staging systems include ones published by the International Society of Lymphology [58] and Corradino Campisi [34]. With reconstructive microsurgeons playing a significant role in the management of lymphedema, staging systems with surgical considerations have been developed [59]. It is important to note that all staging systems describe the same disease progression. We do not favor one system over another.

Standard Technical Performance

Lymphaticovenular Anastomosis

Lymphaticovenular anastomosis (LVA) is most effective when created with functioning lym-

phatic vessels. ICG lymphography can help determine which patients have preserved lymphatic systems. If there are high-quality linear patterns on ICG lymphography, LVA is the procedure of choice. LVA is typically performed under general anesthesia for patient comfort but can be performed under local anesthesia just as easily in selected cases [60]. Using the sequential injection technique [61–63], mapping ICG lymphography [54, 64–67] is performed to define all available superficial lymphatic vessels in a distal to proximal fashion. Superficial veins are mapped using infrared vein localization for the LVA (Fig. 34.1a) [61, 62]. Incisions are strategically placed at points where lymphatic vessels and veins lie in close proximity (Fig. 34.1b). With deliberate incision placements, 1–1.5 cm incisions are sufficient for successful LVA construction (Figs. 34.1c, and 34.2a, b) [62].

The microscope should be set at an initial magnification level of 10–15×. Then, 0.05 mL of isosulfan blue is injected at 2 cm distal to the planned incision site prior to the partial-thickness skin incision. With needle electrocautery set at 8 W, the dermis is delicately divided. The surgeon must be careful when dividing the last strands of dermis because the veins appropriate for LVA are often found just deep into the dermis. Following complete division of the dermis, the magnification should be increased to 18–25×,

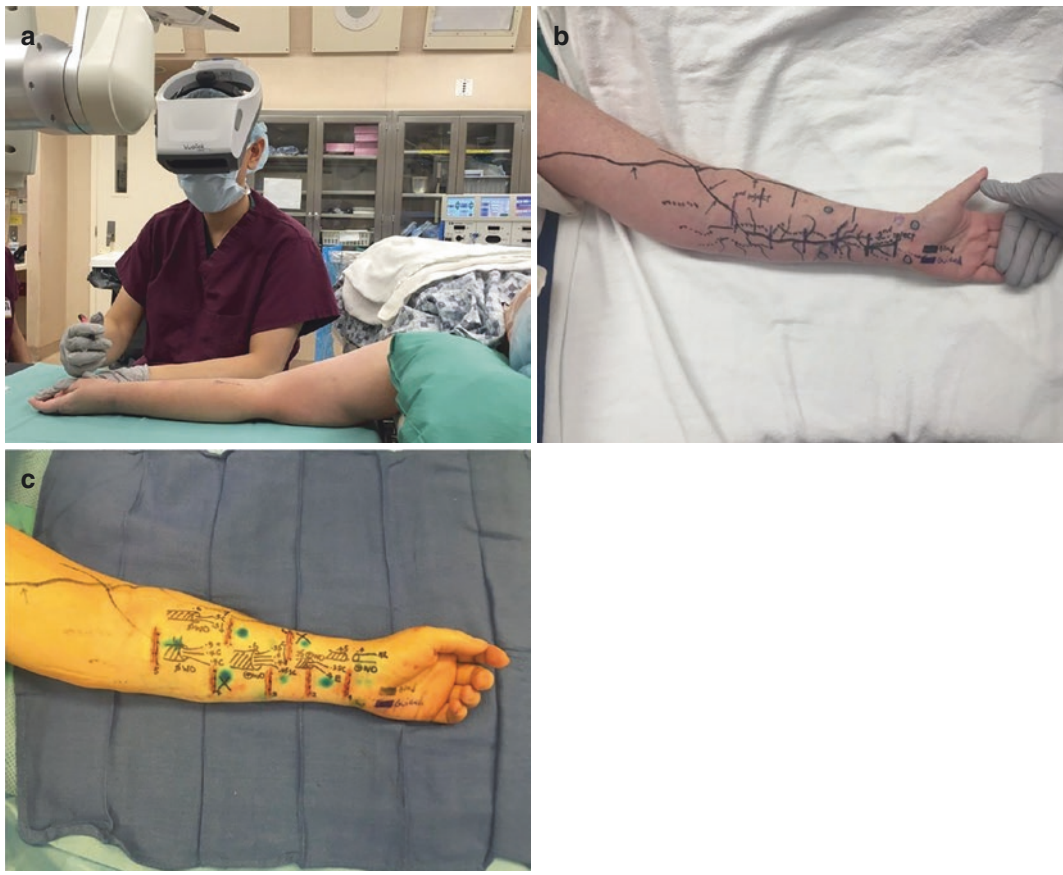

Fig. 34.1 (**a**–**c**)—Head-mounted near-infrared vein finder was used to localize superficial veins adjacent to the lymphatic vessels mapped using ICG lymphography (**a**). The solid lines represented lymphatic vessels seen on ICG lymphography. The dotted lines were veins visualized using the near-infrared vein finder (**b**). Incisions were preferentially made where both the lymphatic vessel and vein were present. Anatomically based incisions (following the anatomic course of cephalic vein, top two incisions) can also yield successful LVA construction, albeit with a lower efficiency (**c**). (Reprinted with permission from Chen [61])

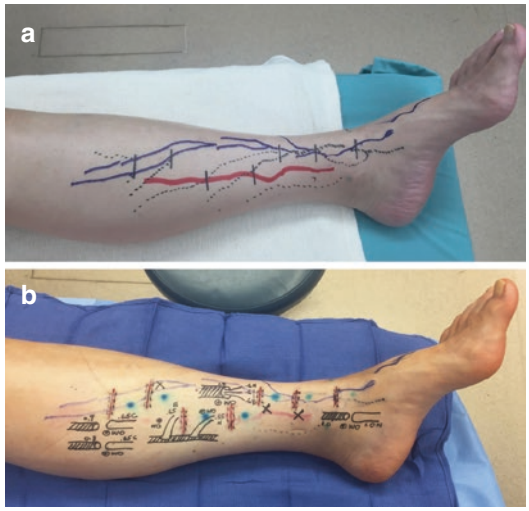

Fig. 34.2 (**a**, **b**)—(**a**) Solid blue and red lines represented lymphatic vessels mapped with indocyanine green lymphography from different injection sites. Dotted lines were superficial venules visualized using the infrared vein finder. Incisions were planned at where the lymphatic vessels and the superficial venules intersected. (**b**) Postoperative skin markings showing LVAs constructed with various anastomotic techniques [85]

and a micro-dissector is used to dissect through the superficial and deep fat layers. The surgeon needs to preserve and carefully skeletonize all veins and lymphatic vessels that are encountered. Lymphatic vessels can be found anywhere between the skin and deep fascia but are often located just deep to the superficial fascia (Fig. 34.3a–c). The final point of dissection is indicated when there is complete exposure of the underlying deep fascia. All the available lymphatic vessels and veins should be cleanly dissected. The surgeon should decide on the anastomotic configuration that recruits all available lymphatic vessels to maximize the drainage pathways [61, 62]. The nomenclature for LVAs is configuration of lymph vessel-to-configuration of vein. Side-to-end and side-to-side anastomoses are performed whenever feasible, because both provide dual drainage pathways—both antegrade and retrograde drainage pathways [68–70]. In general, the relative calibers and positions of the vessels indicate a specific anastomotic configuration. When lymphatic vessels and veins are comparable in size, end-to-end anastomosis should be considered (Fig. 34.3a). Side-to-end anastomoses should be formed when the lumen of the lymphatic vessel equals or exceeds that of the vein. If the lymphatic vessel is smaller than the recipient's vein, end-to-side anastomosis should be performed (Fig. 34.3b) [68–70]. Multiple lymphatic vessels can be anastomosed to the lumen of a single vein using the "octopus" technique (Fig. 34.3c, d) [71]. Supermicrovascular surgeons need to be trained and able to perform all configurations in order to manage difficult vessel positions and sizing [61].

As the surgeon completes the steps of the initial incision to the supermicrosurgical anastomosis, the magnification level of the microscope should be gradually increased. LVAs involve vessels that are between 0.2 and 0.6 mm and are best seen with 25–35× magnifications. Higher magnifications have not been found to be helpful, due to excessive narrowing of the operative field [61]. A 12-0 nylon suture on a 50 μm is best, but 11-0 nylon is also appropriate for vessels larger than 0.5 mm. We advise LVA surgeons to use the chicken thigh simulation model to hone the skills needed for the procedure before operating on patients. The chicken thigh model is an effective simulation for LVA (Fig. 34.4a–d) [72, 73]. The surgeon should place an adequate amount of sutures until a leakproof anastomosis is accomplished. With a leakproof anastomosis, lymphatic pressure can build to overcome the venous pressure and subsequently be "washed out" in the blood of the venous circulation (Fig. 34.3a–d) [61, 62]. Disease-compromised lymphatic vessels can demonstrate a delayed "washout" and needs to be reassessed several minutes after completing the anastomosis. If a "backflow" sign is present, this indicates that the venous pressure is greater than the lymphatic pressure [74, 75]. This places the LVA at risk of anastomotic thrombosis. External compression should be applied if "backflow" is seen in order to attempt to convert it to a "washout" [61]. Immediate postoperative limb compression is needed (Figs. 34.5, 34.6a, b, and 34.7a, b).

The ideal number of anastomosis is based on individual surgeons' experiences, and as of today has not been objectively investigated. In our

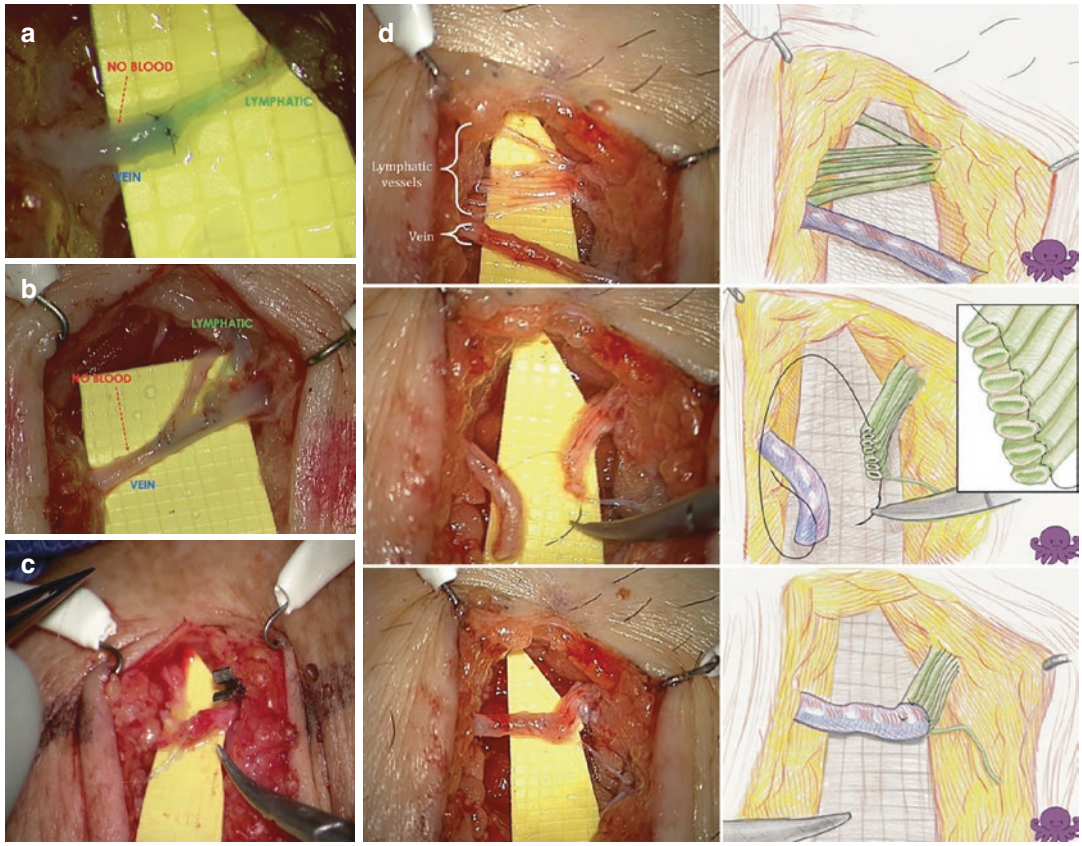

Fig. 34.3 (**a**–**d**)—Standard end-to-end anastomosis (**a**), double end-to-side anastomosis (**b**), and the octopus anastomosis (**c**, **d**). "Washout" sign can be clearly seen by the absence of blood in the vein and the simultaneous presence of the green/blue-stained lymphatic fluid in the vein (**a**, **b**). Four-to-one octopus LVA with a U-shaped stitch that "intussuscepted" all four lymphatic vessels into a single vein (**c**). Cartoon illustration of the transadventitial suturing that bundles the lymphatic vessels together in the octopus technique (**d**). (Reprinted with permission from Chen et al. [72])

experience [61, 62, 71], the more the drainage pathways that are created, the better the outcome until a point of diminishing return is reached. The quality of the lymphatic vessels is more important than the number of connections. Highly functioning lymphatic vessels can generate a similar efficacy with less LVAs. At the University of Iowa, 8–15 anastomoses are typically completed over a 5-hour surgery. Further research is needed to determine the ideal number of anastomoses, although such a study is conceptually difficult to perform due to variables involved, including disease severity, variable individual anatomy, variable incision placement, anastomotic technique, and last but not the least, surgeon skill.

Expected Outcomes

LVA is an effective treatment modality that not only reduces volume but significantly improves symptoms including swelling, heaviness, tightness, restricted range of motion, fibrosis, and recurring infections. Patients are evaluated with self-assessment, circumference measurement, quality of life assessment (LYMQOL) [61, 76–78], bioimpedance spectroscopy (BIS) [79], and indocyanine green (ICG) lymphography at preoperative visits [80], as well as 3-month, 6-month, and 12-month postoperative visits [61, 62]. In the early stage, in patients with an abundance of high-quality "linear" patterns in ICG lymphography, we expect that symptoms will improve soon

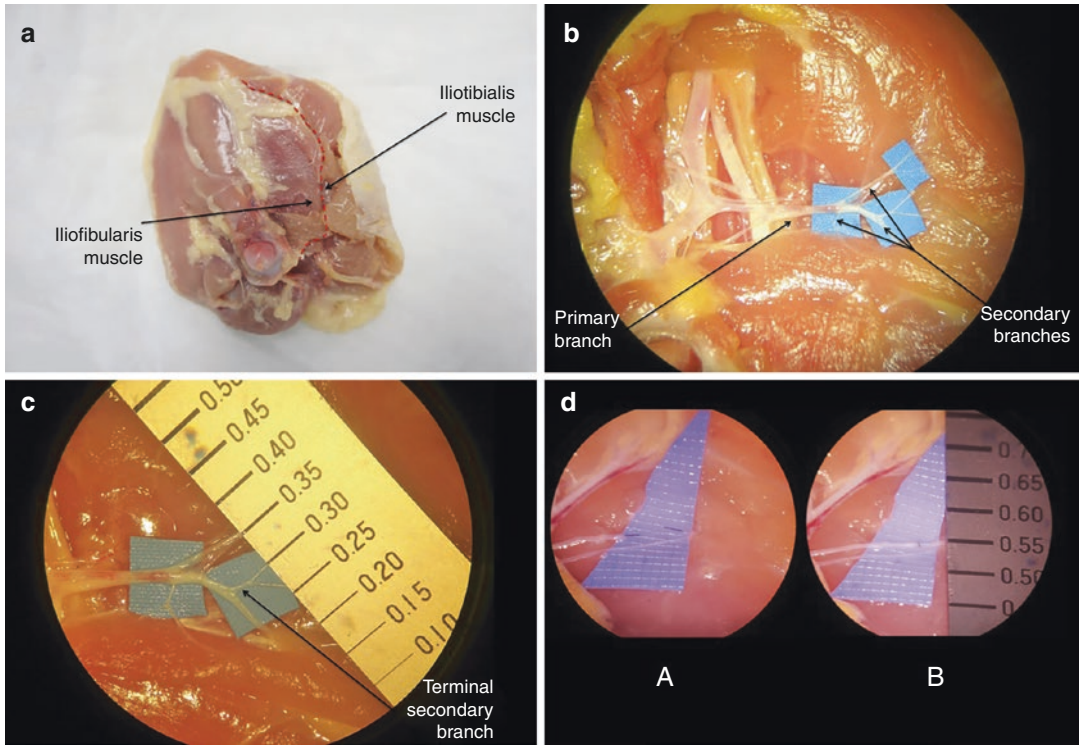

Fig. 34.4 (**a**–**d**)—Store-bought chicken thighs can be used to train LVA supermicrosurgeons. It is important to buy ones with bones, as the ischiatic neurovascular bundle is intimately associated with the bone. The red line indicates the areolar plane between muscles where the neurovascular bundle can be found with minimal dissection (**a**). The ischiatic neurovascular bundle and its associated branches are seen here under 10× magnification. The secondary and tertiary branches are usually adequate for supermicrosurgical training, while the main trunk and the primary branches are suitable for regular microsurgical training (**b**). In our study, 0.2-mm and 0.3-mm vessels could be found in all chicken thighs (**c**). A 7-0 nylon can be used as a vascular stent to prevent the vessel lumen from collapsing. Shown here is a 0.55-mm vessel anastomosed with 12-0 nylon using the 7-0 nylon stent training technique (**d**). (Reprinted with permission from Chen et al. [72])

Fig. 34.5 After having documented the initial LVA flow pattern, bandage compression was applied proximal and distal to the incision to simulate the effect of immediate postoperative limb compression [85]

after the surgery. The healthier the lymphatics, the more effective the LVA procedure. For patients with "diffuse" pattern, but who show a confirmed fluid predominance by BIS [61, 79, 81] or MRI [82–84], we also expect that the symptoms will improve shortly after the operation. The senior author's experience shows patients with the "diffuse" pattern of stage III disease who also had significant improvement of their symptoms after surgery (Fig. 34.8). This suggests that the lymphatic vessels demonstrate nonfunctionality due to high pressure built up by the blockage. Once the outlet of newly created drainage pathways is established, the pressure gradient allows the lymph fluid to easily drain

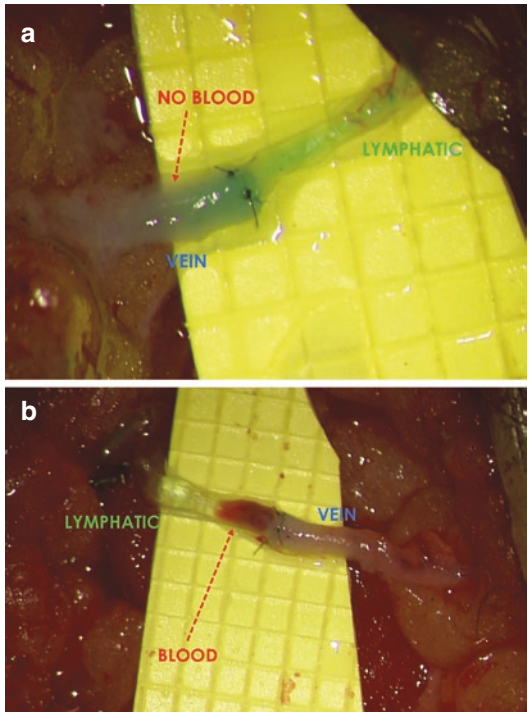

Fig. 34.6 (**a**, **b**)—(**a**) A favorable "washout" sign was observed when the lymphatic pressure exceeded the venous pressure and antegrade flow occurred. (**b**) Conversely, retrograde flow occurred when the venous pressure exceeded the lymphatic pressure and an unfavorable "backflow" sign was shown [85]

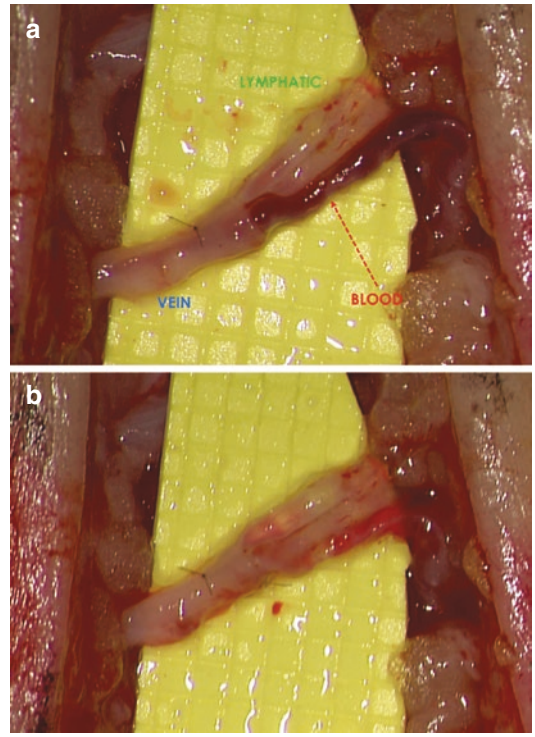

Fig. 34.7 (**a**, **b**)—(**a**) Before compression. Three lymphatic vessel-to-one vein LVA anastomosed using the "octopus" technique showing "backflow" in all three lymphatic vessels. The "backflow" sign was particularly prominent in the most inferior lymphatic vessel. (**b**) After compression. Conversion to "washout" was seen in all three of the lymphatic vessels. Note how the blood was "washed out" of all three of the lymphatic vessels and the vein. Engorgement of the lymphatic vessels was clearly seen in the top two lymphatic vessels [85]

into the venous system. As the pressure is released, the non-sclerotic lymphatic vessels return to functional status, allowing symptoms to improve continuously [62]. For patients with no-signal congenital lymphedema [67], we plan the incisions along the vein and build a successful LVA where improvements can be seen, suggesting the lymphatic vessels are still functional in moving the lymph fluid to the venous system as the new pathway is created [44].

We expect the volume change is different based on the predominant component of disease. For the patients with stage 1 and 2 lymphedema whose diseases are fluid-predominant, the volume will change significantly in the first 3–6 months and will continuously improve up to 12 months postop, or longer in some cases [6, 8, 36]. For patients with stage 3 and 4 lymphedema, the volume change will be less significant, given the solid component formed by lipodystrophy, but the volume reduction will still be seen [62]. We also saw significant reduction in the lower extremity cases. Some stage 1 or 2 lower limb cases demonstrated the visible difference postop 4–7 days [62]. The compression right after surgery and the good compliance of patients help result in favorable outcomes in our center [85]. Generally, chances of success are better with surgical intervention in the earlier stages of lymphedema, before fibrosis and complete loss of lymphatic valvular function develop, and peripheral lymphatics are damaged.

To assess and monitor outcomes, volume-based measurement is most commonly used, indicating postoperative volume reduction. Examples of methods used include limb circumference mea-

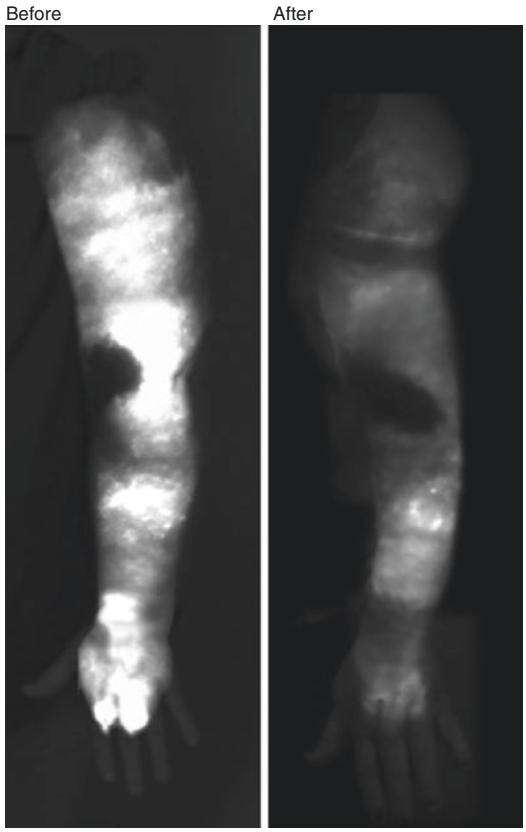

Fig. 34.8 Before/After comparison of a patient with postmastectomy Campisi stage III lymphedema of left arm. The preoperative picture demonstrated severe dermal backflow patterns on the hand dorsum, elbow, and upper arm. The 1-year postoperative picture showed global improvement of the entire limb with a striking near-complete resolution of the dermal backflow pattern at the hand dorsum. (Reprinted with permission from Chen [61])

surements, water displacement, tissue tonometry, perometer, bioimpedance spectroscopy, and contrast-enhanced magnetic resonance lymphangiography. At our center, we track volume change with circumference-based lymphedema indices [86–89]. The indices can reduce the bias, as the changes in BMI are taken into account in the calculation. In our center, patients treated with LVA had improvement demonstrable in at least one tracking modality. We recommend that postoperative outcome monitoring should be a multimodal outcome assessment, including a comprehensive clinical assessment due to the presence of certain limitations for each [62].

Postoperative Care

LVA is a minimally invasive supermicrosurgery. At our center, LVA is an outpatient procedure where the patient will go home on the same day. Regular diet can be continued once the patient has an appetite. Showering can be resumed after 3 days, and the patient should be instructed to avoid rubbing or scrubbing of the incision, and to pat dry.

The LVA is fragile for about 4 weeks, so a bandage wrap is placed on the limb for compression immediately following surgery [85]. The application of the ace bandage will start at the fingers or toes with the greatest pressure and decrease in pressure as the ace bandage is applied moving toward the shoulder or thigh. The patient should also be supplied with a sling for arms, or ask the patient to purchase a foam block for the leg/arm. During the first 3 weeks postoperation, patients are advised to elevate the limb above the level of their heart when resting and encouraged to stand for a minimum of 10 minutes every hour where the patient uses their pain and swelling as a guide to tolerance. Following 3 weeks of limb elevation, the patient is encouraged to partake in light activity, along with limb elevation, whenever possible [61, 62].

At 4 weeks postoperation, sutures are removed, and the patient should be released to resume normal activity and can begin seeing a lymphedema therapist. Home exercises allow for acceleration of the process. During this consultation, the patient should be fitted for a new compression garment to be worn daily at 30–40 mm/Hg that aids in improvement of pain, tightness, and discomfort for the patient [90–92]. It prevents recurrence and exacerbation of edema by applying external force and increasing tissue pressure [4]. A retrospective chart review of patients with lymphedema who underwent complete decongestive therapy followed by surgical treatment with liposuction, LVA, or VLNT concluded that lymphedema precautions should be continued despite the results achieved with surgery. This includes compression garment use while partaking of strenuous physical activity and airline travel, as well as vigilance against

cuts and scratches [5]. Improvement can progress over a year, although, if no improvement is seen in the period of a month, home therapy can be discontinued. If symptoms recur, ongoing therapy with daily lymphedema exercises and a compression stocking may be indicated.

At the 3-month follow-up, the SPY procedure will need to be performed, allowing to visualize and assess flow post-LVA [80]. This procedure should be repeated at 6 months, 12 months, and then yearly. If the patient is ready, the compression garment can begin to be weaned off at 6 months postoperation, meaning either reducing the number of hours per day the garment is worn or reducing the strength of the garment. If unsuccessful at 6 months, the garment can begin to be weaned off again at 12 months.

LVA Tips and Tricks

Having discussed the standard LVA technique above, we will now describe our tips and tricks.

1. *Proper patient selection facilitates surgical success*. As discussed previously, LVA is the treatment of choice for fluid-predominant disease with functionally preserved lymph vessels. These patients are characterized by fully reversible limb edema that pits. MRI and/or bioimpedance spectroscopy (BIS) can be obtained to further confirm the clinical impression, or in clinically equivocal cases. On MRI, the fluid and adiposity signals can be easily differentiated [83, 84, 93–96]. BIS provides segmental quantitative measurement of fluid content and clearly demonstrates fluid-predominant state [81, 97, 98].

   ICG lymphography is the tool used to demonstrate the condition of the lymph vessels [55, 67, 99]. "Linear" lymphographic pattern indicates healthy, functioning lymph vessel. LVA is an obvious choice and is highly recommended for patients demonstrating an abundance of "linear" patterns. In these cases, the performance of LVA is technically straightforward. The surgeon can simply map the lymph vessels/veins and cut down to the desired vessels. In these cases, the surgery is expected to be easy and speedy, and highly favorable results can be expected.

   Comparing arm and leg lymphedema, while both can respond favorably to LVA (Figs. 34.9 and 34.10) [71, 85], it is the senior author's experience that arm lymphedema improves more remarkably following LVA than leg lymphedema does [62]. This may have to do with the fact that arm is anatomically more elevated than the leg. Elevated position of the arm facilitates lowering the venous pressure, facilitating a favorable lymph-to-vein pressure gradient. Therefore, while it remains true that LVA works best in limbs with relatively preserved lymphatic function, the surgeons may still obtain satisfactory LVA results in arms with rather compromised lymphatic function. The same cannot be said for leg lymphedema [100].
2. *Absence of "linear" pattern is not a contraindication for LVA*. LVA is commonly thought to be contraindicated when no "linear" pattern is seen on ICG lymphography. This has not been the senior author's (WFC) experience. Makoto et al. [50] classified lymph vessels into normal, ectatic, contracted, and sclerotic, based on the degree of injury. In WFC's experience, all except the sclerotic lymph vessels can effectively transport lymph and can be used to build LVA. If a surgeon uses normal, ectatic, and contracted lymph vessels to build LVA, then there is 100%, 70%, and 53% probabilities of finding recruitable lymph vessels in "linear," "stardust," and "diffuse" lymphographic patterns [50]. What this means is that even when a patient dem-

onstrates only "stardust" and "diffuse," LVA remains feasible.

What if no ICG signals were seen? This situation can be encountered in both congenital and acquired lymphedema. ICG signals may not be visualized due to (1) limited penetration depth below the skin, (2) sluggish lymphatic transport, (3) injection sites not drained by all relevant lymphosomes, and (4) individual anatomy. In this situation, we recommend mapping the veins using near-infrared technology and plan the exploratory incisions based on the locations of the veins. This "follow-the-vein" (FTV) approach works due to the lymphatic anatomy that runs closely parallel to the vein anatomy, particularly in the superficial fat layer [6, 8, 9, 36, 101]. In WFC's experience, if vein is present at a particular spot, lymph vessel(s) can usually be found in its 3-cm radius vicinity (Figs. 34.1 and 34.2) [61, 62]. With the FTV approach, the senior author has been able to perform LVA in lymphedema patients without "linear" pattern and with reproducible success.

3. Strategic incision placement *using lymph vessel/vein mapping increases LVA success*. As indicated above, one can expect successful LVA by either planning incision according to lymphatic or venous anatomy. What if locations of the lymph vessels and veins are both taken into consideration when planning the incision? As can be expected, the success of LVA further increases. In a prospective study, our team demonstrated higher success rate in creating LVA per incision, higher number of LVA per incision, and smaller incisions when the incision placement was guided by both mapping ICG lymphography and near-infrared venography (Figs. 34.1 and 34.2) [61, 62, 85].
4. *Maximize the number of lymph drainage pathways, not necessarily the number of LVAs*. When performing LVA surgery, think quality first, then quantity. In terms of quality of the lymph vessels, ectatic > normal > sclerotic [50]. Ectatic vessels are best because their transport function is preserved, and their diameters have been enlarged. Although the optimal number of LVAs per surgery is to date not scientifically identified, it is generally agreed upon that more LVAs is better. We recommend that considering the number of drainage pathways is more relevant than considering the number of LVAs. With this in mind, a side-to-end LVA is more favorable than an end-to-end LVA, because the side-to-end configuration provides two drainage pathways, both retrograde and antegrade [69, 70, 102], while the end-to-end configuration only provides one. On the same token, if the surgeon finds multiple lymph vessels with only one vein available, we recommend performing the "octopus" technique (Fig. 34.3c, d) (Fig. 34.11), because all of the available lymph vessels can be recruited to create more drainage pathways [71].
5. *Intraoperatively observed pressure gradient is prognostic, and do immediate postoperative compression*. When preparing a lymph vessel for anastomosis, the lymph vessel is either cut (for end-to-end anastomosis) or a lymphotomy is created (for side-to-end anastomosis) [6, 8, 100]. The rate of lymph egress from the vessel is indicative of its intra-luminal pressure. The lymph vessels demonstrating brisk spontaneous lymph egress are considered favorable. A prompt postoperative improvement can be expected if multiple LVAs are built with such lymph vessels. On the other hand, lymph vessels lacking spontaneous lymph egress and requiring distal massage to

"squeeze out" the lymph indicate poor peristaltic function. LVAs built with these qualitatively poor lymph vessels tend to show the unfavorable "backflow" sign, indicative of retrograde blood-to-lymph flow [103]. However, they can still be converted to the favorable "washout" sign with external compression (Figs. 34.5 and 34.6). Our prior study demonstrated that immediate postoperative limb compression can help increase the procedural efficacy of LVA (Figs. 34.5 and 34.6) [85].

6. *Proper instrumentation is of paramount importance*. Frequently, LVAs involve lymph vessels ranging 0.2–0.6 mm [104, 105]. Using standard microsurgical instruments to perform LVA will likely result in suboptimal performance. Standard microsurgical #3 and #5 jeweler's forceps have 0.3 mm tips. Imagine how difficult it would be using them to handle/grasp a 0.3 mm lymph vessel. Similarly, 9-0 and 10-0 sutures and their associated needles commonly used in microsurgery are too thick for LVA. We recommend using dedicated supermicrosurgery instruments with forceps tips sharpened to 0.05 mm [106]. Due to stainless steel's insufficient structural rigidity, these instruments are currently made of titanium only. For sutures, 11-0 suture with 70-micron needle is recommended for 0.5–0.8 mm vessels, and 12-0 suture with 50-micron needle is recommended for 0.2–0.4 mm vessels [106, 107]. At the time of the writing of this chapter, 13-0 suture with 30-micron needle was just created, although it was not available in the United States.
7. *Use* airborne suture technique *to increase technical efficiency and decrease vessel trauma* (Fig. 34.12). Airborne suture is a microsurgical suturing technique initially described by Chen et al. [108] in 2003 to make microsurgical knot tying more efficient. The technique does not lend itself well to verbal description. Please see our demonstration video (Fig. 34.12). Putting it simply, it involves keeping the short suture end "airborne" during knot tying [109]. This technique not only makes microsurgical knot tying faster but also helps decrease the trauma to the involved vessels from having to repetitively pick up the short end, which, when leaving it to self, frequently sticks to the adventitia of the adjacent vessels [110]. Once conceptualized and understood, the technique is fast to learn. Although originally developed for microsurgery, the airborne suture technique did not gain widespread practice, mostly because microsurgical suturing is relatively easy, and there was not a need to further simplify it with any special technique. In our opinion, the airborne suture technique is a valuable technical adjunct to the performance of supermicrosurgical LVA [111]. It is recommended that supermicrosurgeons invest time and effort to get proficient in this technique.
8. *Create venotomy/lymphotomy using* "ripping" technique *or* needle-guided technique *for increased precision* (Figs. 34.13 and 34.14).

   Creating a side-opening on lymph vessels and veins involved in LVA is technically challenging, particularly when they are <0.5 mm. The two technical tricks introduced here—the "ripping" technique and the needle-guided technique—are helpful. The "ripping" technique is performed by ripping the vessel layer by layer until a side-opening of appropriate size is created. This technique is easy to perform. It also provides the surgeon with complete control on the size of the opening. The needle-guided technique [112] is performed by gauging the size of opening needed with an 11-0 or 12-0 needle and placing the needle partially through the sidewall of the lymph

vessel or vein to be cut. Using supermicrosurgical scissors, the opening is then created by cutting immediately under the suture needle, using it as a cutting guide (Figs. 34.15 and 34.16).

9. *Using 6-0 to 8-0 sutures to "stent" the lumen of vein/lymph vessel to prevent the lumen from collapsing during anastomosis*. This technique was originally described by Narushima et al. [113, 114]. It is now widely used by supermicrosurgeons, particularly for vessels <0.5 mm or for side-to-end/end-to-side anastomoses [69, 115]. The technique is also a helpful "training wheel" technique for surgeons who are starting to perform supermicrosurgery. Suture of appropriate caliber is selected depending on the size of the vessel being sutured. A short segment of the suture is cut to be used as a stent (Fig. 34.4d). It is important to examine the cut edge under the microscope prior to insertion to ensure that the edge is smooth and will not injure the vessel's intima.
10. *Overcome the learning curve and become proficient on simulation model*. Supermicrosurgical LVA has a steep learning curve. Even for experienced microsurgeons, we do not recommend starting to offer the procedure to patients without further simulation training. Biologic simulation models are in general superior to synthetic simulation models, due to superior fidelity. Multiple biologic simulation models have been described [116, 117]. We recommend the chicken thigh simulation model [72, 73]. The model can be built based on chicken thigh with bone purchased from the grocery store. The simulation vessels can be prepared quickly by dissecting along the fat plane between iliotibialis and iliofibularis on the medial side of the chicken thigh. The ischiatic neurovascular bundle can be easily identified in the fat plane. Upon skeletonization of the main trunks of the ischiatic artery and vein, the primary branches can be seen taking off in the middle of the main trunks. By tracing the branches to secondary and/or tertiary branches, vessels ranging 0.2–0.8 mm can be dissected for simulation training (Fig. 34.14). All anastomotic configurations can be practiced on this simulation model. In our experience, a minimum of 50 patent supermicrosurgical anastomoses is necessary prior to achieving competency in supermicrosurgical technique [72].

Fig. 34.9 Image showing patient 4 who suffered from postmastectomy Campisi stage III right arm lymphedema. She had 16 LV drainage pathways created in five "octopi." Her disease severity regressed to stage II, and she experienced complete relief of stiffness and paresthesia. LV, lymphatic vessel. (Reprinted with permission from Chen et al. [71])

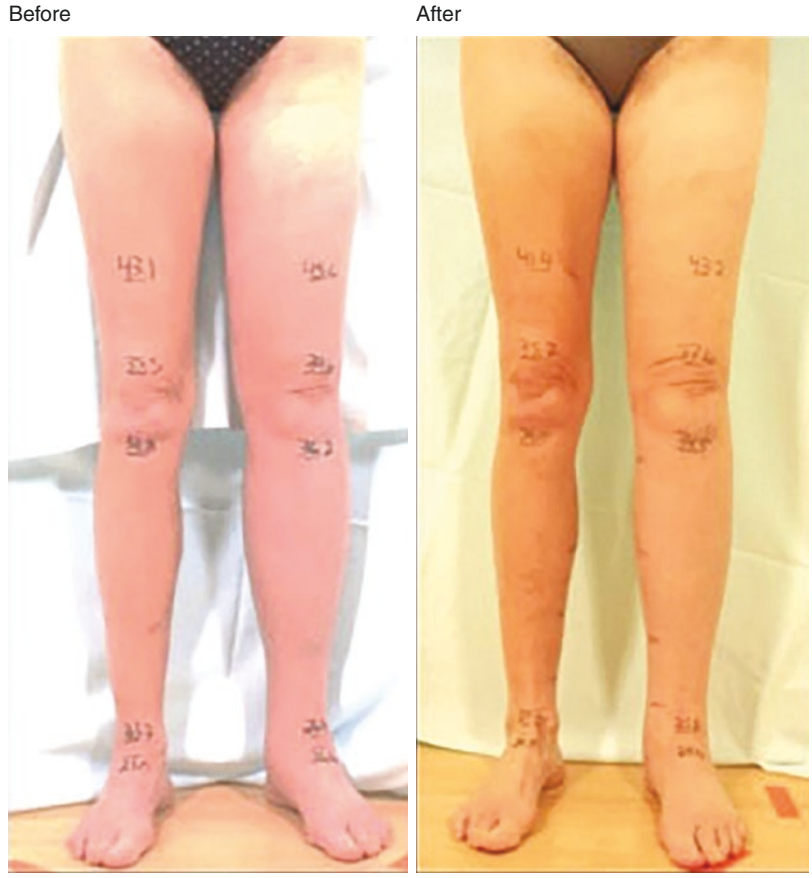

Fig. 34.10 Image showing patient 5 who suffered from secondary Campisi stage IV left leg lymphedema. She had 13 LV drainage pathways created in four "octopi." Her disease severity regressed to stage II, and she experienced complete relief of pain and paresthesia associated with prolonged standing. LV, lymphatic vessel. (Reprinted with permission from Chen et al. [71])

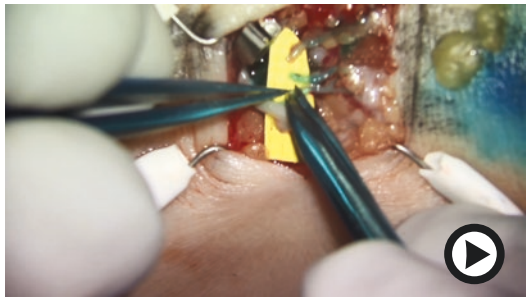

Fig. 34.11 Octopus LVA (▶ https://doi.org/10.1007/000-3vd)

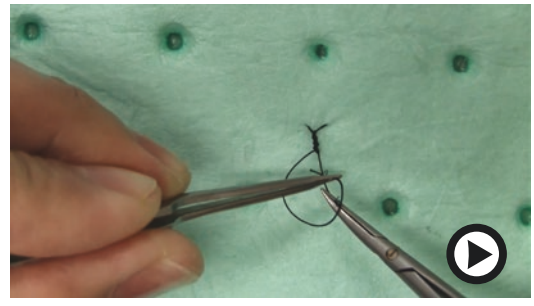

Fig. 34.12 Airborne suturing technique (▶ https://doi.org/10.1007/000-3vc)

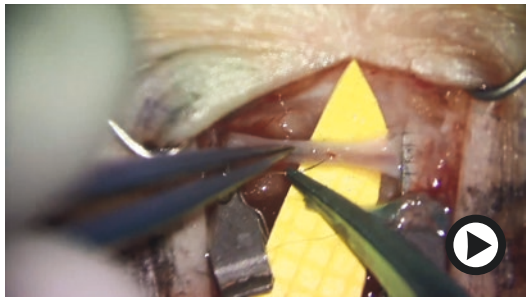

Fig. 34.13 Ripping venotomy for end-to-side LVA (▶ https://doi.org/10.1007/000-3vb)

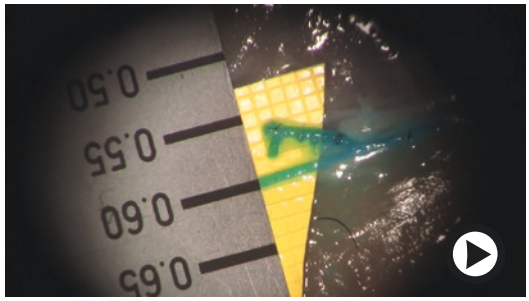

Fig. 34.14 One-stitch needle-guide venotomy for supermicrosurgical end-to-side anastomosis (▶ https://doi.org/10.1007/000-3ve)

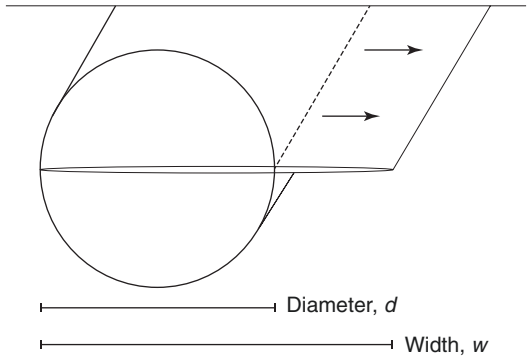

Fig. 34.15 Exposition of the mathematical basis for the measurements used in our technique for end-to-side venotomy. Illustrated is a physiologically inflated end vessel, compared with its flattened intraoperative state, as shown by horizontal arrows. Measurements of the inflated diameter, *d*, and flat width, *w*, are used in a mathematical proof (Expressions 1–3) to show a *venotomy* with a diameter two-thirds the width of the flat end vessel is ideal for the best size coherence between end lumen and side window. (Reprinted with permission from Zeng et al. [112])

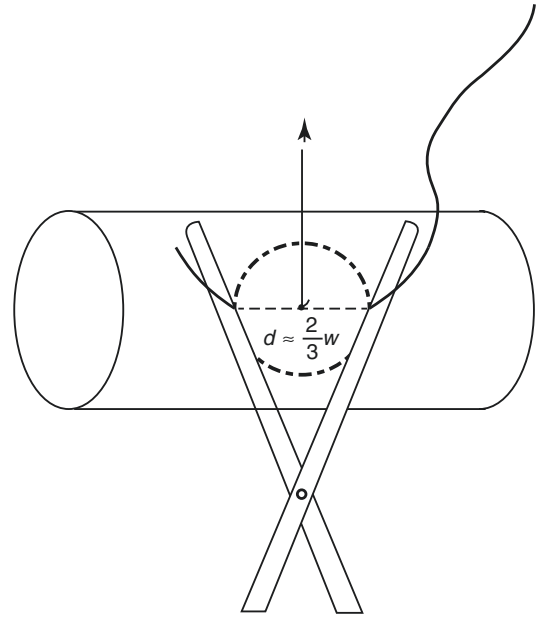

Fig. 34.16 Diagrammatic illustration of the intraoperative moment before the side-vessel window is created. A floating square knot has been tied at the center of the desired *venotomy* position and cut with a long tail. A needle has then been passed with entry and exit bites spaced (2/3)*w* apart, as previously measured compared with the flat end vessel and centered. The center knot has been gently elevated as curved scissors have prepared to cut along the curvature of the needle. This cut will remove all materials and leave a *venotomy* of ideal size for anastomosis with an end vessel of diameter, *d*. (Reprinted with permission from Zeng et al. [112])

Conclusion

While performing with these LVA "tips and tricks," we have consistently found LVA to be effective in treating fluid-predominant extremity lymphedema. We hope that the technical pearls we have provided can be helpful for the other supermicrosurgeons when developing their lymphedema reconstruction with LVA.

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Skin Tumors

35

George W. Elgart

Introduction

The skin, as the avenue to the outside world, is the body's source primary immune response, enabled to keep what is within on the inside and what is without at a distance, and as such is comprised of numerous cells, structures, and tissues. It is one of the rare organs that contains ectodermal, mesodermal, and endodermal rests from embryology. Thus, it should be quite unsurprising that this organ is also the site of tumors of many derivations and types.

While most skin tumors, and nearly all the common ones, are of epidermal derivation, many tissues of the skin all give rise to skin tumors, and both benign and malignant tumors frequently give rise to a need for removal for structural, cosmetic, or medical purposes. For that reason, it is important for the surgeon to be knowledgeable of at least the most common skin tumors, and to be alert to the potential of these skin tumors to give rise to medical issues.

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Benign Skin Tumors

Melanocytic Nevi

While melanocytes represent only about 3% of the cells of the epidermis, their tumors are important and lead to consideration of removal in many cases. As the pigment cell (melanocyte) is the cell from which this tumor is derived, most examples are pigmented clinically, leading at times to significant cosmetic effects, even from flat lesions.

Benign Melanocytic Nevi: Junctional Melanocytic Nevi

In these nevi, the melanocytes are limited to the dermal, epidermal junction. The cells are often deeply pigmented, and the lesions occur most commonly in younger patients. Because of the location on the epidermal junction, the lesions are clinically very striking. As the lesions are benign, excision margins can be very narrow to optimize the cosmetic result.

Dermal Melanocytic Nevi

Dermal melanocytic nevi are benign tumors, often skin colored rather than pigmented, although both appearances are possible. The melanocytic cells

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in these tumors are confined to the dermis, and the surrounding fibrosis and collagen are in part responsible for the clinical appearance. In many instances, a free margin is not needed for these tumors, as the deeper aspects of these tumors generally do not lead to recurrence.

Compound (Both Junctional and Dermal Components) Melanocytic Nevi

Compound melanocytic nevi are of many types and variations. These tumors are the most common melanocytic neoplasms to be removed. While congenital forms are well known and can require removal, acquired melanocytic nevi are the most important, as they may be confused with or emulate features of malignant melanoma. In circumstances where clinical concern or confusion exists, the lesion should be treated with an excisional biopsy. The pathology of these lesions is notable for nevus cell nests that involve both the epidermis and the dermis, which leads to the designation of compound (Fig. 35.1).

Dysplastic Melanocytic Nevi

Dysplastic melanocytic nevi are a special subset of compound melanocytic nevi. Originally appreciated in families who demonstrated high incidence of familial melanoma and had a clinical presentation of multiple pigmented nevi with unusual features, the diagnosis is now much more frequently made in patients with sporadic acquired dysplastic nevi. In this sporadic setting, the lesion is often confusing and may be suspect for melanoma. In that setting, an excisional and complete biopsy is indicated. In view of the historical association with the syndromic presentation associated with melanoma, all of these patients should be carefully examined for other worrisome lesions that could represent veritable malignant melanoma [1].

Blue Nevi

Blue nevi are so named by their clinical appearance. These are generally entirely dermal neoplasms that clinically are often slate-colored or a deep blue, similar to the hue of India-ink tattoos. These nevi demonstrate their blue appearance due to the deep pigmentation and the dermal location of the pigment. Histologically, blue nevi typically demonstrate both considerable pigments in dendritic processes of the tumor cells along with fibrosis in the surrounding dermis (Fig. 35.2). These features also are a representation of why these lesions are so frequently

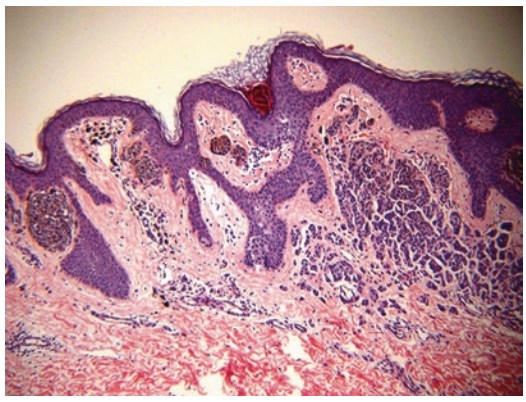


Fig. 35.1 The tumor can be seen both on the base of the epidermis (the junction) and in the dermis itself, the features that lead to the designation of these tumors as "compound" melanocytic nevus

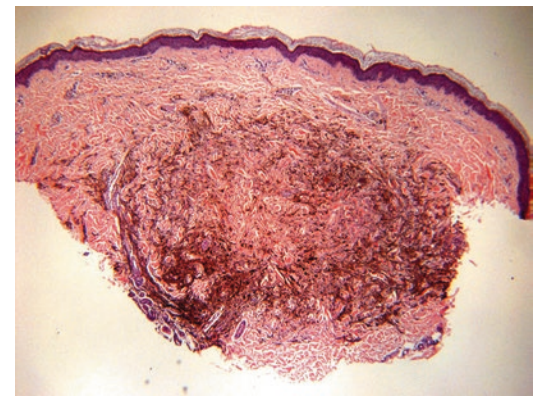


Fig. 35.2 A "blue" nevus has melanocytes and dense pigment within the dermis. This pigment is highly characteristic of a blue nevus and leads to absorption of the longer wavelengths of ambient light so that the reflected light has a more blue color

removed. Many patients dislike the poorly circumscribed and dark irregular pigment seen in these cases. In addition, the typical fibrosis is often bothersome as a firm nodule.

Epidermal Tumors

Seborrheic Keratosis

Seborrheic keratosis is by far the most common skin tumor. Unusual before the age of 25, with increasing age they are much more frequent. They often enlarge when inflamed or irritated, which can lead to an impression that the lesion is growing rapidly. These features may lead to removal of the tumor for pathological evaluation. In general, these lesions have been associated with induction of the gene for fibroblast growth factor receptor 3 (*FGFR3)* and a catalytic subunit of phosphatidylinositol 3-kinase *(PIK3CA)*, as well as other well-known oncogenes. Despite the presence of these cancer-associated mutations, seborrheic keratoses are considered entirely benign. While removal is generally not needed, patients often request removal, and lesions often respond to various destructive methods (cryosurgery, electrosurgery with or without curettage) in addition to scalpel surgery [2].

They are easily recognized with pathology so that any lesion that is concerning for a different skin tumor can be sampled, and with pathology results it can be determined if the lesion is anything more important than this type of tumor. Many lesions demonstrate a lacy basaloid epidermis and a somewhat linear aspect to the base of the lesion. Both clinically and histologically, many lesions are deeply pigmented (Fig. 35.3).

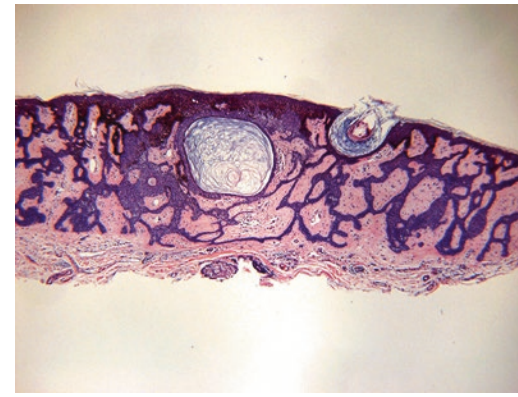


Fig. 35.3 An example of seborrheic keratosis, perhaps the most common benign neoplasm in the middle aged or elderly. The network of epidermis is described as "lace-like." The cystic structure within is called a "pseudohorn cyst." These features are typical in some of the many types of seborrheic keratoses

Epidermal Cysts

These very common lesions are generally associated with follicular or perifollicular damage, which leads to entrapment of a small fragment of skin which grows. As the skin is renewed and replenished, dead skin cells have no place to escape and accumulate in a cystic growth. These collections have a cheesy appearance and may be seen to be somewhat liquid. The cyst should be entirely removed, as any residual keratin is highly immunogenic and leads to pus-filled collections usually interpreted as infection, although most are just a reaction to the inspissated keratin.

Follicular Tumors

Trichoepithelioma

While pathologists often differentiate follicular tumors into many subtypes, they are benign lesions that may occur as individual lesions or as multiple lesions in syndromes. Individual lesions are generally skin-colored tumors that grow slowly over months to years. Excision of the sites of lesions may occur for pathological evaluation. The tumor is otherwise not specifically clinically concerning. These lesions often demonstrate a more dramatic stroma than that seen in basal cell carcinoma, and lesions tend to cleft within the dermis, rather than at the epidermal–dermal interface (Fig. 35.4).

Additional criteria exist, and in challenging cases, immunopathology stains may help to differentiate trichoepithelioma from basal cell carcinoma [3].

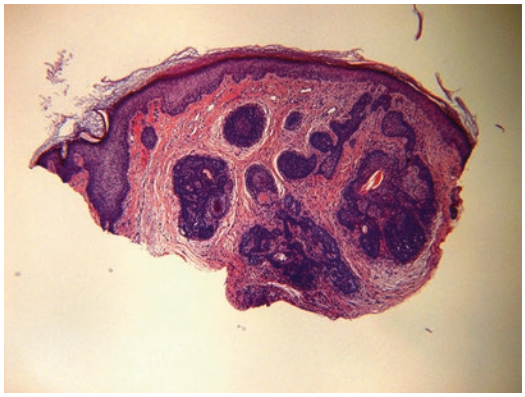


Fig. 35.4 This lesion is a trichoepithelioma. While benign, it shares many characteristics of a basal cell carcinoma, and reliable differentiation likely requires an expert opinion. The lack of direct connection to the epidermis and the very cellular stroma favor the benign diagnosis

Sweat Gland Tumors

There are many benign sweat gland tumors, but we will focus on these two types, as they represent some of the most common examples. All of the tumors, when individual, are treated with simple excision or benign indifference as indicated clinically.

Syringoma

These are probably the most common eccrine sweat gland tumors. They are manifest as small, minimally elevated clinical papules which are firm and may grow in small grouped collections. They are generally entirely skin colored and are often not treated. If needed, a small excision of the site is generally adequate.

Hidradenoma

This tumor, by contrast with the syringoma noted above, is almost always solitary and, when viewed histologically, may demonstrate some worrisome features (necrosis, high mitotic rate, etc.) despite its benign nature. Simple excision is adequate therapy.

Dermal Tumors

Dermatofibroma

These very common tumors are generally notable clinically by a firm nature to palpation, flattish, pigmented surface, and tendency to pucker the skin (called Fitzpatrick sign) when manipulated. They are easily ignored, as their clinical appearance is mainly fibroblastic, and removal can easily lead to a scar more vexing than the original lesion.

Lipoma

These very common lesions are comprised entirely of subcutaneous fat. They are often bothersome to patients and may be excised with open surgery or with liposuction in appropriate cases. Most lesions are easily visualized on pathology, and while bland fat is present in essentially all cases, some of the more tender lesions frequently demonstrate features of an angiolipoma and include numerous blood vessels in the dermal process (Figs. 35.5, 35.6, 35.7, and 35.8).

Malignant Skin Tumors

Melanocytic Malignant Tumors

Melanoma

Malignant melanoma is the most serious of the common skin malignancies. Despite advances in clinical evaluation using dermoscopy and other methods, a recent study by the Centers for Disease Control and Prevention (CDC) indicated an overall mortality rate from melanoma of 2.5 per 100,000 population. This number was much higher in males, and in particular white males, in that study. Thus, malignant melanoma continues to be appreciated as an important and serious cause of skin cancer death. Because early

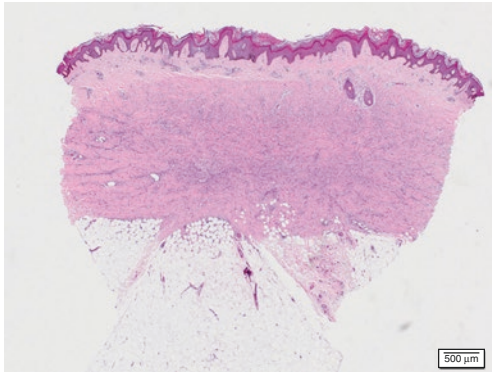
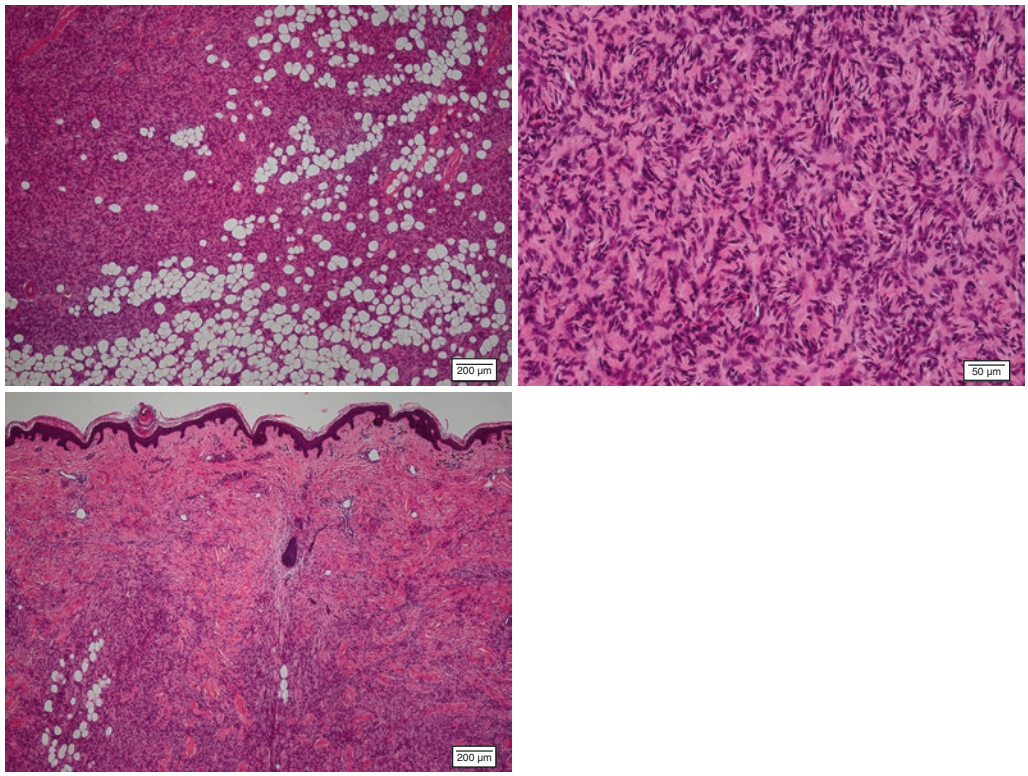


Fig. 35.5 A dermatofibroma. These benign tumors are often best appreciated at scanning magnification. Note the thickened epidermis with a bumpy (papillomatous) surface and downgrowth of the rete. This induction phenomenon is typical. Also, these lesions often appear quite "square" with vertical edges in a punch biopsy. The fibrotic nature of the tumor leads to this feature

detection and surgery can avoid nearly all deaths, it is important to emphasize screening and early therapy of these patients.

The most common presentation of malignant melanoma is on the trunk or extremities. These lesions are characteristically very irregular and often demonstrate rapid growth. An irregular, bleeding, or multicolored change in an existing melanocytic neoplasm is very concerning for malignant melanoma. Histopathologically, lesions are generally grouped into four categories: superficial spreading melanoma, nodular melanoma, acral melanoma, and lentigo maligna (sun-exposed) variants.

While unusual lesions may lack clinically worrisome features, many melanoma cases are straightforward with regard to the clinical presentation. A growing lesion may demonstrate the



Figs. 35.6, 35.7, and 35.8 Dermatofibrosarcoma protuberans shows a more disorganized proliferative appearance and less epidermal thickening. The presence of many adipocytes (fat cells) is typical as the process appears to flow through the entire dermis

"*ABCDs*" of melanoma including *A*symmetry, irregular *B*orders, a very dark or multiple *C*olors, and generally demonstrate a *D*iameter greater than 6 mm, the width of a pencil eraser. Many of these features can be seen in the examples in Figs. 35.9, 35.10, and 35.11.

Each has some variation in clinical outcome and warrant special consideration. However, it is important to note that patients with malignant melanoma all share significant risk and all are best treated surgically. Recently, immune checkpoint inhibitors and targeted therapies have been added to the therapeutic armamentarium for advanced disease.

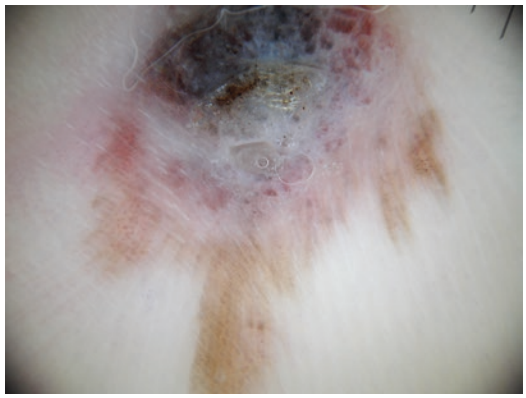


Fig. 35.9 On close clinical inspection, there are shades of many colors: brown, tan, black, pink, and whitish areas are seen in this lesion. When present, these "multicolor" lesions are highly suspicious for malignant melanoma

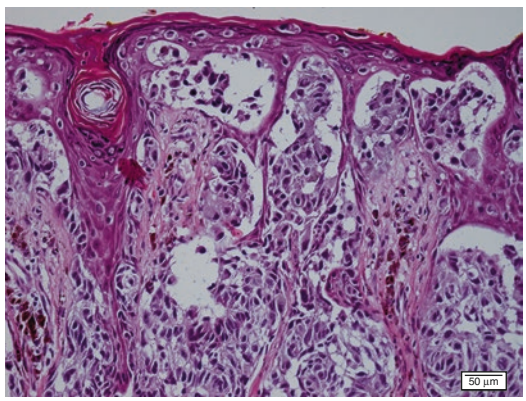


Fig. 35.10 Example of malignant melanoma. While benign melanocytic processes often demonstrate the pigment cells only at the dermal–epidermal junction, usual examples of malignant melanoma show the pigment cells at all epidermal levels. They extend in a fashion similar to that seen in Paget's disease and are thus dubbed "pagetoid melanocytes." While not universal in cases of melanoma, this finding is rather suggestive of melanoma in itself, and in conjunction with the proper clinical and histologic features is an important diagnostic finding

Melanoma pathology is complex, and cases should be evaluated by an experienced expert. Any pathology report on a lesion of melanoma should at minimum include TNM staging of the lesion and measurement of tumor depth. While recent research suggests that the story may be more complex, a measurement of tumor depth does correlate with recurrence and mortality in primary lesions of malignant melanoma. In addition, guidelines for surgical care of these lesions depend on the measured depth of invasion, sometimes called "Breslow depth" to honor the pathologist who first published the association of depth with clinical outcome. In general, *in situ* lesions (T stage 0) can be treated with a narrow margin of 0.5 cm, while lesions less than a millimeter in measured depth (T stage I) require a 1 cm margin. Deeper lesions generally are treated with a 2 cm margin surgically [4].

The question of sentinel node examination is complex. While many centers routinely perform these studies on lesions between 1 and 4 mm in depth, there has been no controlled study that clearly indicates benefit from these studies. However, the availability of effective therapeutic

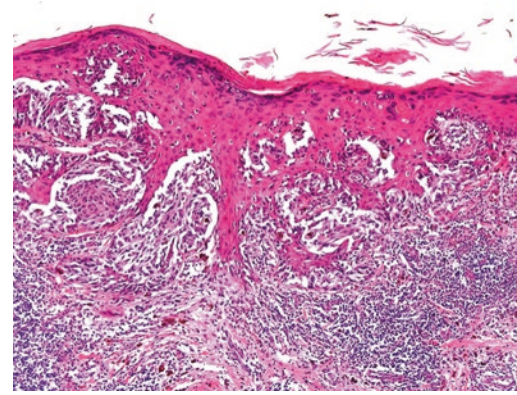


Fig. 35.11 The prominent clefting of the melanocytes from the epidermis suggests a highly proliferative lesion, either an early malignant melanoma or perhaps a severely dysplastic melanocytic nevus. In either event, removal of the entire lesion is paramount

drugs is limited to recent years, and time will tell if the information from sentinel node examination proves its value in advancing early therapy of patients with advanced disease. At this point we generally do offer this technique, and it appears helpful in determining risk for some patients.

Epidermal Tumors

Actinic Keratosis

Actinic keratoses are among the most common skin tumors in sun-exposed sites. Patients with a fair complexion, particularly Fitzpatrick types I and II, are particularly prone to these lesions (Fig. 35.12). Some evidence suggests that lesions occasionally progress to squamous cell carcinoma, although actinic keratoses, without doubt, are a marker of sun-associated skin cancer risk. Patients frequently request treatment of these lesions, which may be treated by a variety of methods.

In patients with limited extent of clinical keratoses, simple removal by epidermal shaving is often adequate. As involvement expands, other treatments including cryotherapy or electrosurgery are often preferred. These tumors are also amenable to treatment with chemical therapies including topical 5-fluorouracil, ingenol mebutate, diclofenac gel, or imiquimod in cream formulations; all have efficacy and are reasonable choices in extensive involvement.

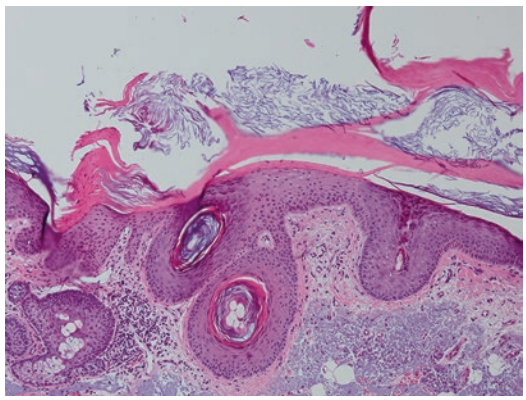


Fig. 35.12 Typical example of an actinic keratosis which shows alternating hyper- and parakeratosis, known as the "flag sign" for the presence of red and white stripes like an American flag. The blue color of the dermis is caused by sun damage and is referred to as "elastosis." The atypia present is not through the full thickness of the lesion, which is why these lesions may be amenable to therapy without any surgery (image below)

Field treatment with photodynamic therapy is also widely used, although results are variable [5]. In all cases, topical treatments do lead to some discomfort and are tolerated variably by patients. Any individual with actinic keratoses is a candidate for close follow-up for more serious skin tumors and for sunscreen to avoid future involvement.

Squamous Cell Carcinoma *In Situ*

Squamous cell carcinoma limited to the epidermis is a relatively common tumor. There are two main clinical variants. The flat lesion is remarkably well demarcated and easily observed on the skin (called "Bowen's disease"). As the macular lesion of in situ carcinoma, it can be recognized by the surface changes. A reddish or darker color is often observed, and the lesion margins are directly observed clinically. Other types of *in situ* lesions are associated with elevation of the skin lesion, sometimes similar to an irritated keratosis. Because in each case the lesion is limited to the epidermal surface, it can often be removed with quite narrow margins.

The pathology of these lesions characteristically shows very dramatic nuclear pleomorphism. Frequent mitotic figures are seen, and the lesions are generally seen to demonstrate parakeratosis in a confluent array above the epidermis (Fig. 35.13). This feature accounts in part for the tendency of these lesions to appear scaly on clinical examination. Some of these lesions are pigmented and are clinically confused with melanoma or other pigmented neoplasms (Figs. 35.14, and 35.15).

Squamous Cell Carcinoma

Invasive squamous cell carcinoma has several variants. Most common is a cup-shaped superficial lesion which is similar or identical to keratoacanthoma (Fig. 35.16). These relatively well-differentiated lesions, often on extremities, develop rapidly and then become stable. Less

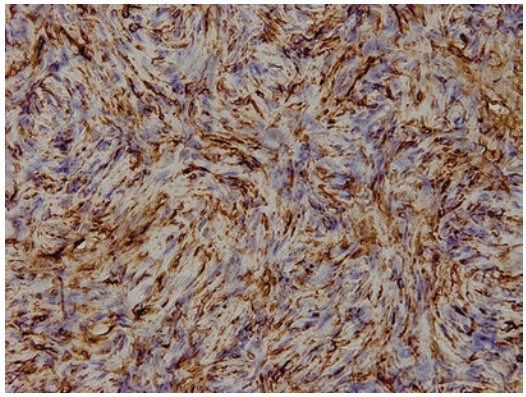


Fig. 35.13 The brown staining represents staining for CD34, a consistent and common feature is dermatofibrosarcoma protuberans

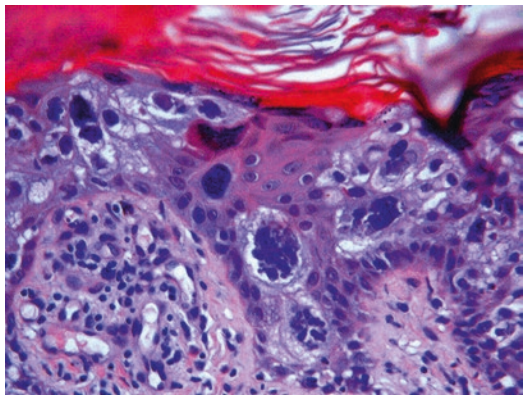


Fig. 35.14 Large or bizarre nuclei and a "windblown" pattern of the nuclei are expected in squamous cell carcinoma *in situ*, including Bowen's disease

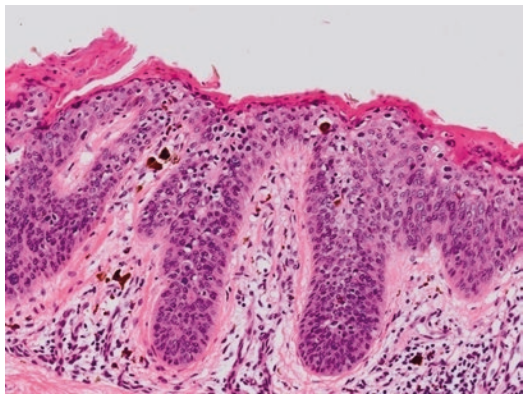


Fig. 35.15 Some examples of *in situ* squamous cell carcinoma may be pigmented, but most demonstrate the presence of somewhat uniform, confluent parakeratosis overlying the epidermis

common invasive variants include more extensive involvement of the deeper dermis. They may erode clinically and many have irregular borders (Fig. 35.17). They may be less well differentiated or frankly atypical, and there is some thought that pathological atypia portends a worse clinical outcome. There are many variants that are so atypical that immunostaining is required to assure the diagnosis. Such lesions are reliably positive with keratin staining such as keratins 1 and 10, and often also stain strongly with P63. Such lesions should be adequately excised and closely followed for spread, as metastatic lesions are very dangerous. Only in 2018 was a medication

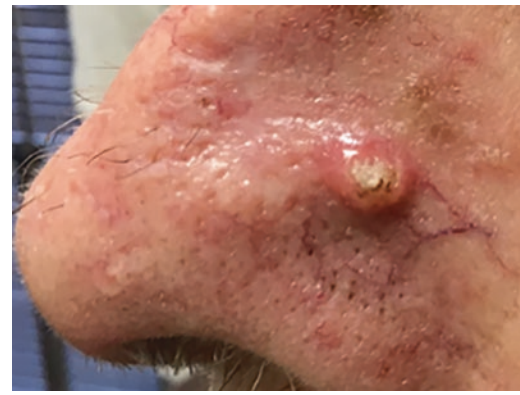


Fig. 35.16 This type of cutaneous squamous cell carcinoma is often relatively well differentiated and may do quite well with simple excision. They are typically seen on the head or extremities and can be simply excised

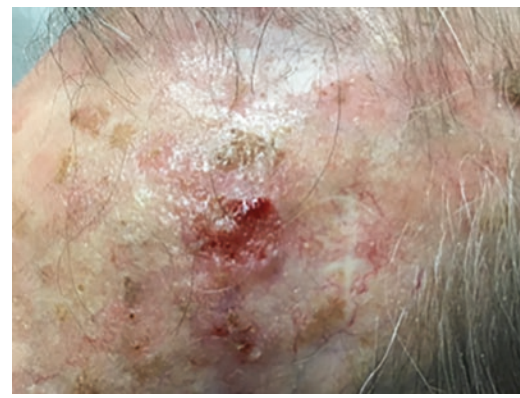


Fig. 35.17 Cases such as this are less circumscribed, and surgical margins are generally larger. The lesion may be quite difficult to interpret histologically, and use of immunostaining to confirm the diagnosis is common

(cetuximab) finally approved by the U.S. Food and Drug Administration (FDA) for use in metastatic cutaneous squamous cell carcinoma. However, this therapy is far from sufficient, and most patients recur, so surgical excision of early lesions is both the preferred and most successful method for cutaneous squamous cell carcinomas.

Adnexal Tumors

Basal Cell Carcinoma

By far the most common malignant skin tumor, basal cell carcinoma is mainly seen in sun-damaged skin and is most often seen in patients older than 45 years. There are multiple forms, and histological subtype impacts excision margins and risk of recurrence [6].

The most common type is the nodular variant, which clinically represents the typical "rodent ulcer" lesion with a heaped-up, somewhat translucent, border with central erosion (Fig. 35.18). These lesions are very commonly seen on the face, extremities, or upper back.

The most common clinical subtype would be the nodular or nodular/ulcerative variant. Pathology shows irregular islands, which frequently "cleft" from the surrounding dermis when the specimen is processed (Figs. 35.19 and 35.20).

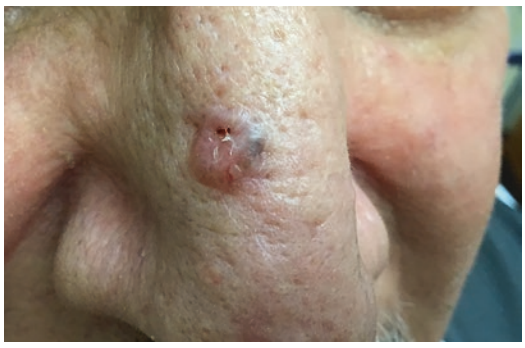


Fig. 35.18 The central erosion of this elevated pink papule is well seen in this clinical example. As photo-exposed areas of the skin are most involved, it is unsurprising that surgical planning and closure are critical as there are generally extensive cosmetic implications in many cases

Less common are sclerosing or morpheaform variants, which show distinctive fibrosis of the dermis and demonstrate the tendency for tumor islands to progress along the adnexal structures or nerves of the region (Fig. 35.21). These lesions may be amenable to the Mohs surgical technique, with active evaluation of surgical margins by frozen section. Many dermatologists and a few plastic surgeons rely on this technique for this somewhat common variant, and indeed for many examples of basal cell carcinoma occurring on

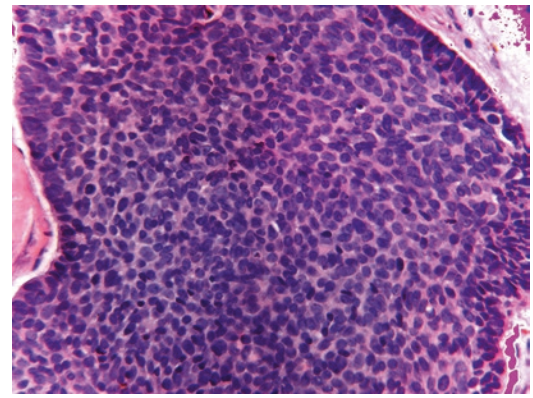


Fig. 35.19 Note how some of the basal cell carcinoma islands separate or "cleft" from the surrounding dermal tissue. This feature may be due to production of type IV collagenase by tumors and is highly characteristic of basal cell carcinoma

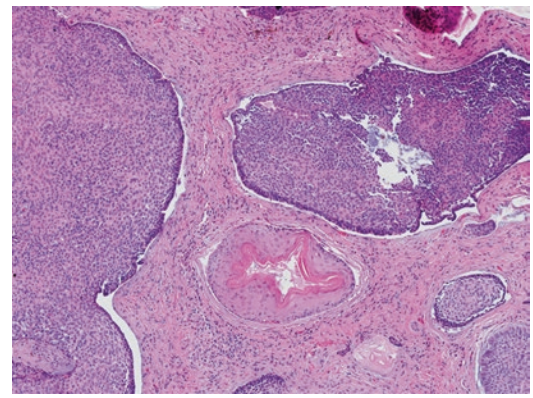


Fig. 35.20 Basal cell carcinoma clearly clefts from the surrounding dermis, and the peripheral nuclei are aligned in a coordinated pattern called a "palisade." The presence of this feature helps to distinguish basal cell carcinoma from other "small blue cell tumors" like Merkel cell carcinoma

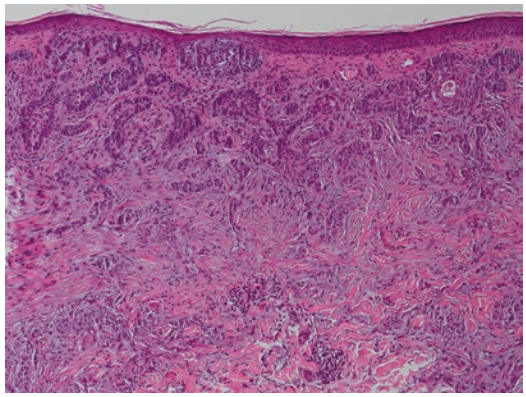


Fig. 35.21 Morpheaform basal cell carcinoma differs from other variants by the presence of many thin and narrow islands of basal cell carcinoma extending within a very fibrotic stroma

the face or other cosmetically sensitive sites. Because morpheaform basal cell carcinomas are difficult to remove in their entirety, even cases that are not treated with the Mohs technique may benefit from more extensive or exacting surgical treatment, and evaluation of surgical margins is always indicated.

There are a range of additional subtypes including adenoid, superficial, and metatypical variants. For the most part, these different variants have similar outcomes to more routine types, and complete excision remains the suggested therapy.

Basal cell carcinoma lesions are very rare on the palms or soles, and lesions in those sites raise consideration of the syndromic variant named Gorlin syndrome, also called nevoid basal cell carcinoma syndrome. The abnormality observed in this variant is also commonly seen in acquired tumors. The most important associations with the syndromic variant are the tendency to occur early, be associated with potential for the development of neuroblastoma, and extreme sensitivity to radiation, which can lead to remarkable numbers of lesions in the radiation field. These patients are also notable for a characteristic facial appearance and the presence of bifid ribs, frontal bossing, and calcification of the falx cerebri on radiographic evaluation. In addition, numerous skin findings including pitting of the palmar skin are noted in many cases.

Dermatofibrosarcoma Protuberans

This very interesting tumor is a proliferation of fibroblasts in the dermis that can take on a very large size when not adequately treated. Dermatofibrosarcoma protuberans is often called by the initials DFSP for brevity. The "protuberans" portion of the name can be a misnomer, as this lesion has a somewhat variable clinical appearance, and while there are lesions with an exophytic profile, many are quite flat, or even appear atrophic. They vary from skin colored to pink, and a few variants, called Bednar tumor, are very dark due to the content of very copious melanin pigment. It is common to see these tumors on the trunk, and it is highly advisable to obtain surgical margins. Many tumors extend deeply into the surrounding tissue and involve the subcutis, so routine margins may be inadequate since a centimeter or more around the tissue may excise the process laterally while allowing extension into the dermis. Fortunately, these lesions have a consistent immunohistological imprint, and among other markers most stain very deeply with CD34, a cell surface sialomucin associated with T-cell function, in addition to its marked staining on a number of soft tissue tumors including DFSP [7].

Conclusion

Beyond the tumors covered in this chapter, there are many less-frequent types that have been omitted for consideration of space. The general strategy remains the same. For benign lesions, removal of the lesion is warranted if the patient has bothersome symptoms. Malignancy is an indication for removal, and most skin tumors are readily amenable to excision. A competent pathologist reviewing the specimen with interest and experience in skin tumors is certainly preferred, and if unavailable locally, frequent authoritative consultation is advised to assure accuracy and optimize patient outcomes.

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Part V

Hand and Upper Extremity

Fractures and Dislocations

36

Subhas Gupta and Amir Arsalan

Fractures

To serve as a reference, we have created a treatment algorithm for phalangeal and metacarpal fractures. Refer to the figures noted as you follow the text.

Phalangeal (Fig. 36.1)

Distal Phalanx

Tuft fractures usually occur secondary to crush mechanism and are typically associated with soft tissue injury. Subungual hematomas that involve >50% of the nail plate are often suggestive of nailbed injury and should warrant nailbed exploration, whereas those <50% can be managed conservatively with or without trephination [1].

Shaft fractures of the distal phalanx are considered stable due to the support provided by the nail plate dorsally and fibrous septae volarly. Although these structures serve as an internal splint, one may also use an external splint. Percutaneous pinning is another option for displaced shaft fractures [2].

Fractures at the base of the distal phalanx should trigger concern for tendon injury. An avulsion fracture at the dorsal base may represent injury to the extensor tendon insertion. This condition is known as "mallet finger," and patients will often present with extensor lag. Conservative treatment consists of continuous extension splinting for at least 8 weeks. Operative management, such as extension block pinning or suture button, may also be considered [3].

Middle and Proximal Phalanx

Non-articular fractures of the middle and proximal phalanges must be evaluated for stability. Nondisplaced and stable fractures can be managed conservatively with splinting for 3 weeks. Malrotation, angulation, or comminution are indications for operative management—open reduction internal fixation (ORIF) versus closed reduction percutaneous pinning (CRPP). Unstable fractures such as oblique, spiral, or transverse are unlikely to maintain reduction with closed treatment and have the potential for rotation or angulation. These are also managed operatively.

Non-articular base fractures usually present with apex volar angulation due to the vector of pull created by interossei attachments. Any

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_36) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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https://doi.org/10.1007/978-3-030-78028-9_36

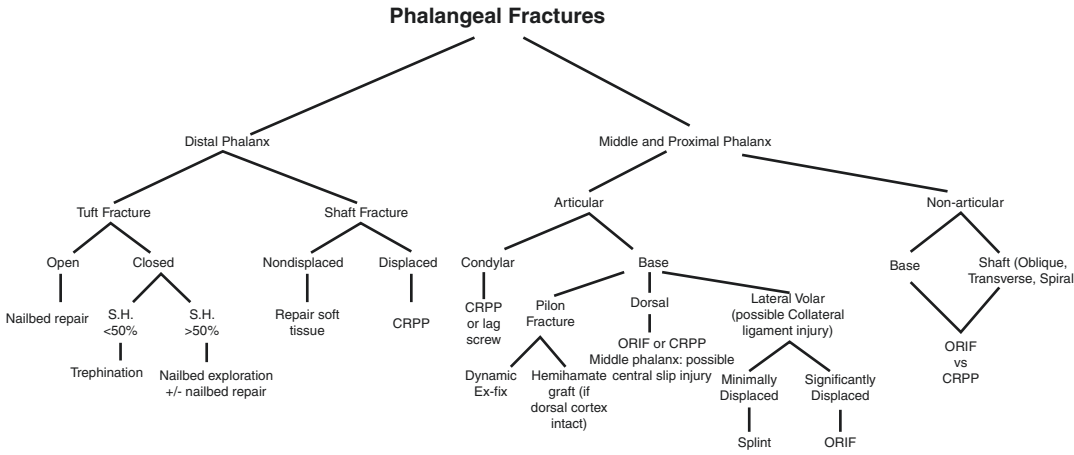

Fig. 36.1 Phalangeal fractures. SH subungual hematoma, CRPP closed reduction percutaneous pinning, ORIF open reduction internal fixation

angulation greater than 25 degrees in the adult patient is unacceptable, as this leads to a significant loss of motion and reduced function. Closed reduction with immobilization is recommended if the reduction remains stable; otherwise, operative interventions will be necessary. Chronic injuries require osteotomies to correct residual angulation [1].

Articular fractures are unlikely to do well with conservative treatment, as the likelihood of developing stiffness is high. The primary goal is to restore the gliding surface of the joint. Condylar fractures can be addressed with CRPP or ORIF with lag screw technique. Percutaneous pinning with single K-wire is often inadequate, and multiple treatments may be necessary.

Pilon fractures can result from axial load injuries. In the acute period, they can be managed with dynamic external fixation. The advantage of this technique is the potential for early motion. If the dorsal cortex is intact, a hemihamate osteoarticular graft is another option. The main disadvantages are additional donor site morbidity and relative difficulty in application [4].

Dorsal base fractures of the middle phalanx present unique challenges related to injury to the central tendon insertion. The tendon insertion site must be restored in addition to fracture stabilization. Displacement greater than 2 mm of the avulsed fragment is poorly tolerated and can lead to extensor lag and eventually boutonniere deformity [1]. As such, it is crucial to obtain accurate reduction with either ORIF or CRPP.

Metacarpal (Fig. 36.2)

Head

Although metacarpal head fractures are rare, they usually have intraarticular involvement. In addition to a standard three-view X-ray, a special Brewerton view will provide a much more detailed look at the articular contour. Careful evaluation of the soft tissue should always be performed, as any lacerations or wounds overlying the dorsal metacarpophalangeal (MP) joint is a "fight bite" until proven otherwise. These wounds are presumed to have oral contamination and will require thorough irrigation and debridement [5].

Comminution presents technical challenges during surgery. If operative management is not feasible, then the fracture can be immobilized with the MP joint at 70 degrees. Prosthetic arthroplasty is an option in the setting of bone loss; however, this should not be performed for the index finger, given high rates of implant failure from shear stress during pinch [1]. All patients should be counseled about stiffness and the potential need for secondary operations such as tenolysis and capsulotomy.

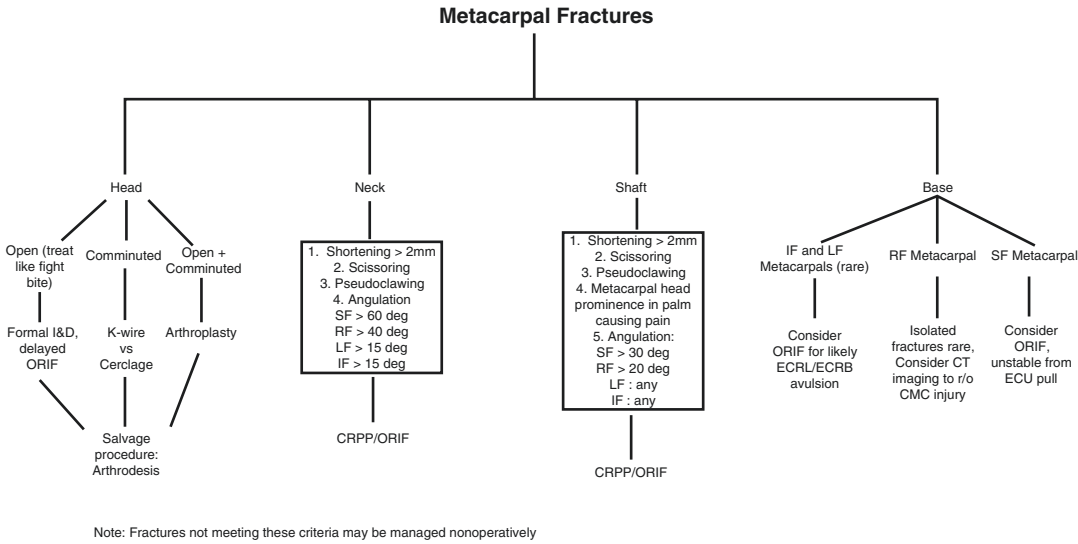

Fig. 36.2 Metacarpal fractures. CRPP closed reduction percutaneous pinning, ORIF open reduction internal fixation. Note: Fractures not meeting these criteria may be managed nonoperatively

Neck

Metacarpal neck fractures often present with apex dorsal angulation, given the relationship of the intrinsic muscles to the MP joint. Optimal management of these fractures remains controversial, but important factors to consider include shortening, rotational deformity, and the degree of angulation [6]. The small and ring fingers have relatively mobile carpometacarpal (CMC) joints compared to the index and long, and therefore are more forgiving for any residual angulation. The small and ring fingers can tolerate 50–60 degrees and 30–40 degrees, respectively, whereas anything greater than 15 degrees of angulation for the index and long fingers is generally unacceptable [7]. Compensatory MP joint hyperextension and proximal interphalangeal (PIP) joint flexion during attempted extension, also known as pseudo-clawing, is another indication for operative management [8].

Shaft

Similar to its phalangeal counterpart, metacarpal shaft fractures can be characterized as transverse, oblique/spiral, or comminuted. Management is also similar. Transverse and comminuted fractures result from axial loading. Oblique and spiral fractures should be carefully examined for malrotation. Angulation is not as well tolerated in the metacarpal shaft compared to the head. The small and ring fingers can tolerate 30–40 degrees and 20–30 degrees, respectively. Anything greater than 10 degrees for index and long fingers is unacceptable. Fixation options include K-wire, plates and screws, or lag screws alone [9].

Base

Isolated fractures of the index and long finger metacarpal base are rare, as the corresponding CMC joints are relatively immobile. These fractures can be associated with extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) injury [10]. Nonoperative management is reasonable; however, if injured, ECRL and ECRB insertion should be restored. It is our preference to use a bone anchor in this situation.

Thumb

Because of its relatively mobile CMC joint, extra-articular thumb fractures are forgiving.

Thumb phalangeal fracture management follows similar principles used for finger phalangeal fractures. Special considerations include fracture–dislocations of the ulnar base of the proximal phalanx, which typically represents an ulnar collateral ligament (UCL) injury. This is referred to as a skier's thumb for acute injuries or gamekeeper's thumb when chronic. Treatment consists of ORIF and immobilization for 4 weeks. A Stener lesion can occur if the adductor pollicis muscle becomes interposed between the UCL and its insertion site. The patient must understand that UCL will never heal with conservative measures alone if a Stener lesion is present [11].

Extraarticular thumb metacarpal fractures typically occur at the base and present with apex dorsal angulation. Although closed reduction can be achieved with longitudinal traction and volarly directed pressure, these fractures are inherently unstable due to the deforming forces of the various tendinous insertions. Thus, ORIF with immobilization for 4 weeks is recommended. Angulation of less than 30 degrees is acceptable due to the mobile CMC joint.

Intraarticular thumb metacarpal base fractures present as either a Bennett fracture (without comminution) or a Rolando fracture (with comminution) [12]. ORIF with immobilization for 4 weeks is recommended for both, given the unstable nature of these fractures. We prefer a Wagner incision for our approach. The reduction maneuver consists of longitudinal traction, firm ulnarly directed pressure at the thumb metacarpal base, and mild pronation.

Dislocations

Finger DIP Joint

The distal interphalangeal (DIP) joint has a fairly stable construct, and therefore, dislocations affecting this joint are uncommon (Fig. 36.3). The dislocations are usually dorsal or lateral. Reduction can be achieved with longitudinal traction with pressure in the opposite direction of dislocation, for example, volarly directed pressure for dorsal dislocations. If unstable post-reduction, an extension-blocking splint can be considered [13].

Finger PIP Joint

Proximal interphalangeal (PIP) joint dislocations represent the most common ligamentous injury of the hand. A dorsal dislocation results from hyperextension combined with an axially directed force. Usually, there is injury to both the volar plate and collateral ligaments. Longitudinal traction must be avoided with dorsal PIP joint dislocation as the condyles can become trapped by the collateral ligaments with volar plate interposition in the joint, resulting in an irreducible dislocation [4]. The appropriate maneuver is to hook the middle phalanx over the PIP joint. If the reduction is unstable, an extension-blocking splint should be used. Operative management is indicated if the dislocation is irreducible or if the extension-blocking splint requires more than 30 degrees of flexion.

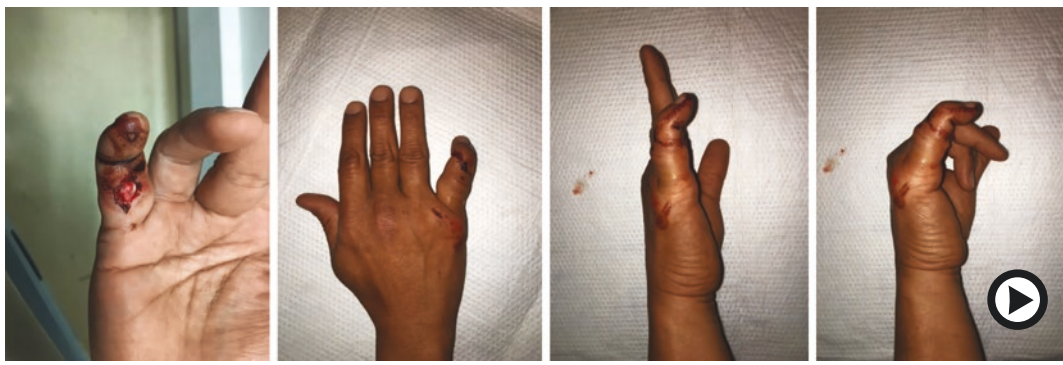

Fig. 36.3 A DIP joint dislocation (▶ https://doi.org/10.1007/000-3vf)

Volar dislocation of the PIP joint is uncommon but can occur due to a rotatory or non-rotatory mechanism. With the rotatory mechanism, injury has occurred to one of the collateral ligaments, and likely the central slip as well. Longitudinal traction should be avoided during reduction because the condyles can become trapped by the lateral bands. The MP and PIP joints are flexed to relax the lateral bands, followed by careful rotatory motion to free the lateral bands. Post-reduction, the finger is splinted in extension for 4–6 weeks.

Volar dislocations without a rotatory mechanism have associated central slip disruption with a likely soft tissue interposition. These injuries may require open reduction [1].

Finger MP Joint

The finger metacarpophalangeal (MP) joint will dislocate in either the dorsal or ulnar direction. This pattern of injury results from hyperextension. Reduction is similar to the principles used for PIP joints. Traction should be avoided, as this may pull the volar plate into the joint, thus converting a reducible injury into an irreducible one [14]. The maneuver consists of hooking the proximal phalanx over the metacarpal head by applying constant volarly and distally directed pressure. Wrist flexion may be helpful with relaxing the flexor tendons [1]. Irreducible fractures will require ORIF and splint immobilization for at least 4 weeks.

Conclusion

Thorough understanding of the anatomy and mechanics of the hand is critical in achieving satisfactory patient outcomes. Each component of the hand requires an individualized approach. The algorithms in this chapter will provide guidance and an understanding of the various treatment pathways for fractures and dislocations of the hand.

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Tendon Injuries

37

Robert M. Teixeira, Paul A. Sibley, and Robert X. Murphy Jr.

Tendon Anatomy, Blood Supply, and Healing

Tendons are units of connective tissue which transmit forces from muscles to bones. The basic unit of the tendon is collagen, which is secreted by tenocytes—fibroblast-like cells. The secreted collagen polypeptides self-aggregate in the extracellular matrix (ECM) into triple helices, which in turn cross-link with adjacent helices and form collagen fibrils. The majority of this collagen is type I, whereas type III collagen is the major form of collagen in the endotenon, epitenon, and the early tendon scar. The extracellular matrix is composed of proteins such as elastin and proteoglycans. A tendon is about 55% water by weight, most of which is found in the ECM [1]. Water in the ECM is theorized to reduce friction and improve tendon gliding.

Collagen fibrils are bundled together to form collagen fibers. The collagen fibers are organized in parallel to the tendon's longitudinal axis. They are surrounded by tenocytes, which secrete collagen and maintain the ECM. The collagen fibers themselves are grouped into fascicles, which are encased by endotenon. Endotenon contains the vasculature, lymphatics, and nerves. Epitenon encases the groups of fascicles, and it also contains vasculature, lymphatics, and nerves. In the fingers, flexor tendons are surrounded by sheaths. Tendons not surrounded by sheaths are instead surrounded by paratenon. This is a loose connective tissue that contains blood vessels that vascularize the epitenon and epitenon.

The tendon sheath secretes synovial fluid, which reduces friction during tendon excursion. The sheaths have thickened areas known as pulleys. There are five annular (A1–A5) and three cruciate (C1–C3) pulleys (Fig. 37.1). They improve mechanical efficiency by holding the tendons close to the bone throughout the arc of motion of the phalanx. The A2 and A4 pulleys are the most important to prevent bowstringing; however, several studies [2–4] have demonstrated that half of A2 and all of A4 can be vented without untoward consequences.

The extensor tendons at the level of the wrist course through one of six fibro-osseous tunnels, for example, dorsal compartments. Their shape flattens out as they course distally. On the dorsum

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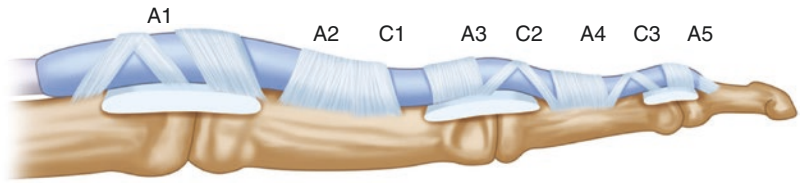

Fig. 37.1 The flexor pulley system. Note the five annular pulleys and three cruciate pulleys. Pulleys A2 and A4 are most crucial to prevent bowstringing

of the hand, there exist interconnections between extensor digitorum communis tendons named juncturae tendinum. At the metacarpal phalangeal (MCP) joint, the extensor tendon is centralized by the sagittal band as it continues onto the finger. The extensor tendon, radial and ulnar slips of interossei, and lumbrical tendons all contribute to form the extensor hood mechanism (Fig. 37.2a, b).

Tendons receive their vascular supply via many sources. The myotendinous junction and insertion on bone junction via Sharpey's fibers provide vascularity of the end segments. Vincula, fibrovascular structures within a tendon sheath of a digit, provide dorsally based blood vessels to the flexor tendons. Synovial fluid provides a medium for nutrients to diffuse through the tendon sheath. Endotenon, paratenon, and epitenon all contain vasculature that provides nutrients to the tendon.

Tendons heal in a similar manner to any wound. They undergo three stages in their repair process: inflammatory, proliferative, and remodeling [5]. In the inflammatory stage, a hematoma is formed due to disruption of the blood vessels. Various chemotactic factors are released, promoting local vasodilation and inflammatory cell migration. The wound bed is cleared of debris, clot, and foreign bodies via phagocytosis. Local angiogenic factors are released, and fibroblasts are recruited to synthesize ECM. During the proliferative stage, fibroblasts proliferate to synthesize ECM. The various components are deposited in disorganized fashion. The ECM at this point is comprised of mostly type III collagen. The remodeling stage begins 6–8 weeks after injury. The ECM is reorganized and type I collagen is deposited longitudinally to the long axis of the tendon. The repaired tendon increases in tensile strength but never reaches pre-injury strength.

Motion is critical to tendon healing [6]. A lack of mechanical stimulus has been shown to promote tendon adhesions. It has been shown to improve scar strength and improve gliding. A multitude of studies has proven that early range-of-motion therapy protocols have improved results after tendon repair.

Evaluation of Tendon Injury

When evaluating patients with suspected tendon injuries, a thorough history and physical is important. Age, handedness, occupation, mechanism of injury, time since injury, previous injuries or upper extremity surgeries, hand hobbies, history of tobacco or nicotine use, and pertinent medical history should be assessed. Assess the wound for tendon or neurovascular exposure, osseous integrity, the presence of periosteum or paratenon, and the amount of soft tissue coverage available. Perform a sensory and vascular examination prior to injecting the patient with local anesthesia.

By blocking the patient, a tendon examination devoid of pain may be performed. First, classify which flexor or extensor zone the injury is in. Examine the resting posture of the hand and the cascade of digits. Evaluate this cascade with the wrist flexed and extended. Any deviation from the normal of the cascade could signify a tendinous injury. Evaluate each tendon individually. Examine the flexor digitorum superficialis (FDS) by blocking flexion of the adjacent digits, and examine the flexor digitorum profundus (FDP) by blocking flexion of that digit's proximal interphalangeal (PIP) joint. An Elson's test can be performed to evaluate for central slip injury. This is done by asking the patient to extend a 90 degree flexed PIP joint while applying counterforce on the middle phalanx. A normal test results in active extension of the PIP and a floppy distal interphalangeal (DIP) joint. An abnormal test results in no active PIP extension and a slightly extended, taut DIP.

Posterior-Anterior (PA), lateral, and oblique X-rays of the hand or affected digit are recom-

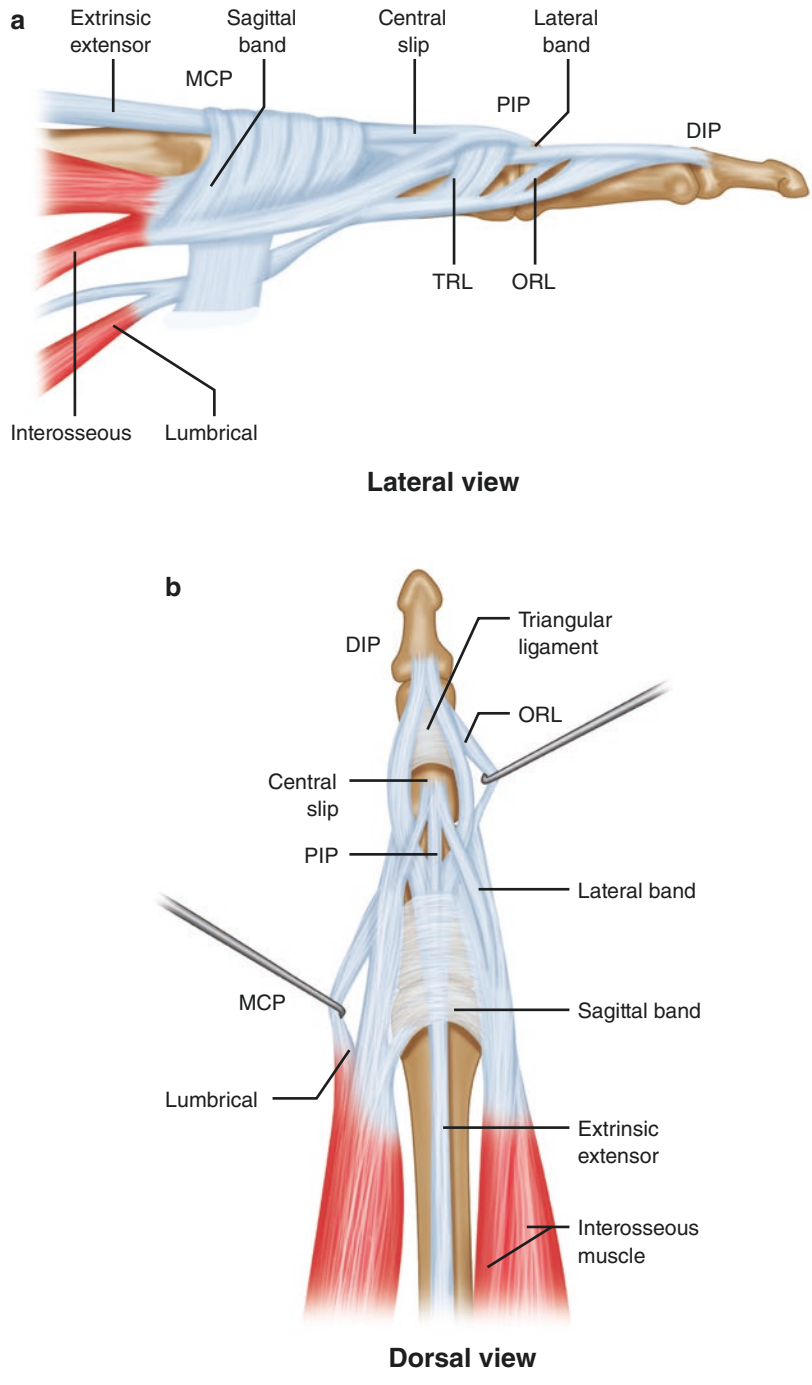

Fig. 37.2 Lateral (**a**) and dorsal (**b**) view of the extensor hood mechanism. TRL transverse retinacular ligament, ORL oblique retinacular ligament

mended to evaluate for fractures or foreign bodies. Ultrasound can be helpful in evaluating tendon lacerations. Magnetic Resonance Imaging (MRI) or Computed Tomography (CT) scan is generally not necessary.

Tendon Injury Zones

There is well-established nomenclature when discussing tendon injuries. They are classified based on their location on the flexor or extensor

Table 37.1 The flexor zones of the upper extremity

Non-thumb	Thumb
Zone I: Distal to FDS insertion	Zone TI: Distal to IP joint
Zone II: From A1 pulley to FDS insertion	Zone TII: From A1 pulley to IP joint
Zone III: From distal end of carpal tunnel to A1 pulley	Zone TIII: Over the thenar eminence
Zone IV: Within the carpal tunnel	Zone TIV: Within the carpal tunnel
Zone V: Proximal to the carpal tunnel	Zone V: Proximal to the carpal tunnel

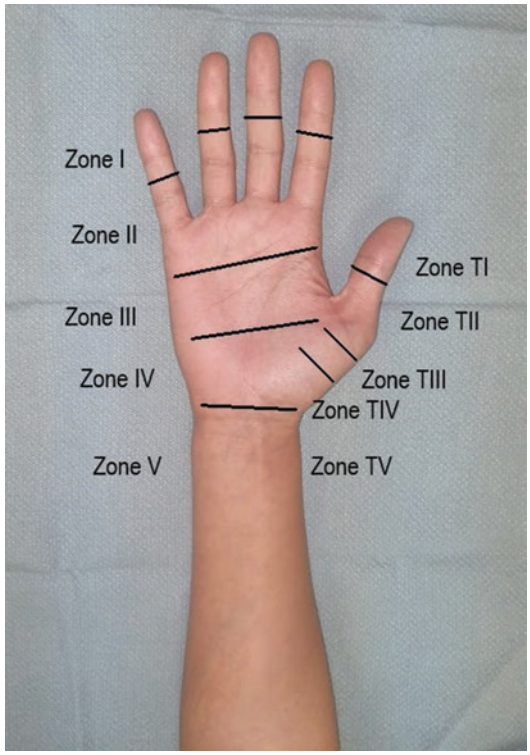

Fig. 37.3 Flexor zones of the upper extremity. See Table 37.1 for the exact anatomical borders of each zone

surface of the affected extremity. The nomenclature for the thumb is modified. See Tables 37.1 and 37.2, Figs. 37.3 and 37.4 for more information regarding these zones.

Timing of Tendon Repair

There is no emergent need for tendon repair in an injured extremity with intact vascularity. Tendon repair <24 hours from injury is contraindicated in the heavily contaminated or actively infected wound and those injuries which lack stable soft tissue coverage. Delayed primary repair, defined as less than 2 weeks, but more than 24 hours since the time of injury, has comparable results as

Fig. 37.4 Extensor zones of the upper extremity. See Table 37.2 for the exact anatomical borders of each zone

Table 37.2 The extensor zones of the upper extremity

Non-thumb	Thumb
Zone I: Over the DIP joint	TI: Over the IP joint
Zone II: Over the middle phalanx	TII: Over the proximal phalanx
Zone III: Over the PIP joint	TIII: Over the MCP
Zone IV: Over the proximal phalanx	TIV: Over the metacarpal
Zone V: Over the MCP joint	TV: Over the carpus
Zone VI: Over the metacarpals	–
Zone VII: Over the carpus	–
Zone VIII: Over the distal forearm	–
Zone IX: Over the proximal forearm	–

those repaired within 24 hours of injury [7, 8]. Secondary repair, defined as repair more than 2 weeks since the time of injury, has worsened outcomes as compared to primary repair, due to muscular contraction and scarring, and tendon edema and softening. Early secondary repair is from 2 to 5 weeks since the time of injury. Repair without a tendon graft is possible, but adhesions and need for future tenolysis may be necessary [9]. Late secondary tendon repair often requires a tendon graft or transfer, due to a heavily scarred muscle and tendon [10]. Advancing an FDP tendon more than 1 cm can lead to the quadriga effect, defined as an active flexion lag in fingers adjacent to a digit with a previously injured or repaired FDP tendon, which should be avoided.

Anesthesia

Tendon repair can be performed under any form of anesthesia. We avoid general anesthesia when possible, and, in cases requiring sedation, we employ regional anesthesia techniques such as supraclavicular or wrist blocks. Our preferred anesthesia technique is to utilize local anesthesia only.

WALANT

Wide-awake hand surgery has proven an effective anesthetic strategy for tendon injuries at our institution. Wide-awake local anesthesia no tourniquet (WALANT) relies on patient education, deliberate local anesthesia injection, and patience in order to obtain an optimal result [11].

WALANT allows for surgery to be performed safely without sedation, which can be a major benefit in patients who are at elevated risk for anesthetic complications. The lack of sedation permits for intraoperative patient education by discussing the surgery as it is happening, and by showing the patient their own anatomy and repair. This enhances the patient knowledge of their pathology and allows the patient to play a more active role in their postoperative care and rehabilitation. A significant advantage of WALANT is the ability to inspect the tendon repair by having the patient demonstrate active range of motion [12]. The repair may be revised if there is gapping or limited excursion due to a variety of factors. This direct inspection of repair excursion allows us to start early active range of motion sooner, which has, in turn, decreased the need for tenolysis.

WALANT relies on infiltration of lidocaine with epinephrine, buffered with sodium bicarbonate, into specific locations (see Figs. 37.5 and 37.6) to achieve anesthesia in the surgical site and to provide field hemostasis. We perform our injections 30 minutes prior to surgery in the preoperative holding area. This allows for the epinephrine to take maximal effect (at least 26 minutes) [13] to provide a bloodless field. Furthermore, anesthetic injection also hydrodissects surgical planes. The standard concentration

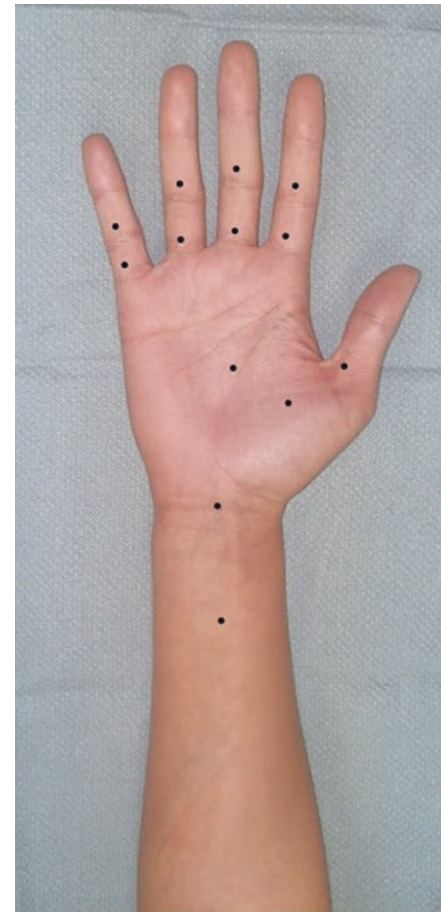

Fig. 37.5 The various injection locations to anesthetize the volar hand

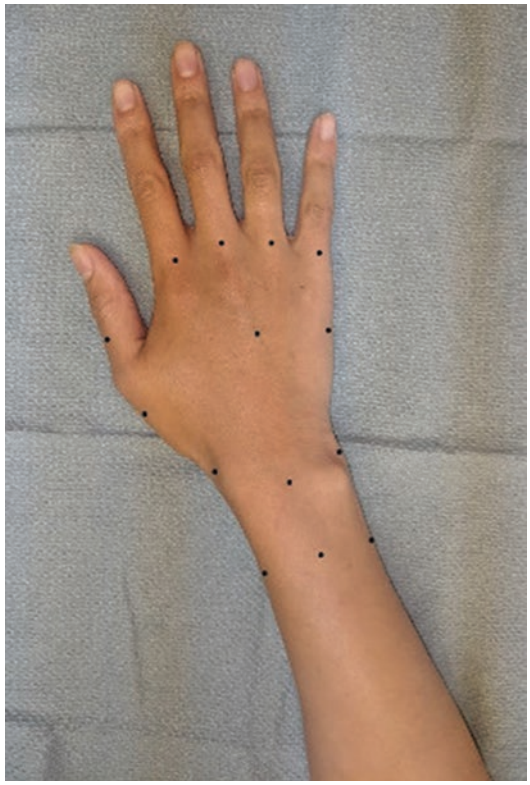

Fig. 37.6 The various injection locations to anesthetize the dorsum of the hand

used is 1% lidocaine with 1:100,000 epinephrine. 10 mL of this mixture is buffered with 1 mL of 8.4% sodium bicarbonate to neutralize the pH, helping with infiltration pain.

The WALANT injection technique employs a series of tricks to help decrease the pain of local anesthetic administration. First and foremost, a small needle is used—generally 27 gauge or smaller. The needle is injected perpendicularly into the skin while being stabilized with two hands. A small aliquot (~0.5 mL) is injected slowly subdermally, and time is given for the sting of the needle insertion to abate (about 60 seconds). Sensory noise, such as firmly pressing skin proximal to the injection site, can decrease needle insertion pain. Slow injection is critical to reducing the pain of distention of the tissues. After the initial pain has stopped, another 1.5 mL is slowly injected without moving the needle. After this bolus is given, the needle is advanced. It is important to only advance the needle tip into an anesthetized field. There should

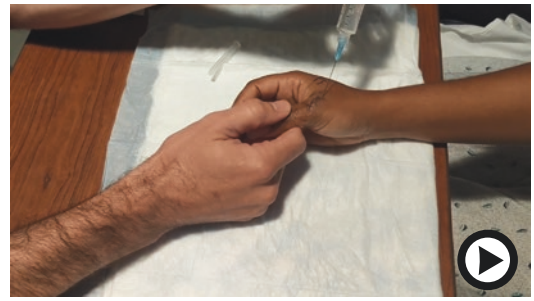

Fig. 37.7 This demonstrates the injection technique for WALANT (▶ https://doi.org/10.1007/000-3vh)

be a bolus of local anesthetic ahead of the needle. If the needle must be repositioned, it should only be reinserted within 1 cm of the blanched/unblanched border. Injection of anesthetic must proceed slowly while advancing the needle. Consider switching to a blunt-tipped, larger cannula if one is available. (View Fig. 37.7 to watch injection technique.)

Considerations on Tendon Repair

We perform our tendon repairs utilizing WALANT technique when able. Repairs are performed utilizing loupe magnification. Lacerations are extended as necessary, such that exposures of tendon stumps and skin flap viability are maximized. Generally, we utilize Brunner zigzag incisions, ensuring we do not cross a joint crease longitudinally, as this may worsen postoperative scarring. After providing operative exposure, cleansing, and debridement of devitalized tissues, the wound is explored from "known to unknown," or from uninjured tissues to injured. Normal tissue planes and neurovascular structures are identified and traced throughout the zone of injury. After identification of all injuries, the order of repair is as follows: skeletal fixation, tendon repair, nerve repair, arterial and venous repairs, and skin coverage. If the hand or digit is vascularly compromised, revascularization may be given the priority.

Both stumps of the tendon laceration must be visualized prior to repair. If the wrist or digits were flexed or extended at the time of the injury, the tendon laceration may not be directly visible within the wound. In this case, it is important to

flex or extend the wrist and digits to bring the tendon laceration into the field. Partial tendon lacerations <50% do not require repair if there is no triggering or entrapment during range of motion. If there is, the partial tendon laceration is either trimmed or repaired [10].

Fully lacerated tendons sometimes may retract proximally. The vincula of the flexor tendons or a bone fragment may prevent proximal retraction of a stump. On the dorsum, the juncturae tendineae may prevent extensor tendon retraction. There are several methods for proximal tendon stump retrieval. The simplest method is milking the tendon from proximal to distal while flexing or extending the wrist and affected digits. Handling of the tendon should be minimized, as the more traumatized the tendon, the more adhesions are likely to develop. Only one pass with a hemostat should be attempted blindly to avoid iatrogenic injury to local structures.

If the tendon cannot be easily retrieved, a more proximal exploratory incision may be necessary. Once the proximal stump is identified, it may be passed distally. On the flexor surface, the proximal stump may be too frayed to pass through the flexor sheath. In this case, an incision is made to expose the A1 pulley and employ an 8 French pediatric rubber feeding tube. We pass the tube proximally into the flexor sheath from the lacerated end. Once fed through the A1 pulley, the feeding tube is secured to the end of the proximal stump with sutures, and the feeding tube is pulled distally through the sheath, bringing the proximal tendon stump along with it. A 25-gauge needle is passed through the stump and tendon sheath, securing it in place for repair.

Tendon repair is a fine balance between repair strength and bulk. Repair strength is proportional to the size and number of suture strands (core sutures) crossing the repair site [14]. However, the bulkier the repair, the more likely adhesions are to form. We select suture size based on the tendon size at the injury site. We aim to take at least 1 cm core suture bites, as this has been shown to be superior to shorter bites [15]. Locking suture configurations are biomechanically superior to grasping (non-locking) repairs [16]. Epitendinous suture placement can improve tendon gliding and improve the strength of the repair [14, 17, 18]. We aim to perform at least a 4-strand repair, as this is

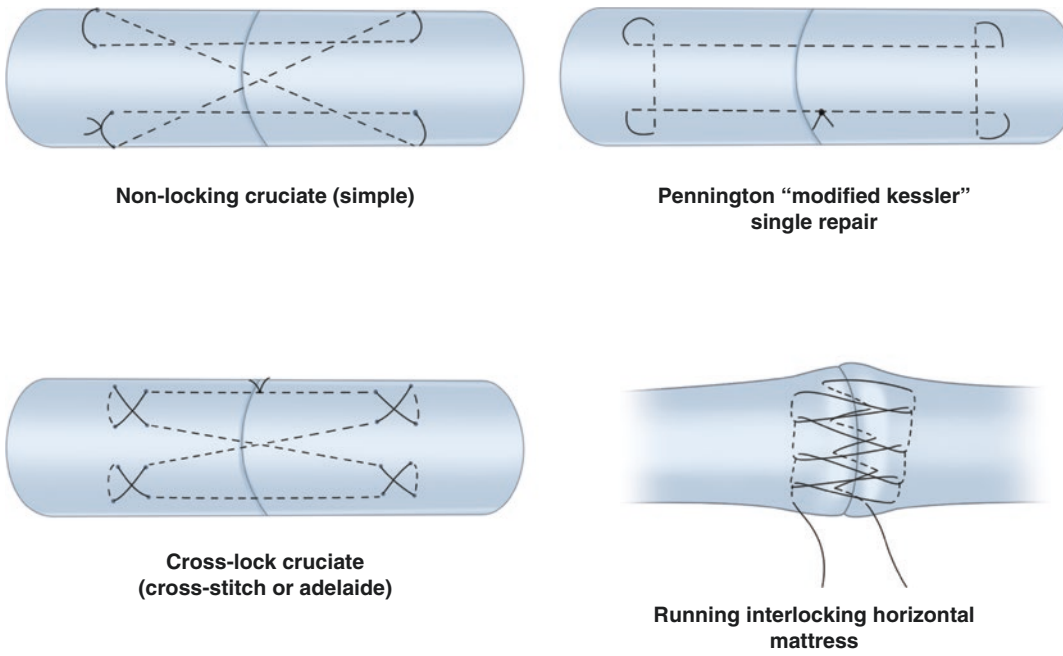

Fig. 37.8 The various suture techniques for tendon repair. Our institution utilizes the running horizontal interlocking mattress suture and the cross-lock cruciate repair

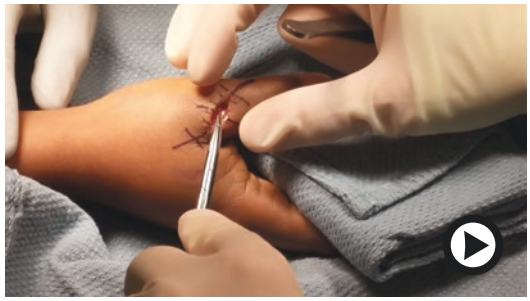

Fig. 37.9 This demonstrates the surgical exposure and repair technique for a patient undergoing WALANT extensor tendon repair (▶ https://doi.org/10.1007/000-3vg)

the minimum amount of core sutures necessary to start early active range-of-motion rehabilitation protocols [19–22]. See Fig. 37.8 for an illustration of our commonly utilized suture techniques.

Fig. 37.9 demonstrates how to perform an extensor tendon repair under WALANT.

Flexor Tendons

Zone I

Defined as any flexor tendon injury distal to the FDS insertion, these injuries are the result of lacerations or avulsions of the FDP. If there is more than 1 cm of FDP stump available, primary suture repair is available. We prefer to use a cross-lock cruciate repair with a 3-0 or 4-0 Fiberwire followed by an epitendinous running suture with a 6-0 prolene. If less than a 1 cm FDP stump is available, the tendon must be secured to the bone. This may be accomplished with internal suture anchors or Bunnell pull-through sutures tied over an external button.

Leddy and Packer described FDP avulsion injuries [23]. They are classified into types I–IV. Treatment varies based on bony and soft tissue involvement. The FDP is avulsed from the bone and vincula, and it is retracted proximally in type I injuries. They should be treated urgently, as the tendon could scar proximally. Type I avulsions are managed with suture anchors or Bunnell pull-through sutures tied over external buttons. In type II FDP avulsions, the proximal tendon stump is held in place by the vincula. There is no urgency to repairing these injuries. They are treated the same as type I injuries. Type III FDP avulsions are fractures of the FDP insertion. The tendon does not retract into the tendon sheath due to the bone fragment. Type III FDP avulsion injuries are managed by fixation of the small bone fragment with a lag screw or hook plate. Type IV injuries involve both a fracture and tendon avulsion. Management is individualized based on the situation. Generally, the bone fragment is fixated to the distal phalanx with a lag screw, followed by tendon fixation similar to type I or type II injuries. Occasionally, the bone fragment may be excised, and the tendon can be advanced and secured to bone.

Zone II

Zone II, or "No Man's Land," had traditionally poorer outcomes due to the limited space within the tendon sheath and the potential need for repairing two tendons. A bulky repair followed by prolonged immobilization led to adhesions and stiff digits. At our center, we aim to perform at least a 4-strand repair, which is the minimum to allow for early active range of motion. We perform 4-core suture, cross-lock cruciate repairs with 3-0 Fiberwire and a running 6-0 prolene as an epitendinous suture. We respect the orientation of the tendons in the flexor sheath. Generally, we repair both FDP and slips of FDS. If after the repair there is too much bulk or tendon entrapment, half of A2 and all A4 can be vented without untoward consequences [2, 4]. Additionally, a slip of FDS can be left unrepaired, as this will allow for adequate tendon gliding in the sheath. Occasionally, a slip of the FDS may have to be excised in order to facilitate tendon gliding. Immediate referral to a qualified hand therapist is paramount for a successful outcome, and we start early active range of motion 5–7 days after surgery.

Zone II flexor tendon injuries can also be repaired with a series of sheathotomies [24].

Once the tendon stumps are identified and brought into view through the lacerated sheath, transverse sheathotomies are created 1 cm proximal and 1 cm distal to sheath laceration. These sheathotomies are then used as access points to aid in suturing the tendon. This ensures a 1 cm bite of each core suture placed. An epitendinous suture is also placed using this technique. The repair is ranged, adjustments are made, and then the sheathotomies may be closed with fine absorbable sutures.

Zones III–V

Tendon injuries in zones III, IV, and V carry better prognoses compared to zone II, due to the lack of a tendon sheath. In these zones, wide exposure is critical to evaluate for concomitant neurovascular compromise. Zone III injuries are repaired with a cross-lock cruciate 3-0 Fiberwire with a 6-0 running prolene epitendinous suture. Zone IV injuries lie underneath the transverse carpal ligament and are repaired in a similar fashion as Zone III injuries. The transverse carpal ligament should be repaired if there is bowstringing of the tendons with range of motion. The neurovascular compromise associated with Zone V injuries may carry more morbidity than the tendon injuries themselves. In Zone V, the tendons should be repaired from deep to superficial. 4-strand 2-0 Fiberwire cross-lock cruciate sutures may be placed. Epitendinous sutures are optional in Zone V. If there is a laceration at the musculoaponeurotic junction or in the muscle belly itself, horizontal mattress or figure-of-eight sutures with large bites may be used. Slips of extensor retinaculum or muscle fascia grafts can be used to aid these repairs.

Rehabilitation After Flexor Tendon Injuries

Postoperative rehabilitation is as important as sound surgical repair of tendon injuries. Three basic protocols exist: passive extension and flexion to promote tendon gliding (Duran), rubber-band-assisted passive flexion and active extension (Kleinert), and early active motion [22]. Lately, there has been emphasis on early active motion protocol. Mobilization of a tendon repair improves tensile strength and tendon gliding, and it decreases tendon adhesions as compared to immobilized tendons. We place our flexor tendon injury patients in a dorsal-blocking splint with the wrist in 30 degrees of flexion and MCPs at 70 degrees of flexion. The rehabilitation regimen is dictated by quality of the tissues and tendon repair and the expected patient compliance. In compliant patients with durable repairs, we commence an early active range-of-motion protocol about 5–7 days postoperatively with a hand therapist. We rarely use the Duran or Kleinert protocols. Complete immobilization via casting is limited to children and non-compliant adults. With an early active range-of-motion protocol, the splint is normally weaned off by 8–9 weeks postoperatively.

Extensor Tendon Repair

Zone I

Injuries in zone I represent mallet fingers. They occur with forced flexion, while the Distal Interphalangeal Joint (DIP) is actively extending. The injury can be either an open laceration of the terminal extensor tendon, closed avulsion of the tendon insertion, or an open or closed fracture of the dorsum of the base of the distal phalanx. In patients with closed tendinous avulsions or small dorsal chip fractures, the mallet finger may be treated with 24/7 extension splinting for 6–8 weeks, followed by nighttime extension splinting for another 6–8 weeks. Any flexion of the DIP resets the clock. Open soft tissue mallets should undergo irrigation and debridement, tendon repair, and skin closure. Repair is performed with a running interlocking horizontal mattress with a 4-0 Fiberwire. Alternatively, if there is <1 cm of terminal extensor tendon stump, a suture anchor may be used. Postoperative splint-

ing is similar to that of closed soft tissue mallets. In a bony mallet finger, if there is an incongruous joint surface or volar subluxation of the distal phalanx after splinting, extension dorsal block pinning should be considered. Pins are generally removed 6–8 weeks postoperatively.

Zone II

Management of tendon lacerations in zone II is dictated by the percentage of cross-sectional area lacerated and the existence of extensor lag. If <50% of the tendon is affected without extensor lag, the wound is irrigated, closed, and the digit is splinted in extension for 1–2 weeks. Active range of motion is then initiated after this period. If >50% of the tendon is lacerated or if there is extensor lag, the tendon is repaired with a running interlocking horizontal mattress technique with a 4-0 Fiberwire. Postoperative splinting protocol is similar to that of a closed soft tissue mallet finger.

Zone III

Zone III injuries represent central slip lacerations or avulsions. These injuries can often be subtle. Patients will present with PIP joint swelling, mild PIP joint extension lag, and a positive Elson test. The central slip can become attenuated over time; thus, a high index of suspicion must be maintained. Otherwise, a boutonniere deformity may develop. For central slip injuries with or without small bone fragments, the PIP joint should be splinted in extension for 6 weeks, with the MCP and DIP joints free. Thereafter, they are transitioned to nighttime splinting for another 6 weeks. Open central slip injuries can be repaired directly with a running interlocking horizontal mattress 4-0 Fiberwire suture, or with a suture anchor if there is <1 cm of tendon stump available. Central slip injuries with a large bone fragment undergo fixation with a min-frag screw. After surgical management, the PIP joint is splinted in extension for 4–6 weeks. Early active motion can be initiated thereafter.

Zone IV

The tendon in this zone is flat and wraps around the proximal phalanx. Therefore, lacerations tend to be partial. If there is no extensor lag on physical examination, the patient should be splinted and commence active range of motion 1 week after splinting. If there is extensor lag, the wound should be explored, and the tendon repaired. We perform a running interlocking horizontal mattress suture with 4-0 Fiberwire, followed by early active range-of-motion protocols. If the patient is non-compliant, they are splinted with their MCP and PIP joints in full extension for 4 weeks and then allowed to start active motion.

Zone V

Tendon injuries in this zone are often the result of fight bite—a punch to another human's mouth, resulting in a laceration. The wound is inoculated with mouth bacterial flora, and the patient runs the risk of developing an infection, from a simple abscess to a septic MCP joint. Irrigation, debridement, and antibiotics are just as important as tendon repair. Tendon lacerations >50% can be repaired with a running interlocking horizontal mattress 3-0 or 4-0 Fiberwire suture once the wound is clean. The finger is then splinted with a relative motion extension splint for 4 weeks. Relative motion extension splints maintain the affected digit's MCP in 30 degrees more extension compared to the rest. This splint prevents tendon adhesions and allows patients to return to work early. After 4 weeks of splinting and active motion therapy, the splint is discontinued.

Blunt trauma to the MCP joint can cause a sagittal band injury [25]. Type I injuries are contusions and are stable. Type II injuries have subluxation of the extensor tendon past midline of the metacarpal head but still maintaining contact. Type III injuries are dislocations of the extensor tendon between the metacarpal heads. Patients with type II and III injuries experience painful snapping with flexion and extension of their MCP joint. If the patient is within 3 weeks

from injury, they are treated with a relative motion extension splint for 4–6 weeks. If the patient is beyond 3 weeks from injury or if they have continued pain after 3 months of relative motion extension splinting, then an operative approach must be considered. Direct suture repair with 4-0 or 5-0 suture if primary repair is possible. Otherwise, the extensor tendon should be reconstructed. Options include utilizing slips of extensor tendon, the juncturae tendineae, or a dynamic lumbrical transfer.

Zone VI

Injuries in this zone have better prognoses related to decreased adhesion formation and less of a chance for concomitant joint injury. Patients are often able to still extend the MCP joint of the affected digit through either an accessory tendon (EIP, EDM) or juncturae; therefore, it is important to have a high clinical suspicion and to thoroughly evaluate for extension weakness. Tendons at this level are larger and are repaired with a running interlocking horizontal mattress 3-0 or 4-0 Fiberwire suture. Relative motion splinting and early active range-of-motion protocols are used at our institution.

Zone VII

The extensor retinaculum is injured in this zone. The retinaculum must be released for visualization of the tendon laceration. This is often performed in a step-cut manner at our institution. The proximal tendon stumps will occasionally retract proximally into the forearm, and they must be retrieved. Repair is performed with running interlocking horizontal mattress 2-0 or 3-0 Fiberwire suture. The retinaculum is then repaired with 3-0 absorbable suture. The patients are then splinted with the wrist at 30 degrees and MCP and IP joints free for wrist extensor tendon lacerations and the wrist in 30 degrees, and MCP joint in full extension, and IP joints free for finger extensors. They are splinted for 4 weeks prior to mobilization. The compliant and motivated patient can benefit from early active motion protocols.

Zone VIII/XI

Lacerations in extensor zone VIII and XI can have concomitant nerve injuries, so a thorough examination is necessary. These injuries lack quality tissues for repair, as the injury lies over the muscle belly or the musculotendinous junction. Repair is performed with several figure-of-8, 2-0 absorbable sutures, ensuring to take large bites of tissue. Like extensor injuries in the same region, retinacular or fascial grafts can help supplement the repair. The wrist and affected digits are generally splinted for 4 weeks postoperatively.

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Upper Extremity Nerve Injuries and Compression Syndromes

38

Ammara E. Ghumman, Vincent A. Chavanon, and Zubin J. Panthaki

Nerve Injuries

Peripheral nerve disorders in the upper extremity are common within the general population. These disorders include compression neuropathies, traction injuries, and direct traumatic injuries. Vital to the management of these conditions is a robust understanding of nerve anatomy and disorder pathophysiology, conduction of a detailed patient workup, followed by accurate diagnosis and appropriate treatment.

Anatomy

Peripheral nerves are comprised of motor axons, sensory axons, or a combination of both. These nerves can be myelinated or unmyelinated (Table 38.1).

Peripheral nerve anatomy can be deconstructed into three basic structures:

1. Neurons—Cell bodies and axons making up the building blocks of nerves.
2. Connective tissues—Enveloping each axon is the endoneurium. Bundles of axons, known as fascicles, are surrounded by perineurium, while nerves in their entirety are wrapped by epineurium and supported by adventitial mesoneurium.
3. Schwann cells and nodes of Ranvier—These glial cells produce myelin for expedient nerve transmission through saltatory conduction at nodes of Ranvier in myelinated nerves.

Recovery of end-organ function is dependent on time since injury and nerve type. Loss of motor endplates occurs after 12–18 months, and loss of two-point sensory discrimination after 6–12 months, with recovery limited to protective sensation after that [1].

Nerves receive extrinsic and intrinsic blood supply. Segmentally, the arteriae nervosa contribute to longitudinal blood supply of the nerve through epineurial anastomoses with the intrinsic vascular plexuses. The epineurial blood supply communicates with the perineurial and endoneurial plexuses via a host of capillary networks, resulting in a robust intrinsic nerve blood supply allowing for dissection over a great distance [2]. If endoneurial pressure rises with injuries, such as with crush or edema, the capillary plexuses become occluded. Pressures in excess of

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Table 38.1 Nerve fiber types, designations, and function

Nerve fiber type/ designation		Function
A—alpha	Myelinated	Motor
A—beta	Myelinated	Touch/pressure
A—gamma	Myelinated	Vibration
A—delta	Myelinated	Pain/temperature
B	Myelinated	Preganglionic autonomic
C	Unmyelinated	Pain/temperature

Table 38.2 Seddon–Sunderland classification of nerve injuries

Degree of injury		Pathology	Tinel's	Recovery	Surgical management
I	Neuropraxia	Segmental demyelination w/ *no Wallerian degeneration*	–	Complete; Fast—days to weeks	–
II	Axonotmesis	Axon disrupted w/ Wallerian degeneration	+	Complete; Slow—up to 12 weeks (1 inch/ month)	–
III	Axonotmesis	Disrupted axon + Endoneurium	+	Partial; Slow—up to 12 weeks (1 inch/ month)	None or neurolysis
IV	Axonotmesis (Neuroma in continuity)	Disrupted axon + Endoneurium + Perineurium	+ but stagnates at NIC	None	Nerve repair, graft, or transfer
V	Neurotmesis	Disruption of all nerve layers	+ but stagnates at nerve laceration	None	Nerve repair, graft, or transfer
VI	Mixed injury	Mix of I–V	+/–	Some	Neurolysis, repair, graft, or transfer

20 mmHg result in nerve ischemia and can result in nerve injury and demyelination [3].

Etiopathogenesis

Nerves can be injured by the way of acute crush/ progressive compression, laceration, or traction mechanisms. Nerve injuries can be classified according to the Seddon–Sunderland classification of nerve injuries with the Mackinnon modification (Table 38.2).

In this classification, there are six classes of nerve injury. First-degree injuries are focal areas of conduction block, or demyelination, without any Wallerian degeneration. Second- and third-degree injuries are axonotmetic injuries with Wallerian degeneration, characterized by positive Tinel's sign with progression with healing. In second-degree injuries, full healing is anticipated, while third-degree injuries have some limitations in healing due to scarring within the nerve itself.

After third-degree injuries, surgical intervention is recommended for treatment. In fourth-degree injuries, there is scarring of the nerve as in third-degree injuries, but more severe such that the entire nerve is blocked by scar tissue, resulting in a neuroma in continuity. Fifth-degree injuries are neurotmetic or transected nerves, and sixth-degree injuries are those with a combined injury pattern.

Injuries other than neuropraxia result in a process called Wallerian degeneration. This refers to the process by which there is distal degeneration of axons with proliferation of Schwann cells and

macrophages. This leads to myelin degradation and phagocytosis in order to reorganize the neural tube into Bands of Bunger to provide a scaffold for distal nerve regeneration. Proximally, chromatolysis occurs with proximal neuronal cell body damage and axonal degeneration. Regeneration starts proximally with a neural growth cone forming within 24 hours of injury. Filopodia from the growth cone grow toward the distal stump by a chemotactic gradient of neurotrophic factors released from the latter. Filopodia making incorrect interconnections are denied maturation factors. Meanwhile, neurotrophic factors, such as nerve growth factor (NGF) and epidermal growth factor (EGF), support the growth, survival, and development of interconnections of new axons. Growing axons will progress at the speed of 1 mm/day or roughly 1 inch/month, after 1 month delay.

Evaluation

Evaluation of a peripheral nerve injury begins with a comprehensive history and physical examination of the injured upper extremity. Importantly, in obtaining a history, the mechanism, resultant deficiencies, and time course of the injury are crucial to delineate, as these will guide treatment. A general musculotendinous exam progresses to a focused physical examination for nerve findings when nerve injuries are suspected.

Common nerve-focused examinations include light touch, temperature, pain, position, vibration, localization, and pressure. Additionally, Tinel's sign, in which digital tapping along the course of nerve reveals the site of nerve injury, is helpful. An advancing Tinel's sign signals axonal regeneration and can be used to track nerve healing.

Sensory-specific tests include static and dynamic/moving two-point discrimination (S2PD and M2PD) and Semmes-Weinstein monofilament tests (Table 38.3). Reference values for the 2PD examination vary in the literature, with the general consensus that the M2PD values, which test fast-adapting nerve fibers, are lower than the S2PD values, which test slow-adapting nerve fibers. Abnormal 2PD values in the digits, in our experience, are >8 mm, with S2PD normally being 4–6 mm and M2PD being 2–3 mm. Care is taken to prevent crossing over the territories of the radial and ulnar digital nerves during the assessment. Delta 2PD values, which assess the difference between the normal, non-injured side, and the injured side, are important in both baseline assessment of nerve injuries and tracking of nerve regeneration post-intervention [4]. The Semmes-Weinstein monofilament (SWM) test measures slow-adapting fibers and is a very sensitive test which may reveal abnormalities in compression syndromes in advance of altered 2PD testing.

Table 38.3 Common peripheral nerve sensory tests

	Test maneuver	Normal responses
Static 2PD	Apply dull pointed calipers in a longitudinal direction without blanching the skin	4–6 mm
Moving 2PD	Apply dull pointed caliper moving from proximal to distal using just enough pressure for the patient to appreciate the stimulus	2–3 mm
Semmes-Weinstein monofilament	Apply monofilament perpendicularly to the volar digital surface with just enough pressure to cause the monofilament to bend	Correct localization, with eyes closed, of digit being stimulated
Vibration	Strike 256 Hz tuning fork on hard surface, then apply tine to fingertip tangentially and compare with contralateral side	Subjective patient assessment of equal sensation

Motor-specific tests will vary by the nerve being tested and the expected level of injury. In our experience, if upon testing the distal-most target for the major nerves there is a deficit, the injury can be localized more specifically by a

detailed knowledge of the nerve branching and innervation order. The test for most distal motor target for the ulnar nerve is the first dorsal interosseous, for the radial nerve is the extensor pollicis longus, and for the median nerve is the abductor pollicis brevis with the flexor digitorum longus to the index for the anterior interosseous nerve branch of the median nerve.

The motor strength is graded on the Medical Research Council (MRC) scale, and the delta with the contralateral, normal side is elucidating here as it is with the sensory examination. The MRC scale exists for both motor and sensory examinations and helps to evaluate outcomes. The motor scale grades muscle strength and is graded from 0 to 6. Grades M0 to M3 progressively represent no contraction to weak muscles functioning against gravity only. Grades M4 and M5 denote stronger muscles, with grade M5 representing normal strength. Meanwhile, the MRC sensory scale grades sensory recovery, incorporating subjective examination findings at its early grades S0–S3 and later with S3+ onward, and 2PD findings also (Table 38.4).

Finally, while not in every patient, it is important to remember aberrancies in nerve innervation patterns when performing nerve assessments of the upper extremity. This knowledge is critical, as these interconnections may mask true injuries. These anomalies include the following:

1. *Martin-Gruber anastomosis*
   (a) Motor connection from the median to ulnar nerve in the forearm
   (b) Present in up to 19.5% of patients [5]
2. *Riche-Cannieu anastomosis*
   (a) Motor connection between the median and ulnar nerves in the palm
   (b) Relatively common, found in 55.5% of patients [5]
3. *Froment-Rauber nerve*
   (a) Interconnection between the radial and ulnar nerves providing anomalous radial innervation of the first dorsal interosseous [6]
4. *Berrettini anastomosis*
   (a) Sensory interconnection between the ulnar and median nerves in the palm
   (b) Prevalence is 60.9% [5]
5. *Marinacci communication*
   (a) Motor connection from the ulnar to median nerve in the forearm
   (b) Exceptionally rare, its prevalence is estimated at 0.7% [5]

Table 38.4 MRC grading sensory and motor

Motor recovery		Sensory recovery	
M0	No recovery	S0	No recovery
M1	Perceptible contraction in proximal muscles	S1	Recovery of deep cutaneous pain
M2	Perceptible contraction in proximal and distal muscles	S1+	Recovery of superficial pain and sensibility
M3	Contraction possible against gravity	S2	Recovery of superficial pain and some touch
M4	Contraction possible against resistance	S2+	S2 recovery with hypersensitivity
M5	Full recovery in all muscles	S3	Recovery of pain and touch without hypersensitivity
		S3+	S3 recovery with localization and some 2PD
		S4	Complete recovery with normal 2PD (4–6 mm)

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Electrodiagnostic Testing

Electrodiagnostic studies (EDS) are comprised of nerve conduction studies (NCS) and electromyography (EMG); these studies are generally performed with a physiatrist or neurologist. Nerve conduction studies involve percutaneous stimulation of nerves—motor and sensory action potentials (AP)—with measurement of the AP at a distance away from the stimulus. NCS findings are reported as conduction velocity (which represents the integrity of the myelin sheath), amplitude (which represents the number of functioning axons), sensory nerve action potentials (SNAPs), and compound muscle action potentials (CMAPs).

SNAP amplitudes reflect the number of nerve fibers activated, while CMAP amplitudes reflect the number of muscle fibers activated. With injury, the expected changes in both sensory and motor APs are decreased amplitude, due to axonal degeneration, and increased latency, due to demyelination. CMAP amplitudes correlate well with the severity of injury, and the finding of a good amplitude CMAP in a clinically weak muscle denotes neuropraxia. Similarly, the finding of no CMAP indicates no surviving axons and muscle denervation.

EMG tests muscle activity with the insertion of needles into the target muscle. Findings on EMG can be indicative of denervation, such as positive sharp waves (PSWs) and fibrillations. Early findings of muscle denervation are PSWs, which are found only in denervated muscles, and occur by 2–3 days. Over time, as the muscle atrophies, PSWs are decreased. Fibrillations represent spontaneous muscular activity that confirms axonal loss and therefore are not present until Wallerian degeneration has occurred by about 3 weeks' time. The amplitude of fibrillations correlates with recency of injury, with large amplitude fibrillations representing recent injury, and small amplitude fibrillations representing more remote injury (e.g., >6 months ago), see Table 38.5.

EMG findings of reinnervation include nascent potentials (NPs) and motor unit potentials (MUPs). The presence of NPs on electrodiagnostic testing indicates that reinnervation is occurring within the muscle, with new axons being formed. MUPs represent surviving axons and are present with voluntary muscle contraction. Unstable polyphasic units, or irregular MUPs, suggest ongoing muscle reinnervation. Mature, electrically complete reinnervation demonstrates longer duration and larger amplitude MUPs.

With regard to timing of EDS, it is important to note that in settings of nerve injury, neuropraxia may be indistinguishable from more severe injuries in the early stages. This occurs because it takes up to 7 days for Wallerian degeneration to take place, thus rendering the nerve electrically active during this time. Intraoperative motor nerve stimulation, therefore, is best performed <72 hours after injury, before Wallerian degeneration has manifested clinically [7].

EDS are often performed serially in closed mechanism injuries in order to delineate injury type, assess for healing potential prior to intervening surgically. EDS are often also performed before and after an intervention in order to document recovery. As with physical examination findings, it is helpful in EDS interpretation to

Table 38.5 Electrodiagnostic testing and nerve injury

	Electrodiagnostic testing			
Degree of injury	Fibrillations	MUPs	Latency	Amplitude
Normal	–	Normal	Normal	Normal
Neuropraxia	–	Normal	Proximal—normal/prolonged Distal—normal	Proximal—normal /decreased (focal conduction block) Distal—normal
Incomplete—Axonotmesis	+	+	*Before WD* Proximal—prolonged Distal—normal *After WD* Proximal—prolonged Distal—prolonged	*After WD* Proximal—decreased Distal—normal *After WD* Proximal—decreased Distal—decreased
Complete—Axonotmesis (Neuroma in continuity), neurotmesis	+	–	*Before WD* Proximal—absent Distal—normal *After WD* Proximal—absent Distal—absent	*Before WD* Proximal—absent Distal—normal *After WD* Proximal—absent Distal—absent
Mixed injury	–/+	–/+	Variable	Variable

compare to the contralateral side for each individual patient.

Other investigations for patients with potential upper extremity nerve injuries include imaging, such as radiography, ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI). These modalities may assess for external causes of compression, may be able to visualize nerve lesions (transection, compression, post-traumatic lesions), and could demonstrate pseudomeningoceles post-nerve root avulsions.

Prognosis

Nerve injuries can be devastating without proper early identification and appropriate intervention. The best outcomes occur in young, healthy patients (<20 years old). Functional outcomes to muscle are best if axonal regrowth reaches the target motor endplates by 12–18 months. Past this time, the muscle will have undergone significant fibrofatty degeneration and will not result in functional recovery, as at least 25% of motor endplates are required for functional nerve firing. Functional sensory reinnervation also optimally returns if axons reach their end target organs by 12 months' time. Sensory reinnervation may occur after this time; however, protective sensation will predominate [1].

Compression Syndromes

Successfully treating compression neuropathies of the upper extremities requires an accurate assessment of patient symptoms and exam findings. A routine office visit and workup includes a thorough history and physical exam, with performance of the appropriate provocative maneuvers. The presence and distribution of sensory and motor symptoms and exam findings can help pinpoint the affected nerve and the level of compression. A judicious use of electrodiagnostic tests and imaging modalities can help confirm the diagnosis, clarify confusing exam findings and anomalous nerve connections, and/or provide an etiology for compression (e.g., soft tissue mass, aneurysms, etc.), see Table 38.6.

Table 38.6 Common compression sites of each nerve

Nerve	Compression points
Radial nerve	Fibrous bands of radiocapitellar joint Leash of Henry (radial recurrent vessels) ECRB tendinous leading edge Arcade of Frohse Supinator distal edge
Median nerve AIN	Ligament of Struthers Lacertus fibrosus Pronator teres FDS leading edge (sublimis bridge) Pronator teres FDS leading edge Aberrant vessels Accessory muscles (Gantzer's accessory FPL)
Ulnar nerve	Arcade of Struthers Medial intermuscular septum Hypertrophied medial triceps Osborne's ligament Anconeus epitrochlearis FCU between two heads Guyon's canal

Evaluation

History

Common complaints in peripheral nerve compression include a progression of paresthesias, pain, and weakness. Clumsiness with use of the hands and dropping objects may be reported. In motor nerves, the findings present in stepwise progression starting with weakness, followed by numbness and tingling, and finally muscular atrophy. It is important to elucidate precisely which fingers and areas of the palmar/dorsal hand and arm are experiencing sensory changes. The duration and rate of progression of symptoms, the patient's work and common activities, any exacerbating motions and extremity positions, and nocturnal symptoms may help provide insight on the diagnosis. Associated comorbidities are important to note, including pregnancy, hypothyroidism, amyloidosis, and collagen vascular diseases, which are all associated with carpal tunnel syndrome, while cubitus valgus and varus and medial epicondylitis are associated with cubital tunnel syndrome [8, 9].

Examination

Examination of the hand and arm begins with a visual assessment of soft tissue volume of the hands. Thenar atrophy occurs with median nerve compression, whereas atrophy between the metacarpals, hypothenar flattening, and first web space atrophy is representative of an ulnar pathology.

The shoulder and scapular movements should be assessed for strength and abnormal movements (winging), as muscular imbalances may produce soreness and discomfort in the arm.

Provocative maneuvers at each compression site with direct pressure or joint movements increase pressure on the nerve, temporarily exacerbating symptoms. Digital tapping (Tinel) at these points may cause radiation of electrical sensations in the nerve distribution or up the arm. Any cervical nerve root impingement should be evaluated with the Spurling's test. Higher levels of nerve compression may decrease the threshold for nerve injury at more distal levels and vice versa via the reverse double-crush phenomenon [10–12].

Sensory thresholds will elucidate early nerve compression and are assessed with pressure (slowly adapting receptors) and vibration (quickly adapting receptors). Sensory discrimination reflects sensory end-organ density, which is affected later in nerve compression, and is assessed with moving and static two-point discrimination.

Testing

After a thorough history and physical, the patient may be referred for electrodiagnostic studies (EDS); however, EDS should not replace the clinic exam. While some clinicians utilize EDS in all patients presenting with nerve compression, there is growing evidence that supports forgoing the testing in "textbook" cases of carpal tunnel syndrome [13].

We expect increased signal latency across areas of compression where the myelination of the nerves has been adversely affected by compression. Decreased amplitude of the SNAP and/or CMAP indicates decreased numbers of sensory or motor nerve fibers that are activated when the nerve is stimulated. As the compression progresses to late disease states and axons are lost, SNAP followed by CMAP amplitudes will be affected. EDS are also valuable for evaluating other etiologies, such as cervical compression and other myopathies and neuropathies.

Imaging of the hand and arm may be useful to rule out or confirm a secondary cause of nerve compression. After trauma, plain X-rays may demonstrate a fracture or dislocation causing acute nerve compression. Ultrasound may reveal soft tissue mass, aberrant musculature, and vascular malformations causing progressive compression of the nerves. CT scan and MR imaging and angiography may help reveal soft tissue masses, neuromas, and vascular pathology responsible for the symptomatology.

Median Nerve Compression

The median nerve is one of the main terminal branches of the brachial plexus formed by the lateral (C5–7) and medial cords (C8–T1), see Fig. 38.1. With carpal tunnel syndrome (CTS), it is the nerve responsible for the most compression neuropathies in the upper extremity. Approximately, 10% of the population will develop CTS [9].

In the arm, the nerve crosses the brachial artery and travels between the medial intermuscular septum and the brachialis. It crosses the antecubital fossa and enters the forearm under the lacertus fibrosis, traveling between the ulnar and humeral heads of the pronator teres, then giving off the anterior interosseous nerve. Coursing between the flexor digitorum superficialis and profundus muscle bellies, it gives off the palmar cutaneous branch. At the wrist, it supplies the recurrent motor branch and travels beneath the transverse carpal ligament and divides to supply cutaneous innervation of the thumb, index, middle, and radial half of the ring fingers.

Carpal Tunnel Syndrome

The most common compression neuropathy of the upper extremity, carpal tunnel syndrome (CTS), is caused by compression of the median nerve at the

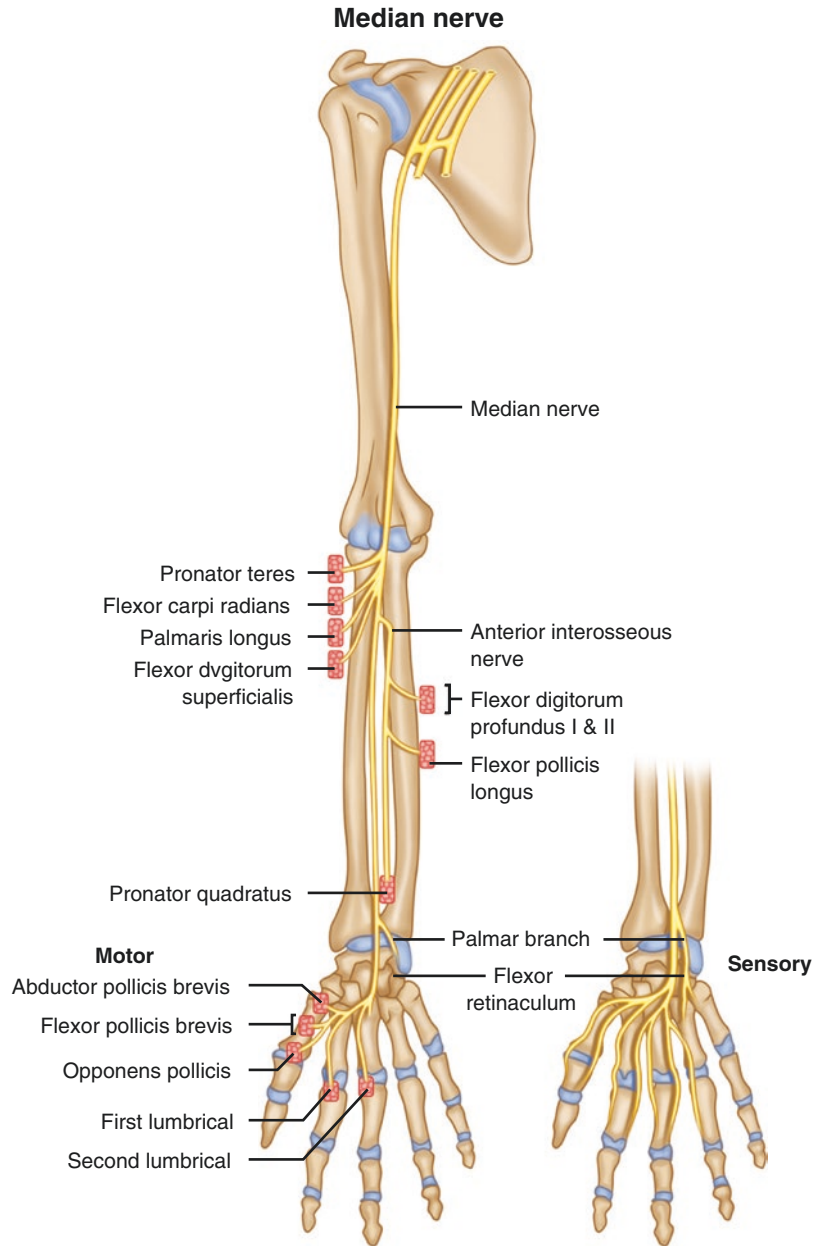

Fig. 38.1 Median nerve course and motor and sensory innervation

wrist. The carpal tunnel is bound volarly by the transverse carpal ligament, dorsally by the proximal carpal row, radially by the trapezium and scaphoid, and ulnarly by the hook of the hamate and pisiform. Within the carpal tunnel are the median nerve, flexor pollicis longus tendon, and the eight flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) tendons.

Variations in the anatomy of the recurrent motor branch have been defined by Lanz and should be well understood to avoid a devastating iatrogenic injury and loss of thenar function (Fig. 38.2) [14].

The branching of the palmar cutaneous branch is also an important consideration. Variations in its course have been noted, but generally it

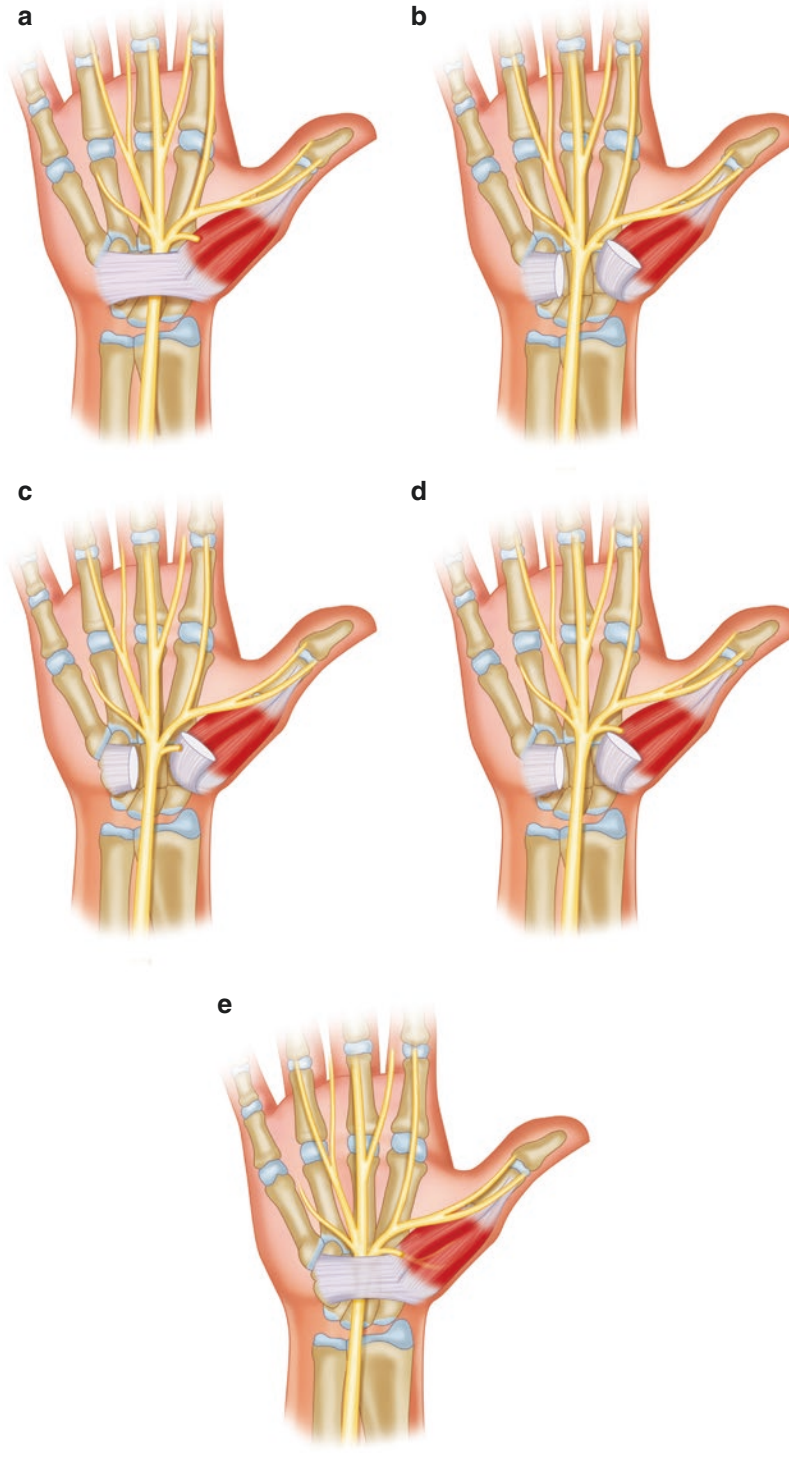

Fig. 38.2 RMB of the median nerve. (**a**) extraligamentous; (**b**) subligamentous division of the median nerve; (**c**) transligamentous course of the recurrent motor branch; (**d**) branching from the ulnar aspect of the median nerve; (**e**) on top of the TCL

emerges radial to the palmaris longus tendon and ulnar to the flexor carpi radialis [15, 16].

Symptoms are progressive and begin with paresthesia and/or numbness of the thumb, index, middle, and half of the ring fingers. The patient may experience thenar soreness from compression of the recurrent motor branch. Early in the disease process, symptoms may be intermittent and without any evidence of weakness. Often there is nocturnal aggravation of symptoms and patients may be woken from sleep. As the disease progresses, numbness worsens and atrophy and flattening of the thenar eminence are noted. Sensory examination as described above with 2PD and SWM may also be performed. Provocative testing at the carpal tunnel includes the Tinel, Phalen's test, and Durkan's compression test.

In obvious cases of CTS, a clinical diagnosis may suffice in determining treatment [13]. However, in ambiguous clinical scenarios, EMG and NCS may help to better characterize the diagnosis and severity. When mass effect is suspected, ultrasound or MR may be used to assess the carpal tunnel for persistent median artery, anomalous muscular anatomy, and soft tissue masses (neuroma, lipoma). Additionally, preoperative baseline EDS may help assess improvement after release, as EDS typically improve but do not normalize after surgery [17].

Nonoperative treatment of CTS is appropriate in early disease, with modalities ranging from rest and splinting and steroid injection to ketoprofen phonophoresis. Splinting the wrist in a neutral position is preferential; however, due to the impaired functional biomechanics of the wrist position, patients may only tolerate night splinting. Oral steroids may improve symptoms, but no benefit has been found with oral non-steroidal medications. Ketoprofen phonophoresis has been shown to help alleviate symptoms [18]. More commonly, corticosteroid injection at the carpal tunnel may be attempted, with up to 32% of patients showing long-term benefit [19]. Steroid injection does have some risk of injury to the median nerve, skin atrophy, and hypopigmentation.

Surgical treatment involves division of the transverse carpal ligament (TCL) and has been shown to have better outcomes at 6 and 12 months compared to nonoperative management [18]. Carpal tunnel release techniques range from open to mini-open incision to single- or dual-port endoscopic release. Several studies, including a 12.8-year randomized trial, did not reveal any long-term benefit to endoscopic versus open release, though patients may initially have less pain and a faster return to work [20–22].

In open carpal tunnel release, the important considerations are avoiding injury to the median nerve, the recurrent motor branch, and the palmar cutaneous branches, while ensuring adequate release. Incisions vary by surgeon preference for carpal tunnel release. Usually, an adequate length incision is marked ulnar to the thenar crease, approximately 2 cm in length without crossing the wrist crease. Under local anesthesia with lidocaine and epinephrine, the incision is made and dissection is carried down through the skin and volar fat to the superficial palmar fascia. The oblique and longitudinal fibers of the superficial palmar fascia are divided, and dissection is continued to the transversely running fibers of the transverse carpal ligament. The ligament is inspected to ensure the transligamentous recurrent motor branch is not present, and then it is divided carefully until the carpal canal is entered. An instrument may then be inserted through the defect in the ligament to protect the underlying median nerve and flexor tendons. The distal extent of the ligament is divided until the fat surrounding the superficial palmar arch is encountered. Proximally, blunt-tipped scissors are used to free the volar aspect of the ligament from the subcutaneous tissue and then to free the contents of the carpal tunnel from the undersurface of the transverse carpal ligament. Then, with the operative surgeon at the end of the table, the ligament is divided under direct visualization. Hemostasis is achieved using bipolar electrocautery. The canal and nerve may be inspected for anomalous structures and abnormalities. It is not necessary to explore the recurrent motor branch of the median nerve in a routine carpal tunnel release unless preoperative indications exist.

Skin closure is performed with non-absorbable horizontal mattress sutures, and the wound is dressed with a sterile gauze dressing.

Acetaminophen is used for postoperative pain control. Patients are instructed to remove dressings after 48 hours and cover the wound with sterile bandage. Light use of the hands is allowed. Patients are seen in follow-up at 1–2 weeks. Sutures are removed at 2 weeks. Patients are counseled against heavy lifting, and unrestricted use is allowed after 6–8 weeks [23].

Complications include the aforementioned iatrogenic nerve injuries, as well as infection, dehiscence, and wrist pain. Recurrent or persistent carpal tunnel syndrome can occur after inadequate initial release or initial misdiagnosis (proximal lesions, peripheral neuropathies, malingering); heavy scarring around the nerve; regeneration of the transverse carpal ligament; or extremely severe disease. Treatment of recurrent carpal tunnel involves exploration with extended exposure to ensure adequate release and may be augmented by external neurolysis if scar is present, or a pedicled soft tissue flap (palmaris brevis, pronator quadratus, or hypothenar fat flap) to help pad the nerve and prevent recurrence [24, 25].

In cases of recurrent carpal tunnel syndrome, the senior author's preferred method begins with more thorough investigation preoperatively. This includes obtaining available prior operative reports, obtaining an MRI without contrast of the wrist, and new electrodiagnostic studies. The MRI is used to clarify whether recurrent symptoms are from nerve injury, from the scarring of the transverse carpal ligament, or from relative decrease of carpal tunnel volume as a result of flexor tenosynovitis. This will guide preoperative discussion with the patient and help tailor further surgical treatment. For recurrent carpal tunnel syndrome, typical tricks used to try to prevent further recurrent symptoms could involve a more extensive carpal tunnel release using a classical incision extending proximal to the wrist crease, wrapping the nerve with a synthetic nerve protector such as conduit wrap, and finally performing a hypothenar adipofascial perforator flap. The flap serves two functions: both to attempt to revascularize any potentially ischemic nerve segment and to interpose itself between the two leaflets of the transverse carpal ligament to try to prevent re-scarring of the edges.

Pronator Syndrome

- Rare cause of median nerve compression (Fig. 38.3):
  - Compression under lacertus fibrosus, between the heads of the pronator teres or arch of the flexor digitorum superficialis
  - Anomalous vascular anatomy of the proximal forearm
  - Entrapment beneath ligament of Struthers between distal humerus supracondylar process and pronator teres fascia
- Symptoms worse with sustained power grip, repeated pronation, and supination
  - Sensory changes in carpal tunnel distribution, but *also of thenar eminence* (palmar cutaneous branch)
  - Pain in the proximal volar forearm
  - No weakness or atrophy
- Diagnosis is clinical
  - Paresthesias with tapping over the pronator teres, elbow flexion, pronation, and resistance to finger flexion
  - EDS usually negative
- Treatment
  - Activity modification and splinting should be mainstay of therapy
- 50–70% will improve conservatively [26]
  - Operative release of ligament of Struthers, bicipital aponeurosis, and FDS arch
- About 90% of patients experience relief [26]
- Postoperative splint at 45–95 degrees of flexion for 5 days, then start mobilizing elbow

Anterior Interosseous Nerve (AIN) Syndrome

- Symptoms
  - No sensory alteration
  - Pain in the proximal forearm with early fatigue (opening doors, screwdriver)
  - Weakness of flexor pollicis longus, index and middle finger flexor digitorum profundus, and pronator quadratus
- Cause (Fig. 38.3)
  - Entrapment of the AIN at the tendinous edge of the deep head of the pronator teres or origin of FDS

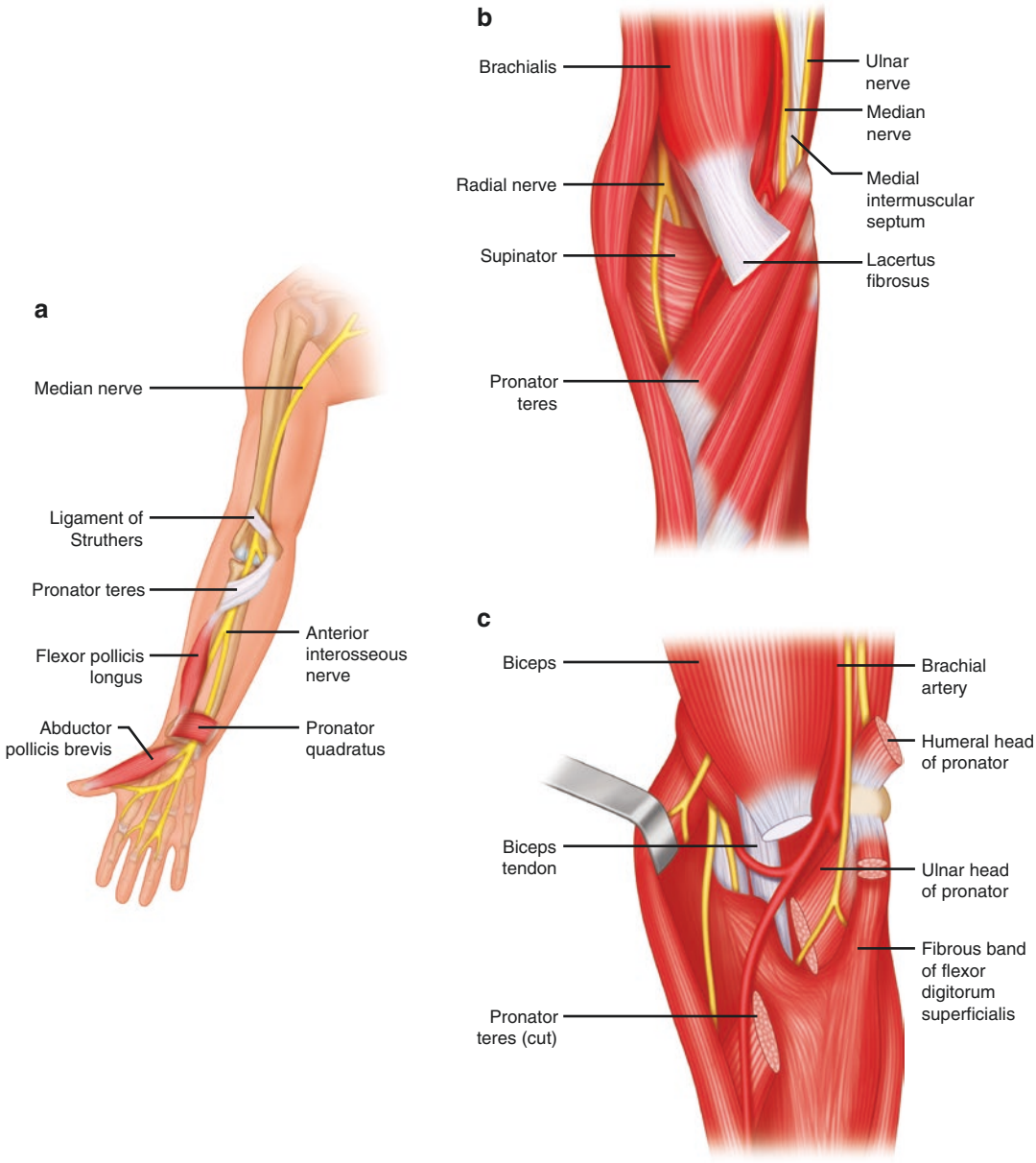

Fig. 38.3 Median nerve compression sites causing pronator syndrome and AIN syndrome

- Diagnosis
  - FDP and flexor pollicis longus (FPL) weakness
- Proximal inter-phalangeal (PIP) flexion, distal inter-phalangeal (DIP) extension causing pinch deformity
- Difficulty with "OK" sign
  - Weakness of PQ
  - Electrodiagnostic studies
- Treatment
  - Splinting and activity modification for several months [26]
  - Operative intervention similar to pronator syndrome
- Performed after failure of nonoperative measures
- 75% of patients improve

Ulnar Nerve Compression Syndromes

The ulnar nerve arises as another major peripheral nerve of the brachial plexus formed as a terminal branch of the medial cord (C8-T1), see Fig. 38.4. Compression of the ulnar nerve occurs most commonly at the elbow in a condition known as cubital tunnel syndrome, which is the second most common form of upper extremity compression neuropathy. Reported rates of cubital tunnel range from 24.7 to 30.0 per 100,000 person-years with a slight male predominance (31.2 vs. 28.8) [27, 28]. Compression at the wrist within Guyon's canal, known as ulnar tunnel syndrome, is less common, but may be seen in hook of hamate fractures and trauma, anomalous muscles, ulnar artery aneurysms, and other space-occupying lesions [29].

The ulnar nerve courses posteromedially to the brachial artery in the upper arm and courses distally between the medial intermuscular septum and the medial head of the triceps. Approximately 8 cm from the medial epicondyle, the nerve is covered by the arcade of Struthers, a thick fibrous band connecting the medial intermuscular septum and medial head of the triceps. The nerve then courses posterior to the medial epicondyle and enters the cubital tunnel, where it is covered by the ligament of Osborne and a thick fascial layer from the flexor carpi ulnaris (FCU). As it continues to course distally, it travels between the humeral and ulnar heads of the FCU. In the forearm, it continues beneath the FCU muscle and tendon, running with the ulnar artery. Approximately 5 cm proximal to the ulnar styloid, the dorsal cutaneous branch arises. As the nerve enters the wrist through Guyon's canal, it runs radial to the FCU and ulnar to the ulnar artery. As it passes through the canal, it is divided into three zones: Zone 1) both sensory and motor components, then after the nerve bifurcates; Zone 2) deep motor branch; and Zone 3) the superficial sensory branch.

The sensory innervation of the ulnar nerve includes the ulnar half of the ring and the entire small finger and the ulnar hand via the dorsal cutaneous branch and a palmar sensory branch. In the forearm, the FCU and flexor digitorum profundus muscle to the ring and small fingers are innervated by the ulnar nerve. The deep motor branch innervates the hypothenar muscles, all the interossei, the ulnar two lumbricals, the adductor pollicis, and the deep head of the flexor pollicis brevis.

Cubital Tunnel Syndrome

Cubital tunnel syndrome (CuTS) is caused by compression of the ulnar nerve at the elbow. The cubital tunnel is formed by the medial collateral ligament of the elbow and the elbow capsule on the deep surface, the medial epicondyle and olecranon form the medial and lateral walls, and the roof is comprised of the ligament of Osborne and the FCU fascia. However, CuTS commonly occurs outside of those borders. Proximally, it may be compressed by the arcade of Struthers or may be impinged by the medial intermuscular septum. Distally, the aponeurosis between the two heads of the FCU is a common site for compression. Other causes of compression include the anconeus epitrochlearis, fascial bands of the medial head of the triceps, cubitus valgus, osteophytes, and other masses.

The most common symptoms of CuTS include paresthesias of the ulnar ring and the small finger. There may also be pain and aching at the medial elbow and proximal forearm. Because the volume of the cubital tunnel is decreased with elbow flexion, patients may complain of worsening symptoms with telephone use or when brushing hair. Particularly advanced states may present with intrinsic weakness, clawing, and positive Froment's or Wartenberg's sign.

The hand should be inspected for atrophy of the intrinsic muscles. Just as with median nerve compression, the sensory exam should include both threshold and discrimination measurements as described above. Subluxation of the nerve with elbow motion may be palpated (this may cause repeated irritation-producing symptoms). Provocative maneuvers include a positive Tinel at the elbow—though it may be overly sensitive—and the elbow flexion test with pressure over the ulnar nerve proximally, which is 98% sensitive [30].

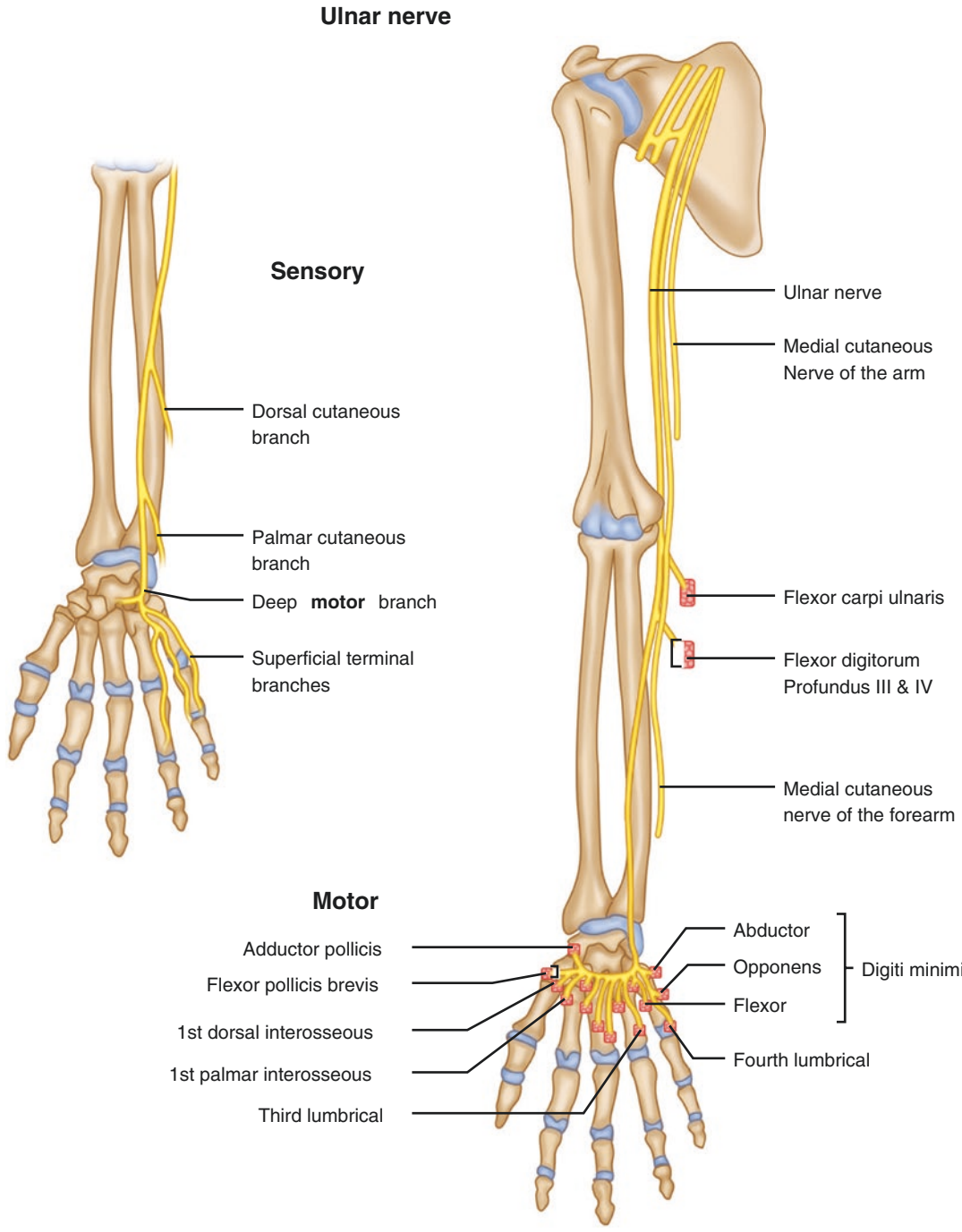

Fig. 38.4 Course, compression sites, and innervation of the ulnar nerve

The diagnosis is mainly clinical, as EDS have a high false negative rate, around 30%, but may be useful to help confirm diagnosis or in ruling out other diagnoses. Nerve conduction less than 50 m/s at the elbow is diagnostic for cubital tunnel, and low SNAP and CMAP amplitudes may also be seen [30, 31].

Just as with carpal tunnel syndrome, in CuTS, a trial of nonoperative therapy should be attempted. In cases of mild or moderate severity, nearly 90% of patients will have resolution of symptoms [32]. Conservative therapy includes activity modification (avoiding elbow flexion and external elbow pressure) and nighttime splinting with the elbow at 30 degrees of extension to decrease pressure in the cubital tunnel. Steroid injection is not recommended. Mackinnon has recommended conservative therapy for patients whose conduction velocities at the elbow are greater than 40 m/s for a period of 3 months, and surgery for those whose nerve conduction velocities are below 40 m/s [33].

The goal of operative intervention is decompression of the nerve, but significant controversy exists regarding the best management. Potential surgical management options include in situ decompression, anterior transposition (subcutaneous, submuscular, or transmuscular), medial epicondylectomy, and endoscopic release. Medial epicondylectomy may be useful in traumatic settings, but risks destabilizing the elbow. It, along with endoscopic release, is beyond the scope of this chapter and will not be discussed. Two important structures to identify and protect during and cubital tunnel decompression are the medial antebrachial cutaneous (MABC) nerve and nerve branches to the FCU distally (Fig. 38.5). The posterior branches of the MABC cross the ulnar nerve at or near the medial epicondyle, so consideration of their presence is important to avoid forearm anesthesia or painful neuromas from iatrogenic injury [34, 35]. Injury to branches from the ulnar nerve to the FCU may cause weakness with elbow flexion.

In Situ Decompression

The use of in situ decompression is indicated in mild-to-moderate cases of CuTS that have been recalcitrant to conservative therapy. Under sedation or general anesthesia and tourniquet, a 6- to 10-cm incision is made at the medial elbow centered over the cubital tunnel. Longitudinal spreading is used to dissect through the subcutaneous space to avoid injury to the MABC. The ulnar nerve may be found under the flexor carpi ulnaris muscle heads by identifying the chevron-shaped decussation of the fibers. Dividing the muscle in this decussation line will help to identify the ulnar nerve deep to the FCU, while making sure to identify and protect nerve branches to the FCU.

Alternatively, identifying the medial intermuscular septum proximally, the ulnar nerve is identified just posterior to it. The cubital tunnel is then divided, and decompression is carried distally through the leading edge of the FCU tendon, where care is taken to avoid injury to any branches to the FCU. Proximally, the arcade of Struthers is divided. The elbow is then flexed and extended to inspect and excise any points of impingement from brachial fascia or the medial intermuscular septum. If the nerve is noted to sublux over the medial epicon-

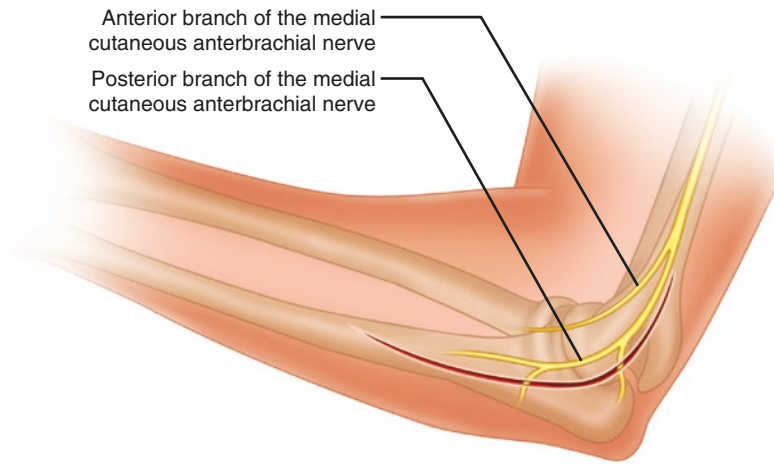

Fig. 38.5 Cubital tunnel release incision (red) and medial antebrachial cutaneous nerve about the elbow

dyle, strong consideration should be given to performing an anterior transposition to avoid postoperative pain and nerve irritation (Fig. 38.6).

If there is any doubt about hemostasis, and in revision cubital tunnel releases, the tourniquet is deflated prior to closing to ensure meticulous hemostasis is achieved. The skin is then closed in layers with subcuticular absorbable suture and the elbow is dressed with sterile gauze dressings and light compression wrap. The splint and wrap are removed by 72 hours, and motion is started.

Cubital Tunnel with Anterior Transposition

Anterior transposition of the nerve decreases tension on the nerve, as it no longer passes posterior to the medial epicondyle during elbow flexion. The three main variations of the anterior transposition involve relocating it to a subcutaneous, a transmuscular, and a submuscular plane. Proponents of the subcutaneous transposition argue that it is less disruptive to the native muscular anatomy of the pronator teres and FCU, leading to less scarring and improved motion. The initial steps of the surgery are similar to an in situ release, but with a longer incision (10–15 cm). In a subcutaneous transposition, the nerve is released, and a portion of the medial intermuscular septum is removed to avoid any kinking on the thick band. The nerve is transposed anteriorly, with care taken to preserve its longitudinal blood supply. A fascial or subcutaneous fat flap is used to secure the nerve anteriorly and prevent subluxation. In an intramuscular transposition, a trough is made in the pronator and fibrous septae are removed to provide a smooth without kinking of the nerve. Then, a fascial or subcutaneous flap is used to secure the nerve. In the submuscular transposition, the muscle is elevated off the medial epicondyle, and the lacertus fibrosus is divided to expose the median nerve as it lies on the brachialis. The ulnar nerve is then brought anteriorly to lie adjacent to the median nerve, and the flexor–pronator muscle is repaired (a stair-step incision in the muscle may be used to provide length to decrease pressure under the muscle).

The incision is closed in layers with a final subcuticular closure. Heavy lifting is restricted for 6–8 weeks after surgery. Prognosis after surgery is favorable, with approximately 80–90% of patients reporting improved symptoms after unilateral decompression [36].

Ulnar Tunnel Syndrome (UTS)

Guyon described the eponymous canal in 1861 (Fig. 38.7). It is bounded superficially by the

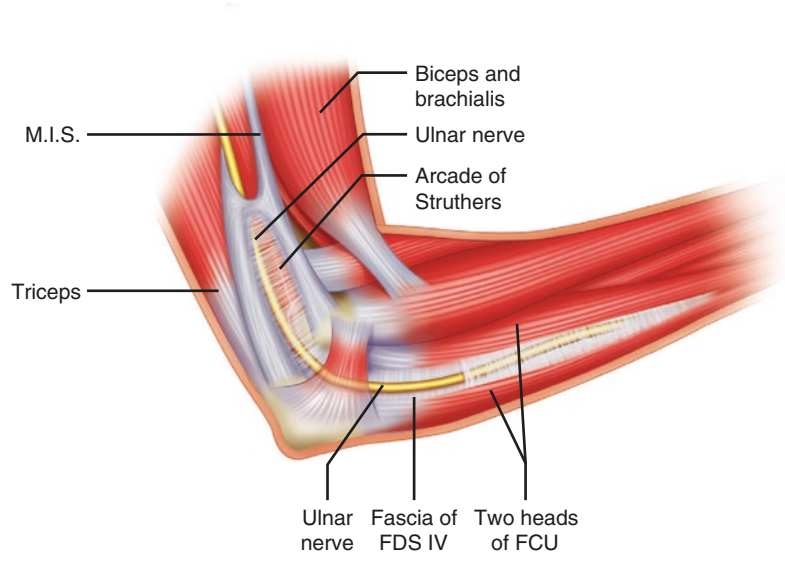

Fig. 38.6 Ulnar nerve compression sites. Note the nerve passing under the decussation of the two heads of the FCU. MIS—medial intermuscular septum

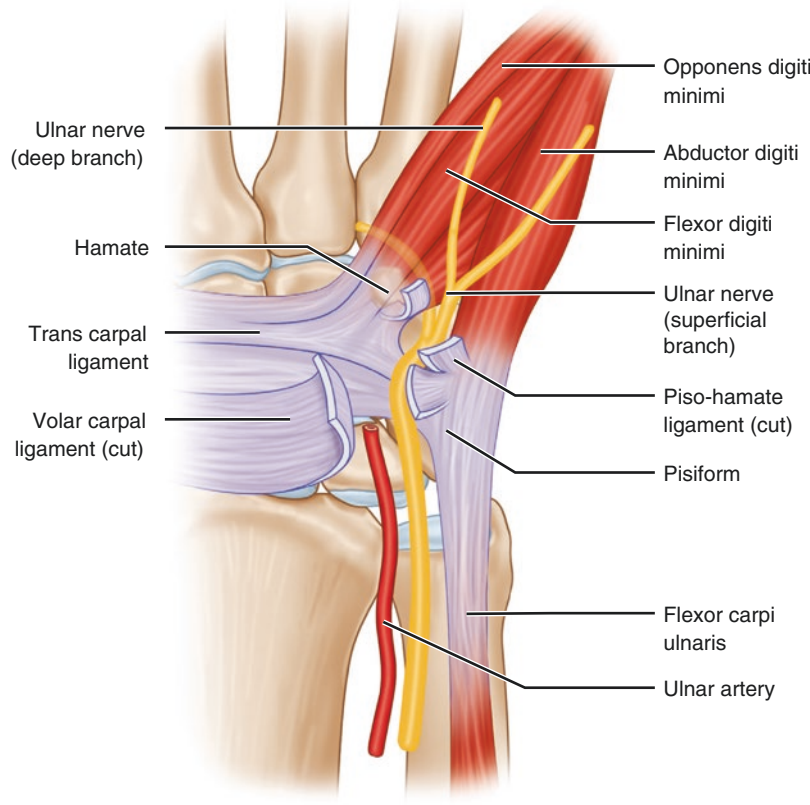

Fig. 38.7 Guyon's canal. Note the ulnar position of the ulnar nerve relative to the ulnar artery at the hook of hamate. The pisiform, opponens digiti quinti, abductor digiti quinti, flexor digiti quinti, and flexor carpi ulnaris are also shown

volar carpal ligament, on the deep surface by the transverse carpal ligament, ulnarly by the pisiform, FCU tendon, and pisohamate ligament, and radially by the hook of the hamate. Within the canal is the ulnar nerve and the ulnar artery, as well as a small amount of fat. Causes of UTS include acute or repetitive trauma (e.g., hook of hamate fracture, hypothenar hammer syndrome, bicycling), soft tissue masses (ganglion cysts, anomalous muscles), synovial inflammation, and ulnar artery thrombosis, malformations, and aneurysms.

Ulnar tunnel syndrome (UTS) is significantly less common than CuTS. Symptoms may be sensory, motor, or both, depending on which zone of Guyon's canal has increased pressure. Symptoms include paresthesias and numbness of the small finger and ulnar half of the ring finger, and if motor branch compression exists, weakness, interosseous muscle atrophy, and the ulnar motor signs discussed above. Notably, proximal muscles (FDP of ring and small finger and FCU) will have full strength if no higher lesions exist. Tinel's sign may be positive at the wrist, and careful attention should be paid to assessing for a thrill of the ulnar artery. EDS may help localize the compression at Guyon's canal. If concern for space-occupying lesion, hook of hamate, or vascular pathology exists, an ultrasound, a CT scan, or MR imaging may be indicated to help guide treatment.

Nonoperative management may be attempted with splinting and activity modification for closed and repetitive injuries. For non-responders and progressive symptoms, and acute compression after fracture, operative decompression may be attempted. The incision is slightly ulnar to a carpal tunnel release but is extended proximally with a zigzag incision past the wrist crease. The nerve is identified proximally, and the volar carpal and pisohamate ligaments are divided in a distal direction to protect the neurovascular struc-

tures. The arcuate ligament (proximal edge of the hypothenar muscles) is the final entrapment point of the deep motor branch and must be released fully until the small finger flexors are visualized. The wound is closed and managed postoperatively like the carpal tunnel release.

Radial Nerve Compression

Radial nerve compression is relatively rare compared to the compression neuropathies discussed above. The radial nerve is formed from the posterior cord of the brachial plexus (C5–T1). It enters the arm proximally through triangular interval bound by the teres major and long head of the triceps muscles. It courses laterally, deep to the long head of the triceps, along the spiral groove between the medial and lateral heads of the triceps muscle. Approximately 10 cm from the lateral epicondyle, it traverses the lateral intermuscular septum, sending branches to the brachialis and brachioradialis as it travels distally. The anconeus muscle and the extensor carpi radialis longus (ECRL) are then innervated proximal to the elbow. As it crosses anterior to the lateral epicondyle, the nerve splits into a superficial branch and the posterior interosseous nerve (PIN). The extensor carpi radialis brevis (ECRB) is then innervated by either a branch from the radial nerve proper or the PIN. The superficial branch travels under the brachioradialis and then emerges approximately 9 cm proximal to the radial styloid between the brachioradialis and ECRL, supplying sensation to the radial and dorsal hand and the dorsal thumb, index, and middle fingers (Fig. 38.8).

The PIN enters the forearm under the radial recurrent artery and venae comitantes (leash of Henry), the arcade of Fröhse (a fibrous band formed from the superficial proximal layer of the supinator connected to the lateral epicondyle; most common site of compression), then between the two heads of the supinator, and finally exits distally under the distal edge of the supinator. After exiting from under the supinator, it divides into deep and superficial branches. The deep branch innervates the abductor pollicis longus,

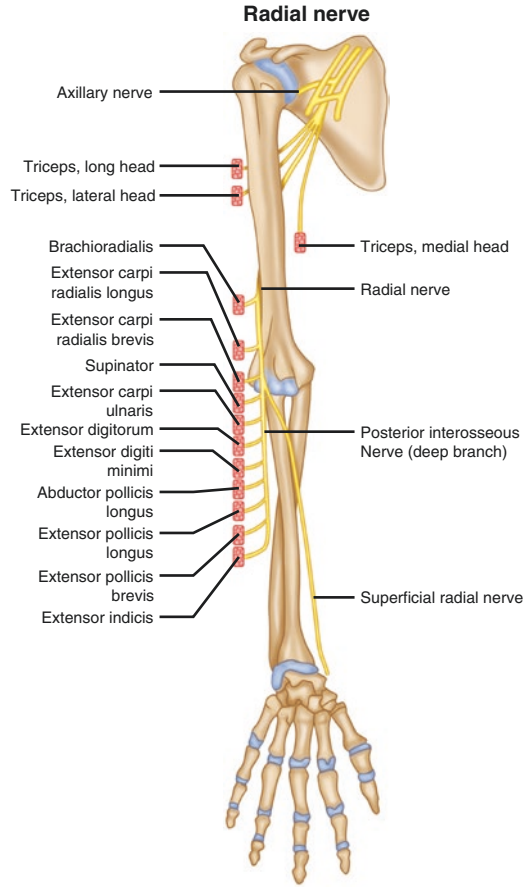

Fig. 38.8 Radial nerve innervation

extensor pollicis longus and brevis, and extensor indicis proprius muscles, and then continues distally through the floor of the fourth extensor compartment to provide sensory innervation to the dorsal wrist capsule. The superficial branch innervates the extensor carpi ulnaris, extensor digitorum communis, and extensor digiti minimi muscles.

In radial nerve pathology, the upper limb should be examined for wrist drop and loss of extension of the digits.

Radial Tunnel Syndrome

The radial tunnel is a 5 cm zone bounded laterally by the ECRL, ECRB, and brachioradialis and medially by the biceps tendon and brachialis;

the deep surface is the radiocapitellar joint, and the roof is the brachioradialis and the superficial head of the supinator as it passes over the nerve from the lateral side, generally thought to be caused by overuse from repetitive elbow extension and rotation against resistance and can coexist with lateral epicondylitis. The nerve may be compressed by fibrous bands of the radiocapitellar joint, a tight leash of Henry, the ECRB tendinous edge, the arcade of Fröhse, and fibrous bands along its course in the supinator (Fig. 38.9).

The patient presents with deep aching pain in the proximal forearm, with elbow movement that radiates distally to the dorsal hand. The pain is worse with rotation. There may be grip weakness, but it is pain-related, not from muscle denervation. Tinel's sign may be positive over the radial tunnel. With the elbow and wrist in extension, resisted supination will worsen the symptoms. The middle finger test can also be performed by placing the elbow in full extension and noting pain at the ECRB with forceful extension of the middle finger. A diagnostic block of the radial nerve, which will produce a temporary radial nerve palsy, may help to confirm the diagnosis. Because the PIN carries unmyelinated group IV fibers and small group IIA fibers, EDS are not helpful [37].

Conservative therapies should be attempted for 3–6 months and include activity modification; rest; splinting to decrease elbow extension, wrist extension, and forearm pronation; and NSAIDs [37, 38]. Steroid injections can also be attempted and may help with diagnosis and offer long-term relief to 70% of patients [39, 40]. Operative decompression, for recalcitrant cases, may be approached anteriorly or posteriorly, and the arcade of Fröhse, the leash of Henry, and any fibrous bands within the supinator must be addressed [37, 38].

Posterior Interosseous Nerve (PIN) Syndrome

PIN syndrome is a very rare entity, found in approximately 3 in 100,000 people, with a predisposition for males and often seen in body-

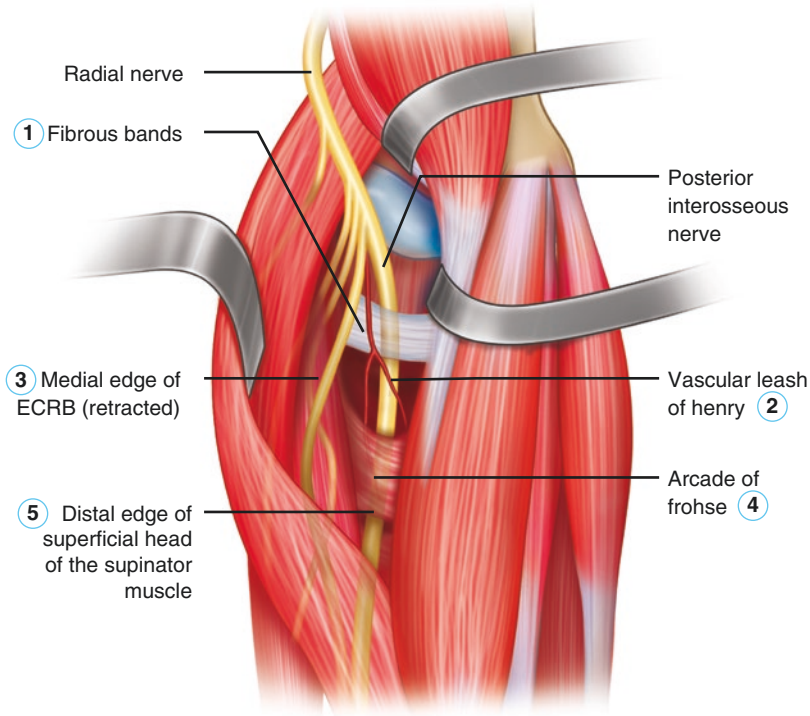

Fig. 38.9 Radial tunnel

builders and manual laborers [41]. It is typically caused by repetitive pronation and supination, trauma (e.g., radial head and Monteggia fractures), soft tissue masses, rheumatoid arthritis, and other inflammatory conditions; or iatrogenic injury from elbow surgery. Unlike in radial tunnel syndrome, the muscles innervated by the PIN are affected, and patients present with pain and weakness; there are generally no sensory complaints. During wrist extension, the wrist tends to deviate radially, because the ECRL is innervated more proximally by the radial nerve. Because the muscles are affected, EDS may aid in ascertaining the diagnosis. The impingement sites are the same as in radial tunnel syndrome. Treatment follows a similar course to radial tunnel, but operative intervention is undertaken after 3 months of conservative therapy without improvement, as significant delay in releasing the compression may cause irreversible muscular denervation.

Wartenberg's Syndrome (*Cheiralgia paresthetica*)

- Compression neuropathy of the superficial branch of the radial sensory (SBRN) nerve, as described by Wartenberg in 1923 [42]
- Presents with pain, paresthesias, and numbness of the dorsal radial hand
- More common in females (4:1 M:F relationship)
- Causes
  - Due to the superficial course, the SBRN is susceptible to external compression
- Tight wristwatch
- Handcuffs
  - May also be caused by repetitive supination and pronation or ulnar flexion
- Screwdriver
- Writing
  - Compression of the radial sensory nerve as it exists between the brachioradialis and ECRL tendons (Fig. 38.10)
- A positive Tinel's sign and a positive Finkelstein test may be noted. The concomitant presence of a Tinel's is suggestive of cheiralgia paresthetica.
- Treatment
  - Remove tight jewelry
  - Splinting, activity modification, steroid injections
  - Decompression

Nerve Injuries

Acute nerve injuries can occur through blunt or sharp mechanisms. Classification by mechanism is helpful, as it guides treatment. Blunt mechanisms are largely closed injuries, including traction and crush mechanisms, with the addition of most open gunshot wounds. Blunt mechanisms of nerve injury lead to Seddon and Sunderland class I–IV injuries, which are initially managed expectantly. Sharp injuries denote a higher likelihood of Seddon and Sunderland class V nerve injury, which requires immediate exploration.

Operative Indications

Surgical exploration and intervention should be undertaken immediately in patients with penetrating injuries overlying nerves with observed clinical deficits (Fig. 38.11).

Other indications for nerve surgery in patients with nerve deficits include those with no evidence of recovery at the anticipated nerve healing rate (1 inch/month after 1 month delay) and those with closed injuries with no evidence of reinnervation by 3 months (e.g., no MUPS). Generally, early operative intervention is not recommended for acute closed nerve injuries, crush mechanism injuries, or gunshot wounds (GSW), unless there is an associated vascular injury with the GSW (Fig. 38.12).

A 2017 study [43] recommended early nerve exploration in upper extremity GSW having found a 27% nerve laceration rate in the presence of nerve palsy; however, generally these injuries are still treated expectantly, unless there is another indication for early operative intervention, until the 3-month mark [44].

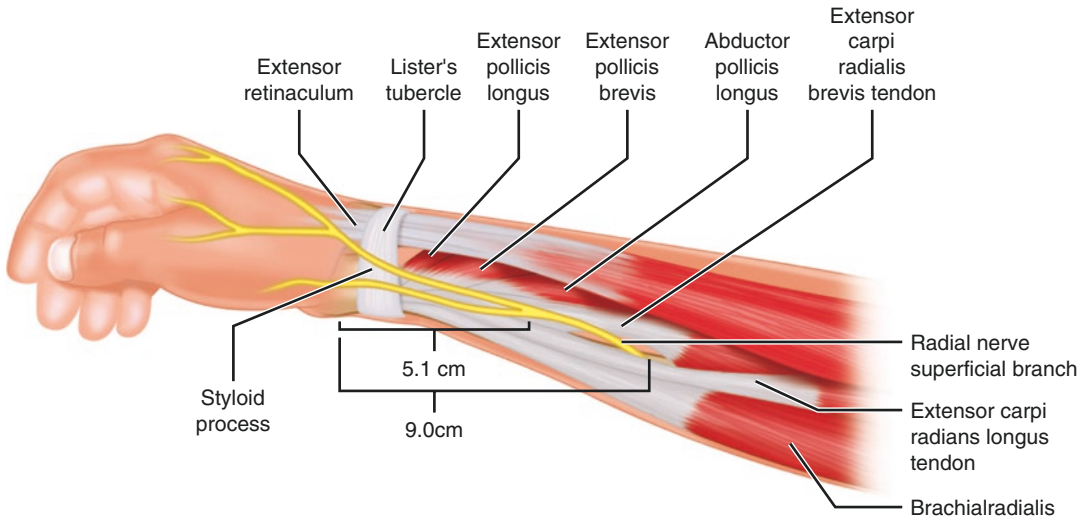

Fig. 38.10 The radial sensory nerve and its relationship with the brachioradialis and radial styloid

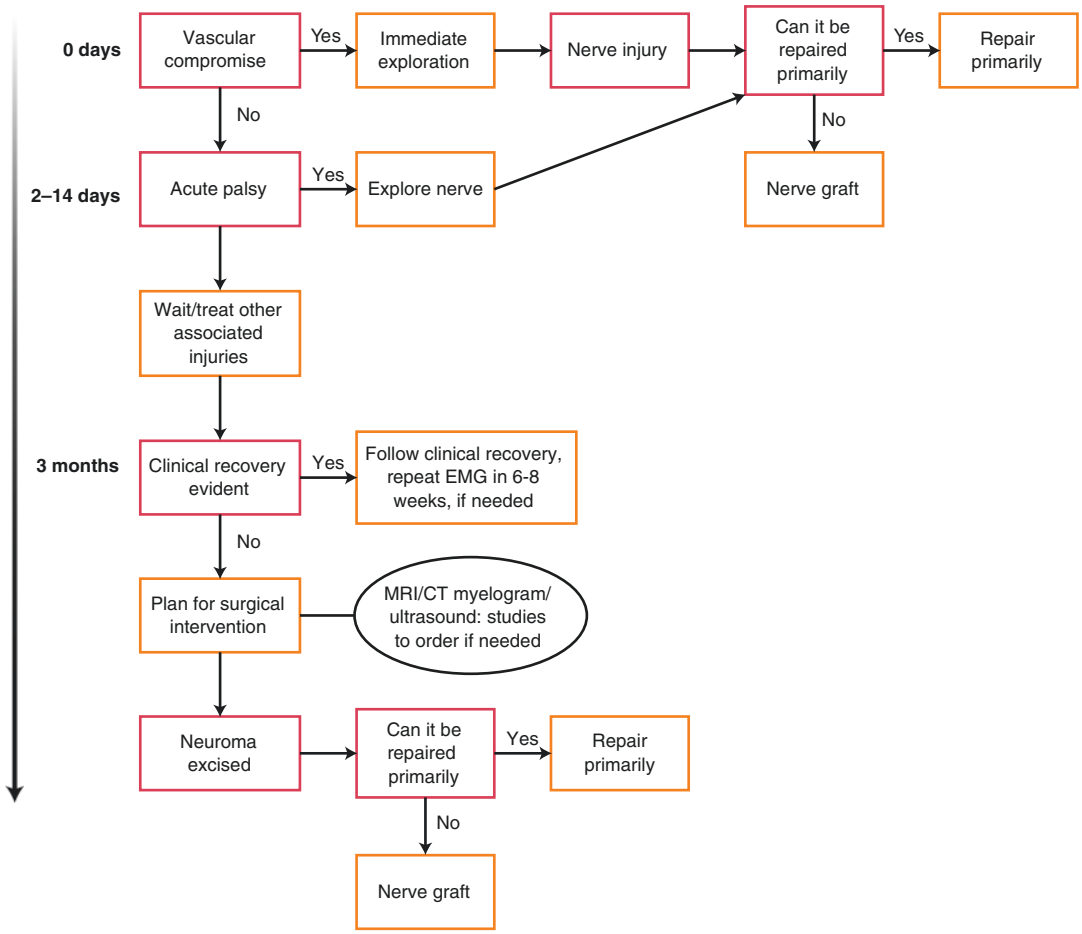

Fig. 38.11 Sharp nerve injury treatment algorithm

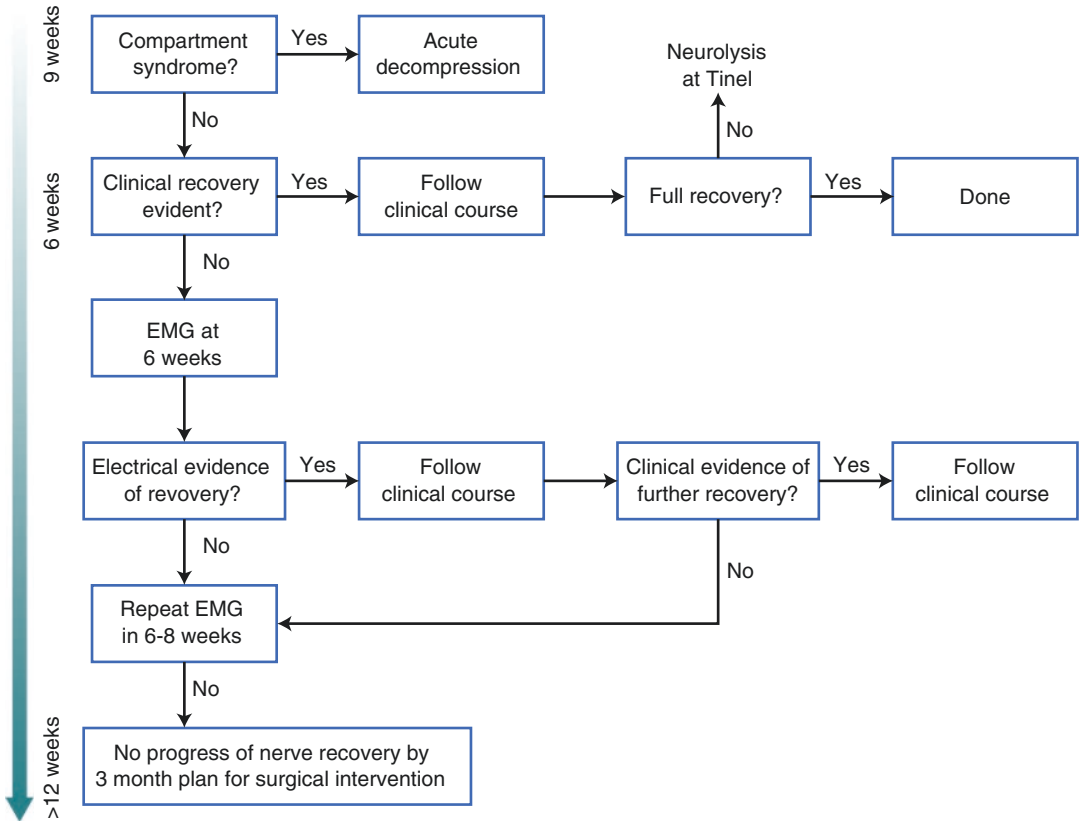

Fig. 38.12 Blunt nerve injury treatment algorithm

Treatment

Nonoperative Treatments

Treatment can consist of expectant management with observation and serial electrodiagnostic studies (EDS). In the early stages of nerve injury, it is difficult to distinguish between neuropraxia and higher-grade injuries, due to the interval required for Wallerian degeneration to occur. For injuries being treated with expectant management (e.g., blunt mechanism nerve injuries), serial examinations and EDS are undertaken. Initial EDS are performed 4–6 weeks post-injury to account for Wallerian degeneration, and follow-up EDS are performed every 6–8 weeks thereafter. If there is no regeneration at the expected rate by 3 months' time, surgical intervention should be considered.

Operative intervention for injured nerves can take several forms. This can occur acutely for sharp/penetrating injuries, or in a delayed fashion after expectant management has failed for blunt injuries.

Principles of Nerve Surgery

There are some principles of nerve surgery to which it is important to adhere, regardless of the type of intervention undertaken. First, injured nerves should be "bread loafed" until healthy fascicles are visualized, to ensure coaptation of healthy, viable fascicles. Early repair increases the likelihood of primary neurorrhaphy, which is the gold standard of nerve repair. However, primary repair should not be performed at the expense of tension-free repair. There should be no tension across the nerve repair site, as tension increases coaptation scarring and impairs regeneration. Delays increase nerve retraction and fibrosis, which can compound nerve gaps.

Technically, nerve repairs should be performed with microsurgical technique, taking care to orient native nerve topography by using fascicular size matching, epineurial arterial patterns, knowledge of known internal nerve topography, and intraoperative nerve stimulation and staining. Nerve repair should be performed in an epineurial fashion with microsutures; 9-0 sutures have shown to be the most resilient; however, 8-0 and 10-0 sutures, nerve wraps, and fibrin glue are all acceptable options [45]. Microsutures may be placed in the epineurium, or perineurium of large nerves, to align fascicles. Care should be taken to ensure there is soft end-to-end contact with no bulging of fascicles.

Operative Treatments

The gold standard of nerve repair is primary neurorrhaphy, in which the distal and proximal ends of the injured nerve are coapted primarily. This can occur within 24 hours of injury, in sharp wounds with minimal crush components and healthy nerve beds, or in a delayed primary fashion within 1 week, which allows for zone of injury demarcation. Secondary repair refers to nerve repair timing after 1 week and is generally used for blunt injuries or sharp injuries with extenuating circumstances such as unstable patients, extremities, or complicating injuries. With the intervening time to secondary repair, the proximal and distal ends of the nerves retract and wound fibrosis develops, complicating nerve repair.

If there is a gap between proximal and distal ends of the injured nerve, the gold standard treatment is with autograft, in the event that primary neurorrhaphy is not an option. To facilitate primary neurorrhaphy in the setting of nerve gaps, one option is to perform neurolysis in order to mobilize the proximal and distal nerve ends to achieve primary coaptation or decrease graft length. In doing so, usually a gap of 1–2 cm can be bridged. If neurolysis is insufficient, the nerve may be transposed (e.g., anterior transposition of the ulnar nerve at the elbow). Other options to address nerve gaps without the use of a nerve graft include bone shortening, as with replanting digits, and direct muscular neurotization by implanting the proximal end of the nerve into the muscle directly to provide innervation.

If the nerve gap is too large to overcome with the aforementioned measures, a nerve graft is required. Nerve grafts heal with a similar sequence to skin grafts, starting with plasmatic imbibition, then inosculation after 3 days, followed by revascularization at approximately 1 week.

Nerve grafts can be performed with autografts, allografts, or nerve conduits. Autografts are the gold standard for nerve gap repair, especially if greater than 5 cm graft is required. Donor sites for autografts are largely nonessential sensory nerves, which can be harvested with minimal donor-site morbidity. Motor nerves grow preferentially along motor nerve grafts, and the same with sensory nerves; however, the donor-site deficit is often unacceptable in harvesting motor nerves; therefore, sensory nerves are largely used for all types of autografting [46]. Any donor-site morbidity can be further minimized with the use of allografts or conduits interposed at the site of autograft harvest to facilitate some sensory recovery. Common autograft donor sites include the sural nerve, and medial and lateral antebrachial cutaneous (MABC, LABC) nerves. Largely, autografts are nonvascularized, but there are less common instances in which vascularized autografts are also employed. Autografts are sutured into the nerve defect in an antidromic fashion, and if the caliber of the injured nerve is large, the autografts are interposed in a cable fashion.

Nerve gaps less than 5 cm, and some studies suggest up to 7 cm, can be treated with interposed allografts [47]. Allografts can be cellular requiring immunosuppression, or more commonly acellular. Acellular allografts retain the scaffold for nerve regeneration by host Schwann cells, with eventual resorption of the allograft material. In assessing outcomes of allografts, a systematic review from 2015 demonstrated that all patients treated with allografts in the included studies achieved meaningful motor recovery and recovered S2PD between 3 and 5 mm and M2PD

between 2 and 15 mm [48]. A histologic study in rat sciatic nerve injuries revealed acellular nerve allograft demonstrated comparable functional recovery when compared to reversed autograft, and superior recovery when compared to antidromic cabled nerve autograft [49]. There were limitations to this study, but the results are promising for the future expanded use of allografts.

In general, in nerve gaps smaller than 3 cm, nerve conduits may be used. Conduits demonstrate equal results to autologous grafts in defects ≤5 mm, with some diminished recovery in >5 mm defects [50]. Although up to 3 cm is advocated by some, in our experience, once the nerve defect exceeds 10 mm, we prefer to use allograft. Conduits can be autologous, such as vein grafts, or non-autologous. Conduits in the latter group are comprised of non-autologous biologic materials, and resorbable synthetic or non-resorbable synthetic materials. Conduits isolate the nerve ends from the peripheral tissues to protect from fibrosis, combat axonal escape, and collect neurotrophic growth factors and axoplasm from the nerve ends to produce fibrin-based scaffold for nerve regeneration [51]. Conduits, unlike allograft materials, lack organized endoneurial architecture and support cells for nerve regrowth. Non-resorbable synthetic materials, such as silicone, present other limitations in use due to risks of chronic nerve compression, fibrosis, and soft tissue reaction. Resorbable synthetic materials, such as polyglycolic acid, and non-autologous biologic conduits, such as collagen conduits, mitigate these limitations. Similar to conduits, nerve wraps can be employed at the sites of nerve coaptation with the goal to prevent axonal loss, bolster the repair, and contain neurotrophic factors.

If the nerve is not amenable to any of these repairs, for example, in the instances of loss of proximal nerve stump or anticipated reinnervation to motor endplates >12–18 months, nerve transfers are employed. Nerve transfers convert proximal injuries into distal injuries and obviate the need for autografts and any associated donor-site deficits.

Nerve transfers are indicated for brachial plexus injuries, unavailable proximal stumps, proximal injuries with long distance to target muscles, scarred wound beds with critical neurovascular structures, major limb trauma with segmental nerve loss, and older injuries in older patients [52, 53]. Donor nerves must be redundant and in close proximity to the target organ. For motor reinnervation, direct end-to-end transfers are advocated, whereas for sensory nerves, end-to-side may also be considered. Another consideration would be augmentation of a result with "supercharging" reverse end-to-side transfers of motor nerves, such as in experimental rat models of allograft use [54], and clinically proximal ulnar nerve injuries through distal AIN to ulnar nerve transfers.

Outcomes

Upper extremities are often splinted post-nerve repair to allow healing across the coaptation site. Depending on the intraoperative assessment, early postoperative range of motion can be initiated (<1 week). Progress of the repair is followed with Tinel's sign. Sensory desensitization and muscle strengthening can occur at 3 months' time. Outcomes from nerve injuries are assessed commonly by the Medical Research Council scale for sensory and motor nerves (see Table 38.4). Other clinical assessments would be development of a painful neuroma, in the treatment of which targeted muscle reinnervation and regenerative peripheral nerve interfaces show promising results, or complex regional pain syndrome.

Conclusion

Peripheral nerve injuries and compression syndromes of the upper extremity are common. Key to management of these conditions is accurate diagnosis and timely intervention. Classically, surgical treatment options include decompression with possible transposition for compressive syndromes, and repair, with or without grafting, for nerve transections. Becoming more routine now are nerve transfers for more proximal nerve injuries and early nerve stump management in cases of amputations.

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Tendon Transfers

39

Harris Gellman

Introduction: What Is a Tendon Transfer?

The tendon of a functioning muscle is detached from its insertion and reattached to another tendon or bone to replace the function of a paralyzed muscle or injured tendon. The transferred tendon remains attached to its parent muscle with an intact neurovascular pedicle and attached to the recipient tendon of the nonfunctioning muscle.

The tendon transfer can help to correct instability, muscle imbalance, and lack of co-ordination and restore function by redistributing muscle force.

Indications for Tendon Transfer

Restore Balance to Deformed Hand: Substitution of Function of Paralyzed Muscle

When there is a peripheral or brachial plexus nerve injury, muscles become paralyzed, which causes weakness, muscle imbalance in the hand, and deformity. Certain neurologic diseases such as multiple sclerosis, or acquired neurologic conditions such as cerebral palsy or brain injury, also result in muscle paralysis and imbalance. These can often be corrected by tendon transfers or tendon release or lengthening [1].

It is important to remember that since you are starting with impaired function, the transfer should not significantly decrease the remaining function of the hand. Taking away a muscle that is critical to hand function may not be the best choice. It is important that the surgeon's expectations of the outcome of the surgery should be balanced with what the patient needs or is expecting as the result of the procedure [2].

Occasionally, nerve function will return after tendon transfer. This is particularly likely if a tendon transfer and radial nerve repair are done simultaneously. The transfer chosen should not create deformity if significant return of nerve function occurs following repair.

Ruptured or Avulsed Tendon-Muscle

While tendon transfers are often the treatment of choice for ruptured or otherwise injured tendon or muscle, other considerations for treatment include tendon graft and free muscle transfer and may be combined with selected joint fusions.

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Considerations for Reconstruction After Tendon or Muscle Injury

When considering whether to perform a tendon graft rather than a tendon transfer, the condition of the injury area, scar in the area of surgery, and soft tissue coverage must all be considered before proceeding with surgery. The length of time since injury may also be a factor in the decision process.

Fundamental Principles of Muscle-Tendon Units Include Correction of Contracture

- In any patient with a peripheral nerve palsy, all joints must be kept supple. Soft tissue contracture is far easier to prevent than to correct.
- Maximum passive motion of all joints must be present before a tendon transfer can be performed. If the joint is not freely mobile, the transfer will certainly fail.
- No tendon transfer can move a stiff joint on its own and do not expect a stiff joint to miraculously move just because it has been attached to a tendon.

Adequate Strength

The tendon chosen as a donor for transfer must be strong enough to perform its new function in its altered position. Selecting an appropriate motor is important, because most muscles will lose one grade of strength following transfer. Do not transfer a muscle that has been reinnervated or a muscle that was paralyzed and has returned to function, as these muscles tend to be weaker than it appears on manual testing [3, 4].

Plan on losing at least one muscle grade when transferring the muscle, so if the muscle you want to transfer is not at least grade 4, does not bother, unless you are doing the transfer for the tenodesis effect only.

Manual muscle testing is not a precise science. Dynamometric testing has shown that muscles have to lose 40–50% of strength until you can perceive weakness. Beasley long ago showed that knee extension strength was often graded "normal" when dynamometry showed it to be only about 50% of normal [5, 6]. Clearly, referring to such strength as normal is a misappropriation of the word. Dvir [7] concluded that elbow and knee actions graded as 4 (good) may be generating as little as 10% of expected maximum output. Unfortunately, calling such output "good" may exaggerate the strength being described.

Tendon Excursion

The tendon excursion of the donor unit must be sufficient to restore the loss of function [8]. For example, in wrist extension and flexion, there is 33 mm of tendon excursion. Finger extension and flexion has a tendon excursion of 50 mm and 70 mm, respectively [8]. Wrist flexion and extension can add 20–30 mm of excursion through the tenodesis effect [4, 9].

Disadvantages of Tendon Transfers

- No increase in strength.
- Normal function of transferred muscle is lost.
- Transferred tendon may perform a different force, amplitude of movement, and functional pattern.
- Transferred tendon must learn a new movement/function.

How to Have a Successful Outcome with Upper Extremity Tendon Transfers [10]

First, you must decide:

1. What are you trying to accomplish?
2. What resources do you have?
3. Which of the resources are expendable?
4. How can you best utilize your resources?

Expendability

Transfers should use muscles that are redundant, or expendable. There are multiple wrist extensors and wrist flexors. The palmaris longus muscle, when present, is an expendable muscle. Remember that the transfer must not result in loss of an essential function [2].

Synergistic or "in phase" muscle groups are generally easier to retrain and often need no retraining. Therefore, try to use a muscle to transfer that is in "phase" with the function you are trying to restore. This will result in the patient being able to easily learn to use the transfer. This is particularly important in older patients.

The easiest way to think of this is to think of muscle function in terms of:

Fist group: Wrist extensors, finger flexors, digital adductors, thumb flexors, forearm pronators, intrinsics. The wrist extensors and finger flexors generally are synergistic and fire at the same time.

Open hand group: Wrist flexors, finger extensors, digital abductors, forearm supinator. The wrist flexors and finger extensors are synergistic and fire at the same time.

In addition, the use of synergistic muscles tends to help retain joint balance.

When attempting transfers in patients with underlying neurologic issues (cerebral palsy, stroke, brain injury), it is important to differentiate spastic muscles from muscles with chronic increased tone. You should not transfer a spastic muscle.

Muscles with increased tone can be released or lengthened to allow antagonistic muscles to function after transfer.

Setting Tension

Rough rules are that if you bring insertion and origin of the donor and recipient muscle as close as possible (flex elbow and wrist) then you can set the tension at resting muscle length.

- Muscles to be transferred must have adequate excursion. Utilizing the tenodesis effect of wrist or finger rom can help to increase excursion.
- If you are putting a transfer in at functional position, then set the tension at 75% of muscle excursion.
- Make sure the tendons are flat when suturing them together. If they are lifted when sutured, the tension will be lax and the transfer may not work.
- Always run the wrist or fingers through a functional range of motion to make sure the transfer is not too tight or too loose.
- Transfer the tendon in a straight line of pull if possible, and use one tendon for one function.
- Combinations of fusions and transfer may give significant improvement when you have limited resources.
- Try if possible not to use one muscle to move two joints or perform two functions. (Exception to this rule is using rerouted flexor pollicis longus [FPL] to extend and abduct the thumb.)
- Although many transfers recommend using the ring flexor digitorum superficialis (FDS), this can be a very difficult transfer for an older person to re-learn.
- Use the simplest transfer when possible; you may not have access to an experienced therapist or the patient may be noncompliant.
- Many transfers will function automatically once healed and require minimal rehabilitation.

One final thought, when planning for transfer, avoid "cookbook" decisions. It is important to evaluate the way the patient uses his/her hand and the patient's greatest subjective and objective needs [9].

Functional Loss and Author's Recommended Transfers

Median Nerve Injuries

Low median nerve injury results in loss of thumb opposition. If the deficit is due to an anterior interosseous palsy, there is also loss of index flexor digitorum profundus (FDP) flexion and flexion of the distal phalanx of the thumb.

Because surgical decompression is unpredictable, it may be better to wait 4–6 months, and if no recovery of function occurs, then perform tendon transfers to restore the lost function.

For high median nerve palsy, the patient needs finger and thumb tip flexion as well as thumb opposition. There may also be decreased strength of forearm pronation. Wrist flexion typically remains intact secondary to the ulnar innervation of the flexor carpi ulnaris (FCU) muscle.

Author's Preferred Transfers

Low Median Palsy

This results in loss of opposition (palmar abduction and pronation). The extensor indicis proprius (EIP) opponensplasty is almost always an option in cases of isolated median nerve palsy and has the advantages that no pulley is required, and the donor deficit is minimal (Fig. 39.1). A dorsal longitudinal incision is made over the metacarpal phalangeal (MCP) joint of the index finger. The sagittal band is carefully elevated off of the EIP for later repair. Remember that the EIP is ulnar and deep to the EDC tendon and juncturae tendinum. The EIP is divided distal to the MCP joint and retrieved to a dorsal forearm incision proximal to the extensor retinaculum (Fig. 39.1). The extensor hood is then repaired. The EIP tendon is passed subcutaneously around the ulnar border of the wrist to a tunnel created across the palm in the subcutaneous plane. Finally, an incision is made over the radial border of the thumb MCP joint, and the tendon is sutured into the APB insertion (Fig. 39.1). The transfer is tensioned with the thumb in maximum palmar abduction and mild flexion [11].

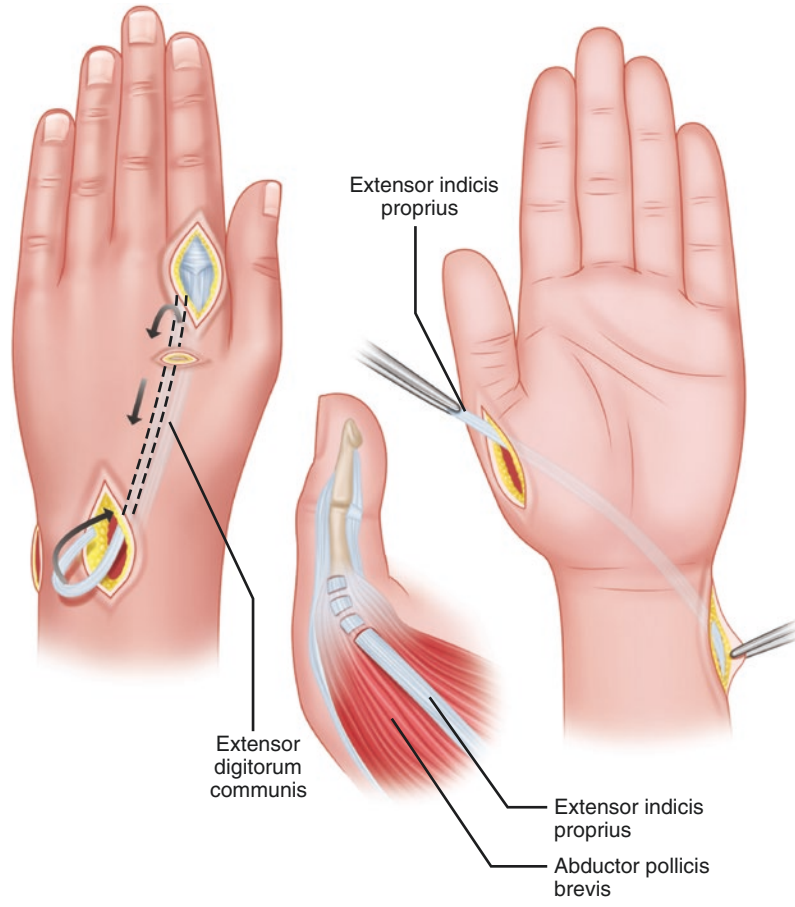

Fig. 39.1 Extensor indices proprius transfer for thumb opposition

In transfers that originate in the forearm, the vector of pull must be changed to allow opposition. This can be achieved by several methods. The pisiform is optimal for placement of a pulley to redirect a tendon for opposition [12].

In a recent biomechanical study of pulley placement in tendon transfers for restoration of thumb opposition, the Thompson pulley, which uses the distal end of the transverse carpal ligament and the ulnar border of the palmar fascia [13], and the Guyon canal pulley, which uses tendon graft placed through the canal and a subcutaneous palmar tunnel [14], were associated with the least amount of frictional force [15].

The advantage of the EIP transfer is that no additional pulley is needed.

High Median Nerve Palsy

With a high median nerve injury, there is the additional loss of all of the superficial finger flexors (flexor digitorum sublimis, or FDS) and the deep finger flexors (FDP) to the index and long fingers, as well as flexion of the thumb (flexor pollicis longus, or FPL).

The simplest and quickest transfer to restore finger flexion is to suture the index and long finger FDP to the ring finger FDP in the distal forearm; this works well since isolated median palsy leaves ulnar nerve function intact and the ring and small finger flexors should function normally. Patients will still have individual extension of the fingers through the radial nerve innervated extensor digitorum communis (EDC).

In high median nerve palsy, thumb interphalangeal (IP) flexion is typically restored with a brachioradialis (BR) to FPL transfer [16]. The brachioradialis is released from the attachment to the radius through an incision in the distal forearm. A second, more proximal incision is necessary to fully free the muscle to get maximal excursion. Typically, the muscle has 2.5 cm of excursion. It is important to identify and carefully free the radial sensory branch which is passing under the distal 1/3 of the tendon to prevent injury to the radial sensory branch.

The tenodesis effect is important when evaluating the tension of these transfers. With the wrist flexed, the surgeon should be able to passively extend the index finger and radially abduct and extend the thumb. This ensures that the transfers are not too tight, reducing the incidence of flexion contracture.

With the wrist passively extended, the index finger should flex into the palm, and the thumb should pinch firmly against the side of the index finger. A sugar-tong splint with a thumb spica extension is applied, taking tension off the transfers. The wrist is flexed to 20°, and the thumb is positioned in palmar abduction and flexion. If a side-to-side FDP suture was performed, all four fingers are immobilized in the intrinsic plus position.

Radial Nerve Injuries

Radial nerve palsy results in loss of the ability to extend the wrist, fingers, and thumb. These movements are essential for functional grasp. The patient loses grip strength because of inability to stabilize the wrist during power grip.

Low (or distal) radial nerve palsy is a result of injury to the posterior interosseous nerve (PIN) which is the deep branch of the radial nerve. This injury occurs distal to the elbow. Wrist extension is preserved because the more proximally innervated extensor carpi radialis longus (ECRL) remains intact. If the PIN is injured proximally, extensor carpi ulnaris (ECU) function may be lost, resulting in radial deviation with wrist extension. If the injury to the PIN is more distal, ECU function is preserved and wrist extension remains balanced.

High radial nerve palsy is defined as an injury proximal to the elbow. Wrist, finger (MCPJ), and thumb extension, as well as thumb abduction are lost.

There are three main goals when treating radial nerve palsy. They include restoration of finger (MCPJ) extension, restoration of thumb extension, and in cases of high radial nerve palsy, restoration of wrist extension [17].

Author's Preferred Techniques

Low Radial Nerve

Need to restore thumb and finger extension: FCR is a good choice for the transfer since it is expendable is synergistic with the finger extensors. Use of the FCR results in no functional loss and improves overall function.

Palmaris longus is most frequently used for transfer for thumb extension. Since both thumb extension and abduction are needed, taking the EPL out of the third compartment and letting it sublux radial and volar will result in the transfer achieving both extension and abduction of the thumb.

High Radial Nerve

This injury typically results in the additional loss of wrist extension. Despite the short tendon, the pronator teres is an excellent choice for transfer, since it will provide both wrist extension and pronation. When harvesting the tendon for transfer, the surgeon will need to strip as much of the tendon as possible off of the radius, tube it, and weave it into the wrist extensor tendons.

The Brand transfer [18] as described below is the most dependable transfer to restore radial nerve function. It uses expendable, synergistic muscles and has consistently good results.

Brand Transfer [18] (Table 39.1)

Brand Transfer for Radial Nerve Palsy (Technique)

The pronator teres tendon, which is short, is harvested in continuity with a 4 cm cuff of periosteum in order to have sufficient length for a weave into the ECRB tendon (Fig. 39.2). The tendon is then routed radially and woven to the ECRB tendon with the wrist in 30–40° of extension while the forearm is held in pronation.

If recovery of the radial nerve is not expected, the transfer may be performed in an end-to-end fashion, meaning that the extensor carpi radialis brevis tendon is transected and the cut end of the pronator teres tendon sutured to it. This creates a direct line of pull and a more efficient transfer. However, if the radial nerve has been repaired and extensor carpi radialis brevis reinnervation is expected in the future, the transfer should be performed in an end-to-side fashion, with the cut pronator teres tendon sutured to the side of the intact extensor carpi radialis brevis tendon [17].

For restoration of finger extension, the FCR tendon is then released distally at the wrist and transferred around the radial side of the wrist to the finger extensors (Fig. 39.3).

Prior to suturing the FCR into the EDC, the tension on the fingers should be set using the tenodesis of the tendons, and the tendons sutured side-to-side so that when the FCR is sutured to the EDC, the tension will pull equally on all of the fingers. If, when the tendon is transferred, any of the tendons are not included, the tension will already have been set by the side-to-side suturing of the EDC tendons.

To restore thumb extension, the EPL (Fig. 39.4) is released from the third extensor compartment and allowed to translate volarly. The palmaris tendon is released as distally as possible, and the tendon is sutured to the translated EPL tendon to achieve thumb extension and abduction.

Table 39.1 Brand transfer

Donor	Insertion	Function
PT	ECRB	Wrist dorsiflexion
FCR	EDC IF – LF	Finger extension
PL	EPL (rerouted)	Thumb extension

Ulnar Nerve

Low The main loss with a low ulnar nerve palsy is intrinsic function. The intrinsics provide pip extension, and not the radial innervated long finger extensors, which extend the MCP joints. The loss of PIP extension and the resultant pull on the long extensors, trying to achieve PIP extension, is the reason that low ulnar nerve palsy patients develop clawing (Fig. 39.5).

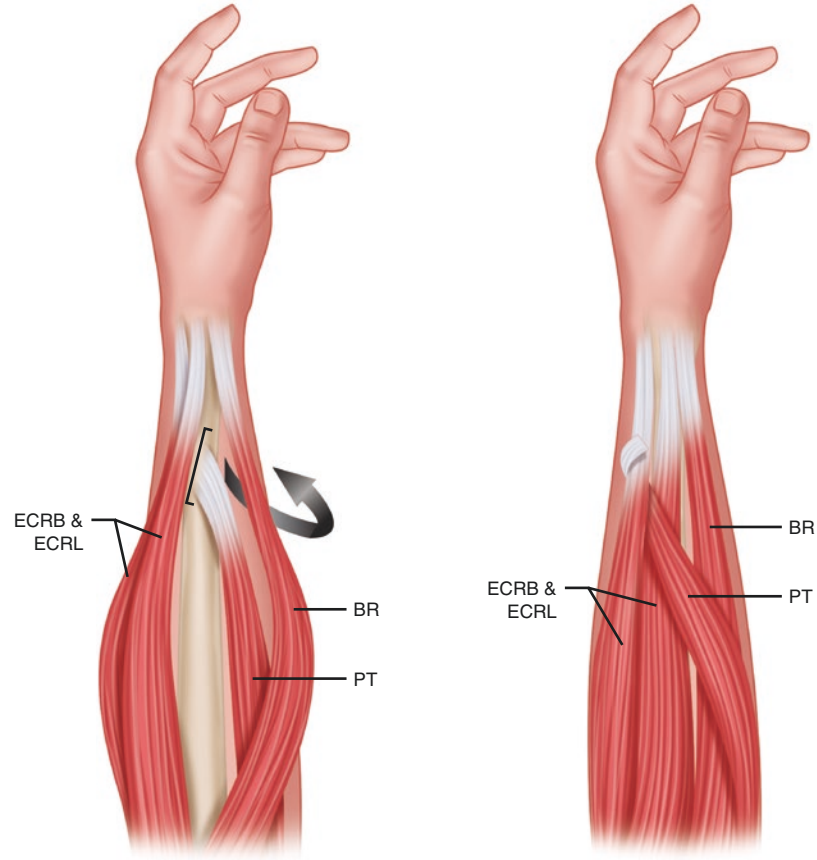

Fig. 39.2 Transfer of the pronator teres to the ECRB for high radial nerve palsy

Clawing usually does not occur with high ulnar nerve palsy because of the concomitant loss of finger flexion. As the ulnar nerve recovers, the finger flexors will return before the intrinsics, and clawing will result.

Intrinsic loss causes asynchronous finger flexion, which results in the IP joints flexing before the MCP joints. This is why patients with loss of intrinsic function push objects out of palm when trying to grasp them (Fig. 39.6).

The Bouvier maneuver is useful in determining if the pip joints are supple or have fixed contracture in patients with ulnar nerve palsy. Dorsal pressure over the proximal phalanx to passively flex MP joint results in straightening of the pip and dip joints and temporary correction of claw deformity.

Extensor digitorum tendon can extend the middle and distal phalanges when the proximal phalanx is flexed at the MCP joint, which prevents the extensor hood from blocking excursion of the long extensors to the fingers.

It is important to start splinting the patients early, with the MCP joints flexed to prevent the development of pip contracture (Fig. 39.7) [19].

Author's Preferred Technique for Ulnar Nerve Palsy

Low Ulnar Nerve Injury

The simplest procedure is a passive capsulodesis, or Zancolli lasso (Fig. 39.8), which will create a flexion deformity at the MCP joint to counteract clawing, which occurs when the MCP hyperextends and the extensor hood blocks full pip extension. The flexor digitorum superficialis (FDS) of the middle finger is divided into four slips (one for each finger) and reattached to itself after passing through the proximal A1 pulley [20].

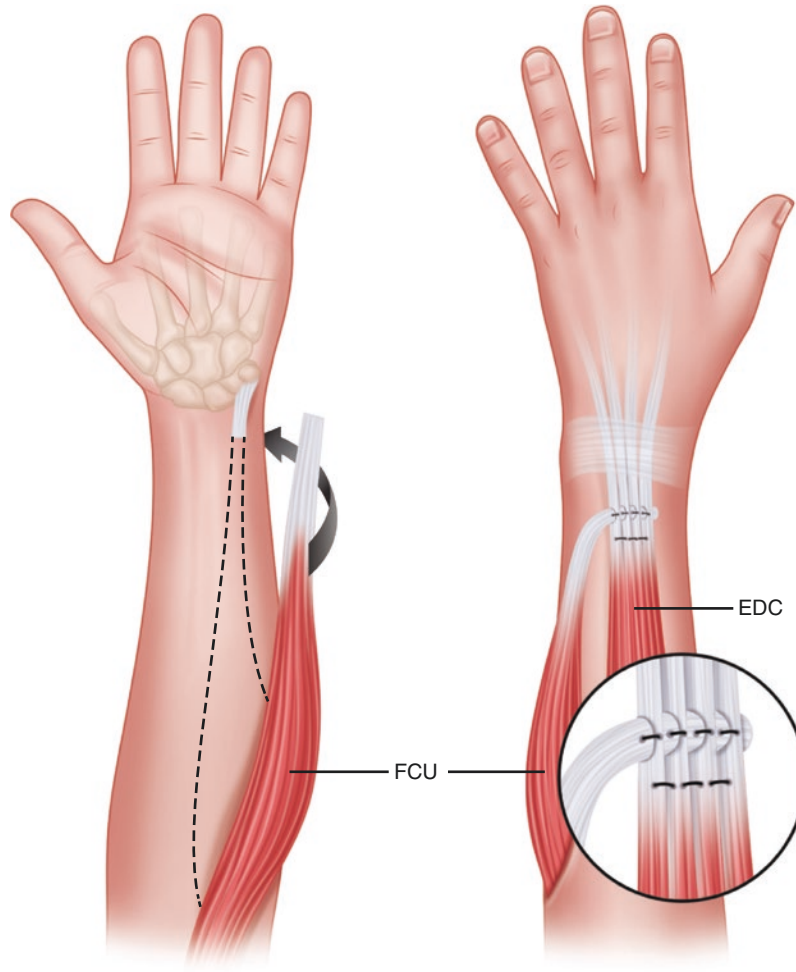

Fig. 39.3 Transfer of the FCR to the EDC to restore finger extension

As the deformity improves, the grip strength increases, as the hand can be put in a more mechanically advantageous position to use the remaining muscle tendon units. The procedure also tends to correct the flattening of the transverse metacarpal arch which occurs in ulnar paralysis. As the transverse metacarpal arch corrects, four-finger pinch improves. The maximum deformity improvement was noticed in patients with shorter duration of paralysis. Correct tension during suture of transferred slips and adequate protection and training of the hand during the postoperative period are important for good outcome [21].

Active Transfer

The ECRB or ECRL transfer using a palmaris graft split into four tails to gain adequate length, as described by Paul Brand, is an excellent choice to correct loss of intrinsic function. If the transfer is placed into the proximal phalanx, it will improve grip strength, but it will not be as effective for improving finger extension at the pip [22].

When attaching the transfer, wrap the tail around the intrinsic tendon rather than try to split the intrinsic and weave the graft. This will prevent accidental rupture of the intrinsic tendon (Fig. 39.9).

No tendon transfer should be performed unless the pip joints are fully supple and have a near normal range of motion.

High Ulnar Nerve Palsy

In addition to loss if intrinsic function, there is the additional need to restore FDP function to

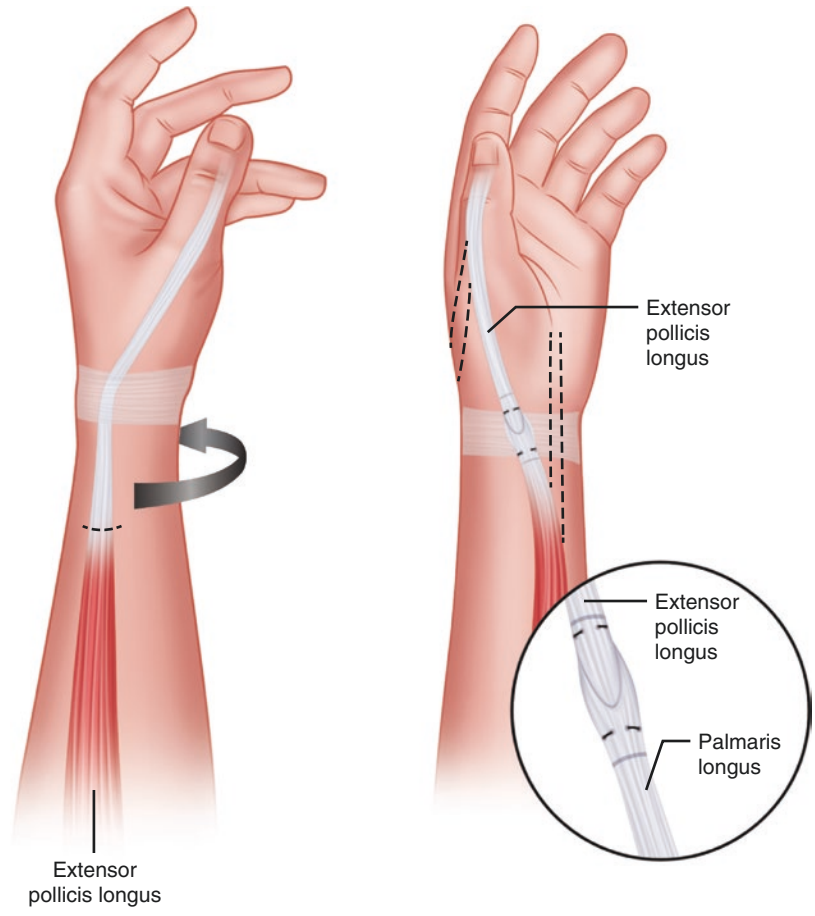

Fig. 39.4 Transfer of the palmaris longus tendon to the re-routed EPL for thumb extension

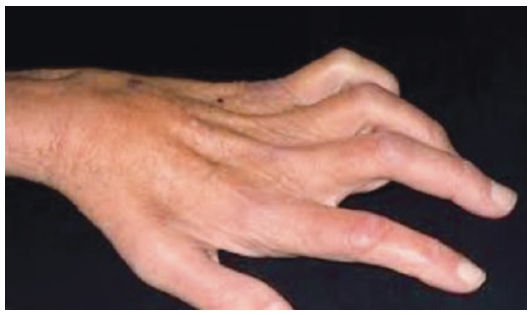

Fig. 39.5 Clawing due to loss of intrinsic function

ring and small fingers. The simplest way to do this is to transfer the ring and small FDP to the long finger FDP in the distal forearm. Set the tension of the ring and small finger flexion just a little bit tighter than the index and long with the wrist in extension and observing passive flexion of the digits (Fig. 39.10).

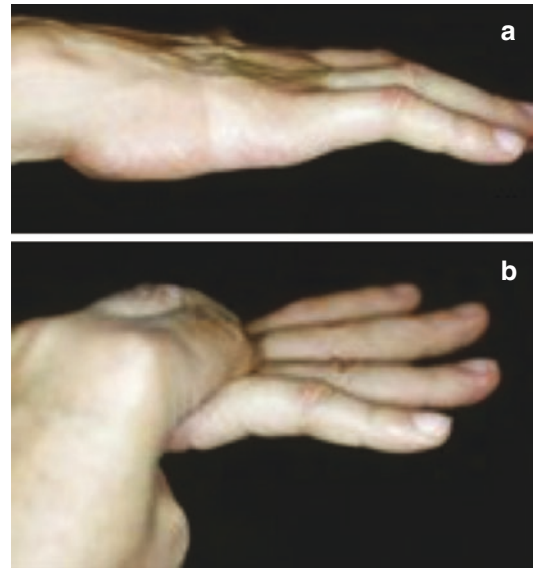

Fig. 39.6 Bouvier maneuver to evaluate pip joints for fixed or passively correctable contracture

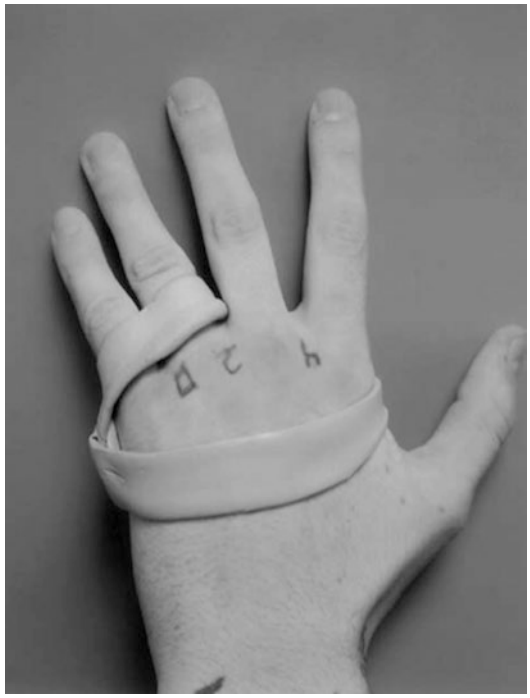

Fig. 39.7 Lumbrical splint to flex MCP joints and allow EDC to extend PIP joints to prevent the development of fixed contracture

Key Pinch

Restoration of key pinch may or may not be required. Many patients are able to function well because of compensation by the FPL, or because the adductor pollicis receives aberrant innervation from the median nerve. No tendon transfer is necessary unless the patient notices a significant loss of pinch function. In addition, when key pinch is required, it is usually only necessary to restore adductor pollicis function [11].

The ECRB or BR may be used to restore key pinch. The tendon must be elongated with a tendon graft (Fig. 39.11). The tendon graft is then routed through the second or third intermetacarpal spaces from dorsal to volar, and into the palm. The graft is then routed radially across the palm, deep to the flexor tendons, digital nerves, and digital arteries, and toward the adductor pollicis insertion. The border of the second or third metacarpal acts as a pulley to achieve the correct line of pull for key pinch.

Postoperative Management

Immobilize the patient for a minimum of 4 weeks, but preferably 6 weeks, in a relaxed position after transfer to allow sufficient healing and scar to form, otherwise the transfer may stretch.

Therapy is started, continuing to protect the transfers in a custom splint, for an additional 6 weeks. Since the transfers described in this chapter are synergistic, very little muscle re-training is required, and most patients will be able to use the transfer as soon as they come out of their immobilization.

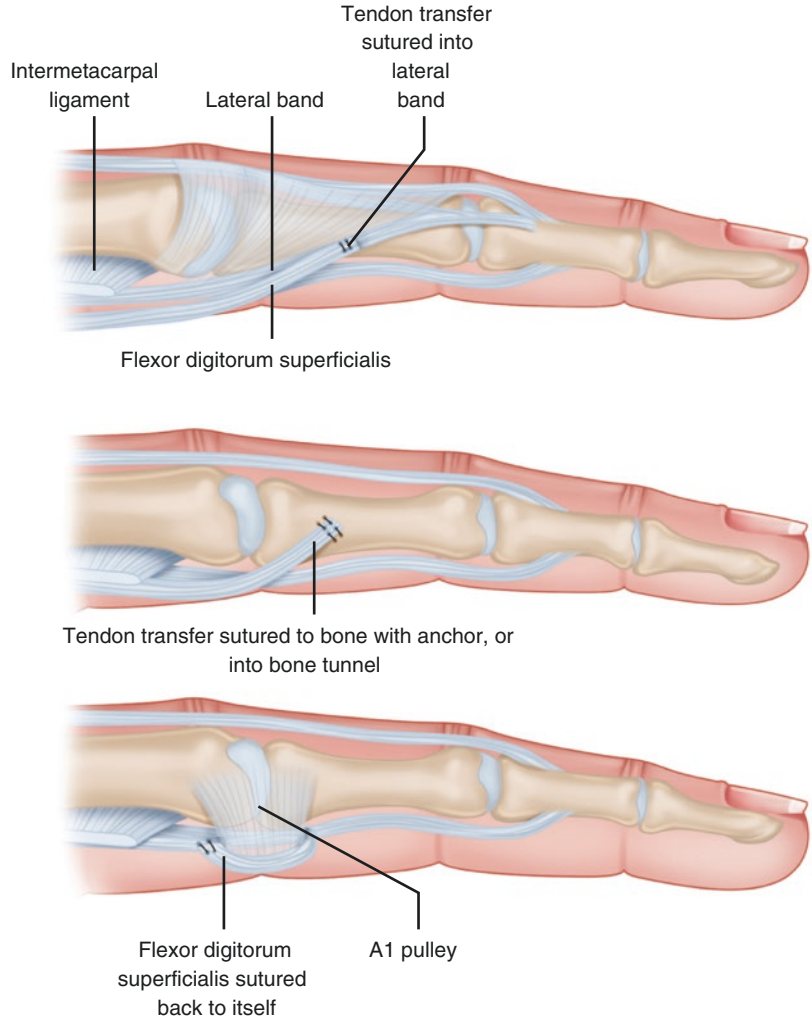

Fig. 39.8 Three classic insertions for transfers to correct clawing: lateral band, bone of proximal phalanx, and the flexor tendon sheath

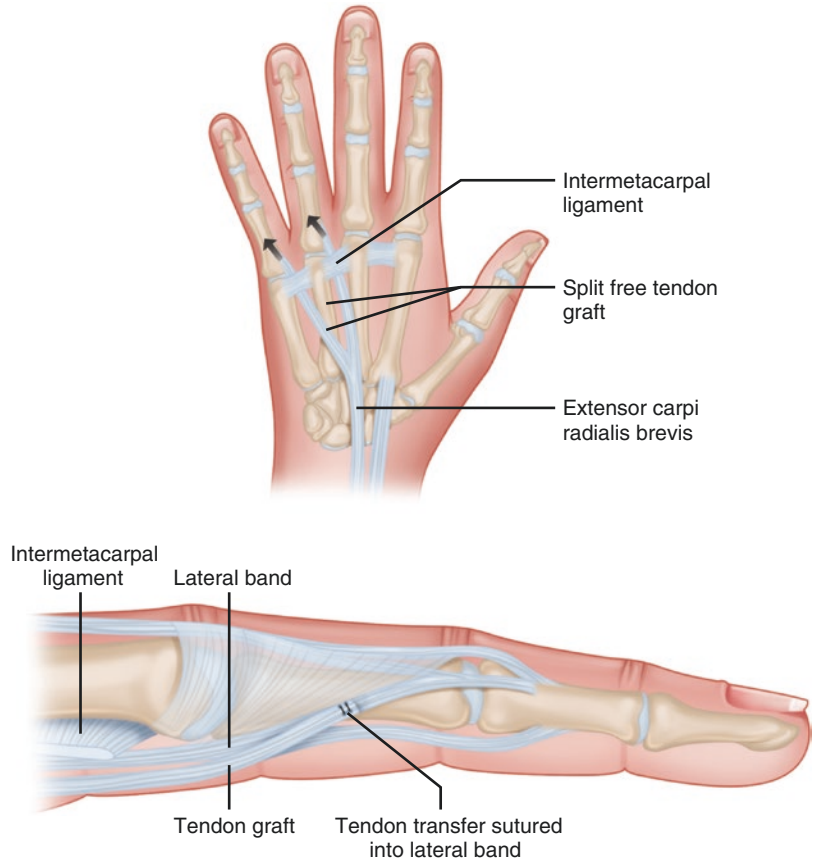

Fig. 39.9 Transfer of elongated ECRL to the radial lateral bands of the ring and small fingers, for dynamic correction of clawing

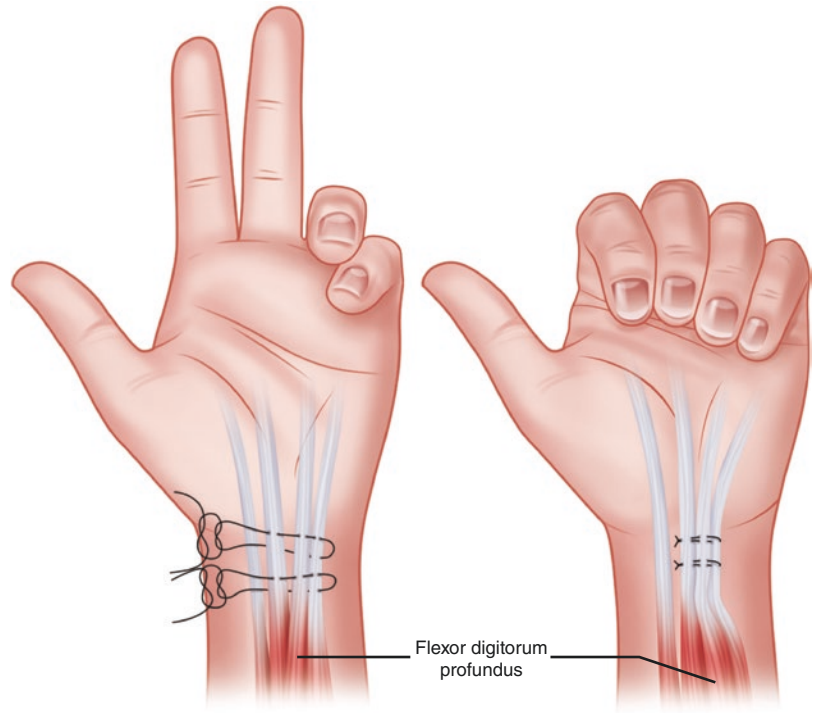

Fig. 39.10 For high ulnar nerve palsy, the FDP of the ring and small fingers are sutured side to side to the FDP of the long finger

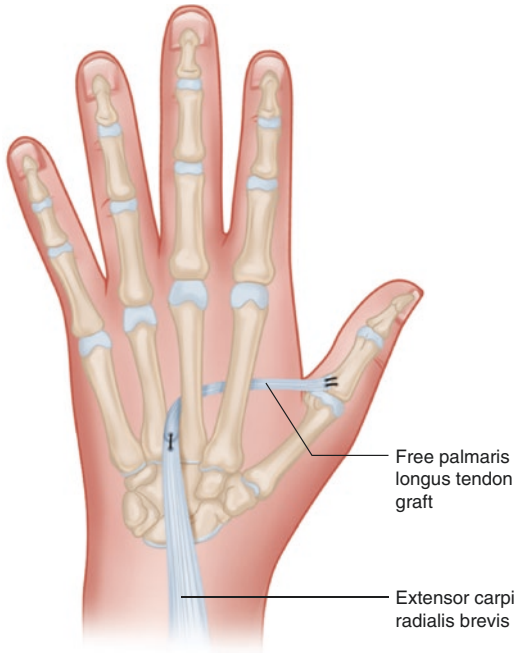

Fig. 39.11 Transfer of elongated ECRB to adductor pollicis insertion for restoration of key pinch

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Congenital Hand Differences

40

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Introduction

Congenital hand differences arise embryologically between the 4th and 8th weeks of gestation, with an incidence of 0.1–0.2% of births [1]. Disruption of signaling centers may be responsible for a wide spectrum of disorders which can present with varying degrees of severity (Table 40.1). This chapter will discuss terminology (Table 40.2) and general tips for dealing with the pediatric surgical patient. The most common of the congenital hand disorders and pediatric hand conditions requiring surgical referral will be reviewed, emphasizing tips and tricks for diagnosis and treatment.

General Evaluation of Pediatric Hand Patients

Hand examination for very young patients is challenging and requires some creativity. A good way to begin the examination is having the child seated on a parent's or caregiver's lap, playing with a toy. Observation of hand function is quite revealing, particularly with regard to thumb function and active motion of joints. Look for exclusions or substitutions of digits. Save direct "hands-on" examination for last, as the child may become frightened and uncooperative. Serial examinations over time are very helpful in determining existing function. These multiple visits are also helpful in preparing parents for their child's surgery.

A full history and exam are critical to investigate for associated abnormalities. This includes a thorough family history for relatives with similar hand differences or other congenital differences of any type. Consider a consultation to a geneticist if there is concern for possible syndromic features, or if the parents desire further genetic evaluation for heritability.

Counseling Parents

As the hand surgeon, you will likely be the first person parents have met with who has any true expertise regarding their child's condition. Parents may be quite anxious for their visit, as they want to know the impact their child's condition is going to have on his or her life. Conversely, in the age of the Internet, it is also common for the parents to have read a great deal of information (and misinformation) regarding their child's condition, as well as conditions not relevant to their child. It is the job of the hand surgeon to

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Table 40.1 The International Federation for Societies for Surgery of the Hand (IFSSH) Classification [2]

I. Failure of part formation
A. Transverse deficiencies
B. Longitudinal deficiencies
1. Phocomelia
2. Radial (radial club hand)
3. Central (cleft hand)
4. Ulnar (ulnar club hand)
II. Failure of part differentiation
A. Synostosis
B. Radial head dislocation
C. Symphalangism
D. Syndactyly
E. Contracture
1. Soft tissue
(a) Arthrogryposis
(b) Pterygium
(c) Pediatric trigger thumb
(d) Absent extensor tendons
(e) Hypoplastic thumb
(f) Clasped thumb
(g) Retroflexible thumb
(h) Camptodactyly
(i) Windblown hand
2. Skeletal
(a) Clinodactyly
(b) Kirner deformity
(c) Delta phalanx
III. Duplication
A. Thumb
B. Triphalangism/hyperphalangism
C. Polydactyly
D. Mirror hand
IV. Overgrowth
A. Limb
B. Macrodactyly
V. Undergrowth (e.g., Brachydactyly, brachysyndactyly)
VI. Congenital constriction band syndrome
VII. Generalized skeletal abnormalities

The IFSSH classification is perhaps the most widely used schema of congenital hand differences. It attempts to organize diagnoses by embryological etiology

Table 40.2 Definitions of terms

Term	Definition
Syn-	Fused transversely
Sym-	Fused longitudinally
Clino-	Deviated in the coronal plane
Campto-	Flexed in the sagittal plane
Acro-	Peripheral, distal
Dactylos	Finger
-melos	Limb

provide them with clear and accurate information at the first visit, and it is important to discuss the expected outcome and function of their child as an adult. For the majority of congenital hand conditions, the child's expected *functional* outcome will be excellent. However, it is just as important to discuss with them what cannot be corrected and thus to identify future challenges for the child. This includes aesthetic as well as functional challenges.

The vast majority of congenital limb differences are the result of either spontaneous or inherited mutation. Environmental factors such as teratogens almost never play a role. This is important to understand when meeting parents of children with limb differences, as they often bear a great deal of unwarranted guilt. The surgeon treating congenital limb differences has the primary responsibility for educating parents, as well as following the child throughout development, often until they reach skeletal maturity and beyond. It is also the surgeon's responsibility to ensure that the patient has had appropriate evaluation for associated conditions (renal, cardiac, and neurologic) when warranted.

Finally, it is always important to consider the viewpoint of the parents. A hand surgeon may think their outcome looks good, while parents and others may be more likely to focus on the differences that remain. Instead of saying "it looks really good," say "this is how it is supposed to look." Showing parents postoperative pictures ahead of time is also very valuable.

General Timing Considerations

In most cases, surgery is delayed until around 12 months of age, when structures are larger and easier to manipulate. Also, general anesthesia may become safer as the child ages, due to maturation of the airway. Earlier intervention should be considered, however, if the condition affects limb development or interferes with developmental function. For example, border

digit syndactyly may interfere with growth due to length discrepancy of digits (see below for further discussion). An additional consideration regarding timing is that children start to experience peer pressure at around 4 years of age. Correction should ideally be planned before this time to facilitate social development and prevent children from being stigmatized.

Immobilization

As with hand surgery in adults, immobilization should only be used when necessary. Trigger finger releases and type B postaxial polydactyly excisions require no immobilization. For more complex procedures, some immobilization is often indicated. Recognize, however, that the active forces that can be generated by an infant or toddler are small and the "strength" of the needed immobilization is less than what we associate with similar procedures on adults. For these younger patients, excellent immobilization can often be achieved with cotton gauze alone. To create a cotton gauze splint, the hand should be surrounded by unfolded Kerlix or cotton fluffs. The cotton gauze is then saturated with saline and the dressing is compressed around the area to be immobilized. The dressing is then completed with additional dry cotton gauze, with or without a cast or splint. When the dressing is removed, one can see that the compressed cotton has been formed into an immobile mass that conforms to the contours of the hand.

Young children are escape artists and will try to get out of any cast or splint placed on them. There are many cases where immobilization or protection of the surgical site is critical for success, for example, syndactyly reconstruction, opponensplasty, or pollicization. A long-arm cast or splint can be made with fiberglass or plaster. To prevent inadvertent removal of the cast or splint, flex the elbow to 100° during application. Make certain that there is sufficient padding over the ulnar nerve at the medial elbow. An adult might not tolerate this position, but children tend to do fine. Cast material extends to the tips of the fingers, completely covering them. Great care must be taken when applying the cast to avoid any excessive pressure, which may result in pressure ulceration. Parents are encouraged to cover the dressing with a tube sock that can easily be exchanged whenever it gets dirty.

Specific Conditions

Syndactyly

Background

Syndactyly is fusion of two or more digits to each other. Syndactyly is one of the most common congenital hand conditions, with an estimated incidence between 1:1000 and 1:3000 live births [3]. Approximately half of cases are bilateral, and syndactyly is more common in males (2:1). Most are spontaneous, isolated mutations, but sometimes autosomal dominant inheritance with variable penetrance is seen (10–40% hereditary). Complex syndactylies are more often part of a syndrome such as Apert, Carpenter, or Saethre-Chotzen syndrome.

Syndactyly encompasses a spectrum of presentations and severities (Fig. 40.1). "Simple" syndactyly means that only the skin and soft tissues are fused, versus "complex" syndactyly in which fusion of bony elements is involved. "Complete" syndactyly means that the fingers are joined all the way to the fingertips, versus "incomplete" where the fusion does not extend to the fingertips. "Acrosyndactyly" refers to the situation where only the fingertips are fused, and the more proximal elements are not fused. Acrosyndactyly is classically a feature of Apert's syndrome.

Evaluation

Thorough past medical, family, and birth history should be obtained. Hand examination should determine what digits are involved and the extent of involvement. Look for fusion of the nails (synonychia), which is indicative of underlying bony fusion (complex syndactyly). When border digits are involved, there may be resulting deviation of the longer digit toward the shorter one (clinodactyly), as well as proximal interphalan-

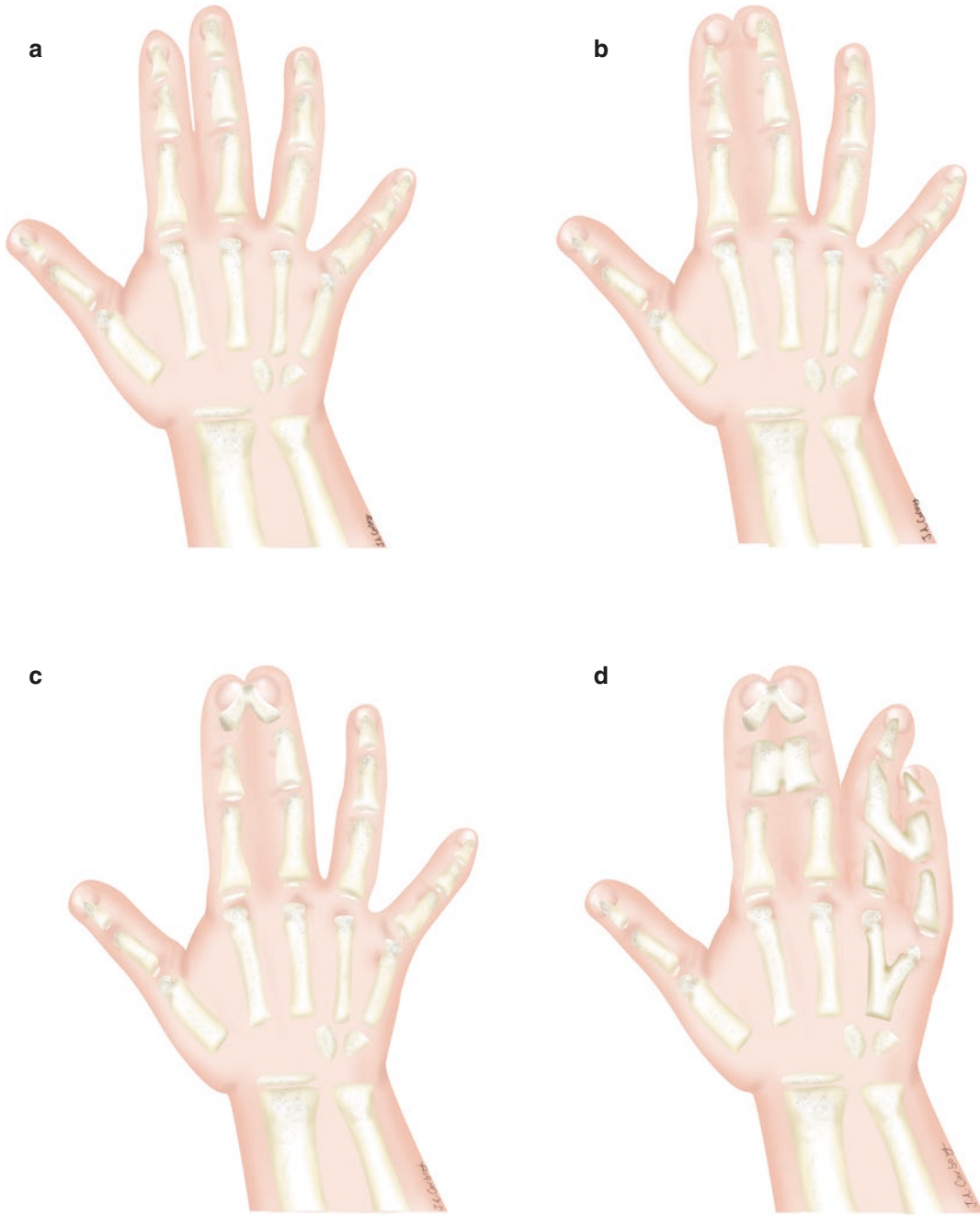

Fig. 40.1 Classification of syndactyly. (**a**) Simple incomplete. (**b**) Simple complete. (**c**) Complex. (**d**) Complicated. (Illustration by Jourdan A. Carboy)

geal (PIP) flexion contracture, which can be progressive with growth and is difficult to treat. Exam should include the entire involved and contralateral upper extremities, the chest wall (specifically looking for absence of pectoralis musculature and abnormalities of the bony thorax indicative of Poland syndrome), and the feet.

Plain radiographs of the hands should be obtained to evaluate for bony involvement.

Associated syndromes include Aperts, Crouzon, Pfeiffer, Saethre-Chotzen, and Poland syndrome. Syndromic syndactyly is more often complex and complicated, frequently with multi-digital involvement.

Treatment

Surgery is typically performed between 1 and 2 years of age, or earlier if border digits are involved or if there is other potential for progressive deformity of involved digits. If multiple web spaces are involved, do not separate two adjacent web spaces at the same time, as there is greater risk of ischemia of the central digit. The goals of syndactyly reconstruction can be broken down into (1) separation of the digits, (2) creation of a web space, and (3) soft tissue coverage.

Many different incision designs are described. The most important common feature is a dorsally based flap to create a web space. Avoid using skin grafts in the web space, as recurrence (i.e., "web creep") will be likely.

Though techniques have been described that avoid skin grafting altogether, these are demanding and rely on the mobilization of a large amount of dorsal hand skin. The authors routinely use full-thickness skin grafts, harvested from the volar wrist crease, volar elbow crease, or groin, depending on surgeon preference. All of these locations leave well-concealed donor sites.

- Always use full-thickness grafts, as split-thickness grafts undergo a greater degree of secondary contracture, provide less durable coverage, and have greater donor site morbidity.
- Separation of the digits, after elevation of flaps, involves dividing fascial interconnections between the two digits. To accomplish this safely, the neurovascular bundles of each finger must be identified and protected.

The authors' incision pattern for complete or incomplete syndactyly involves a dorsal rectangular flap for web space reconstruction and triangular flaps designed in a mirror-image fashion on the volar and dorsal surfaces of the fused digits (Fig. 40.2).The dorsal rectangular commissure flap should extend approximately 2/3 of the distance to the PIP joint. The distal edge of the flap extends to the dorsal midline of each digit. The lateral margins may be designed concave to match the curvature of the digits and decrease the need for skin grafts in this area. Draw the dorsal commissure flap first. Next draw a transverse line volarly. Keep in mind that the normal web space has a slope of approximately 45 degrees. The location of the volar extent of the web space can be designed by projecting its position from the adjacent uninvolved web spaces and is roughly half the distance between the palm crease and the PIP flexion crease.

The triangular flaps should also extend to the mid-point of each digit (although some advocate 1/3, saying the scars are better hidden). The size of the flaps can be varied, but in general we create one or two flaps per phalanx. Draw the dorsal triangular flaps before volar. After the pattern has been drawn dorsally, make marks on the lateral borders of the digits corresponding to the points of the triangles, as this will facilitate creating mirror-image flaps volarly and ensure the flaps interdigitate appropriately (Fig. 40.3). Every triangle tip on the dorsum should correspond the middle of a triangle base on the volar side. Every triangle base midpoint on the dorsum should correspond to a triangle tip on the volar side. When designing the flaps, keep in mind that there will be areas, typically at the base of the digit, which will require skin grafting. Attempt to design flaps so that the grafts will be located over the inner proximal phalanx, where they will be less visible and won't overly joints or involve the web-space.

In the case of synonychia (nail fusion), which is a sign of complex syndactyly, opposing narrow triangular flaps are designed distally as described by Buck-Gramcko (Figs. 40.4 and 40.5) [4]. These flaps serve to recreate the missing lateral nail fold once the digits are separated. Be careful, as these thin flaps are easy to accidentally damage or amputate.

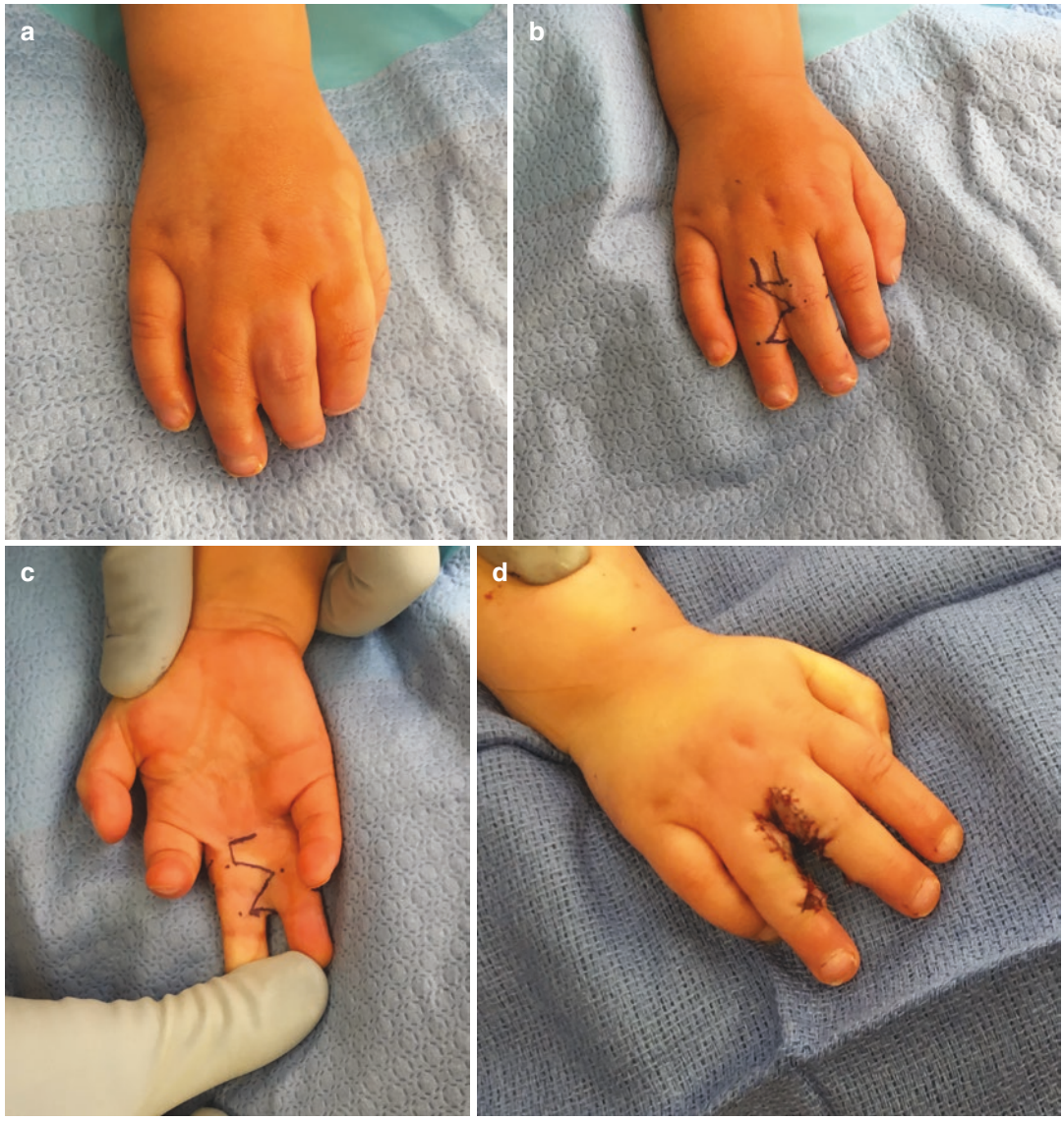

Fig. 40.2 (**a**) Incomplete simple syndactyly of the 3rd web space. (**b**, **c**) Incision markings. (**d**) After flap inset and skin grafting

Surgical Steps (Separation of Simple Syndactyly)

- Start by making all incisions through the dermis only. Then proceed with elevating flaps dorsally and then volarly. Flaps should be elevated to the dorsal midline of the two digits before proceeding. Make all incisions except for the volar proximal transverse incision: this will receive the tip of the dorsal commissure flap, and it is critical to ensure that the dorsal flap will reach before committing to this incision (after near complete separation of the digits, this can be checked and adjusted as needed).
- In simple syndactyly, there is a dense fibrous transverse band between the two digits. After elevating the flaps, this band is exposed dorsally and volarly through gentle scissor dissection, then divided in a distal-to-proximal fashion while steady retraction (separation

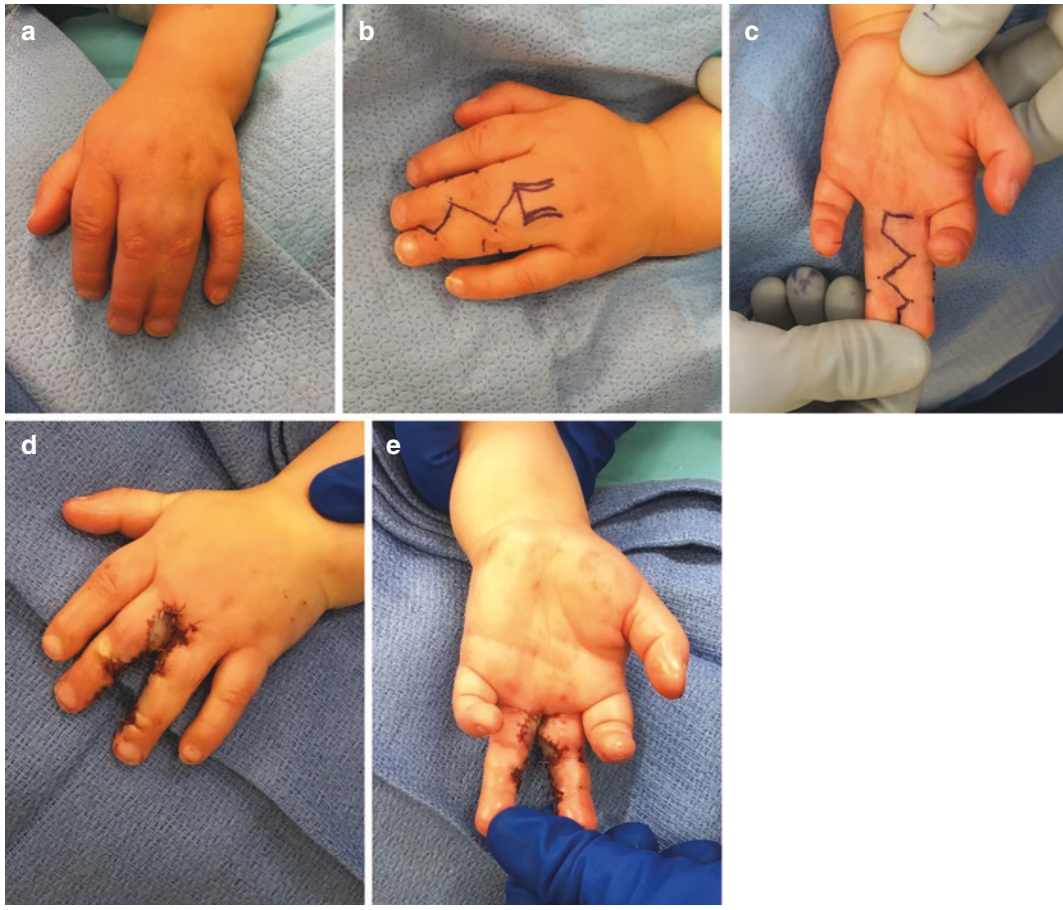

Fig. 40.3 (**a**) Complete simple syndactyly of the 3rd web space. (**b**, **c**) Incision markings. (**d**, **e**) After flap inset and skin grafting

pressure) is applied to the two digits. The surgeon should sit at the end of the hand table, looking down the digits and watching out for the neurovascular bundles—these typically are located clear of the midline and closer to their respective digits.

- Beware that a distal bifurcation of the common neurovascular trunk may exist. In this situation, the nerves may be neurolyzed to create a more proximal bifurcation, but one artery may need to be sacrificed. In this case, choose the smaller of the two arteries to sacrifice, as this generally implies that the remaining artery on that digit is dominant.
- After near full separation of the digits, check that the dorsal commissure flap will reach the desired volar insertion before making the volar proximal transverse incision. At this point, complete the elevation of the dorsal flap, getting thicker as you head proximally and attempting to preserve any veins going into the flap.
- Inset the dorsal flap first with sutures at the two corners and then midline.
- Inset the tips of the triangular flaps. During flap inset, finger contour can be improved by judicious fat removal from the digits.
- Use foil from a suture packet to make precise templates of the open areas. Mark the templates carefully to maintain their orientation, then trace the templates onto the planned donor site (volar wrist, elbow, or groin) such that an ellipse may be drawn encompassing the needed grafts. Test the ellipse using the

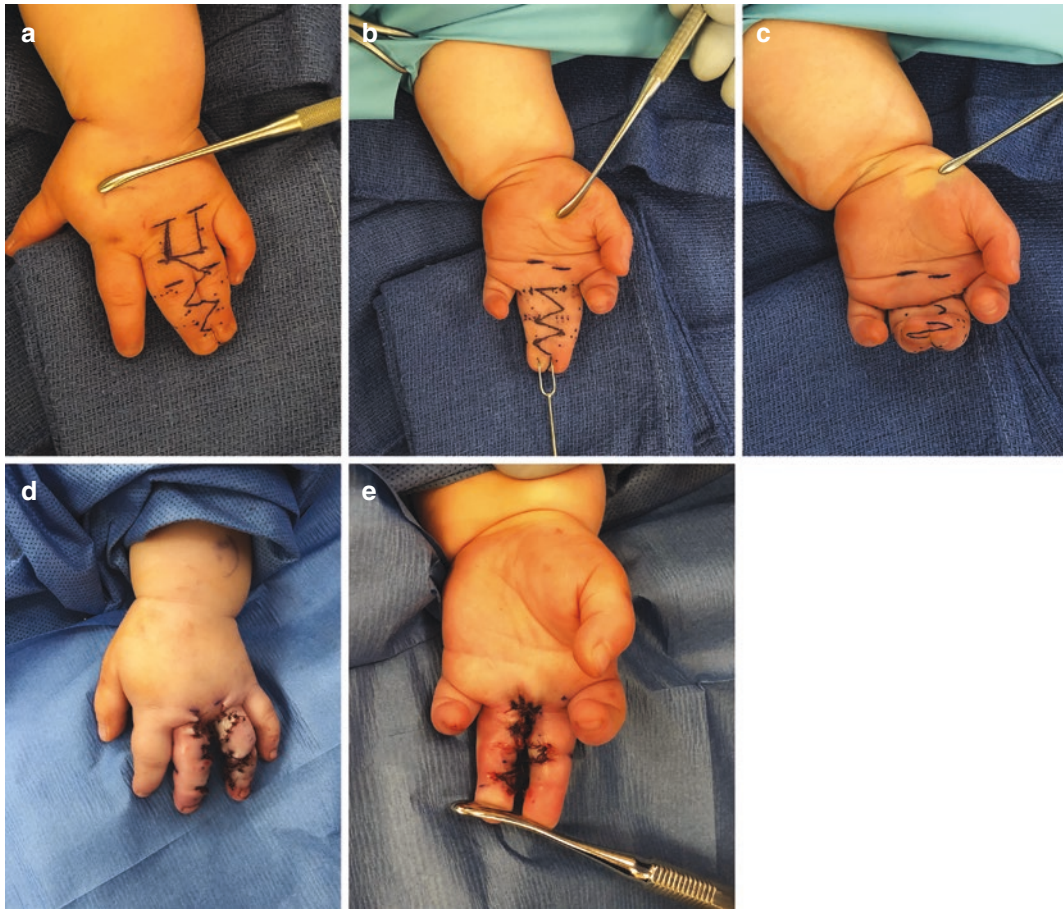

Fig. 40.4 (**a**–**e**) Complex syndactyly with synonychia. Note the markings made laterally on the digits to assist in creating mirror image volar and dorsal flaps. Incisional design incorporates Buck-Gramcko flaps for reconstruction of the nail folds

"pinch test" to ensure it can be closed safely. Using the templates and the pinch test, you can determine whether the wrist, elbow, or groin will supply the required amount of skin. Alternatively, determine the dimensions of each graft needed and excise an ellipse from the groin crease whose width will cover the widest defect and whose length is roughly the combined total length of all needed grafts.

- Inject epinephrine containing local anesthetic subcutaneously under the entire graft donor site for hemostasis/pain control.
- Harvest grafts using a 15-blade scalpel.
- Dressing and cast: xeroform over incisions. 4x4 cut into thirds, dipped in saline and wedged in between the digits to splint open the commissure and bolster the grafts. Over this, webril and long-arm cast or sugartong splint covering the fingers entirely. The elbow is flexed to 100 degrees to prevent cast removal.

Postoperative cast duration varies, but excellent results have been observed in our group with leaving the cast in place for either 1 or 2 weeks. The use of "wedge splints" is attempted by some surgeons postoperatively in hopes of lessening the risk of "web creep," but it can be difficult for parents and patients to comply.

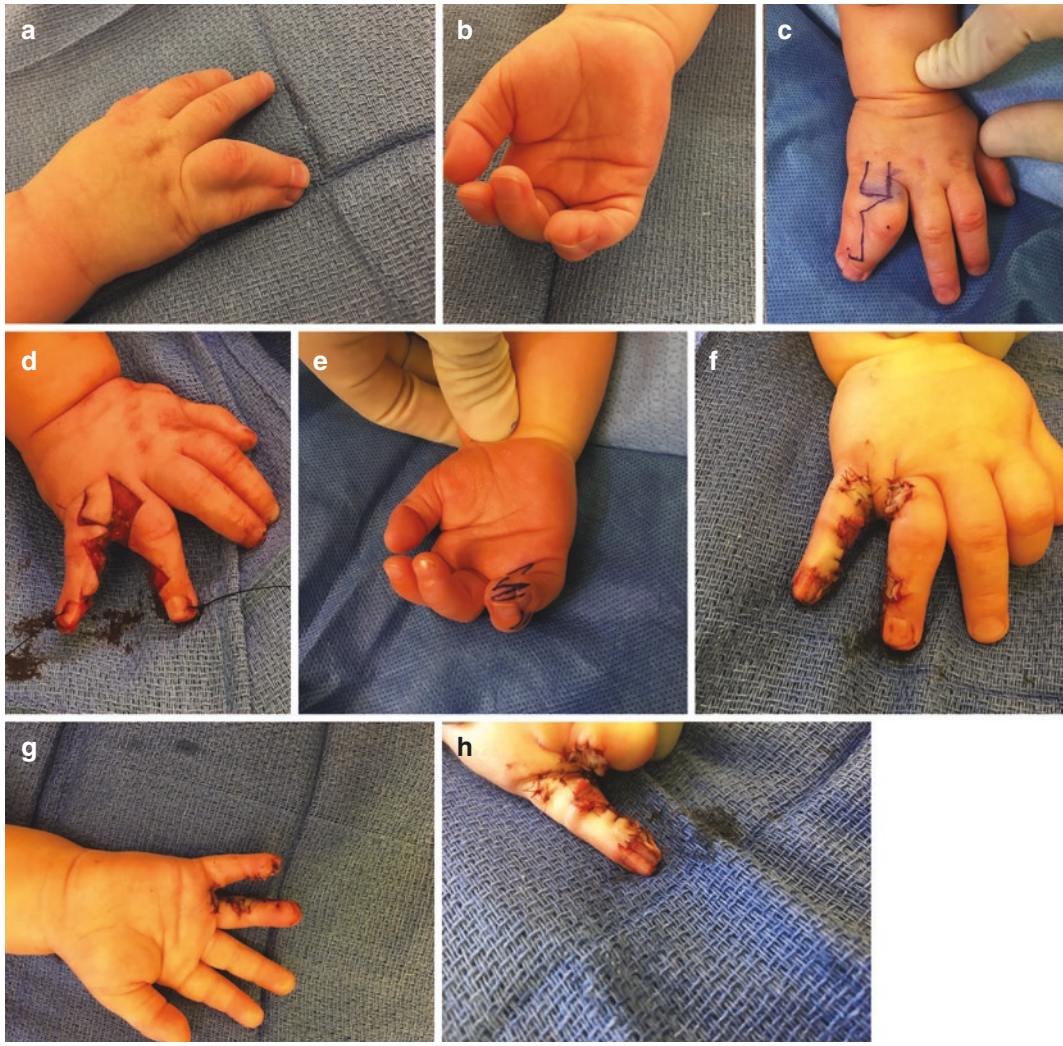

Fig. 40.5 (**a**–**h**) Complex syndactyly of the 4th web space. Note the tethering effect of the small on the ring finger. Buck-Gramcko flaps used for reconstruction of nail folds

Special Situations

Complex Syndactyly

- Defined by the presence of bony fusion.
- In addition to the steps outlined above, bony separation is required. This is done after triangular flaps have been elevated and dissection is proceeding from distal to proximal. A scalpel is usually sufficient to accomplish division of the bone. In complex syndactyly, there is often a more significant skin shortage, requiring more skin grafts than in simple syndactyly.

Minor Syndactyly, Shallow Web Spaces, and Web Creep

Patients may present with simple incomplete syndactyly that does not extend to the level of the PIP joints of the involved digits. This more minor syndactyly may be congenital or can occur following a previous syndactyly release (i.e., web space creep). In some congenital cases, there is a true excess of skin between the involved digits. Nevertheless, surgical techniques to deepen the web space by a dorsal rectangular flap or other means typically cannot make use of this skin and

often require the placement of additional skin graft (see Fig. 40.3). Skin-conserving methods, such as serial z-plasties, rarely provide sufficient deepening. An excellent technique for these shallow web spaces was published by Shinya [5] and is called the Dancing Girl flap. The original mathematical description can be difficult to interpret and implement. A simplified step-by-step method for constructing Dancing Girl flaps is illustrated in Fig. 40.6, and described below.

Designing the "Dancing Girl" Flap for Minor Syndactyly

Design begins on the volar side:

1. Draw volar web space line (a) along the distal border of the existing web
2. Draw line (b) extending proximally from one end of line (a)
   (a) Length of (b) = 0.7 × a
   (b) Angle ab = 120°
3. Draw line (c) proximally from the opposite end of line (a)
   (a) Length of (c) = 0.6 × (a)
   (b) Angle ac = 70°
4. Draw a guide line perpendicular to most proximal point of line (b)

   This guide line will mark the depth of the new web space.
5. Draw line (d) proximally from the intersection of lines (a) and (b)
   (a) Angle bd = 45°
   (b) Length of (d): to intersection with perpendicular from (b)
6. Repeat the pattern on the dorsum of the finger starting with a'
   (a) Length (a') = (a)
   (b) Parallel to (a)
   (c) Distance from (a) = 0.6 × (a)
7. Line (b') goes along opposite side of web to line (b)
8. Line (c') goes along opposite side of web to line (c)
9. Draw an oblique line (e) connecting lines (a) and (a')
   (a) Mark a point along (a) and (a') 1/3rd the length of (a) from the intersection of (a) and (b)
   (b) Connect these two points

Following flap transposition, the new web space is created by flaps (bd) and (b'd'). If the flap is employed for the treatment of web space creep, some effort can be made to align line (b) or line (d) on a preexisting scar; however, the presence of other scar lines does not preclude the use of this flap.

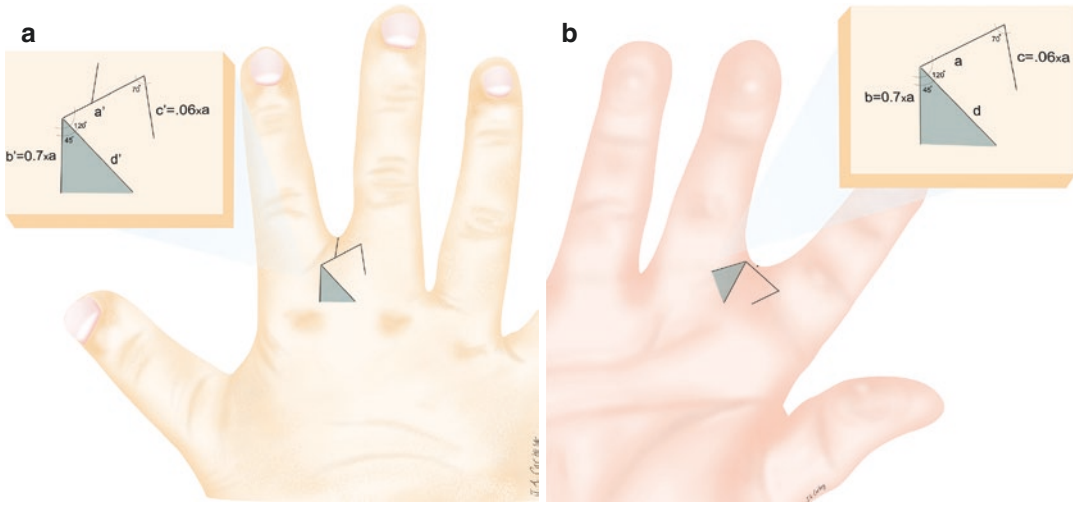

Fig. 40.6 (**a**, **b**) Flap design for the dancing girl flap. The shaded triangles represent the skin flaps that will form the new web space. The depth of the new web space is the proximal base of these two triangles. See text for detailed description. (Illustrations by Jourdan A. Carboy)

Multiple Digit Syndactyly

Multiple digit syndactyly most commonly arises in the syndromic setting, classically in Apert's syndrome. These tend to be complex and often complicated, with highly abnormal formation and sometimes absent bony elements. Achieving five separate digits is not always possible or advisable, and realistic expectations should be set early with parents. Joints are often abnormally formed and may exhibit little or no motion, which should be anticipated and explained to parents. The primary goal should be improvement in function of the hand.

When more than two digits are involved in a single fusion mass, separations should be staged to lessen the risk of devascularizing the central digit. It is recommended that surgeries be spaced 4–6 months apart.

Pediatric Trigger Thumb

Background

Pediatric trigger thumb, or stenosing tenosynovitis of flexor pollicis longus, has an incidence of around 3 in 1000 children [6]. Average age at presentation is 2 years, and approximately 25% are bilateral [7]. Trigger thumb most commonly presents as an inability to extend the thumb IP joint, with the child holding it in a position of fixed flexion. Unlike trigger digit in adults, pediatric trigger thumb is not an inflammatory process and usually not painful [8]. Although the term "congenital trigger thumb" is still widely used, multiple studies have documented that this condition is not present at birth and is, in fact, an acquired condition [9].

Evaluation

The affected thumb often displays a lack of full extension. A prominent nodule (Notta's node) is palpable over the volar metacarpophalangeal joint, representing a nodule in the FPL tendon as well as associated thickening of the A1 pulley (Fig. 40.7).

These children are often erroneously referred for a suspected trauma, with parents and pediatrician suspecting a dislocation of the IP joint despite no witnessed trauma. Trigger thumb must also be differentiated from congenital clasped thumb, which is usually due to a deficient extensor mechanism and has very different treatment considerations. Radiographs are not indicated, as the diagnosis can be confirmed through the history and physical examination.

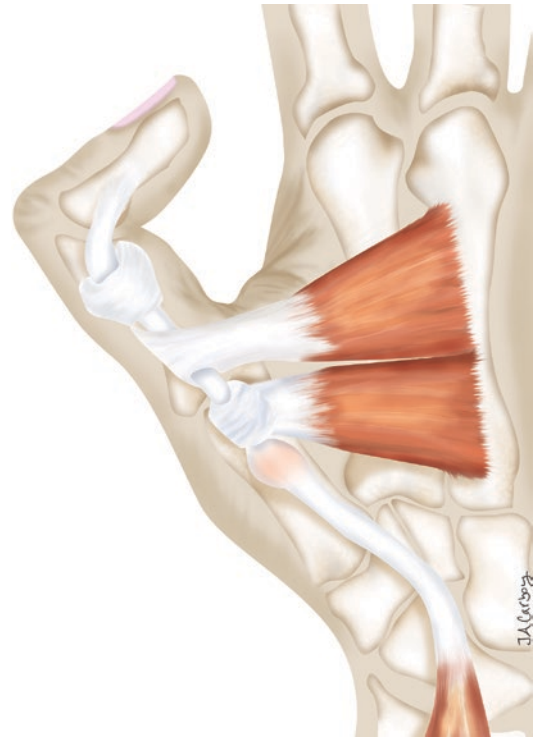

Fig. 40.7 Illustration of Trigger thumb pathoanatomy. Note nodular enlargement of flexor tendon obstructing passage through A1 pulley. The interphalangeal joint is held in a flexed position. Note the oblique pulley distal to A1 upon which adductor pollicis inserts. Division of the oblique pulley must be avoided. (Illustration by Jourdan A. Carboy)

Treatment

Surgery should be considered if trigger thumb is present for greater than 4 months, or if the child is 3 years of age or older. We wait until the child is at least 12 months old before surgery. About 1/3 will resolve spontaneously by 12 months of age.

Surgical Steps

- The surgery is performed under general anesthesia, positioned supine with the hand on the patient's chest or abdomen. The surgeon and assistant stand on opposite sides of the patient, with the surgeon on the contralateral side.
- A tourniquet is placed on the upper arm and set to 200 mmHg.
- Draping consists of a sterile towel with a clamp just below the tourniquet and a 3/4 sheet with a small hole cut in it.
- The assistant's critical job is to hold the thumb abducted and extended to create necessary tension on the tissues, while retracting for the surgeon.
- The incision is transverse and placed in the volar MP crease, directly over the palpable Notta's node. The incision is approximately 1 cm in length (Fig. 40.8).
- A 15-blade scalpel is held upside down so that the tip may be precisely pushed to make the planned incision through skin only. The digital nerves can be extremely close to the skin in children this age.
- After incising through the dermis, gentle longitudinal spreading over the mid-line of the pulley will provide safe exposure while avoiding harm to the neurovascular bundles. Attempt to identify any nerves in the surgical field, but do not search for them if not contained within the field.
- Once the pulley is adequately exposed, a Beaver or Weck blade is used to make a longitudinal "nick" in the center of the pulley through use of a pressing motion. The surgeon will feel the blade "pop" through the pulley without injuring the underlying tendon.
- An iris or similar small scissor is used to complete the pulley release proximally to the leading edge, and distally while preserving the distal oblique pulley; see Fig. 40.7).
- Do not slide the scissors. Rather, see the tips and only cut what can be directly visualized to avoid risk of dividing the oblique pulley.
- When adequately released, the two edges of the divided pulley should open like pages of a book, as opposed to appearing as a funnel when incompletely released.

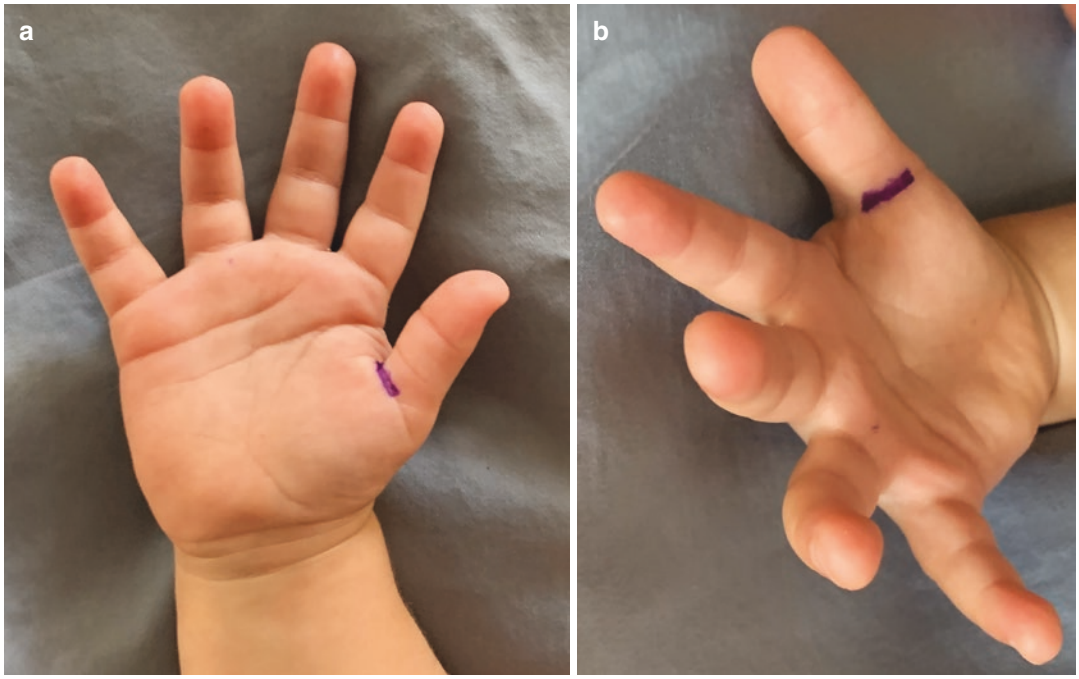

Fig. 40.8 (**a**, **b**) The incision for trigger thumb, placed in the volar joint crease of the metacarpophalangeal joint

- After release, the skin is closed with 5-0 plain gut suture.
- 0.25% bupivacaine is used to block the radial sensory nerve and median nerve at the wrist.
- Dressing is dermabond and a band-aid.
- Tylenol and ibuprofen are sufficient for pain control.

Polydactylies

The presence of extra digits at birth is the most common congenital hand difference. Digital duplications are commonly broken down into three groups: (1) postaxial polydactyly, involving a supernumerary ulnar digit, is the most common; (2) preaxial polydactyly is also referred to as thumb duplication or split thumb; and (3) central digit polydactyly, which is rare and will not be discussed further. Preaxial polydactyly and postaxial polydactyly tend to have different associated mutations and syndromes, different inheritance, and different treatments (Table 40.3 and Fig. 40.9).

Evaluation

Postaxial polydactyly commonly presents as a hypoplastic finger "nubbin" attached to the dominant small finger by a small soft tissue stalk, known as Temtamy and McKusick type B (Fig. 40.10) [10]. But it can also present with significantly formed duplicated small finger ray (Temtamy and McKusick type A; Fig. 40.11). An X-ray of the hand should be obtained prior to surgical revision of type A polydactyly, but is unnecessary in type B. While a referral to Genetics could be considered for any child with a congenital difference in order to rule out associated syndromes, this is particularly true for Caucasians with postaxial polydactyly, as the risk may be as high as 10%.

Preaxial Polydactyly

Preaxial polydactyly is now commonly referred to as "split thumb deformity" owing to the recognition that the thumb that will remain following surgery is always hypoplastic when compared to the opposite unaffected thumb. Treatment is predicated upon (1) the skeletal deformity as classified by the Wassel classification (see Fig. 40.9) [11], (2) the relative sizes of the two thumbs, (3) the motion of the two thumbs, and (4) the expected stability of the postoperative construct. X-rays should be obtained close to the planned surgery date. Wassel type 7 (triphalangeal thumb) is often associated with other abnormalities. Patients with Wassel 7 polydactyly should be referred for a full genetics evaluation.

Treatment

Postaxial Polydactyly

Patients with type B postaxial polydactyly typically present with a hypoplastic digit attached to the ulnar aspect of the small finger proximal phalanx by a tenuous skin bridge. Treatment is encouraged at the time of presentation, as a controlled removal in a clinic setting seems preferable to the predictable traumatic avulsion of the digit during the child's regular activities. Nurses in the newborn nursery commonly ligate the base of the accessory digit with a 4-0 silk suture. The digit undergoes ischemic necrosis and even-

Table 40.3 Polydactyly

Polydactyly type	Digit affected	Dominant digit	Accessory digit	Inheritance	Classification	Associated Syndromes
Preaxial	Thumb	Hypoplastic	Usually radial thumb	Usually sporadic mutation	Wassel 1–7	With Wassel Type 7
Postaxial	Small finger	Normal	Uniformly ulnar small finger	Usually autosomal dominant	Temtamy and Mckusick A or B	Rare, but more common in Caucasians

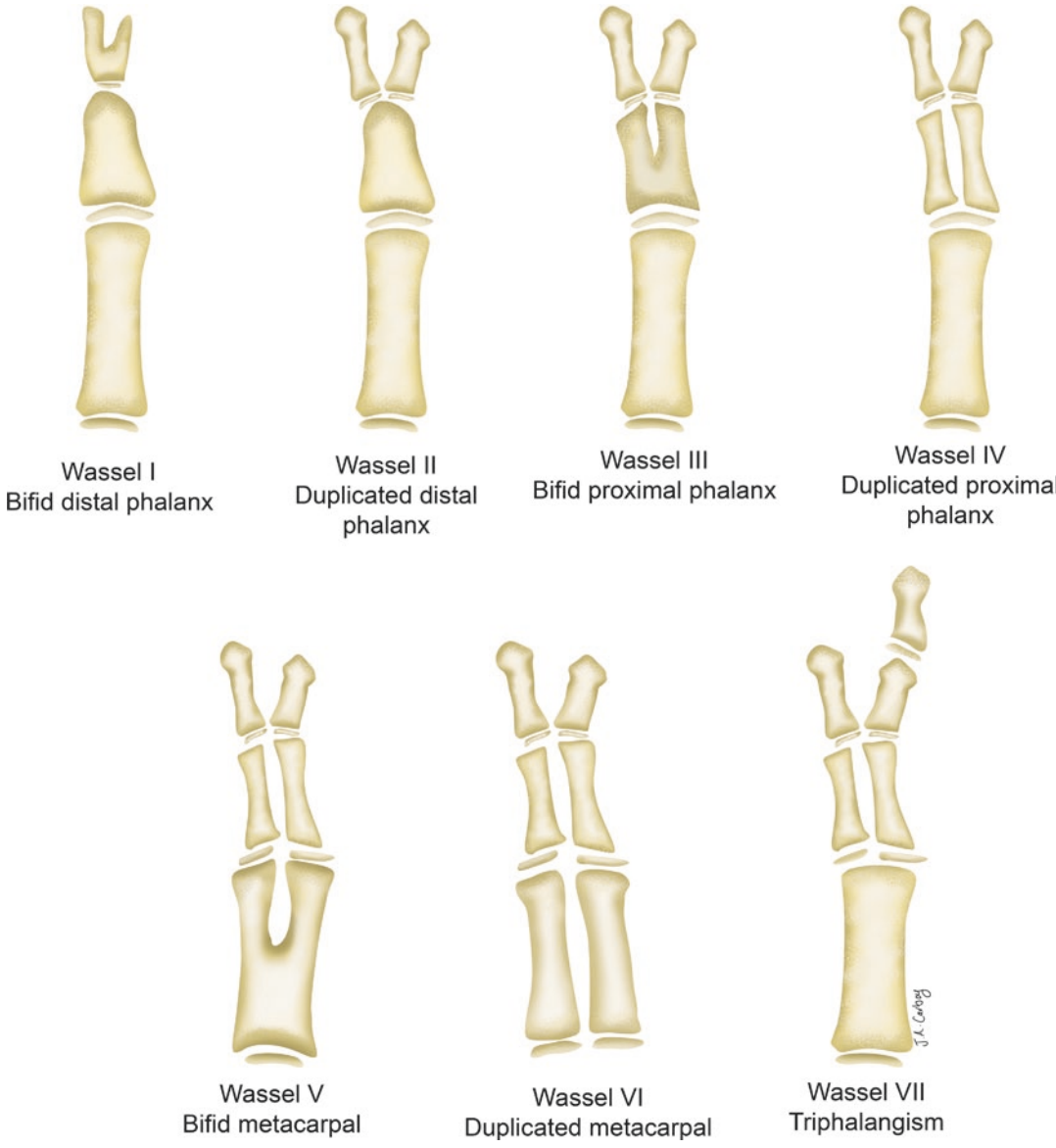

Fig. 40.9 Wassel classification of split thumb deformity (preaxial polydactyly). (Illustration by Jourdan A. Carboy)

tually autoamputates. This technique has some disadvantages:

1. Inadequate ligation may lead to tissue ischemia and pain that requires further treatment.
2. The accessory digit turns black but takes weeks to autoamputate.
3. Nearly half of patients will have residual contour deformity.
4. Many will later complain of a painful neuroma that requires future excision

A preferable alternative is to apply topical anesthetic and excise the accessory digit with a sterile scissors. There will be a genuine neurovascular bundle that can be treated with local pressure and a steri-strip, but our preference is to use a silver nitrate stick or bipolar electrocau-

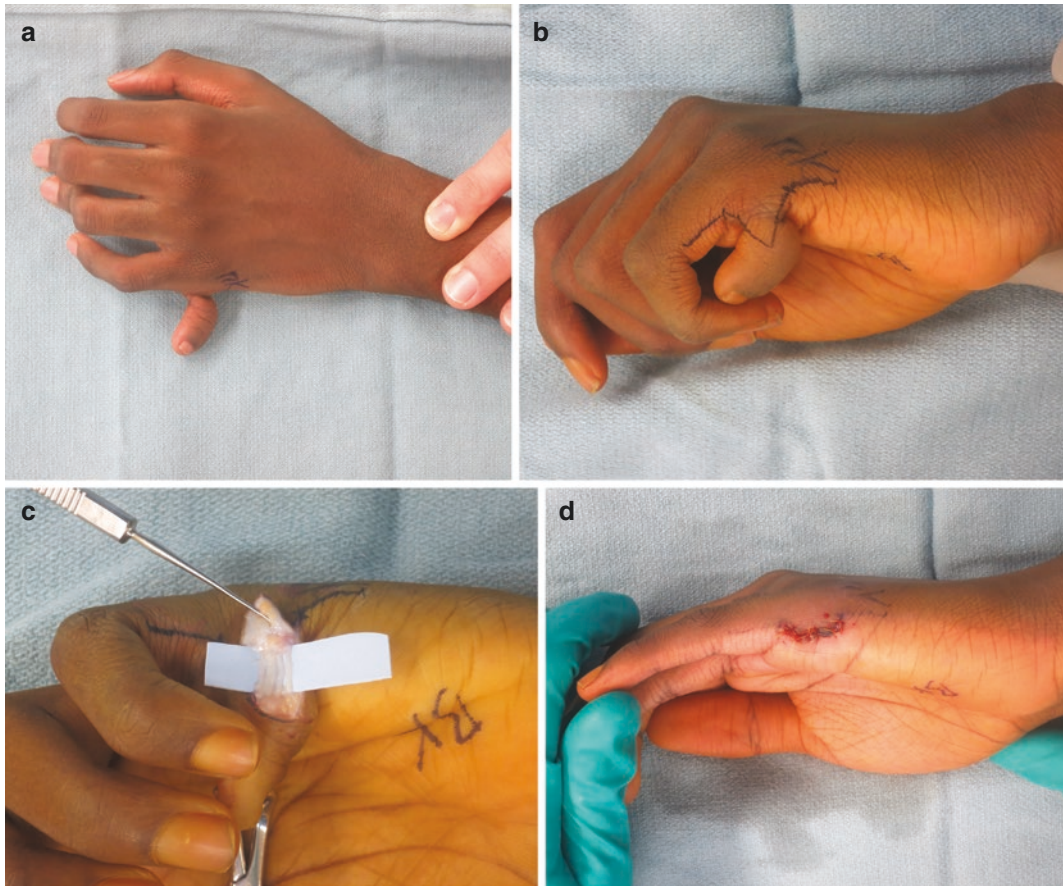

Fig. 40.10 Postaxial polydactyly, Temtamy, and McKusick type B. (**a**) The illustrated case is unusual, involving a previously untreated 15-year-old male. (**b**) Incision design incorporating flap for closure (**c**) Neurovascular structures are present in the digit. Children can develop symptomatic neuroma if nerves not adequately addressed. (**d**) Final closure

tery (Fig. 40.10 illustrates the neurovascular bundle).

For patients with type A postaxial polydactyly, surgery is typically performed under general anesthesia through a modified racquet-shaped incision (see Fig. 40.11). Excess skin from the accessory digit should be preserved. This skin can be trimmed at the end of the case to restore a normal contour to the hand, whereas a skin deficit can leave a soft tissue depression. As with the treatment of Wassel type 4 preaxial polydactyly described below, accessory digit excision at the level of the MP joint can lead to joint instability. If the ulnar collateral ligament or intrinsic muscle insertions are violated in the process of accessory digit excision, these should be reconstructed with suture. Abductor digiti minimi is often found to insert into the base of the accessory digit and should be elevated and reinserted into the ulnar aspect of the extensor mechanism of the small finger to be preserved. When ligament or tendon reattachments are required, a long-arm splint or cast is used for 2 weeks.

Preaxial Polydactyly

The treatment of split thumb is largely determined by the skeletal anatomy of the deformity as classified by Wassel (see Fig. 40.9) [11]. Although not always achievable, all reconstruc-

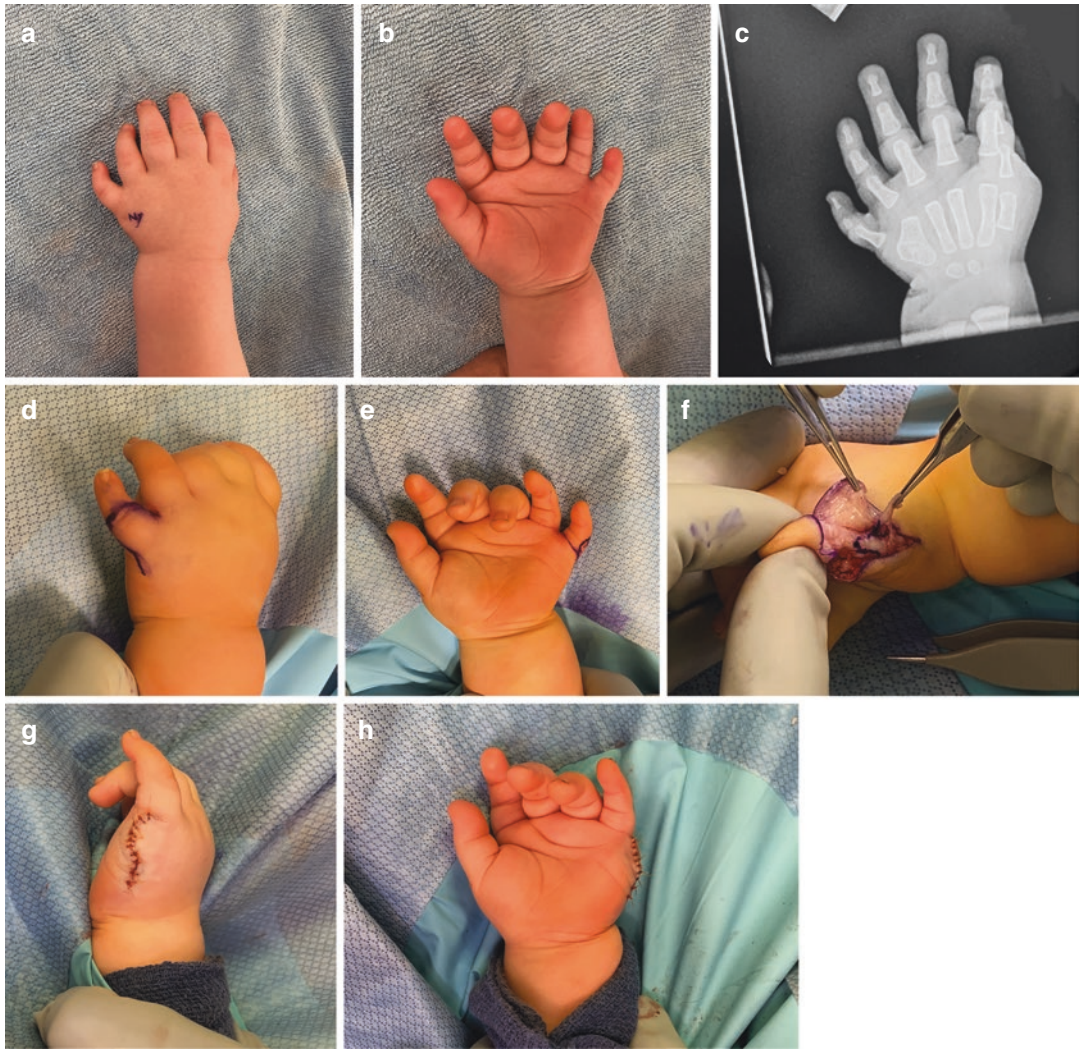

Fig. 40.11 Postaxial polydactyly, Temtamy and McKusick Type A in a 12-month-old male. Bilateral hands were involved (left illustrated). (**a**, **b**) Preoperative appearance. Patient had full mobility of supernumerary digit. (**c**) X-ray demonstrates abnormal 5th metacarpal with synostotic accessory articular element articulating with accessory digit. (**d**, **e**) Incisional markings with dorsal skin flap to be preserved for closure. (**f**) Extensor elements and abductor digiti minimi insertion preserved and reattached to small finger ulnar extensor mechanism. Note collateral ligament with periosteal attachment marked for transfer to proximal phalanx base. (**g**, **h**) After closure

tive procedures share the common goals of providing:

1. A near normal-sized, normal appearing thumb
2. A stable digit with normal MP and IP joint motion
3. Normal growth without developing angular deformity

Wassel type 1 and 2 thumbs typically present with a broad thumbnail or a true cleft separating two equal-sized thumb tips. If there is broad thumbnail that is aesthetically acceptable, no treatment is indicated. In the case of two well-formed "hemi-thumbs," ablation of one of the digital tips will leave an unacceptably small thumb tip. In such cases, the two "hemi-thumb"

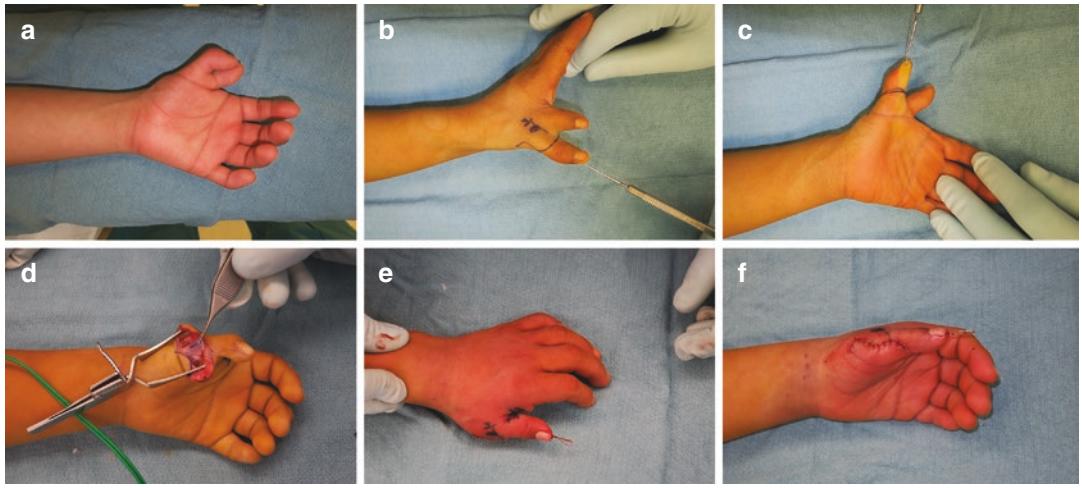

Fig. 40.12 (**a**–**f**) Preaxial polydactyly or "split-thumb" deformity. (**a**) Wassel IV thumb duplication. (**b**, **c**) Preop markings. (**d**) Preservation of tissue for reconstruction of radial collateral ligament. (**e**, **f**) Following closure with K-wire in place

tips are combined according to a modification of the Bilhaut-Cloquet procedure described by Baek et al. in 2007 [12]. In the Baek modification, asymmetric resections of skin, nailbed, and distal phalanx are carried out on the cleft between the two thumb tips and the residual tissues combined (Fig. 40.12).

For most Wassel 3 thumbs and virtually all Wassel 4, 5, and 6 thumbs, the goal is to ablate the smaller, less mobile, and more deformed thumb. The choice of which thumb remains is usually straightforward; however, some cases may require careful clinical and X-ray examination and a balancing of the objectives listed above in order to identify the preferred thumb. Thumb reconstruction proceeds as described for postaxial polydactyly (Fig. 40.13). A modified racquet incision is designed to maintain more skin than will be needed for closure so that the excess skin can be trimmed at the end of the case. Whereas joint instability is uncommon following excision of postaxial polydactyly, intraoperative thumb MP joint instability is common following excision of the accessory thumb. Wassel 4 split thumb is the most common subtype. In such cases, one MP joint collateral ligament will be attached to the resected thumb and must be preserved along with a flap of proximal phalanx perichondrium from the deleted thumb (Fig. 40.13d). If collateral ligament instability has been introduced by resection of the accessory thumb, the ligament must be reconstructed using suture. Gross instability is stabilized using a single 0.028 k-wire passed down the thumb tip and across the MP joint (Fig. 40.13f). The extremity is splinted in a sugartong splint or long-arm cast and the pin is maintained for 4–6 weeks. If minimal joint instability has been introduced, the collateral ligament should still be reconstructed, but sufficient immobilization may be achieved with the cotton gauze splint described above.

When the two thumbs are of similar caliber, motion, and stability, preference is given to maintaining the more ulnar thumb, as this maintains the more functionally important MP joint ulnar collateral ligament. Despite restoration of MP joint stability, the reconstructed thumb may still have residual angular deformity. Such deformity will only get worse as the child grows, and should be treated at the time of thumb ablation with a closing wedge osteotomy to the thumb metacarpal so that the metacarpal and remaining proximal phalanx are collinear. Accessory flexor and extensor tendons from the deleted thumb should be divided distally. If they have normal excursion, they can be transposed onto the retained

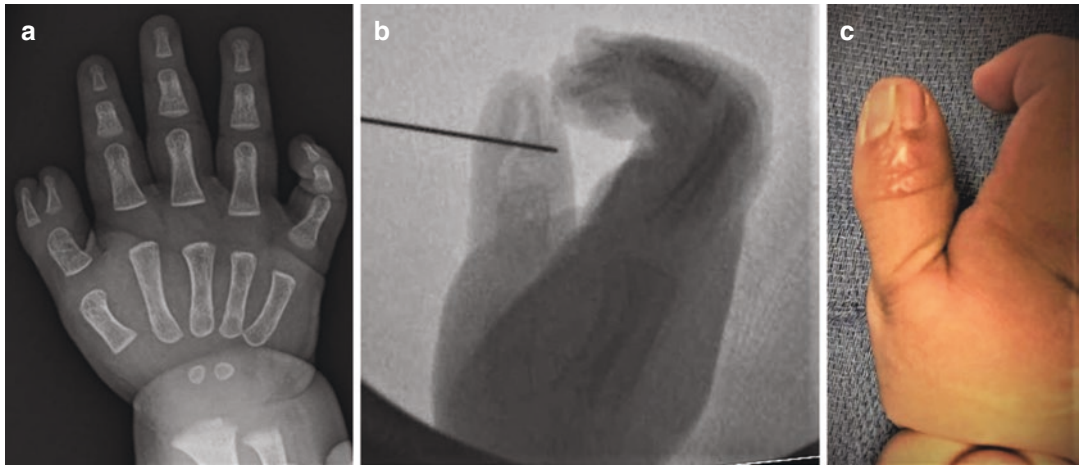

Fig. 40.13 (**a**) Wassel type 2 thumb duplication. (**b**) K-wire fixation during Bilhaut-Cloquet procedure. (**c**) Postoperative result from the Baek modification of the Bilhaut-Cloquet procedure. Note midline nail deformity and eponychial scar, which are downsides of this reconstruction. Benefits of this technique include a wider thumb and avoidance of instability at the interphalangeal joint by preserving native collateral ligament attachments

digit in order to centralize the pull of these tendons. If the tendons have no excursion, they can sometimes be useful tissue for restoring joint stability. Wassel type 7 split thumbs are rare (20% of all split thumbs) and are largely treated as described above; however, the extra joint may require special attention.

Thumb Hypoplasia

Background

Thumb hypoplasia encompasses a wide spectrum of thumb underdevelopment, ranging from subtly diminished size to complete absence. Intermediate grades are characterized by varying degrees of thenar muscle deficits, carpometacarpal (CMC) joint instability, and first web space contracture. The Blauth classification, as modified by Manske [13, 14] (Table 40.4), is most commonly used to describe hypoplastic thumbs. The single most critical factor in determining treatment is the presence of an unstable CMC joint (Blauth 3b or higher). The patient with an unstable CMC joint will require pollicization of the index finger, whereas the thumb with a stable CMC can be salvaged and reconstructed as detailed below. The stable CMC joint is the minimal required base upon which to reconstruct the thumb.

Thumb hypoplasia can be found in isolation or can be part of a larger radial deficiency. Radial deficiency has a very high (up to 80%) association with syndromes, many of which can have life-threatening features. These include VACTERL, Holt-Oram, thrombocytopenia-

Table 40.4 Blauth classification of hypoplastic thumb, as modified by Manske [13, 14]

Blauth type	Description	Treatment
Type 1	Slightly small, with all elements well formed	None
Type 2	Small thumb with: 1. Narrow 1st web 2. Unstable MPJ 3. Deficient thenar muscles	1. First web deepening 2. Opponensplasty 3. UCL repair/ plication
Type 3a	Type 2 plus: 1. Extrinsic tendon abnormalities 2. Metacarpal hypoplasia 3. Stable CMC joint	4. First web deepening 5. Opponensplasty UCL repair/ plication
Type 3b	Type 2 plus: 1. Extrinsic tendon abnormalities 2. CMC instability	Pollicization
Type 4	Floating thumb (pouce flottant)	Pollicization
Type 5	Absent thumb	Pollicization

absent radius (TAR) syndrome, and Fanconi anemia.

Evaluation

Key elements of the physical examination are assessing for the presence and function of the thenar musculature, first web space limitation, and MP and CMC joint stability. Observe the patient during play to determine if the child uses the thumb when grasping objects, versus excluding it from function and using the index finger in its place. This can help to differentiate 3a from 3b and thus predict which children are better served by pollicization. It is also important to assess for normal range of motion of the index finger if pollicization is being considered.

The entire upper extremity should be examined, especially looking for signs of radial deficiency.

Plain radiographs should be obtained and can help in classifying the degree of thumb hypoplasia. Type 3b hypoplasia classically demonstrates a tapered metacarpal without an apparent base. If concern for radial deficiency exists, forearm radiographs should be obtained. Genetics consultation should be sought if there is any evidence of radial deficiency due to the association with the syndromes mentioned above.

Treatment

The overall goal in the treatment of thumb hypoplasia is to achieve the most functional thumb possible for the patient. Basic elements of the functional thumb are the ability to oppose, length to allow prehension, and stability to act as a post for grasp. The specific procedures used are guided by the Blauth classification.

Type 1 thumb hypoplasia is defined by mild generalized decreased size of the thumb with normal function, and no surgical treatment is required.

Type 2 thumb hypoplasia is characterized by decreased overall size, underdevelopment of thenar musculature, narrowing of the first web space, and instability of the ulnar collateral ligament (UCL) of the MP joint. Useful reconstructive techniques include the following:

- First web space widening/deepening. When radial abduction of the thumb is less than 50 degrees, consideration of procedures that widen and deepen the web is warranted. Four and five flap Z-plasty techniques are most commonly employed. The authors' preferred technique is the four-flap Z-plasty (Fig. 40.14).

Technique

- With the thumb and index finger maximally abducted, the central limb of the Z-plasty is marked along the edge of the web (see Fig. 40.8a, b). The length of the central limb determines the length of all of the other limbs. Extension of this limb onto either the ulnar thumb or radial index finger surfaces should be avoided.
- A perpendicular limb of the same length is drawn, arising at the radial-most aspect of the central limb and running proximally, parallel to the first metacarpal. A second perpendicular limb is then drawn arising at 90 degrees from the ulnar-most aspect of the central limb, running volarly near the thenar crease. The two right angles are then bisected with 45 degree limbs, creating four equal triangular flaps. Two of these flaps are on the dorsum, and two are on the volar, glabrous surface of the hand. The volar flaps should be raised first, as it is easier to make small adjustments to the more mobile dorsal skin flaps.
- The volar flaps are incised and raised in the suprafascial plane using careful spreading dissection. The radial digital neurovascular bundle of the index finger and ulnar bundle of the thumb must be identified and protected. Next, the dorsal skin incisions are made, and the flaps are raised suprafascially while protecting the small branches of the radial sensory nerve and any longitudinal veins. If the fascia of the first web is constricting, it should be released as well (see Fig. 40.8b). A small amount of muscle can be resected to further deepen the web space.
- When well designed and completely dissected, the Z-plasty flaps should easily transpose to their new positions. Minor flap adjustments are typically required prior to

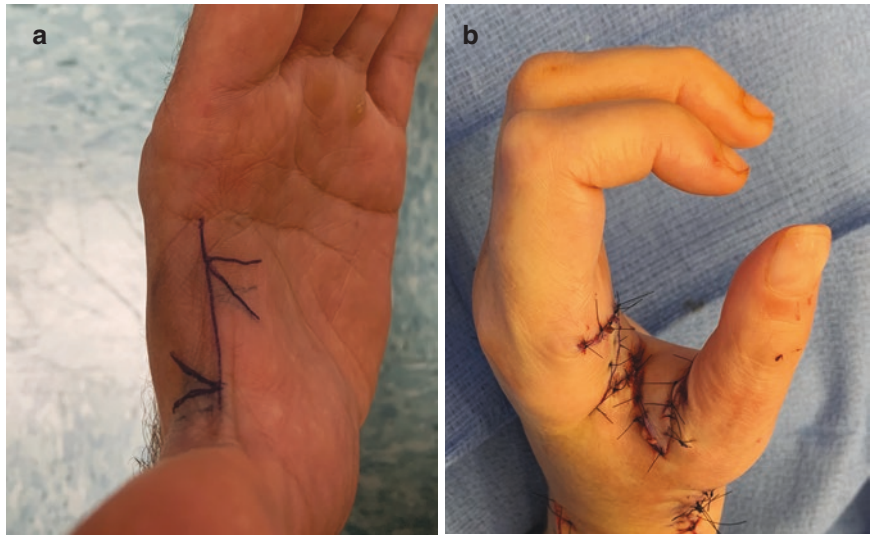

Fig. 40.14 (**a**, **b**) 4-flap Z-plasty for deepening first web space. See text for details

inset. In children, we typically use absorbable monofilament (5-0 fast absorbing gut) sutures. The four-flap design should create s natural concave contour in the first web space.

- Incisions are covered with a nonstick gauze, and a well-padded thumb spica splint or cast is applied with the thumb radially and palmarly abducted and the interphalangeal joint free. In children younger than school age, long-arm splints are less likely to be removed by the patient.
- Opponensplasty. The authors' preferred technique utilizes abductor digiti minimi (ADM; Huber opponensplasty). In addition to providing opposition of the thumb, ADM transfer adds bulk in the thenar region, improving the aesthetic appearance (Fig. 40.15). It is important to identify and protect the neurovascular pedicle to ADM, located proximally, deep to the muscle. The muscle is passed through a generous subcutaneous tunnel and the tendinous end is sewn into the radial aspect of the thumb MP joint, at the APB insertion with nonabsorbable braided suture.
- Repair or reconstruction of the UCL. If there is 20 degrees or more difference in laxity of the UCL as compared to the contralateral side, consider reinforcing the UCL with nonabsorbable braided suture.

Type 3 thumb hypoplasia is divided into 3a and 3b, which are differentiated by the presence or absence of a stable CMC joint. Type 3b or above requires pollicization, as described below. The type 3a thumb is characterized by the deficiencies of type 2 and additional deficiencies of the extrinsic musculotendinous units (EPL and FPL). They metacarpal may also be significantly hypoplastic.

- EPL deficiency may be addressed by performing tendon transfer of EIP to EPL.
- FPL deficiency may be more difficult to treat due to deficiency of the tendon sheath.
- In type 3 hypoplasia, there may be an abnormal connection between FPL and EPL known as pollex abductus. When present, this must be divided, as it interferes with IP joint motion and can weaken the UCL over time.

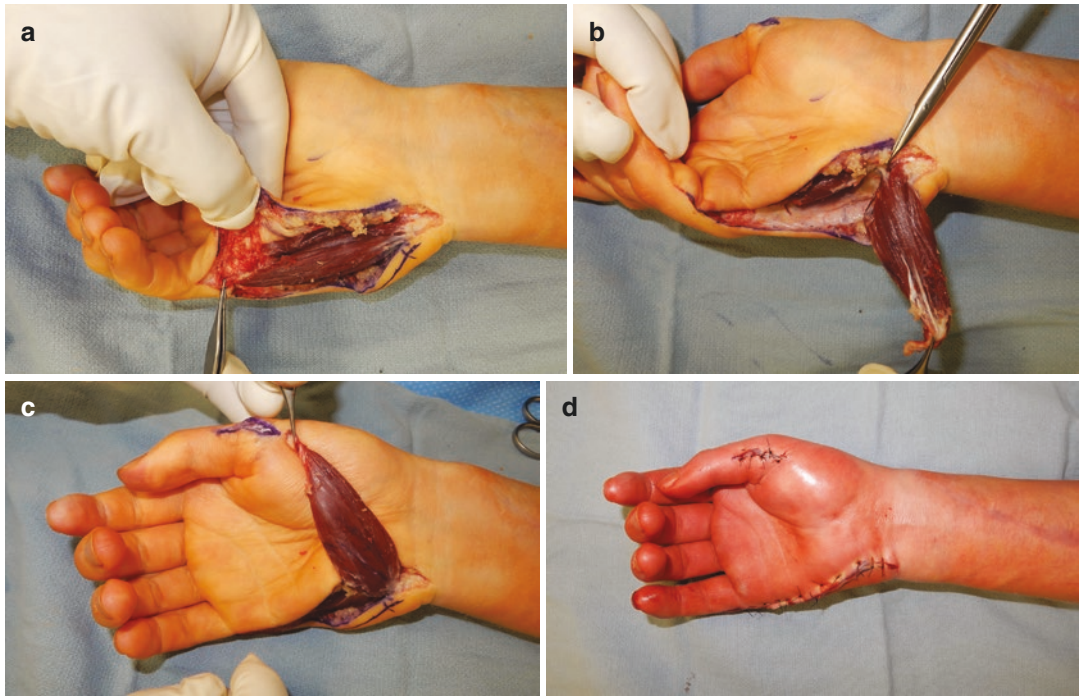

Fig. 40.15 (**a**–**d**) Huber opponensplasty

Pollicization of the index finger is the treatment of choice for type 3b, 4, and 5 thumb hypoplasia. *Index pollicization is a very complex and technically demanding procedure. An in-depth technical guide is beyond the scope of this chapter. What follows is a simplified list of surgical steps to help the reader conceptualize the procedure.*

Steps of Pollicization

1. Incisions are designed as a modified "fish-mouth," with the volar flap extending to the PIP joint and the dorsal flap extending to the mid-point of the proximal phalanx. A curvilinear incision extends along the radial border of the hand for the length of the metacarpal.
2. Identify neurovascular bundles and ligate proper (radial) digital artery to the middle finger.
3. Release A1 and A2 pulleys.
4. Isolate dorsal veins.
5. Divide the EIP and EDC (become EPL and APL).
6. Release the deep transverse inter-metacarpal ligament, preserving the collateral ligaments of the MPJ and a cuff of tissue.
7. Isolate the intrinsics (palmar interossei, 1st and 2nd dorsal interossei).
8. Metacarpal osteotomy through the physis.
9. Epiphysiodesis of metacarpal head (becomes new trapezium).
10. Hyperextend MPJ and pass K-wire (0.035 or 0.045).
11. Fix digit at 20° radial abduction, 35° palmar abduction, and 100° of pronation.
12. Advance interossei:
    (a) 1st dorsal interosseous advanced to base of middle phalanx (becoming abductor pollicis brevis)

(b) 2nd dorsal interosseous advanced to ulnar aspect of PIPJ (becoming adductor pollicis)

13. Plicate EIP (shorten with 3-0 or 4-0 ticron) to become EPL.
14. Shorten EDC (cat and suture to base of proximal phalanx extensor mechanism) to become abductor pollicis longus.
15. Release tourniquet and check perfusion.
    (a) Wrist block with 2% lidocaine.
    (b) 4% lidocaine pledgets to vessels.
16. Closure – be diligent to ensure not constricting perfusion or venous drainage.
17. Dressing – long-arm thumb-spica cast with elbow at 100 degrees of flexion.

Conclusion

This chapter has described practical considerations for some of the more common congenital pediatric hand conditions treated by hand specialists. Congenital hand surgery is an enormous and complex field, and while this chapter only scratches the surface, we hope the fundamental concepts will aid in caring for this patient population by providing practical details not covered in more comprehensive texts.

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Dupuytren Disease

41

Charles Eaton

Introduction

Dupuytren disease affects ten million Americans and varies widely in severity. The majority of those affected have no contractures. The majority of those with contractures have mild disease biology and may require one or two procedures over their lives. Five percent of Dupuytren patients have a treatment-resistant disease and are likely to fail all interventions over time. Because of this variability, overtreatment and undertreatment are common. *Our goal of care is to minimize the lifetime burden of Dupuytren and the complications of Dupuytren treatment*.

Surgeons are the caregivers for Dupuytren disease. The problem is that we don't treat Dupuytren disease. We only treat Dupuytren contracture, one of its many effects. Standard of care has trended back and forth over the last two centuries, from closed fasciotomy to open fasciotomy to fasciectomy, again to closed fasciotomy, back to fasciectomy, to radical fasciectomy, fasciectomy again, and now trending back to closed fasciotomy. Over this time, long-term outcomes have not changed. The primary treatment model has not changed: wait for a contracted finger, make it less bent, ignore all other aspects of the disease, and repeat. The path to better outcomes requires preventive, disease-modifying biologic treatments, not a new technical approach. This chapter offers tips and tricks for the two halves of current Dupuytren care: managing patient expectations and treating Dupuytren contracture.

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Dupuytren Patient Satisfaction and the Doctor–Patient Relationship

Fasciectomy is the most common operation currently performed for Dupuytren contracture. Fasciectomy is technically demanding, but technical expertise ensures neither a cure nor a grateful patient. Appearance, function, and angular contracture separately affect patient satisfaction [1]. Dupuytren patients have Dupuytren-specific dissatisfaction with their care: the surgeon didn't want to talk about anything but bent fingers; their post-fasciectomy recovery was a much worse ordeal than they expected; their procedure didn't last; their treatment only made their hands worse. These common complaints are justified; *compared to other operations of similar magnitude for other benign hand diagnoses, fasciectomy has a greater risk of permanent complications* [2] *and treatment failure over time*.

Long-term patient satisfaction correlates more with residual contracture and absence of complications than with absolute contracture improvement [3]. Initial patient satisfaction

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falls with re-contracture and with persistent treatment complications such as numbness, tenderness, loss of flexion, and cold intolerance. A good doctor–patient relationship is critical to help the patient deal with these issues and promote long-term patient satisfaction. For example, in a 4-year follow-up of fasciectomy, dermofasciectomy, or proximal interphalangeal (PIP) arthrodesis for post-fasciectomy recurrence, 95% of patients reported being unconditionally satisfied and would have their procedure again—despite lack of improvement in average total active motion, half experiencing functional deficits, and a one-in-six incidence of treatment-related numbness. The study author explained: "…these patients were well educated about their disease and were thankful for merely avoiding amputation" [4]. Avoiding amputation isn't fearmongering: failed Dupuytren treatment is the most common indication for elective finger amputation, as common as the next two diagnoses combined [5].

Evaluation

History

Use a checklist approach to avoid pitfalls in the initial patient evaluation. Initial Dupuytren-specific patient histories should include the date of onset of any Dupuytren findings, prior Dupuytren treatment, other previous injuries and treatments of the hand, history of Ledderhose, Peyronie, or frozen shoulder, and Dupuytren history in parents and siblings. When you ask about Peyronie, Ledderhose, and frozen shoulder, briefly describe them: many people don't know these names, and most will assume that frozen shoulder means a rotator cuff problem. Pain, tenderness, or itching affected areas, reported in at least one-quarter of patients, correlates with early age of onset and, by extension, biologically aggressive disease [6]. In addition to asking about these symptoms, patients should be asked specifically about dexterity problems and specific problem activities. Document these common subjective pretreatment issues because they often persist after treatment.

Examination

Documentation

Dupuytren-specific form templates such as those at https://dupuytrens.org/research-publications/forms-for-documentation/simplify and standardize the documentation of Dupuytren findings and procedures. Create images of Dupuytren hands using standard views (Fig. 41.1a–c) to document progress and goniometry [7].

Skin condition impacts the choice of procedure. In previously untreated patients, the skin retains enough elasticity to allow full correction (Fig. 41.2a, b). Assess the palmar skin condition using a modification of Rosenthal's classification [8]: Grade 1: mobile without dimples or blanching (Fig. 41.3a); Grade 2: limited mobility, dimples, blanching with finger extension (Fig. 41.3b); Grade 3: adherent, prominent papillary ridges, blanching at rest (Fig. 41.3c); and Grade 4: maceration (Fig. 41.3d).

Dupuytren-related changes in skin texture and mobility of grades 2 and 3 represent microscopic findings of myofibroblasts and fibrosis, which increase recurrence [9, 10]. These are not a contraindication to treatment but increase the chances of incomplete correction and early recurrence. Grade 3 changes increase the risk of skin tears in minimally invasive procedures and buttonholing and inelastic flaps in fasciectomy. Grade 4 maceration is not always evident before release, but when found should be controlled preop to reduce infection risk.

Nodules of the palm, dorsal finger joint soft tissues, or instep of the feet (Ledderhose) are signs of active disease biology and increase the likelihood of recurrence after treatment.

Palmar nodules Palmar Dupuytren nodules are typically adherent to overlying dermis with indistinct borders, less than 1 cm in diameter, and rarely much larger [11]. Typical palmar nodules are most often confused with local soft tissue changes overlying flexor tenosynovitis. The differential diagnosis of atypical nodules includes flexor tendon sheath cyst and soft tissue tumors. Avoid isolated nodule excision unless the diagnosis is in question, because it may flare disease

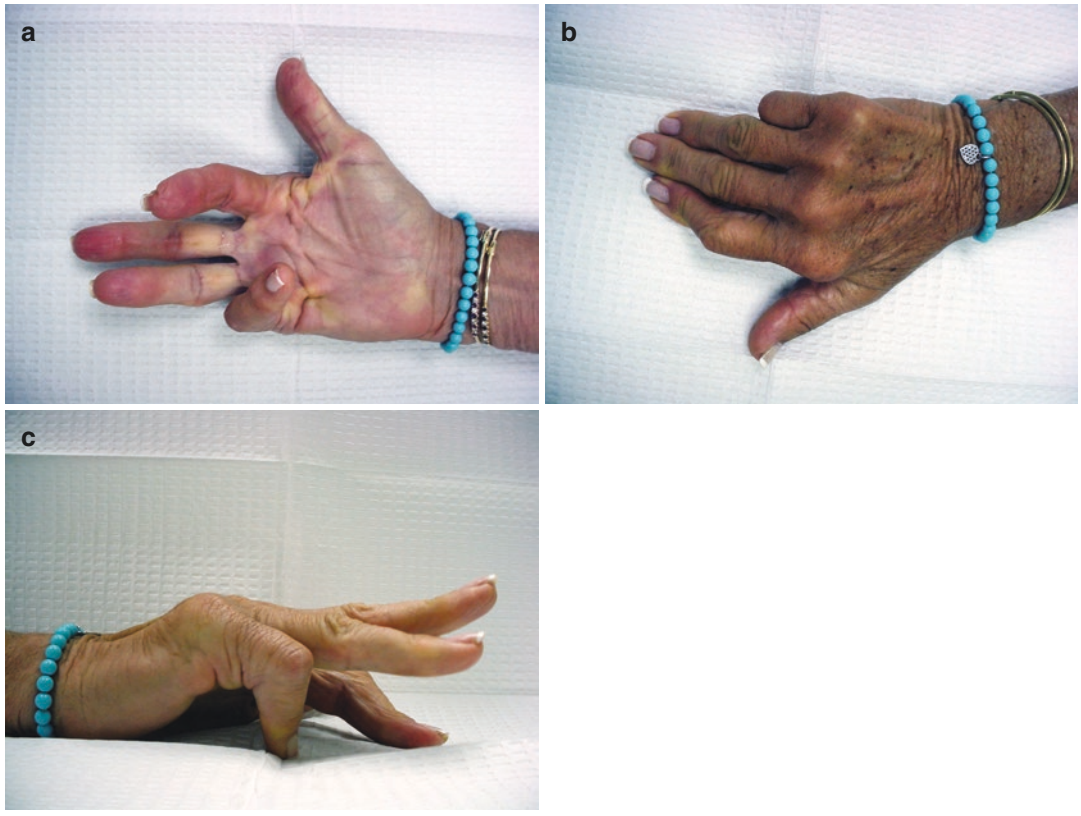

Fig. 41.1 Dupuytren images**.** If possible, take standard views of both hands each office visit. (**a**) palm, (**b**) dorsum, (**c**) ulnar lateral palm down. Include the entire hand, including the wrist with clear margins around the fingertips and thumb tip. Ask the patient to straighten all fingers for each view. Otherwise, the normal resting flexion cascade results in false-positive flexion measurements

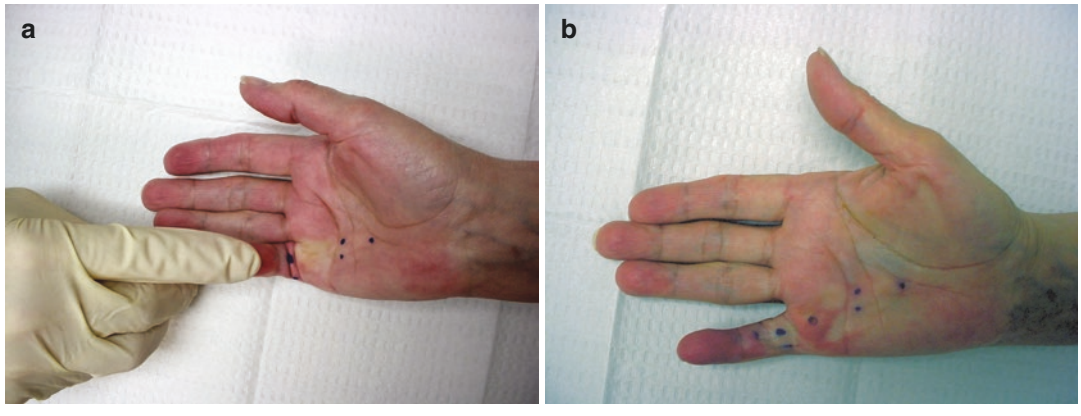

Fig. 41.2 Skin condition. For minimally invasive procedures, the skin must have some elastic reserve or be able to unfurl. (**a**) Folded proximal phalanx pulp skin. (**b**) Unfurled skin following percutaneous needle fasciotomy

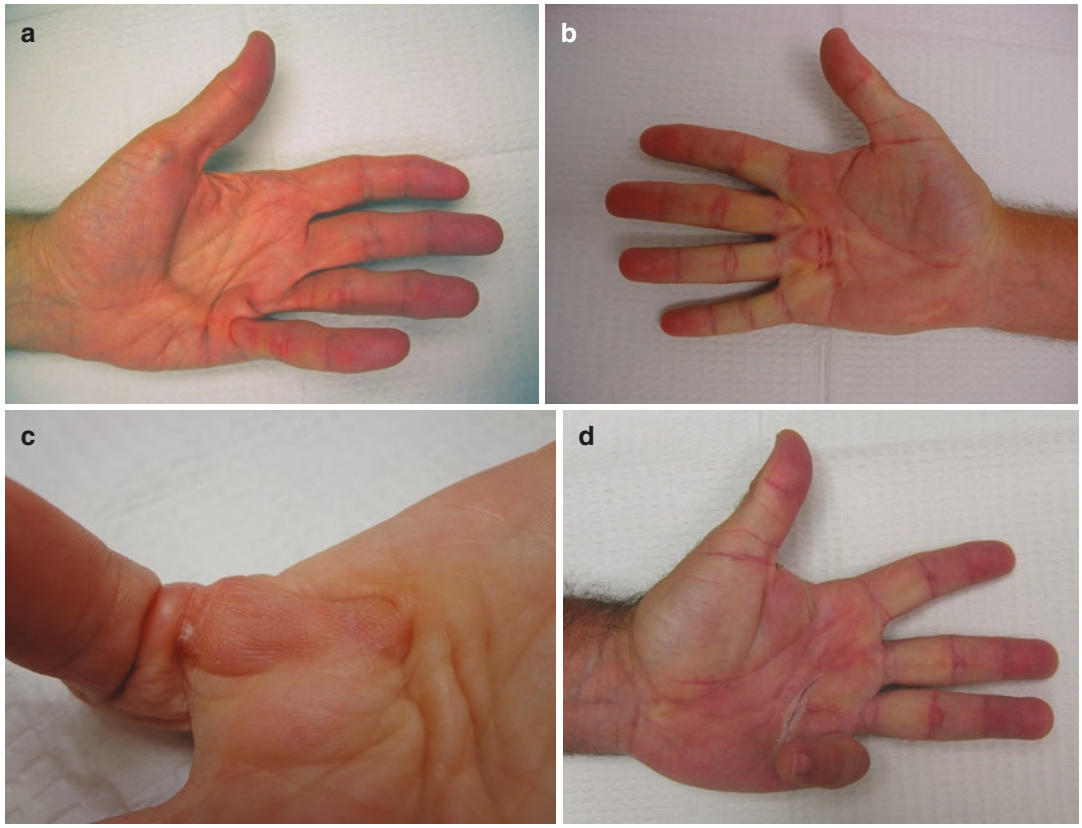

Fig. 41.3 Skin grades. (**a**) Grade 1: Mobile without dimples or blanching. (**b**) Grade 2: Limited mobility, dimples, blanching with extension. (**c**) Grade 3: Adherent, prominent papillary ridges, blanching at rest. (**d**) Grade 4: Maceration

activity. Assess nodularity of cords by palpating the cord while ranging the finger through flexion and extension to vary cord tension—nodular areas remain firm when the cord is not tight; cords without nodules do not.

Dorsal nodules Not all dorsal nodules are Dupuytren-related. Dupuytren knuckle pads (also called Garrod nodes or dorsal Dupuytren nodules) are well-defined, firm, subcutaneous dorsal masses greater than 3 mm in diameter (Fig. 41.4a). These most often involve the PIP joints but may occur over the metacarpophalangeal (MCP), distal interphalangeal (DIP), thumb interphalangeal joints, or their counterparts in the toes. The overlying skin is typically normal and not adherent. They are sometimes tende r and occasionally inflamed (Fig. 41.4b). *Knuckle dimples* have a "pinched" appearance without a palpable mass, resembling palmar dimples (Fig. 41.4c). Dorsal Dupuytren nodules may be confused with dorsal cutaneous pads, which are thickened skin without an underlying mass (Fig. 41.4d). *Dorsal cutaneous pads are unrelated to Dupuytren* and occur with equal frequency in patients with and without Dupuytren disease [12]. Knuckle pads commonly recur after removal, and excision risks flexion loss or boutonniere deformity.

Ledderhose disease Many patients are unaware of their Ledderhose: examine feet routinely. Up to one-third of patients with Dupuytren disease also have Ledderhose disease. The presence of Ledderhose correlates with an earlier age of Dupuytren onset [13] and a family history of Dupuytren [6], which in turn correlates with the risk of treatment-resistant disease.

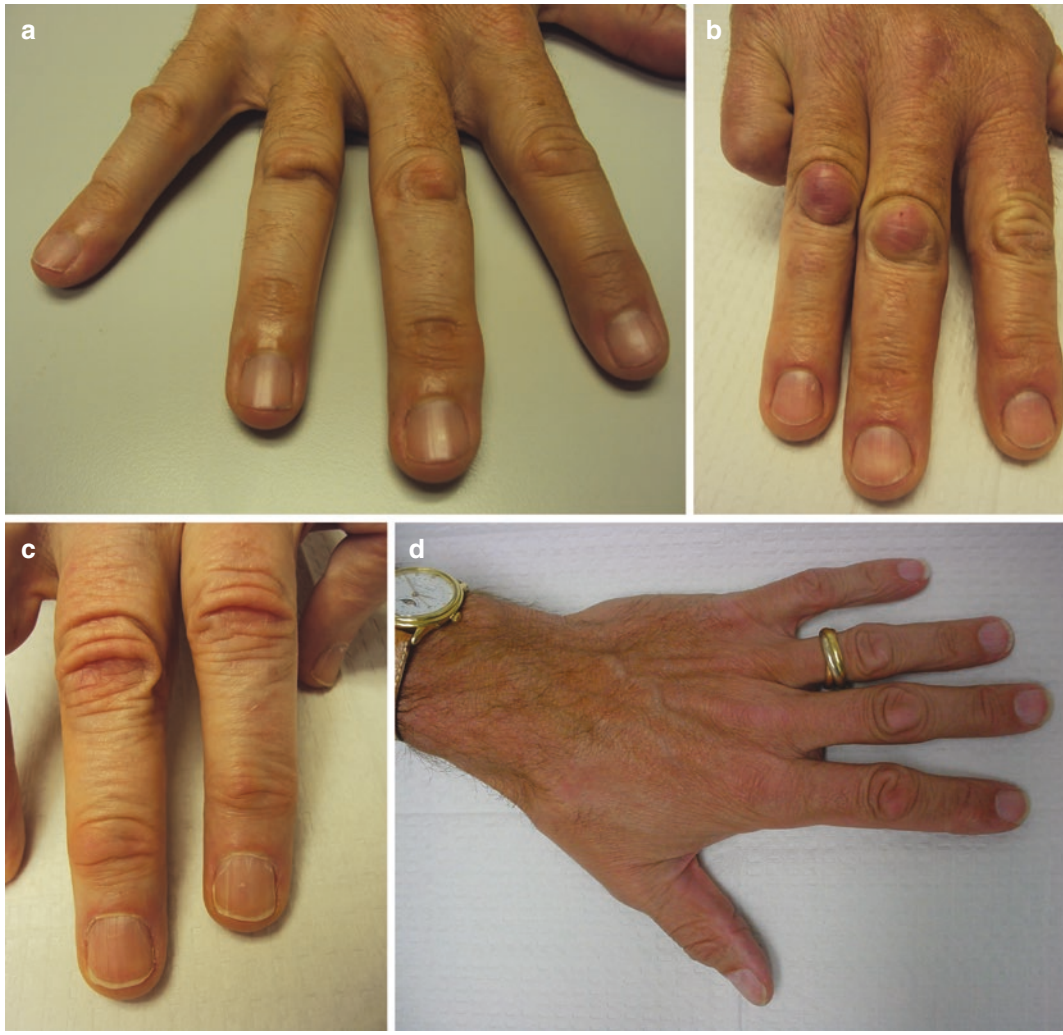

Fig. 41.4 Dorsal Dupuytren nodules**.** (**a**) Dorsal Dupuytren nodules ("knuckle pads") are firm subcutaneous masses with mobile overlying skin. Border skin dimpling is common. (**b**) Inflamed dorsal Dupuytren nodules. (**c**) Knuckle dimples in a patient with knuckle pads. (**d**) Dorsal cutaneous pads are due to skin thickening. They are more common over the MCP than the PIP joints and do not affect Dupuytren prognosis

Cords

Documentation

Document each cord *location* (draw a diagram), *width* (broad or narrow), *definition* (well-defined or not), *skin adherence* (overlying skin mobile or not), *padding* (palpable soft tissue between cord and skin or not), and *nodularity*.

Bowstringing cords are common. Bowstringing makes cords more palpable, which is helpful for minimally invasive treatment (Fig. 41.5a, b). Bowstringing is also useful in fasciectomy: design flaps to convert bowstringing-related transverse skin expansion into longitudinal skin lengthening [14]. It is also favorable for patients. Bowstringing-related contractures progress more slowly because the further the cord is from the joint axis, the less angular contracture results from the same amount of linear cord shortening. Don't confuse pulley incompetence or undiagnosed spasticity [15] for central cord bowstringing: check for tendon bowstringing by palpating the area in question with the finger

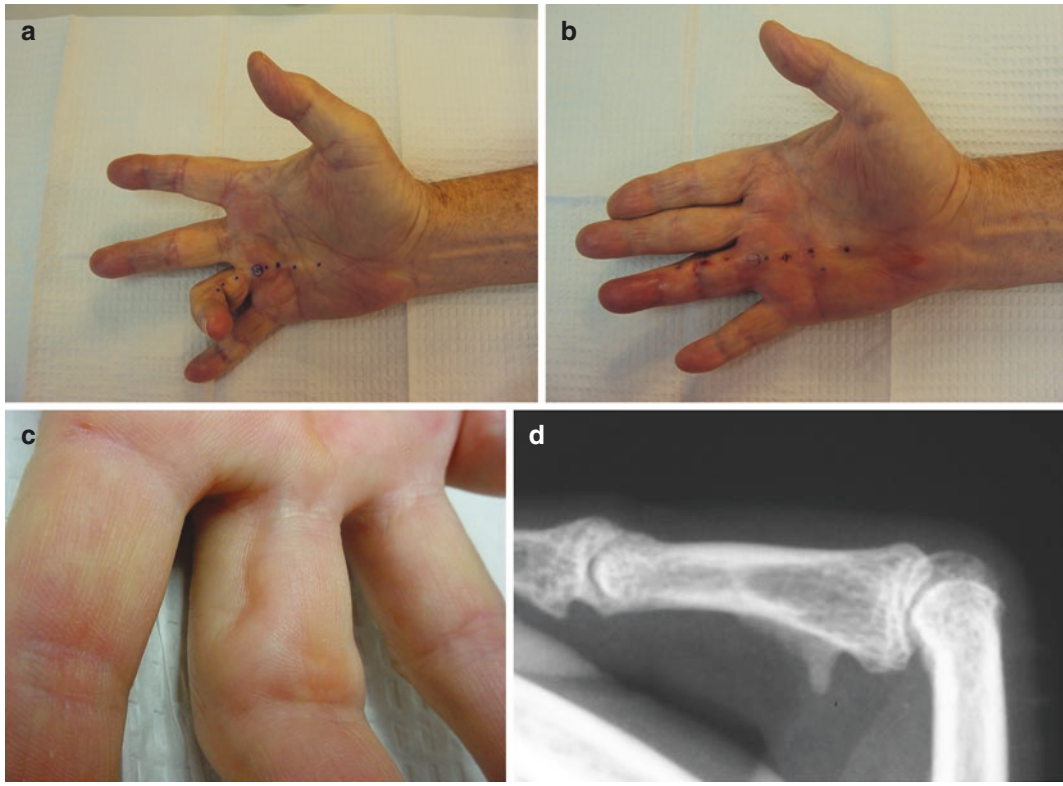

Fig. 41.5 Digital Cord variations**.** (**a**) Bowstringing lateral digital cords are favorable for minimally invasive procedures. (**b**) After PNF. (**c**) Lateral digital dimpling from a retrovascular cord, which is not itself palpable and not suitable for minimally invasive treatment. (**d**) Lateral digital cord traction osteophyte

flexed as the patient intermittently attempts to flex and relax against your resistance.

Hidden digital cords Not all cords bowstring visibly. Digital cords are less likely to bowstring than palmar cords. Central and lateral digital cords can bowstring, but retrovascular cords do not. Retrovascular proximal phalanx cords may retract the lateral digital skin toward the "assembly line" [16], where the distal A2 pulley attaches to the palmar–lateral border of the proximal phalanx (Fig. 41.5c). If there is no obvious cord associated with a PIP contracture, examine for deep lateral or retrovascular cords. With the patient's hand relaxed and the PIP passively flexed, push your palpating fingertip against the lateral finger just dorsal to the mid-axial line to feel the lateral proximal phalanx cortex. Maintaining pressure on the cortex, slide your fingertip palmar to contact the assembly line at the palmar–lateral border of the proximal phalanx. Hold this position to feel any tightening beneath your fingertip as you passively range the digit back and forth between extension and flexion. Normally, there should be no tightening with extension. If there is, it is a deep lateral or a retrovascular Dupuytren cord. If you can't feel any tightening, there still might be a Dupuytren cord that you can't tension anymore because it has become stress-shielded by a contracted palmar plate. Even if a cord is suspected, the lack of a palpable cord contraindicates minimally invasive treatment.

Calcific cords of the proximal palmar–lateral border of the middle phalanx (Fig. 41.5d) may be found incidentally at fasciectomy [17, 18] or percutaneous needle fasciotomy (PNF) for PIP contractures approaching 90 degrees. These are traction osteophytes rather than cord ossification or calcific tendinitis. They may interfere with PNF but need no specific treatment.

Spiral cords have been reported in as many as one-half of operated Dupuytren hands [19, 20]. Spiral cords may develop anywhere between the distal palmar crease and the DIP flexion crease (Fig. 41.6a). Spiral cords may be identified preoperatively with ultrasonography [22] or via a Doppler stethoscope (Fig 41.6b). They are more likely where a fleshy prominence covers a well-defined cord (Fig. 41.7a–d). Spiral cords are more common with greater PIP contracture angles [23]. Spiral cords can occur without a soft tissue prominence [19, 20]. A helpful diagnostic maneuver is for the examiner to passively extend the finger to place the cord under tension, compress the overlying tissue against the cord with a fingertip, and ask if this produces pain or paresthesias.

Angle Measurements

Contracture types Note *fixed, total*, and *dynamic* contractures on examination. Fixed contracture is the extension deficit of a *single* joint, independent of the posture of adjacent joints. Composite contracture (combined digital flexion contracture) is the *sum* of the extension deficit of multiple joints in one ray. The Tubiana score groups composite contractures into 45-degree increments. Dynamic contracture refers to cords spanning *sequential* joints, allowing one joint to extend while flexing the other (Fig. 41.8a, b).

Measurement inaccuracy Finger goniometry has a 5-degree margin of error [24]. With dynamic contractures, composite contracture measurements are greater than the sum of individual fixed contracture. In this situation, individual fixed contracture measurements alone underrepresent the contracture severity of a ray, its impact on functional outcomes, and the risk of complications such as skin tears in minimally invasive procedures. Dynamic cords spanning the ring or small carpometacarpal joint (CMC) link MCP extension to CMC flexion, narrowing span, and preventing a flat palm (Fig. 41.8a, b).

Unusual Findings Prompting Additional Evaluation

Loss of flexion after treatment is more of a problem for the patient than incomplete correction. Loss of flexion may exist before any procedure and should be evaluated and documented before treatment. *Pretreatment generalized stiffness predicts post-treatment stiffness* and is more common in patients with diabetes-related stiffness. In the absence of non-Dupuytren pathology, an inability to touch the thumb to the small fingertip may signal general hand stiffness (Fig. 41.9a). Loss of DIP flexion associated with PIP flexion contracture (Fig. 41.9b) should prompt evaluation of central slip pathology, as discussed below.

Passive greater than active extension Look for differences between active and passive finger extension. These include central slip laxity, active flexion posturing, central motor lesion, and peripheral nerve lesion. Sagittal band rupture may develop secondary to severe MCP contractures. The importance is that *residual non-Dupuytren pathology contributing to contracture will lead to rapid re-contracture*.

Active flexion posturing is seen in some patients with composite MCP/PIP contractures greater than 90 degrees who flex these fingers into the palm to get them out of the way (Fig. 41.10). Over time, this functional amputation may lead to cortical reorganization and persistence of active flexion after a corrective procedure. *Central motor lesions* with mild spasticity and *peripheral nerve lesions* with mild clawing may overlap Dupuytren findings and may not be previously diagnosed.

Pain with passive extension Although one in four patients will describe tenderness or pain in Dupuytren-affected areas [6], *pain with passive extension suggests a non-Dupuytren diagnosis*. Flexor tendonitis, chronic active flexion posturing, arthritis, or spasticity may overlap Dupuytren. Consider this in your treatment recommendations and document: it may prevent a satisfactory treatment outcome.

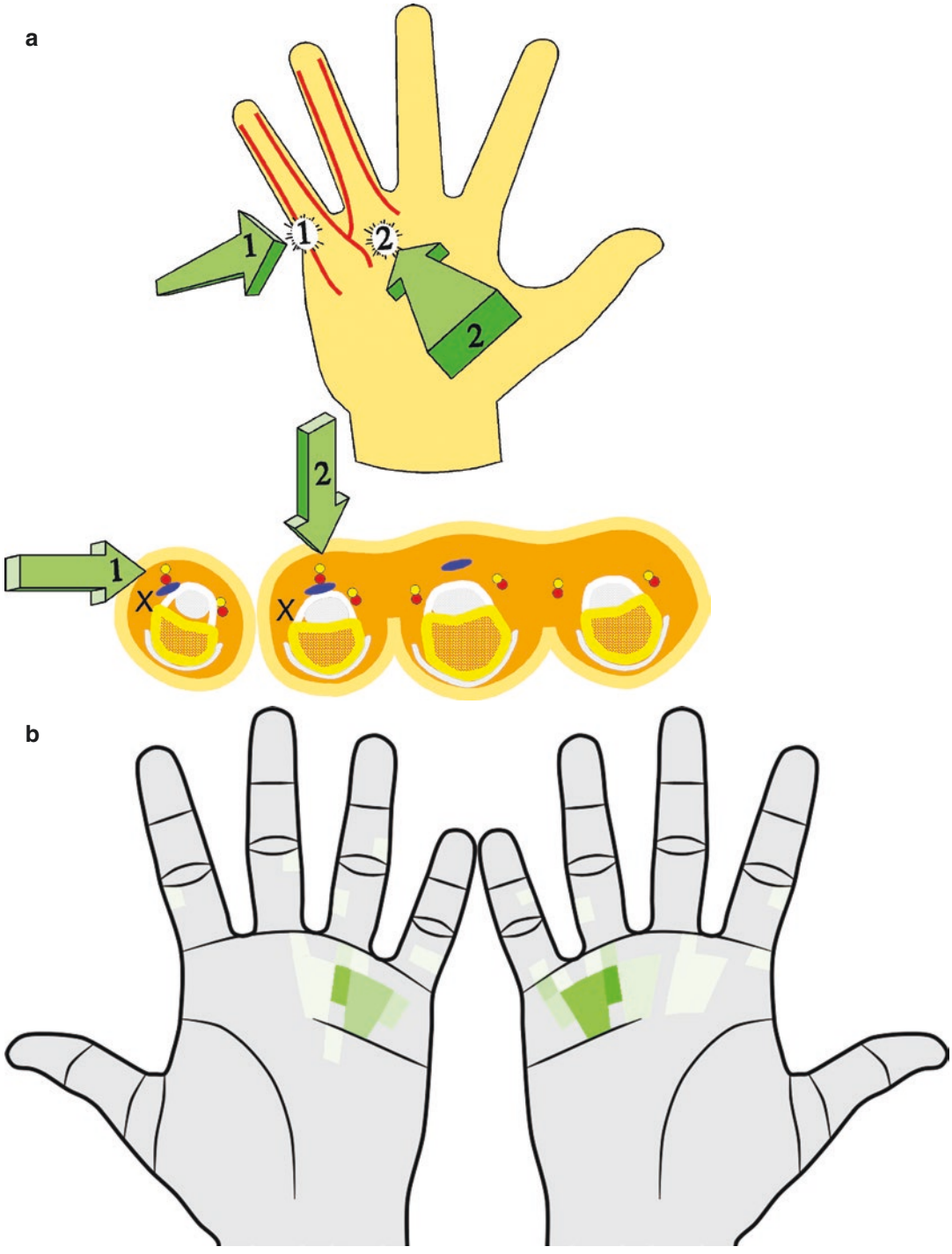

Fig. 41.6 Doppler stethoscope for spiral cords**.** (**a**) Listen for vascular Doppler tones where digital arteries should not be a pulse: superficial (1) or central (2). (Reproduced with permission from Eaton et al. [21]; Copyright (C) 2012). (**b**) Heat map of 75 spiral cord locations identified by Doppler stethoscope in 71 Dupuytren patients

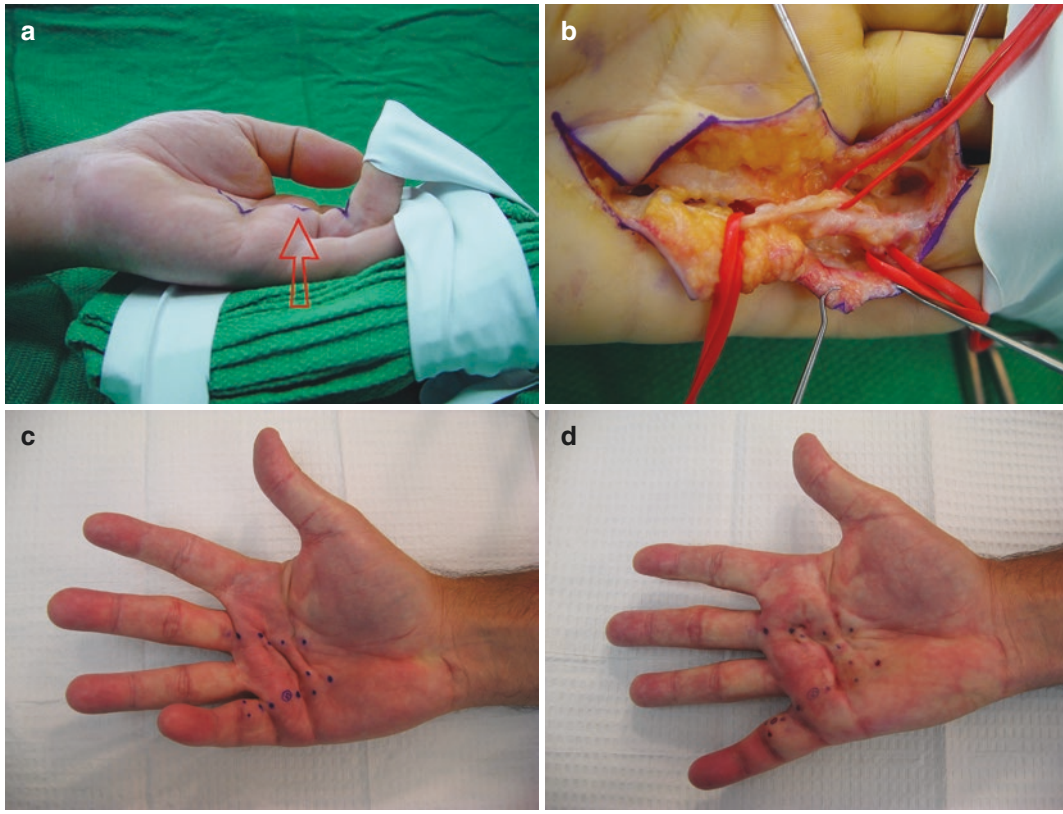

Fig. 41.7 Spiral cords. (**a**) Fleshy bulge between the distal palmar crease and the proximal finger flexion crease. (**b**) Neurovascular bundle crossing superficial to the cord within the soft tissue prominence. (**c**) Spiral cord (indicated by small circled "S") location incorporated into PNF portal planning. (**d**) Completed PNF

Severe contractures Because Dupuytren progresses slowly, composite contractures greater than 90 degrees represent some degree of neglect. "Why did you wait so long?" is a helpful question to predict the patient's compliance with a post-procedure treatment regimen. Severe contractures may be associated with co-pathologies such as spasticity or secondary pathologies such as PIP central slip laxity or MCP sagittal band rupture.

Rotation or lateral angulation *Rotation or lateral angulation at the MCP* level is most often due to oblique cords and is likely to be corrected with a Dupuytren procedure. In contrast, *lateral PIP angulation* usually reflects joint changes visible on X-ray, which will persist after contracture correction. Consider *sagittal band rupture* in severe MCP contractures associated with lateral deviation and pronation at the MCP (Fig. 41.11a, b). It may be difficult to demonstrate before the correction of severe fixed MCP contractures. Sagittal band reconstruction can be performed at the time of PNF or staged after recovery from collagenase clostridium histolyticum (CCH) injection or fasciectomy.

Diathesis

Diathesis can refer either to a predisposition to a disease or the "full version" disease phenotype. Houston popularized the idea of Dupuytren diathesis as predicting increased risk for post-treatment recurrence and extension and as an indication for dermofasciectomy [25]. *There is no standard list of diathesis factors*. Houston

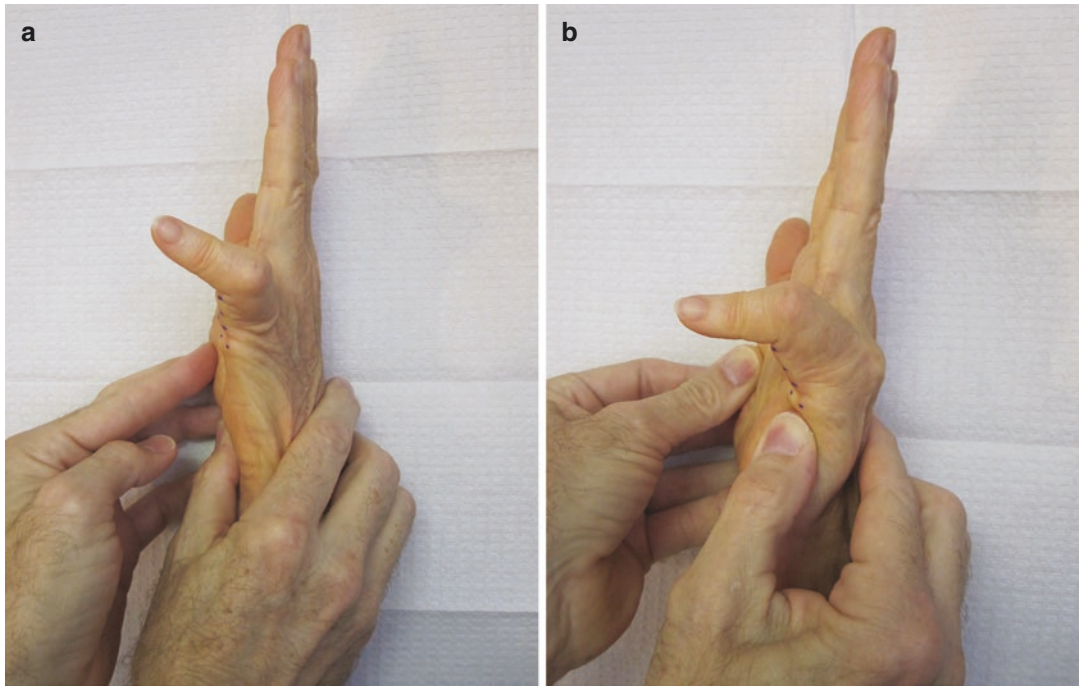

Fig. 41.8 Dynamic contracture. This patient has a cord spanning CMC and MCP, resulting in a dynamic contracture. (**a**) The patient automatically flexes the small finger CMC, cupping the palm when actively extending the finger. (**b**) Blocking CMC flexion and flattening the transverse palmar arch demonstrates the true composite contracture

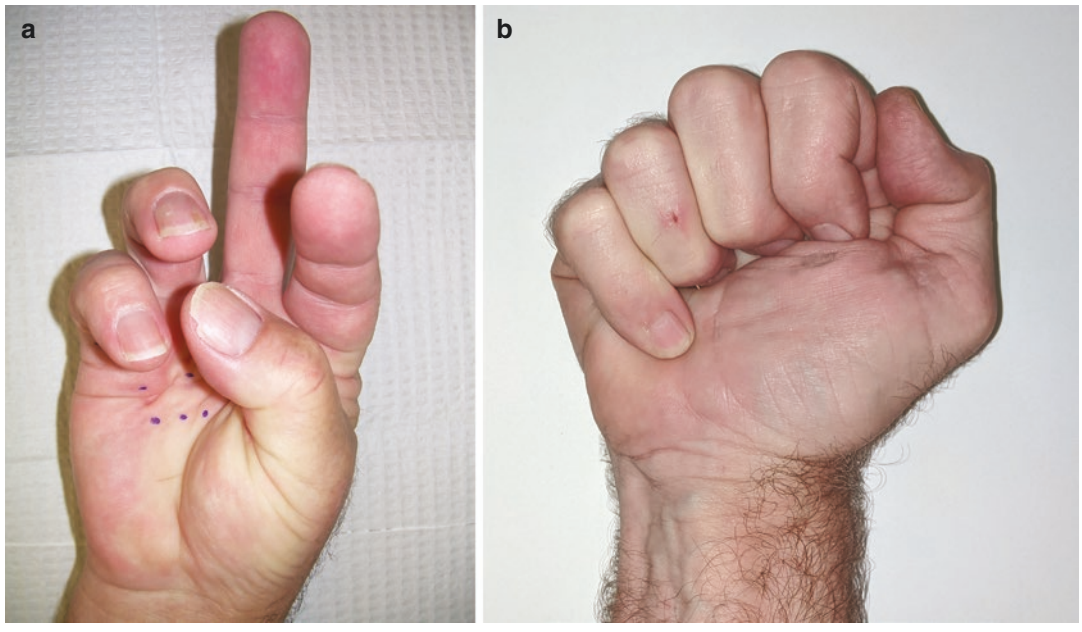

Fig. 41.9 Pretreatment stiffness**.** (**a**) Loss of small finger supination as an index of generalized hand stiffness. (**b**) Loss of DIP flexion indicating boutonniere-type extensor mechanism laxity secondary to PIP contracture

changed his list with every publication, and others have done the same. The most predictive diathesis factors are the *age of onset younger than 50* and a history of a *close relative with Dupuytren*. Other reported diathesis factors include Ledderhose, knuckle pads, male gender, Peyronie disease, bilaterality, more than two rays involved, thumb involvement, the surface area of involvement, and others. Dupuytren Diathesis does *not* correlate with rapid contracture progression *before* treatment, with technical procedure difficulty, or with initial outcomes.

Other than family history, Dupuytren diathesis factors differ from risk factors for *developing* Dupuytren disease. Alcoholism, tobacco use, diabetes mellitus, chronic hand vibration exposure, chronic heavy manual labor, and other factors have been reported to increase the likelihood of developing Dupuytren. These influences are minor compared to the effect size of family history on the risk of developing the disease. These minor factors affect neither treatment outcome nor recurrence risk.

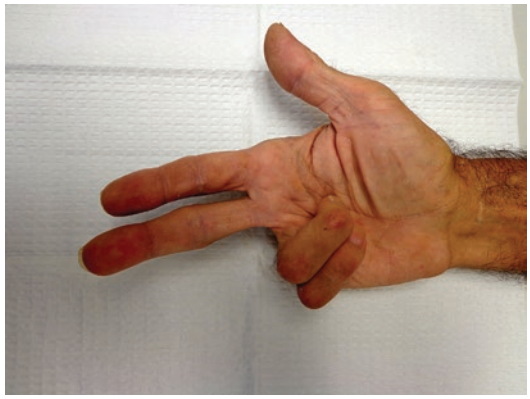

Fig. 41.10 Functional amputation: Active flexion posturing in severe contractures

Patient Discussion: Ancestry

Parents, siblings, and children Dupuytren is polygenetic. A *very* rough estimate is that each child of a parent with Dupuytren has a one-in-four chance of developing the disease. Negative family history is unreliable because of late-onset and lack of awareness of mild disease in senior relatives. In contrast, a positive family history of Dupuytren is the strongest risk factor for developing the disease, for early disease onset [26], and for biologically severe disease. The number of affected parental lines correlates with a lower average age of first Dupuytren surgery: 61 for no family history, 56 for 1 affected parental line, and 48 for both parental lines affected [26]. An affected sibling triples one's risk of developing the disease [27].

Sorry, not Vikings The idea that Dupuytren is a "Viking disease" began as speculation in a 1985 textbook [28] and was widely repeated without

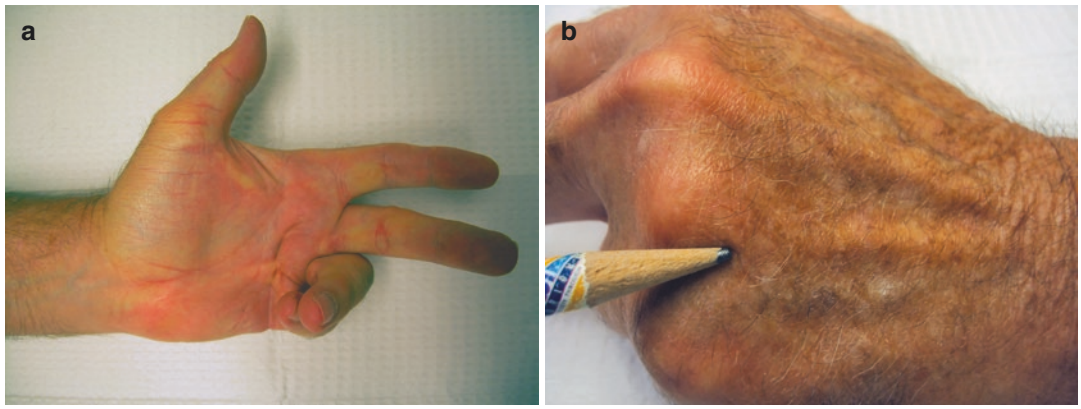

Fig. 41.11 Sagittal band rupture**.** (**a**) Ring finger supination and ulnar deviation. (**b**) Same hand ulnar extensor dislocation from sagittal band rupture

evidence and has been refuted by genetic research [29]. *Dupuytren is a Caucasian disease* [30], and Vikings were Caucasian. That's it. Dupuytren is as common in Bosnia [31] as in Norway [32]. Compared to Caucasian Americans, Dupuytren is one-third as common in Hispanic Americans, one-fifth as common in African Americans, and one-tenth as common in Asian Americans [33], roughly paralleling the percent Caucasian heritage of these American groups [34].

Patient Discussion: Dupuytren Disease *Without* Contracture

The following problem scenario is common and preventable for patients with early Dupuytren. The patient is diagnosed with early disease, handed a brochure, told there is nothing to do now but to come back when they can't place their palm flat on a tabletop. The patient Googles "Dupuytren," sees pictures of worst-case scenarios, panics, and is upset with the doctor for failing to discuss prevention, inheritance, and possibly losing the use of their hands. Discuss these points proactively to avoid this drama:

- Dupuytren is common, but fewer than 1 in 20 have the severe disabling version.
- Dupuytren is common with or without a known family history, but more common with.
- One in 10 Dupuytren nodules will resolve without *any* treatment.
- Only one in five with a first Dupuytren nodule will need a procedure within the next decade.
- The window of opportunity for the best result is when joint contractures are between 20 and 40 degrees.
- There are many potential preventive treatments, but no way yet to test whether they prevent contracture over the long term. The same is true for manual treatments; topical, locally injected, or systemic medicines; and radiotherapy.
- Forcing the fingers backward may stimulate contracture progression rather than preventing it.
- If they want to help, they can participate in research, for example, DupStudy.com.
- If they want to connect, they should join the British or International Dupuytren Societies.

Finally, *don't* just tell the patient to come back when it is worse, when they can't stand it, or when they flunk the tabletop test. That's a setup for them to come back only after they've missed the window of opportunity for a good result. Instead, schedule regular follow-ups at 6-month intervals to stay ahead of it. Dupuytren is a chronic disease. Unlike surgical diseases, proper chronic disease management involves open-ended longitudinal surveillance. Our understanding of Dupuytren is limited by the lack of longitudinal data of its natural history.

Patient Discussion: Dupuytren Disease *with* Contracture

The key to long-term Dupuytren patient satisfaction is managing patient expectations. Dupuytren treatment is the most common reason for a hand surgery patient to announce: "*If I had known what I was going to go through, I never would have had that surgery!*" Involve the patient in the decision-making process. *Fasciectomy complications are common compared to other hand procedures: don't skim over the risks*. Begin with these discussion points:

- There is no prevention. There is no cure. The goal is to make the best of it.
- *Partial improvement is the most common outcome*.
- The more the bent joints are *before* treatment, the more bent they will be *after* a procedure.
- Treatments are either minimally invasive procedures or open surgery called fasciectomy.
- Minimally invasive treatments can delay but may not prevent the need for fasciectomy.
- Fasciectomy procedures last longer but are more likely to have complications.
- The most common *temporary complication* of fasciectomy is a long recovery, sometimes lasting many months. Long recovery may involve prolonged wound healing, swelling, pain, stiffness, inability to make a fist, numb-

ness, tenderness, and difficulty with fine manipulation.
- The most common *permanent complications* of fasciectomy are nerve injury with numbness, tenderness, cold intolerance, loss of strong grip, and difficulty with fine manipulation.
- Recurrence is part of the disease, not a complication.
- Treatment of recurrence is riskier and less effective than the first procedure.
- Warn patients with isolated MCP contractures if there is re-contracture; the PIP joint is likely to be involved. PIP joint procedures are riskier and less effective than MCP joint procedures. The goal of treatment is to minimize the lifetime impact of Dupuytren and avoid the need for amputation.

Treatment

Procedure Categories

There are four categories of Dupuytren procedures. Minimally invasive procedures include collagenase clostridium histolyticum injection (CCH) and percutaneous needle fasciotomy (PNF). Open procedures include fasciectomy and dermofasciectomy. Salvage procedures include PIP fusion, middle phalangectomy, and amputation. Adjunct procedures include external skeletal fixation for fixed PIP joint flexion contractures and middle phalanx extensor tenotomy (Dolphin procedure) for boutonniere-related DIP extension contracture [35].

Treatment Window

Best outcomes are for contractures severe enough to justify risks of treatment but not past the window of opportunity for near-complete correction. The window is contractures of 20–50 degrees for MCP joints and 20–40 degrees for PIP joints. Greater angular contractures are less likely to have complete correction [36–38], more likely to have treatment complications [39, 40], and more likely to have an earlier recurrence [40, 41]. This window of expectations is due in part to secondary changes in tendons and ligaments. Four out of five PIP joints with contractures greater than 60 degrees have central slip lengthening or attenuation [42].

Procedure Expectations

Initial Correction

Anatomy and procedure alone affect initial outcomes, not Diathesis. The likelihood of initial complete correction is affected by anatomy, but not by biological factors such as diathesis factors, age, gender, diabetes, occupation, or alcohol consumption [43–46]. Post-procedure range of motion, Disabilities of the Arm, Shoulder and Hand (DASH), and Michigan Hand Outcomes Questionnaire (MHQ) scores correlate with unilateral versus bilateral involvement, but not with the age of onset, ectopic disease, or family history of Dupuytren [47].

Complete Correction

Correction to less than five degrees of contracture is less likely for PIP than MCP joints, for the small finger PIP than other rays, for greater degrees of angular contracture, for composite PIP and MCP contractures, for hands with more than one ray involved, or with prior Dupuytren contracture treatment [36–40, 43, 44, 48–50]. Averaging all degrees of contracture, *more than three in four MCP contractures but fewer than half of all PIP joint contractures and are fully corrected with a procedure* (Table 41.1).

Composite Contracture

A practical guide for composite (MCP + PIP) contractures is that *overall contracture will improve up to 90 degrees, including up to 50% improvement in PIP contracture* (Fig. 41.12a–d).

Procedure Comparison by Treatment Outcome

Patient satisfaction Head-to-head comparison of patient-reported satisfaction and function

Table 41.1 Outcome statistics using the benchmark of percent of treated joints achieving correction to five degrees or less of complete extension

Immediate outcome procedure comparison: Percent joints achieving complete correction		
Percent complete correction	Minimal	Open
MCP (all)	65–80% [36, 37, 41, 51–54]	78–98% [44, 54–56]
MCP ≤ 50°	72–81% [36, 54, 57]	86% [54]
MCP > 50°	39–68% [36, 54, 57]	74% [54]
PIP overall	27–50% [36, 37, 41, 51–54, 58]	36–83% [44, 54–56]
PIP ≤ 40°	50–52% [36, 54, 57, 58]	88% [54]
PIP > 40°	17–25% [36, 54, 57, 58]	38% [54]

1–5 years after treatment show equivalent outcomes for minimally invasive procedures, fasciectomy, and dermofasciectomy at improving contractures and hand function [59–62].

Direct comparison In head-to-head same practitioner comparisons, improvement in initial angular contracture and hand function is similar for minimally invasive procedures CCH and PNF [51, 59, 63, 64]. Pain and swelling are much more common in the first week after CCH than after PNF [65]. PNF can be performed on multiple fingers at the same setting and on both hands within 24 hours. CCH is limited to two rays on one hand (using the entire vial contents or two concurrent vials) once every 30 days. In head-to-head comparisons, minimally invasive procedures are

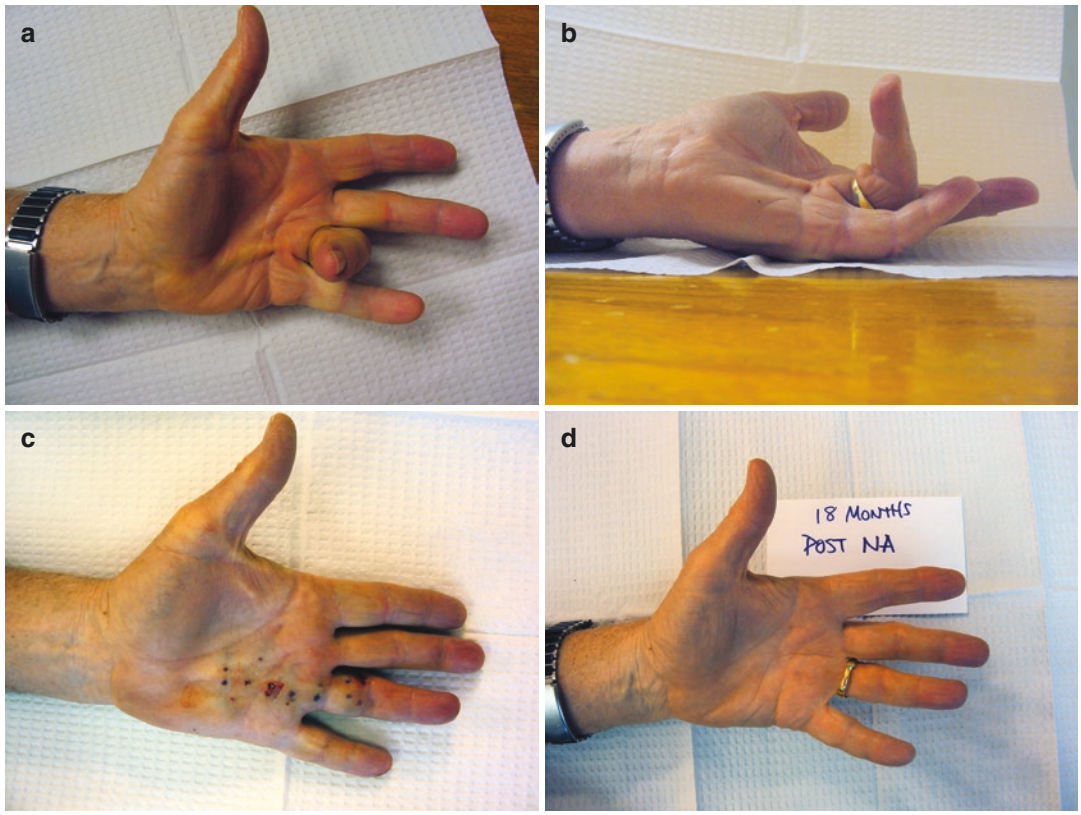

Fig. 41.12 Composite contracture**.** A rule of thumb for composite MCP-PIP contracture improvement is a maximum of 90 degrees improvement including 50% improvement of PIP contracture. (**a**, **b**) Composite MCP-PIP contracture with combined 100-degree contracture. (**c**) Immediate result from PNF and combined 90-degree improvement. (**d**) Stable 18 months post-release

equivalent to fasciectomy for MCP contractures and composite contractures less than 45 degrees, but less effective than fasciectomy for PIP contractures or composite contractures greater than 90 degrees [66, 67].

Cross-study comparisons The common historical outcome measure is the *mean percent improvement*: percentage decrease in the degree of joint contracture from baseline (Thomine coefficient of improvement = (preop extension deficit–postop extension deficit)/preop extension deficit). Increasingly, the measure is *percent complete correction*: the percent of joints having complete contracture correction referred to as "perfect" in older reports and as "success" in CCH studies. There is no way to translate outcomes between these benchmarks. *Similar sounding but non-interchangeable outcome metrics are common, and common terms such as "improved" or "recurrence" are defined differently in different studies*. Table 41.1 summarizes data from studies reporting percent complete correction, and Table 41.2 summarizes studies reporting average percent correction.

Splinting

Despite common use, studies have consistently reported *no evidence of any added benefit from splinting after Dupuytren treatment*, whether static, dynamic, or continuous passive motion, applied either routinely or selectively for progressive extension loss [76–82]. If splinting patients, less is more—painful passive or dynamic extension splints are the gateway to noncompliance and are associated with worse outcomes [79, 83, 84].

Table 41.2 Outcome statistics using the benchmark of average percent improvement of individual joint contractures

Immediate outcome procedure comparison: Average percent correction per joint		
Mean percent improvement	Minimal	Open
MCP (All)	75–91% [36, 53, 64, 68–72]	78–95% [44, 66, 69, 73, 74]
PIP (All)	33–77% [36, 53, 66, 68–70, 72]	32–92% [44, 48, 66, 69, 73–75]

Re-contracture

Re-contracture is common but not inevitable. Re-contracture is influenced *independently* by anatomy (contracture severity), biology (diathesis and histology), and procedure (minimal vs. open). Most patients lose some initial correction in the first year after any treatment, more often in PIP joints [39, 44, 52, 55, 64, 76, 85]. This early loss of correction often stabilizes and is *re-equilibration,* not *recurrence* [39].

Recurrence terminology can be misleading. Be aware that some publications use a selective redefinition of the word "recurrence," which uses post-hoc criteria, excluding poor outcomes. A patient might ask before treatment, "*Doc, what are my odds of having a straight finger five years after CCH treatment?*" Based on the summary figures in a representative study [41], the answer might seem to be 61% for MCP contractures and 34% for PIP contractures. However, "recurrence" used in this study *excluded* fingers that were never straight as well as an undisclosed number of fingers that had re-contracture but no palpable cord. The correct answer is less than 40% for MCP joints and less than 14% for PIP joints when using these exclusions in the calculations.

Recurrence and anatomy Anatomic factors which correlate with re-contracture are PIP joint contracture itself, incomplete initial correction [40, 41, 55, 86, 87], small finger contracture [88, 89], and nodular (myofibroblast-rich) tissues identified preoperatively by physical examination or ultrasonography [90], and greater pretreatment contracture [40].

Recurrence and biology Biological factors correlating most strongly with recurrence risk are younger disease onset (common benchmark younger than 50), cellular histology [91–93], histology showing an increased ratio of type III to

type I collagen [94], and a weighted genetic risk score [95]. Currently, there is *no standard predictive model of biologic risk factors for recurrence;* neither histologic patterns nor a proposed Dupuytren genetic profile associated with recurrence correlates with diathesis factors [92, 93, 95].

Recurrence and type of procedure There is no common metric to retrospectively compare recurrence outcomes for fasciectomy, CCH, PNF, and dermofasciectomy. Different groups have used different benchmarks. Same-center studies have reported overall recurrence rates two to four times greater for minimally invasive procedures than fasciectomy [61, 96] and PIP recurrence rate greater for CCH than PNF [63]. What should you tell your patients? Summarizing available literature and glossing over the facts that recurrence rates are not linear and vary both by joint and by personal biologic risk, a practical guide is *recurrence occurs at a rate of 10–20% per year for minimally invasive procedures, 5–10% per year for fasciectomy, and less than 2% per year for proper dermofasciectomy* [97].

Technical Tips for Procedures/General Recommendations

Review the anatomy Dupuytren cord variations defy definitive classification or comprehensive explanation. Cord locations are influenced by normal anatomy and by directions of tissue tension and relaxation. Some fascial structures are commonly involved, such as the pretendinous bands. Others are rarely involved, such as the nearby superficial transverse palmar ligament. Some Dupuytren cords involve named fascial structures, such as natatory cords. Others arise in areas without any defined fascia, such as central digital cords. The best starting point is a clear understanding of normal surface landmarks (Fig. 41.13) and normal fascial structures (Fig. 41.14a–c).

Corticosteroid injection Local injection of 10 mg Triamcinolone or equivalent dose of another depot corticosteroid will reduce the size, tenderness, and itching of palmar nodules or knuckle pads (Fig. 41.15a, b). Recurrence is common after a few months when local drug levels drop. Repeat injections may also help but need monitoring of steroid atrophy, particularly for knuckle pads. Local steroid injections improve the duration of correction following PNF [98], but the effect is time-limited [99]. As with radiotherapy, the most predictable results are nodules in the palm without contracture. Unless given at the time of a corrective procedure, avoid injecting palmar nodules in contracted fingers as an isolated procedure because of a risk of accelerating the rate of contraction (Fig. 41.15c, d).

Central slip issues Central slip laxity secondary to PIP contracture is a common cause of post-treatment PIP re-contracture. Boutonniere posture may not be obvious until after PIP release (Fig. 41.16a, b). In the absence of a resting boutonniere posture, test the central slip with maneuvers described by Elson [100] and Smith [42] (Fig. 41.17a, b). In the presence of severe fixed PIP contracture, DIP hyperextension from boutonniere may be less awkward than a flexed or fused DIP. There is no evidence-based guidance on the optimum management of Dupuytren-related central slip incompetence. Results of extensor reconstruction in this context are often poor. Long-term outcomes of middle phalanx extensor tenotomy [35] for Dupuytren boutonniere-related DIP extension contracture are unknown. Similarly, there is no evidence-based guidance on splinting for central slip incompetence after Dupuytren PIP release; anecdotal recommendations vary from 2 to 6 weeks.

PIP Manipulation

It is easy to forget that the goal of joint manipulation in Dupuytren is to lengthen a linear tether, not unstick a frozen axel. Excessive force can produce two lasting injuries. The first is *volar plate rupture*. Why worry about PIP hyperextension when the overwhelming problem of

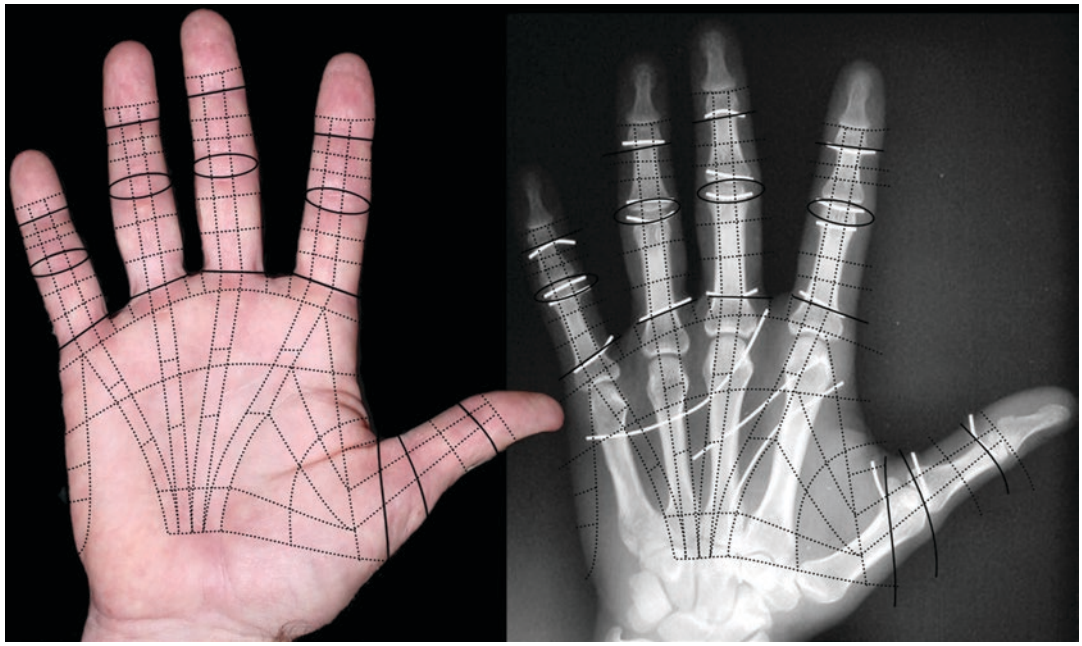

Fig. 41.13 Normal surface and skeletal anatomy**.** The grid represents common zones of Dupuytren involvement relative to skin creases and the underlying bones and joints

Dupuytren is flexion contracture? Because although uncommon, this can progress to swan-neck deformity, loss of flexion, and an unhappy patient with no good options (Fig. 41.18a, b). The second is *cartilage damage*. Rigid resistance to passive extension may give a false impression that the PIP joint is more durable than it is. Mechanically, cords producing PIP flexion contractures are far stronger than the underlying joint cartilage, ligaments, and bone. The cord acts as a fulcrum, converting angular extension stress into compression stress of the thin joint cartilage. Pre-existing cartilage loss is common in the Dupuytren demographic. The patient may have prolonged pain, inflammation, and acceleration of osteoarthritic changes from overzealous closed manipulation. Fractures can occur with aggressive attempts at manipulation [101, 102]. The safest maneuver is gentle, sustained extension stress of the PIP for several minutes with the MCP joint flexed [48]. The goal of manipulation is to rupture weakened cords and pathologic adhesions without damaging normal structures.

Open Procedure Recommendations (Fasciectomy/Dermofasciectomy)

Anesthesia

Open procedures are amenable to general anesthesia, regional anesthesia with tourniquet control, or wide-awake local anesthetic no tourniquet (WALANT) technique [103]. WALANT is *not* recommended for *redo* fasciectomy because scarring from prior surgery may result in persistent oozing despite epinephrine.

Create Optimum Exposure

- Maintain *dynamic finger extension* during dissection. Your goal is to remove the tethering structures which are preventing extension. Static hand-holders require constant readjustment to maintain tension. A simple dynamic hand-holder fabricated from readily available

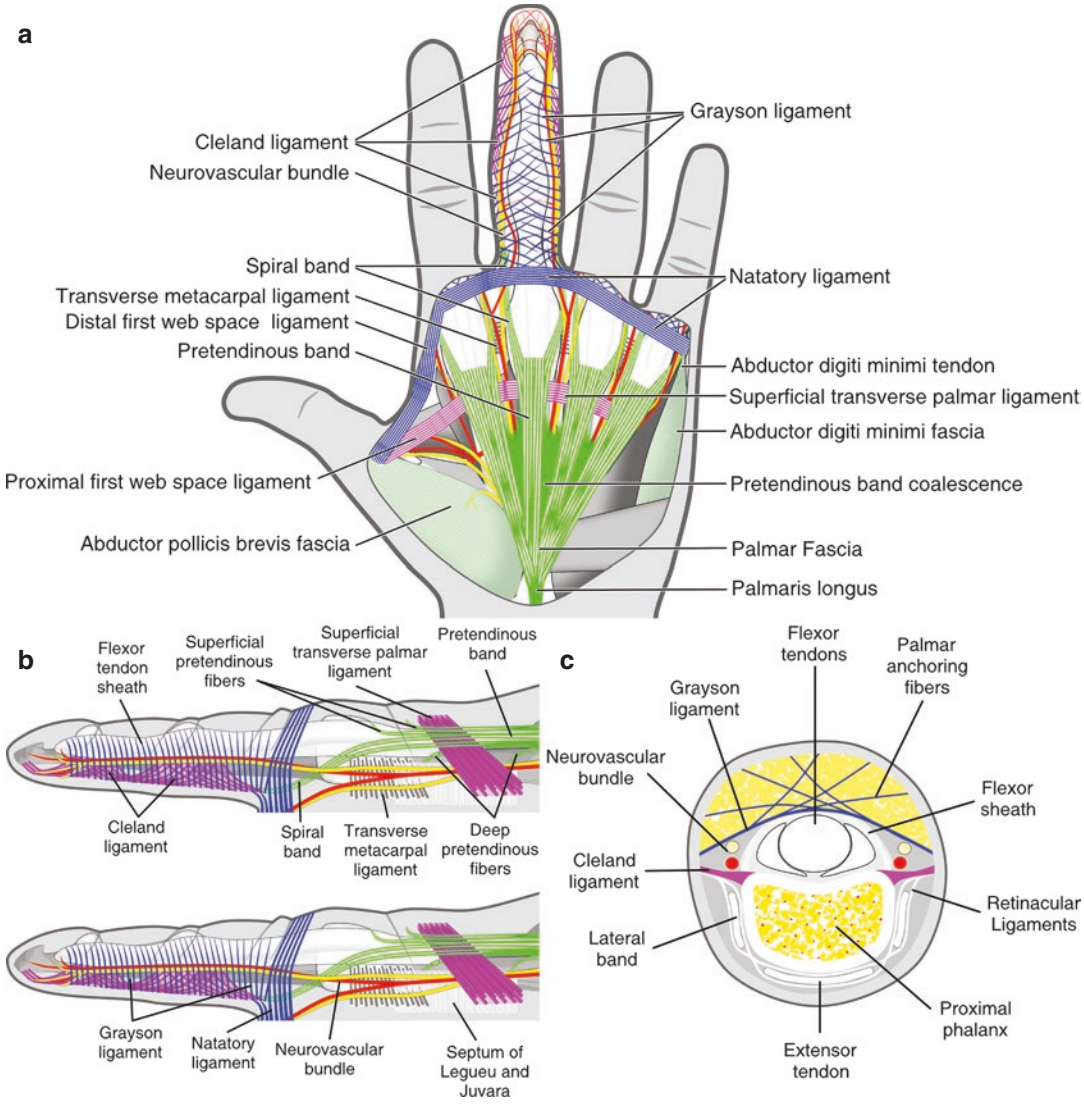

Fig. 41.14 Normal fascia anatomy**.** The most superficial (blue) structures have a transverse fiber orientation. The intermediate-depth (green) structures have a longitudinal fiber orientation. Deep (magenta) structures have a transverse fiber orientation. Historic eponyms are the ligament of Grapow (natatory ligament), Skoog's ligament (superficial transverse palmar ligament), and the septa of Legueu and Juvara (proximal flexor sheath). (**a**) Palm view. (**b**) Lateral digit view. (**c**) Cross-section proximal phalanx mid-diaphysis

items solves this problem, as shown in Fig. 41.7a and 41.19a–e.

- *Isolate and transect the cord proximally* early in dissection to open the field and improve exposure. Clamp and put tension on the distal cut end as needed for exposure.

Avoid Neurovascular Injury

- As discussed above, *anticipate spiral cords*, which are more common in more severe PIP contractures in areas where the cord is not palpably subdermal.

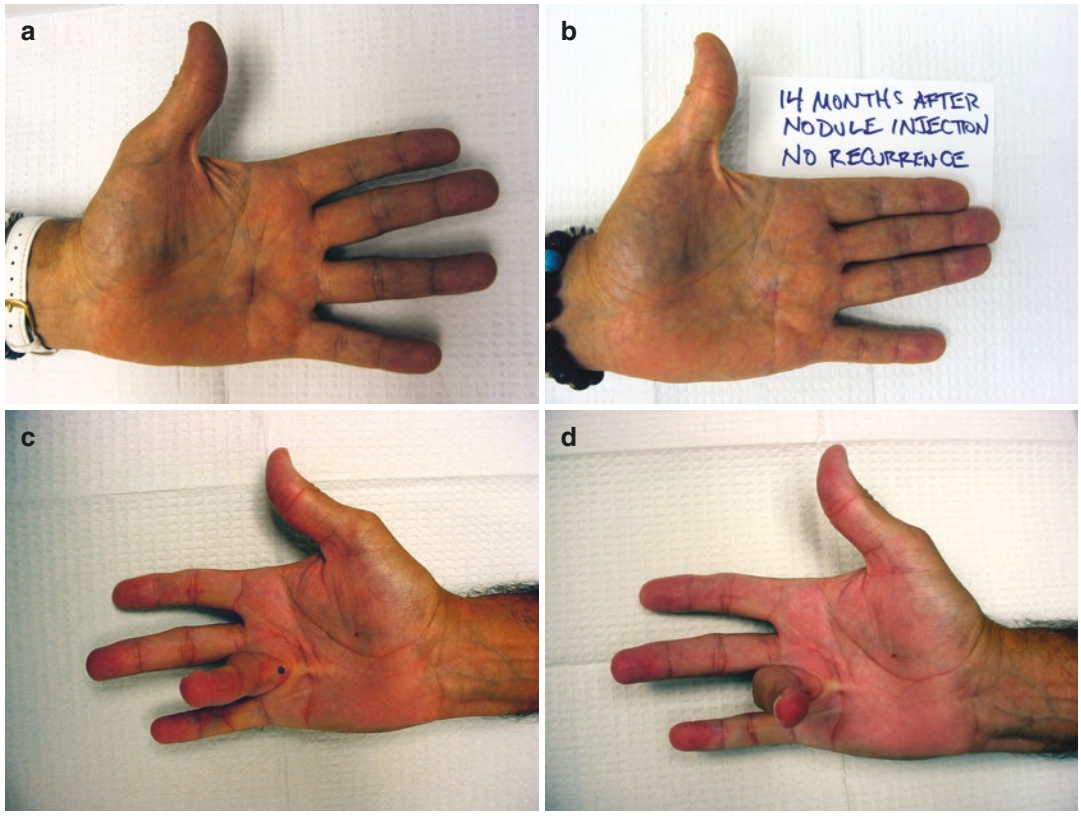

Fig. 41.15 Corticosteroid nodule injections**.** Corticosteroids affect Dupuytren biology in several ways, including reducing cellularity of Dupuytren nodules and increasing local collagenase production. Tissue tension modulates the effects of corticosteroids on Dupuytren biology and may accelerate progression of existing contractures. (**a**) Tender palmar nodule of ring ray at distal palmar crease with no contracture. (**b**) 18 months after nodule injection with 20 mg triamcinolone, nodule resolved with residual trophic skin changes, but no contracture. (**c**) Ring finger with composite contracture and proximal phalanx pulp nodule. (**d**) 20-degree PIP contracture progression 3 months after nodule injection with 5 mg Triamcinolone at site marked in **c**

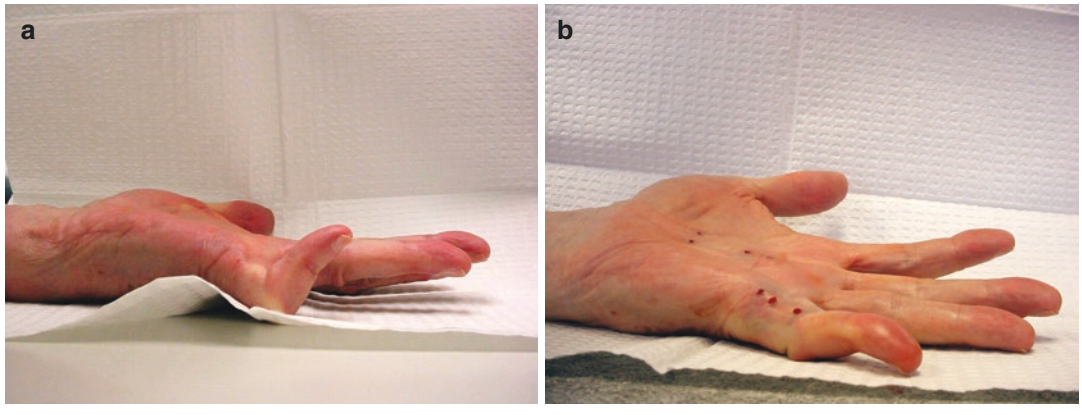

Fig. 41.16 Boutonniere tendon imbalance masked by fixed contracture**.** (**a**) Slight active DIP hyperextension with fixed 85-degree PIP contracture. (**b**) PNF improved PIP extension improved to 30 degrees but increased active DIP hyperextension to 50 degrees

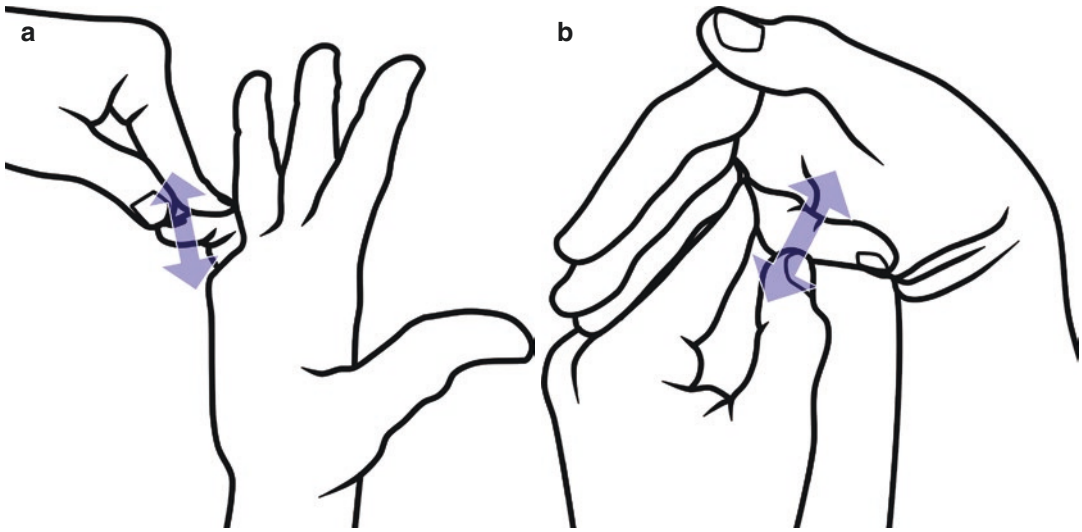

Fig. 41.17 Tests for central slip damage**.** Immediately following the PIP contracture release, there may not be a boutonniere posture despite contracture-related extensor mechanism changes. (**a**) The most reliable test for extensor mechanism pathology after contracture correction is the Elson test, done with the patient awake. Ask the patient to straighten the PIP while you hold it flexed. This action shouldn't change the DIP resistance to passive flexion. If it does, the extensor mechanism is damaged. (**b**) If the patient is asleep, the next best test is the Smith test. Flexing the wrist and MCP should result in PIP extension or at least greater resistance to passive flexion. If not, the extensor mechanism is damaged

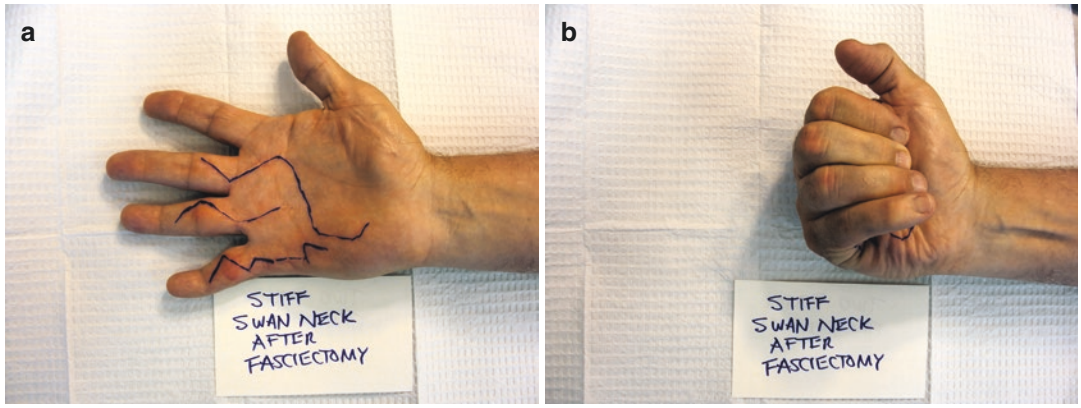

Fig. 41.18 Complications of PIP release**.** Volar plate rupture-related PIP hyperextension and swan-neck deformity can occur from overzealous manipulation with or without open PIP release. This patient developed a stiff swan-neck posture after PIP release at fasciectomy. (**a**) Extension with ring and small finger swan-neck postures. (**b**) Loss of flexion: an insoluble problem

- *Proceed from known to unknown*. Identify neurovascular structures outside involved areas and track them into diseased regions under direct vision.
- *Use sharp dissection* rather than ripping tissues with scissors: neurovascular structures tear more easily than fibrotic tissues. Use scissors with thin pointed tips to isolate structures to be sharply divided. Scissor tips should narrow in two directions to a pyramidal-shaped point. If such scissors aren't available, file and polish off-the-shelf tenotomy scissors, as

shown in Fig. 41.20. These scissors are particularly helpful in dissecting scarred beds in redo procedures.

- *Don't skeletonize the neurovascular pedicles*. Although a common practice in microvascular surgery, skeletonizing neurovascular structures in Dupuytren disease increases the chance of injury and guarantees a greater risk of injury in subsequent redo procedures.
- Have an *operating microscope* available just in case, and always for redo fasciectomy.

Avoid Marginal Skin Necrosis

Delayed wound healing is due to vascular compromise of skin flap margins.

- Use *wide flaps*. Keep flap tip angles 60 degrees or greater.
- *Handle skin flaps only by the undersurface* of the dermis. Don't pinch across the full thickness of the skin flap.
- *Avoid splints until several days postop*. Maintaining extension with splints in the operative dressing has no benefit (wound contraction doesn't begin until a week after wounding) and increases the chance of marginal wound necrosis. If you feel immobilization is needed because of skin grafts or tendon concerns, splint in no more extension than created by extensor tenodesis from wrist flexion.

Minimize PIP Damage

- *Preserve the volar plate*. Volar plate release may be gratifying in the operating room, but gains are usually short-lived. The bulk of evidence demonstrates no predictable long-term benefit [76, 104–109].
- *Don't pin the PIP joint*. When rubbery resistance to PIP extension remains at the end of the procedure, it is tempting to pin the PIP joint in extension, but this only provides false hope. Neither skin nor accessory collateral ligaments lengthen from K wire immobilization. The more the PIP joint is immobilized,

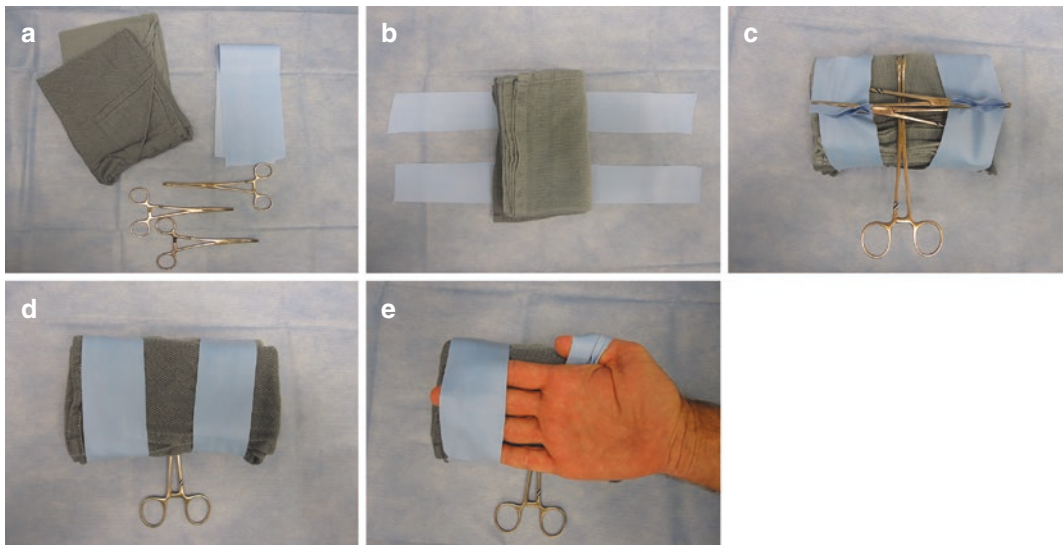

Fig. 41.19 DIY Dupuytren surgery hand-holder**.** (**a**) Materials: two surgical towels, two strips of Esmarch roll, two Kelley clamps, one sponge clamp. (**b**) Esmarch strips and folded towels. (**c**) Undersurface. The sponge clamp acts as a kickstand to block pronation. It is easier to grab the towel here with a sponge clamp than a Kelley clamp. (**d**) Working surface. (**e**) Application. Add additional individual finger retractors strips as needed, as shown in Fig. 41.7a

Fig. 41.20 True pointed dissecting scissors**.** Most pointed tenotomy scissors come to an edge, not a true point. The tip of standard tenotomy scissors has been sharpened to a pyramidal point, compared here to unmodified Littler scissors. Left pair: side view of both scissors, Littler on the right. Right pair: top-down view of both scissors, Littler on the right

the more likely it is to result in stiffness and flexion loss [109].

Avoid Flexion Loss

- *Don't use passive extension splinting*. Compared to active extension splinting, post-fasciectomy passive extension splinting is associated with a greater incidence of postop flare reaction and long-term flexion loss with no added benefit in maintaining extension [79, 83, 84].
- *Don't reconstruct the extensor mechanism*. Treating Dupuytren-related central slip attenuation with PIP extensor mechanism and transarticular pinning leads to flexion loss and a poor overall outcome [48].
- *Again, don't do an open PIP release.* PIP arthrolysis for Dupuytren-associated contractures increases the risk of flexion loss, more so when the joint is pinned [109].

Fasciectomy

Technical variations of fasciectomy follow three choices. The first is the *extent of fascia excision*: regional (removing all visible disease, more popular in the United states) versus segmental (removing a section of visible disease, more popular in Europe) and radical fasciectomy (removing all potentially involved fascia, *not* recommended due to greater risk and no added benefit) [110]. The second is *incision direction*: transverse versus primary zigzag versus zigzag via flap plasty (Fig. 41.21a, b). Longitudinal midline digital should never be used because of scar contracture (Fig. 41.22). Incisions for multiple digits may be kept separate or joined as they converge in the palm. These variations are based entirely on the surgeon's preference. There are inadequate data to show the superiority of any of these recommended options for any long-term outcome measure.

Dermofasciectomy

Concept

Dermofasciectomy is a *functional unit skin replacement*. This procedure was developed following the observation that recurrent Dupuytren cords are rare beneath a skin graft. The reason for this finding is not known. Possible explanations are 1) removal of a reservoir of biologically active factors in the skin or 2) changing the mechanical characteristics of the local soft tissues prevent mechanical stress–relaxation stimulation of Dupuytren pathobiology. Dermofasciectomy

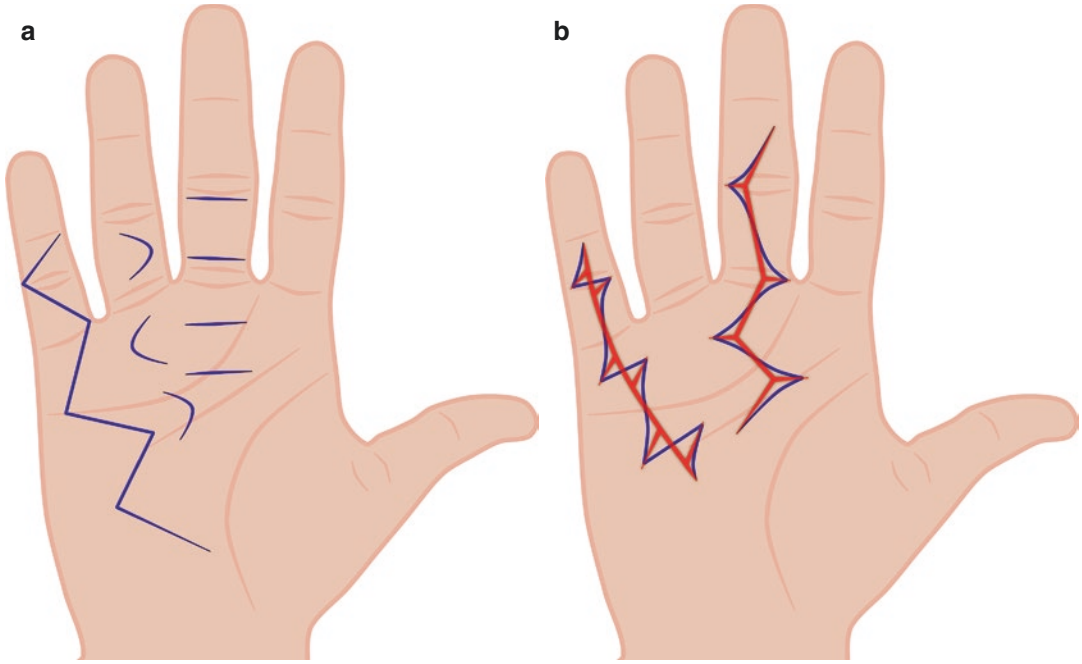

Fig. 41.21 Fasciectomy incisions**.** The goals are to achieve adequate exposure and avoid longitudinal scars. Incisions without skin rearrangement. The incisions shown are not specific to any finger. (**a**) Small finger: Bruner zigzag, ring finger: Moermans curves, middle finger: McCash open palm. (**b**) Skin-lengthening plasties. Incisions are red, closure blue. Small finger: Wakefield Z plasties, ring finger: Watson Y-V plasties

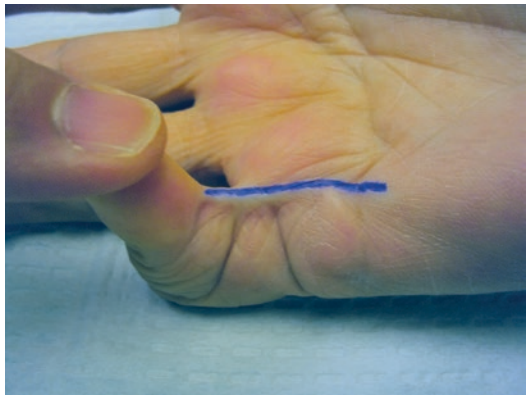

Fig. 41.22 This contracture recurrence after fasciectomy is from a linear fasciectomy (marked in blue), not Dupuytren recurrence

is *not* simply fasciectomy plus a small skin graft used to allow wound closure or as a "firebreak" graft. The technique involves large segmental skin excision and resurfacing with full-thickness skin grafts as shown in Fig. 41.23a–c. Confusion on this issue has led to conflicting outcome reports, but dermofasciectomy remains the best option for long-term disease control. Because the risk of neurovascular injury increases with each redo procedure, dermofasciectomy is best used as the primary procedure for high-risk patients or as the first redo procedure for rapid recurrence after a technically correct fasciectomy. Recovery time after dermofasciectomy averages 50% longer than fasciectomy [111]. All techniques described above for fasciectomy above also apply to dermofasciectomy.

Do Your Homework

Dermofasciectomy is technique sensitive. Read the original technical descriptions by Logan, Armstrong, and Ketchum [112–114]. Key points include the following:

- Segmental excision of all nonessential soft tissues.
- Use mid-lateral incisions or risk re-contracture at the skin graft–skin border.
- Use full-thickness skin grafts.

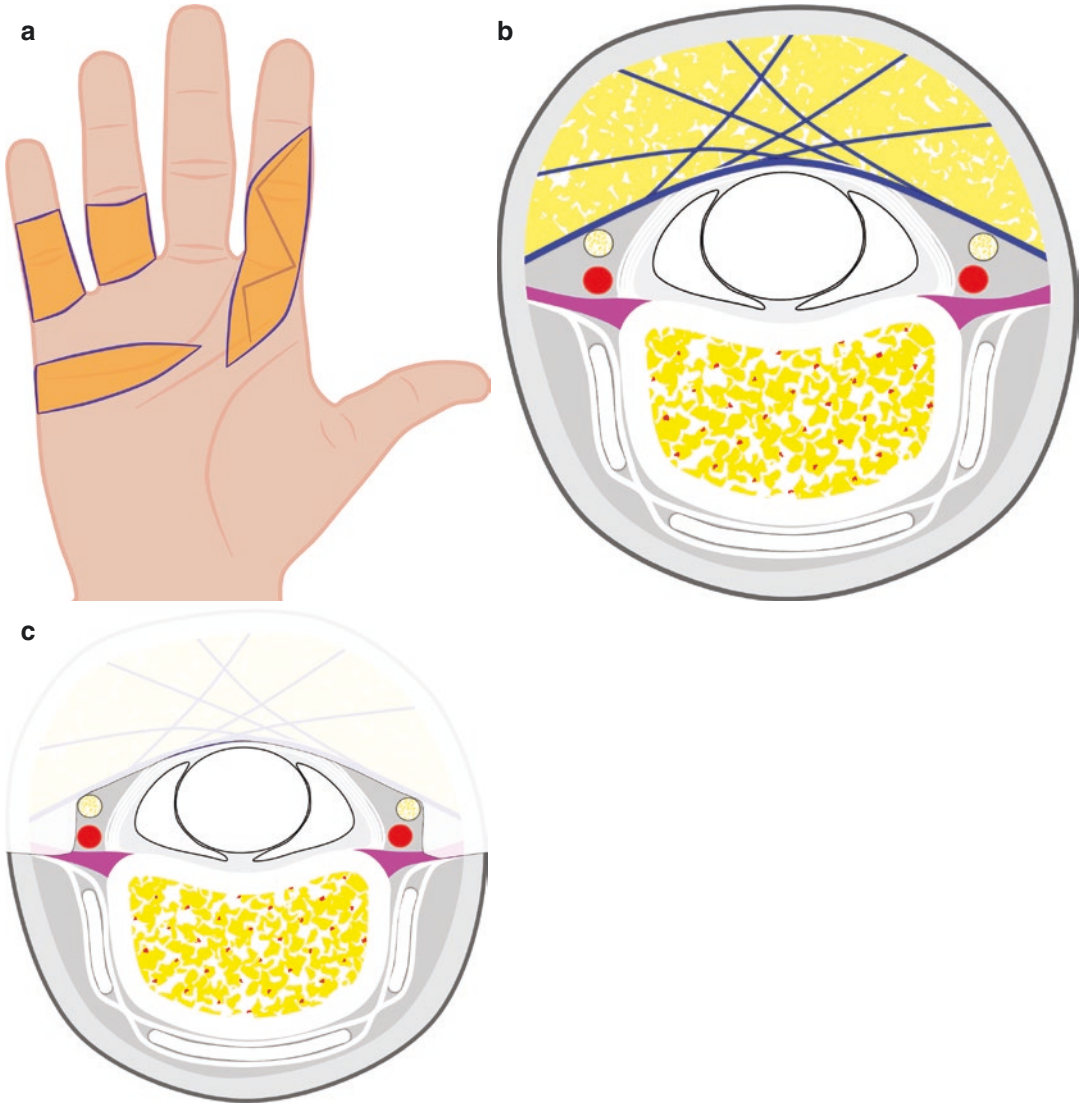

Fig. 41.23 Dermofasciectomy and skin graft incisions**.** The goals are to replace recurrence-prone skin, avoid small or pointed flaps, and place longitudinal graft–skin junctions in mid-lateral positions. The incisions shown are not specific to any finger. (**a**) Small (proximal and middle phalanx pulp skin) and ring (proximal phalanx pulp skin): Segmental skin replacements, leaving metacarpal head skin intact. Index: severely scarred contracted skin from prior surgery can be replaced with a skin graft as shown or left in situ. (**b**, **c**) These palmar hemicircumference structures are removed and resurfaced with full-thickness skin graft

- When possible, do not graft the palmar prominence of the metacarpal heads.
- Choose an extensible skin graft donor site that won't lead you to scrimp on the size of the graft. The author's preference for a large graft and good cosmetic result is to harvest a large graft from the ipsilateral proximal medial forearm with a longitudinal donor site.

Minimally Invasive Procedure Recommendations (CCH/PNF)

These general patient instructions apply to either PNF or CCH performed as an office procedure performed on the day of the initial patient encounter.

Expectations

- Your skin may tear. Most often, this happens while the doctor is pulling on the fingers to straighten them. Sometimes a superficial tear may open further a day or two after the procedure. In either case, it will heal without stitches, which takes a week or more.
- Maximum improvement is up to 90° overall, 50% PIP improvement.
- Recurrence is likely within a few years.
- Redo for recurrence usually possible and reasonable:
  - If this release works well enough for you
  - If this release lasts a year or more
  - If the skin is in good shape, and the surgeon can feel a cord

Medications

- You will be awake for the procedure. If you require anxiety medicine for dental procedures, have your internist prescribe the same medicine for this procedure and take it as directed.
- If you take prophylactic antibiotics for all surgical procedures, have your internist prescribe the same medicine for this procedure and take as directed.
- After the procedure, you may take nonprescription pain medicine according to package directions. Opioids are not usually needed.

The Week Before Your Procedure

- Broken skin increases the risk of infection. Be careful with your hands for a week before your procedure. You may have to reschedule your procedure if you have fresh cuts, scrapes, scratches, burns, blisters, other recent injuries, or broken skin from eczema, psoriasis, or other rashes near the areas where the doctor will work.
- For your safety and the safety of other patients, you should not schedule surgery if you or anyone in your household has required treatment for Methicillin Resistant Staphylococcus Aureus (MRSA) (resistant staph) infection within the last 3 months.

Before Arriving the Day of Your Procedure

- Remove rings, watches, and bracelets from the hand to be treated.
- Put your keys and wallet in a pocket that you can get to with your "good" hand.
- Plan to wear a shirt with loose sleeves, shirt and pants which don't require buttoning, and shoes that don't need to be tied.
- Avoid using lotions, creams, or topical medications on your hands.
- It is OK to take all prescribed medicines recommended by your medical doctors, including aspirin.

After Your Procedure

Wound Care after the Doctor Pulls on Your Fingers

- Keep the bandage clean and dry. Unless otherwise instructed, remove or change bandages if they get wet. It is better to have no bandage than a wet bandage.
- Unless otherwise instructed, you may remove the bandages tonight. Reapply bandages daily until your wounds are healed.
- Numbness from the local anesthesia usually lasts several hours and sometimes overnight.
- While out of bed, keep your hand pointing up toward the sky as much as you can the day of and the day after the procedure. This will reduce pain and stiffness.
- Chill the treated areas for up to 10 minutes once an hour the day of and the day after the procedure. This will reduce pain and stiffness. You can hold a cold can of soda, bottled water, a package of frozen peas, or the type of gel pack sold in drugstores and stored in your freezer.

Activity

- After 2 days, you may resume normal light activities, but only *if they are not painful to do*.
- Don't soak your hands in a bath or go swimming for at least 2 days, and not until all wounds are healed.
- For the first week, avoid strenuous gripping or activities which would make your hands soiled or sweaty, or any heavy work with your hands: no golf, tennis, fishing, gardening, biking, weight training, or carrying heavy bags with the hand which had the procedure, *even if it feels fine*. The areas under the skin which were worked on don't have any feeling, so you may not feel it until it is too late.

Therapy and Splinting

- Your doctor may prescribe a finger splint, hand therapy, or both.

General Technical Tips for Minimally Invasive Dupuytren Procedures

Antisepsis

- The patient washes their hands with surgical soap and dries with a clean towel.
- Use field sterility: prepped skin, sterile needle.
- Prescribe antibiotic prophylaxis according to clean surgery guidelines, case by case.
- The surgeon wears a surgical mask, eye protection, and nonsterile gloves.

Keep cords taut The goal is to have cords bowstring up and away from flexor tendons.

Use active tendon movement and active tendon relaxation The patient can participate in two ways to reduce the risk of tendon–needle contact and tendon damage from CCH or PNF.

Make flexor tendons slack It is common for patients to unconsciously flex their fingers from anticipation during a minimally invasive Dupuytren procedure. While the operator is pulling on a bent finger to tension a cord, it can be difficult to feel whether the flexor tendons are also tight. Under tension, flexor tendons can feel like cords to needle penetration. Also, tendon tension shifts the flexors palmar. Physiologic bowstringing measures 2 mm at the A2 pulley [115] and is greater proximal or distal to this pulley. Physiologic bowstringing increases the risk of needle–tendon contact during minimally invasive procedures. Take the following steps to minimize flexor bowstringing while the needle is in place:

- Repeatedly remind the patient to relax their fingers.
- Selectively tension cords by pulling only on one joint or by pulling on the palmar skin overlying the cord (Fig. 41.24a, b), leaving the distal phalanx free to monitor active DIP flexion.

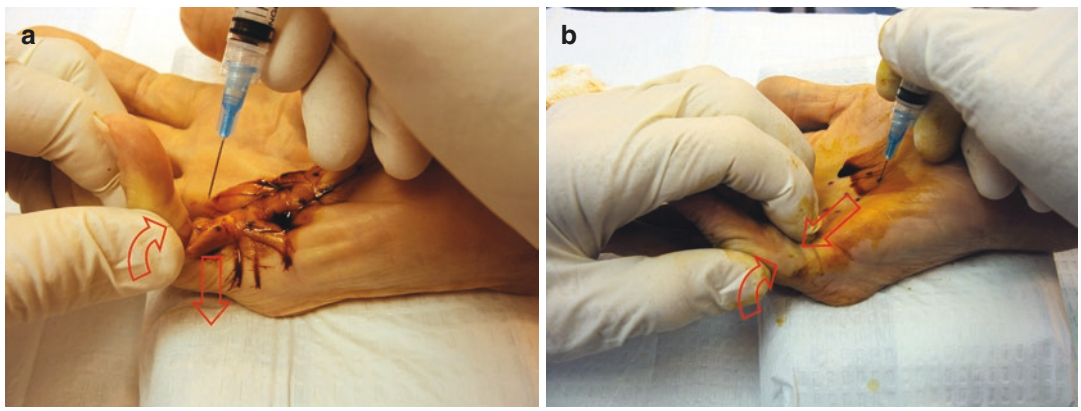

Fig. 41.24 Isolating composite cord tension**.** Two maneuvers isolate tension on composite MCP-PIP cords rather than the underlying tendon during minimally invasive procedures. (**a**) Tension composite MCP-PIP cords in the digit by extending the MCP, flexing the PIP, and leaving the DIP lax. (**b**) Use skin-cord attachments to selectively tension composite MCP-PIP cords in the palm by pulling the skin distal while flexing the MCP joint

- Ask the patient to straighten their fingers. Active extension triggers reflex inhibition of resting flexor tone.
- If the patient can't follow these steps, flex the wrist to create flexor slack.

Use short-arc active flexion and extension When asked to "wiggle your fingers" without other instruction, some patients will abruptly attempt to alternate between a strong full fist and full extension. That's not what you want when checking your needle position. *Before* beginning the procedure, demonstrate to the patient—and have the patient demonstrate back to you—gentle active short excursion flexion and extension "like you're gently scratching your earlobe." *Active tendon motion is a more reliable indicator of needle–tendon contact than passive finger manipulation*.

Manipulation

In open procedures, the goal of manipulation is to lyse intraarticular and other adhesions. The goal of minimally invasive procedures is also to rupture weakened cord structures, which may take more force. Resist the temptation to keep ratcheting up the force of manipulation: *if the cord doesn't rupture, you need to do more release, not pull harder*.

Skin tears The risk of full-thickness skin with manipulation increases with more severe contractures [116, 117]. Skin tears do not affect final patient satisfaction or re-contracture [116, 118].

Avoid a bloodbath Cover the palm with a gauze pad before manipulating. During manipulation, even small skin tears can suddenly spray blood if not covered.

Stretch all possible tethers Manipulate *each joint*, then composite stretches of *each ray*, and then do a composite stretch of *all fingers*. Use isolated stretch maneuvers to rupture cords and adhesions where normal joint range limits your ability to create cord tension, as shown in Fig. 41.25a–c. Natatory cords can be manipulated with a "scissor" maneuver, alternately flexing one MCP joint.

Percutaneous Needle Fasciotomy

Percutaneous needle fasciotomy (PNF) is just what the name describes. The surgeon uses the tip of a hypodermic needle as a miniature double-sided scalpel to cut tethering cord structures by feel. There is a learning curve, and results improve with experience. *The safety of PNF depends on patient participation and minimal anesthesia*. Resistance to learning PNF is often due to skepticism about doing a blind procedure near neurovascular structures, which may be anatomically displaced. The reality is that in large series, the risk of nerve or vascular injury is an order of magnitude larger from fasciectomy [119] than from properly performed PNF [120]. Don't do same-day bilateral releases: patients treated so are more likely to overuse their hands. Patients may have all digits of one hand treated one day, the other hand the following day, and play golf in a week.

PNF requires continuous patient feedback based on instructions such as these:

- "*Other than when I'm giving the anesthetic, tell me if I hurt you. If you have pain, tell me where you feel it and whether it's sharp or electrical*." (nerve monitoring)
- "*If I ask, gently wiggle just your fingertips as if you are scratching.*" (tendon monitoring)
- "*I may touch two of your fingertips and ask if it feels the same.*" (nerve monitoring)
- "*Let me know if your fingertips feel tingly or numb at any time. Numbness can be normal for the procedure, but I need to know.*" (nerve monitoring)
- "*If I do something painful, tell me. Try not to pull your hand away.*" (stay loose)
- "While I'm working, relax your fingers. Don't grip or pull against me. Try straightening them out instead" (cords taut, tendons lax).

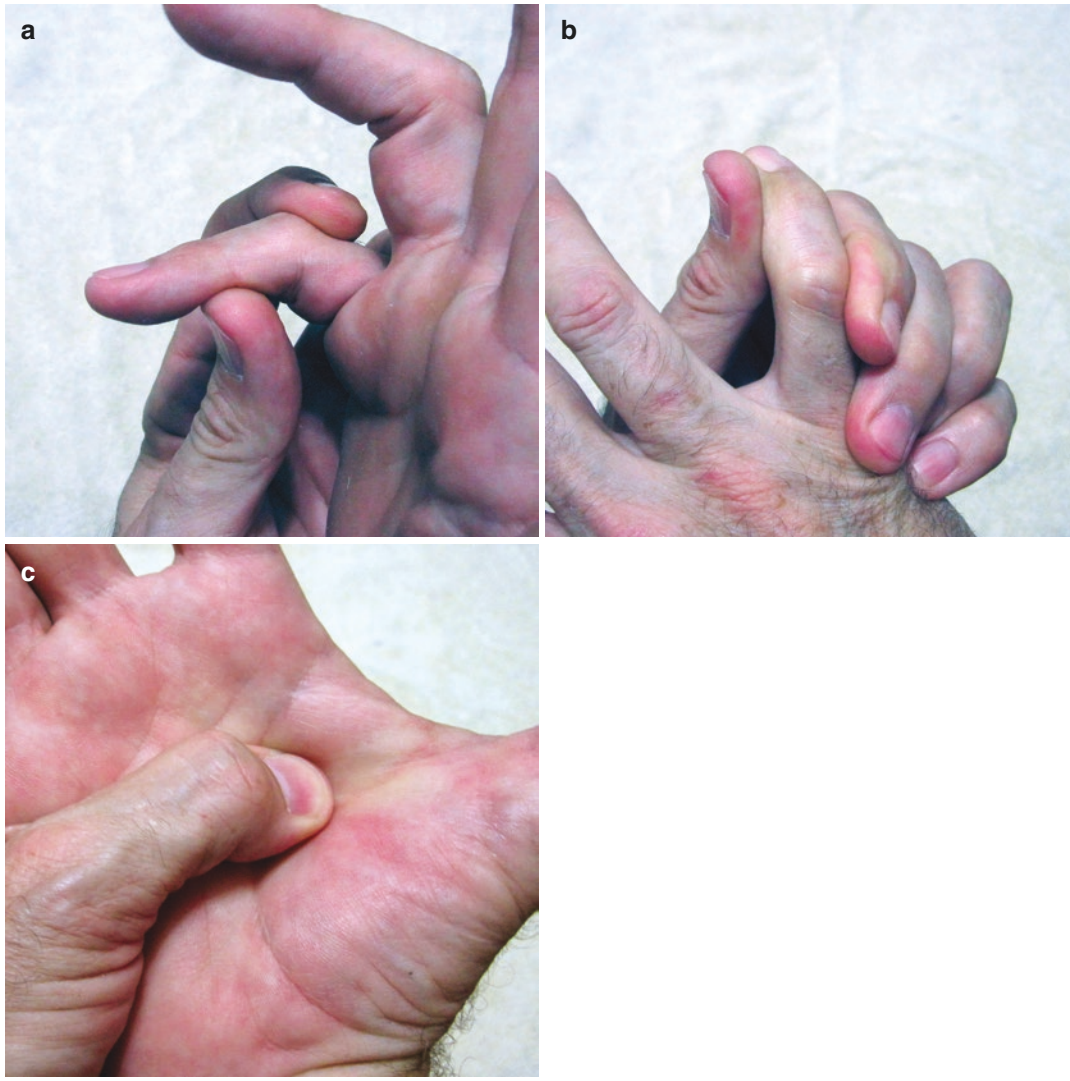

Fig. 41.25 Manipulation without hyperextension**.** All PIP joints and many thumb MCP cannot normally be hyperextended, shielding cords from tension. Natatory cords can be manipulated with a "scissor" maneuver, alternately flexing one MCP joint while extending the adjacent MCP joint. Use these additional maneuvers to isolate and rupture PIP and thumb MCP cords and adhesions. (**a**) Isolated PIP extension manipulation, flexing the MCP, and selectively extending the PIP joint. (**b**) Manipulation of lateral digital structures and PIP accessory collateral ligament with a dorsal–lateral stretch of the MCP and PIP. (**c**) Trampoline. Fingertip or thumb tip pressure stretches proximal first web space cords beyond thumb extension alone

Planning Portals

Plan needle entry locations (portals) to minimize the distance from skin to the cord and maximize soft tissue unfurling on cord release. Well-defined, tensionable cords beneath soft, untethered skin are ideal. Avoid placing portals in areas of limited skin elasticity, such as skin overlying nodules, in scars or flexion creases, or where the skin blanches without bowstringing. Search out dimples and sinuses to avoid unexpected pain and the possibility of infection or inclusion cyst by transecting a sinus (Fig. 41.26a). A simple way to measure sinus depth is to use a small probe and a drop of Betadine as one would use a dipstick to measure an engine's oil level (Fig. 41.26b, c). Plan multiple portals along the

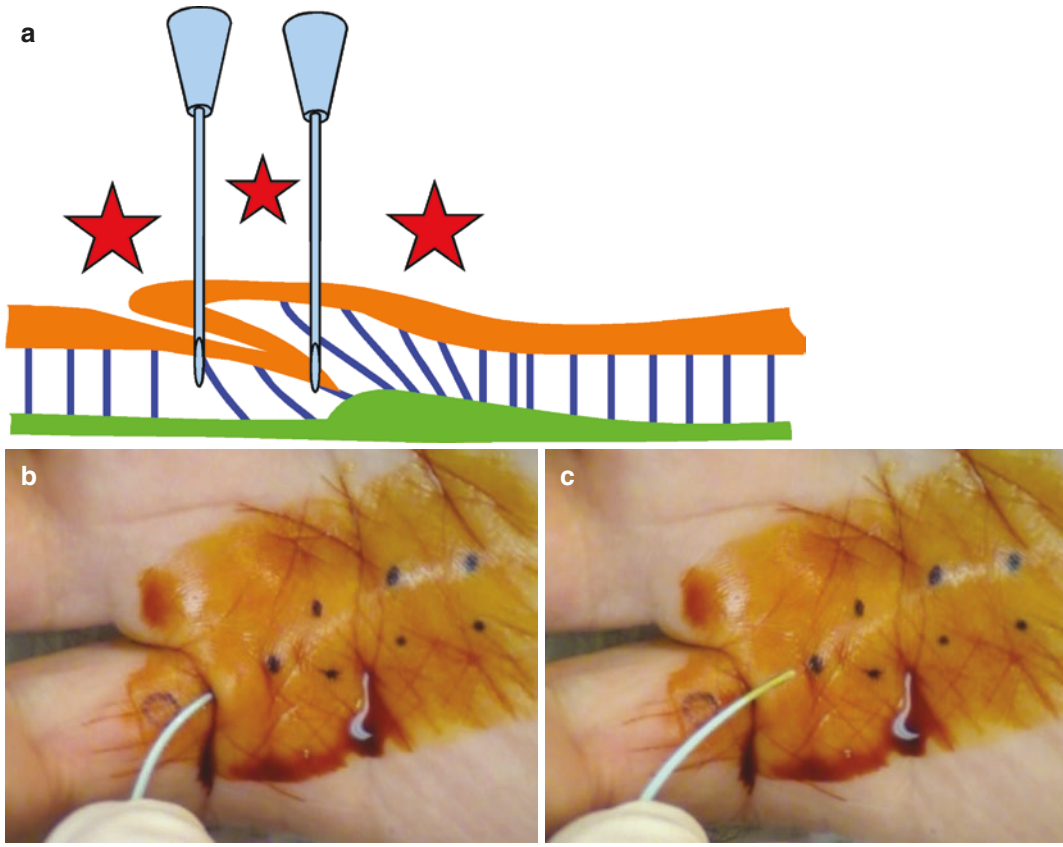

Fig. 41.26 Dimple or sinus? (**a**) Don't mistake skin sinuses for superficial dimples. If sinuses are not recognized and repeatedly breached with the needle, infection or inclusion cyst may follow. A sinus also pulls innervated skin beneath normal skin, resulting in unexpected tenderness deep to an adjacent portal. (Reproduced with permission from Eaton et al. [21] Copyright (C) 2012). Depth gauge, using a disposable dental floss passer as a dipstick with a drop of Betadine. (**b**) Dipstick inserted. (**c**) Depth marked by Betadine on the tip of the dipstick

length of each cord, separated by at least 5 mm, a common minimal distance for a cord to no longer be palpable adjacent to the site of a cord release. For more narrow cords, center portals on the line of maximum bowstringing (Fig. 41.27a–c). Use two portals on each side of broad cords (Fig. 41.26b, c and 41.27d). Consider retrograde portals to access cords for PIP contractures greater than 60 degrees (Fig. 41.28). Mark portals with a surgical marking pen.

Anesthesia

Intradermal anesthesia is ideal for cord releases. Dupuytren cords and nonessential deep structures are insensate. The safety of PNF requires patient feedback throughout the procedure, so the goal is to avoid a conduction block and a numb finger while performing releases. Any local anesthetic will work, but because intradermal injections are particularly painful, use 2% Plain Lidocaine with 1:10 NaHCO3 buffer with a 30-gauge needle. Avoid longer lasting anesthetics to allow the anesthetic to wear off in a short time in the event there is unexpected numbness preventing further work as discussed below. Insert the needle tip into *but not through* the dermis and inject 0.1 cc as you withdraw the needle. Check fingertip sensibility before each shot. Keep checking tip sensibility through the procedure.

Intraarticular PIP joint anesthesia minimizes manipulation pain in more severe PIP joint contractures and avoids a conduction block. A pal-

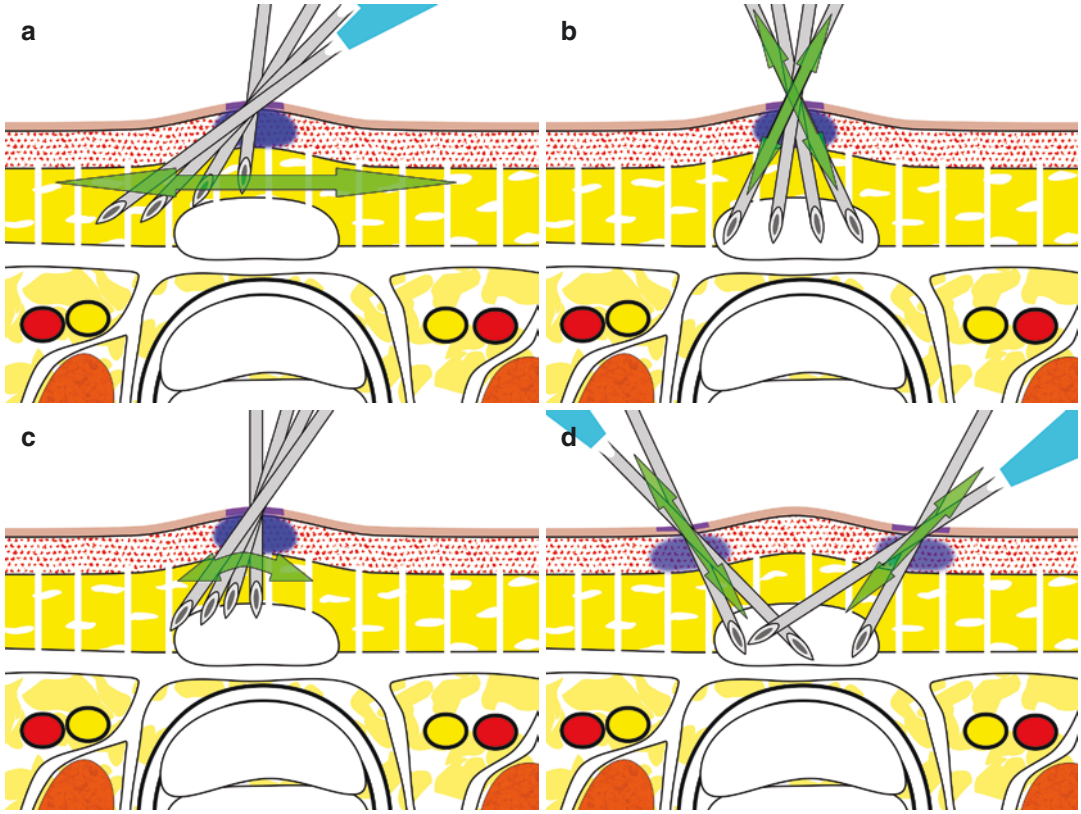

Fig. 41.27 PNF needle maneuvers. The blue dot shows the extent of intradermal anesthetic infiltration. Orient the needle bevel cutting edges perpendicular to cord fibers. Use three maneuvers at each portal. (**a**) *Sweep*. First, clear the vertical septal fiber attachments around the planned cord division site. Alternate perforating and slicing until the cord releases under tension. (**b**) *Perforate*. Penetrate just the surface of the cord. This maneuver weakens the cord, provides a feel for its lateral borders, and gives an early warning of tenderness or paresthesias for structures to avoid. (**c**) ***Slice***. Drag the needle tip back and forth across the surface of the cord. Advance depth slowly and use a light touch: only the bevel of the needle cuts. If the tip is inserted past the bevel, it won't cut, and if you keep increasing the transverse force, the tip may suddenly pop out of the cord and move in an uncontrolled way. (**d**) Dual portals. Portals on each side of a wide cord give better maneuverability for cord release

mar approach to PIP joint injection is reliable (Fig. 41.29). Flex the joint, insert the needle proximal to the PIP flexion crease in the mid-palmar line, and aim the tip toward the dorsal prominence of the proximal phalanx head. At this level, superficialis tendon slips are lateral to the midline. After the needle passes through the profundus tendon, you may feel it "pop" through the volar plate. With the needle in place, let the joint relax, put your fingertip on the dorsal PIP joint line, and feel the dorsal joint capsule bulge as you inject and the joint space fills. Avoid a tendon sheath block by not overfilling; 0.1–0.2 cc is enough.

Wrist block anesthesia should be reserved for final manipulation if needed.

Equipment

- *Bump*. Stack two folded small surgical towels to create a bump to place behind the dorsum of the hand during the procedure. A bump makes the position more comfortable for the patient, allows MCP hyperextension, and prevents wrist extension and secondary flexor tightening during the procedure.
- *Short needle*. Use a 5/8″ 25-gauge needle mounted on a 3-cc Luer-lock syringe as a han-

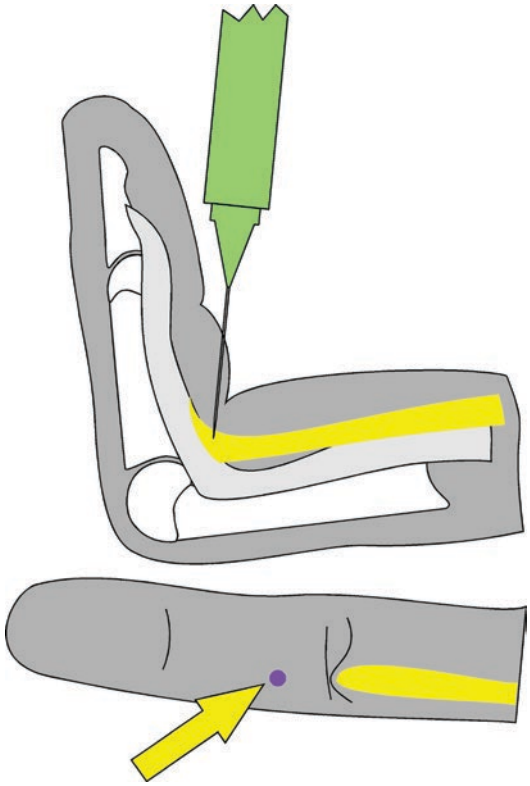

Fig. 41.28 Retrograde portals**.** For PIP contractures greater than 60 degrees, the skin flexion creases are proximal to the joint line. The shortest distance to the distal cord may be through the middle phalanx pulp skin, as shown. (Reproduced with permission from Eaton et al. [21] Copyright © 2012)

dle. Shorter needles are easier to control and give better proprioceptive feedback.

- *Field sterility* is used, as if prepping for intravenous catheter insertion.

Position

- The patient is supine or reclined during the procedure, their arm resting on a small arm table in shoulder abduction and supination.

Procedure

- *Sequence*. Proceed from distal to proximal portals to avoid numbness issues discussed below. For multiple digits, complete all digital releases before proceeding to the palm. At each new level, confirm the cord is still palpable and give anesthetic immediately before beginning work.
- *Stay loose.* Keep a light fingertip hold on the syringe barrel. If the patient suddenly jerks their hand while the needle is engaged, the syringe should slip free of your grasp rather than the needle tip resist their uncontrolled movement. Trying to prevent this by firmly holding the patient's fingers encourages flexing against resistance, tensioning the tendons, and bringing them palmar, potentially into harm's way.
- *Needle maneuvers*. The tip of a standard hypodermic needle has two opposing scalpel-sharp edges. The edges, not the tip, are what cut the cord. Keep these edges oriented perpendicular to cord fibers. One trick is to check the relative orientation of the needle blades to syringe barrel wings so you can maintain this orientation when the needle tip is not visible. Use the needle to *sweep* (developing a plane between skin and cord), *perforate* (reciprocating motion perpendicular to the cord), and *slice* (grazing the surface of the cord transverse to cord fibers). A 25-gauge needle has a diameter of 0.5 mm with a 1 mm blade length, a 21-gauge needle 0.8 mm/1.6 mm, and an 18-gauge needle 1.3 mm/2.6 mm for an 18-gauge needle. Wounds created by perforation are half the length of those from a slice. Perforation is less efficient at cutting a cord than slicing, but also less dangerous near a neurovascular bundle. In the proximal phalanx, the average diameter of a digital nerve is 1.8 mm [121] and digital artery greater than 1 mm [122]. Use a 25-gauge needle. In contrast to larger needles, its blades are not long enough to inadvertently transect a digital nerve in a single pass.
- *It is all about the feel*. PNF depends on the feel relayed by the needle. To the needle tip, collagenous structures under tension feel crisp or gritty like cutting a fresh celery stalk; lax collagenous structures feel rubbery. Keep *cords taut and tendons lax* while using the needle to reduce the risk of cutting normal structures. *If it feels rubbery under tension, don't cut it*. Rubbery resistance to needle penetration means either the structure isn't taut, or the needle tip blades have become dull.

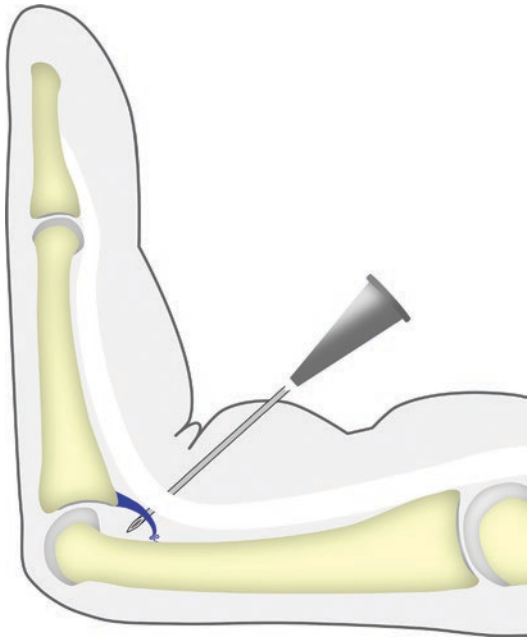

Fig. 41.29 PIP anesthetic injection. Pain may limit PIP extension before the final joint manipulation. PIP flexion contractures tighten the dorsal tissues and make the joint line difficult to palpate for anesthetic injection. A volar transtendinous approach is a reliable way to anesthetize the PIP joint without a conduction block and a numb finger

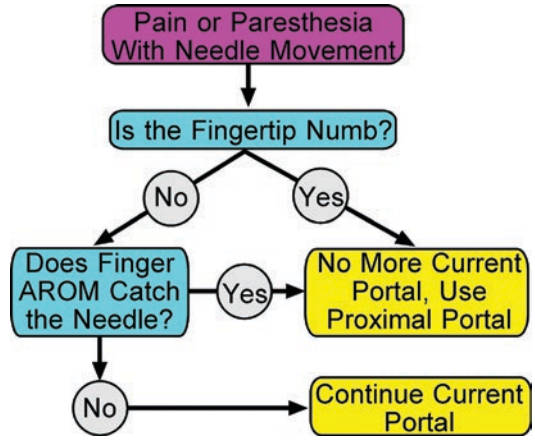

Fig. 41.30 Decision tree for unexpected pain or paresthesia during PNF needle maneuvers. Check fingertip sensitivity before, after, and during needle maneuvers at each portal. Pain may be due to either nerve or tendon sheath contact. (Reproduced with permission from Eaton et al. [21] Copyright © 2012)

Change needles often and as needed. A 5/8″ 25-gauge needle costs about 10 cents. Expect to use one or two fresh needles per portal.

- *Deep needle sensitivity, paresthesias, or numbness*. Deep tissues safe to cut are insensate. With intradermal anesthesia, pain with needle maneuvers beneath the skin signal proximity to the tendon sheath or neurovascular bundle. If the patient develops fingertip numbness while you are working, you've lost the ability to monitor nerve contact at that level or distal. Stop work at that level and move to the next proximal level. This is the reason to proceed from distal to proximal needle portals. If anesthesia is limited to the distribution of the adjacent digital nerve, it is most likely due to anesthetic diffusion or nerve contusion at that portal level, and the nerve should still be responsive to needle pressure or contact at the next proximal level. If the entire digit is anesthetic, anesthetic diffusion may have produced a sheath block. In that event, stop working in the digit and proceed to a different digit or the palm. If this limits the desired release, one option is to stop the procedure, place bandages, and resume later in the day after anesthesia has resolved. If anesthesia does not resolve, the needle may have contused or contacted the nerve. The risk of permanent numbness is less than 1%. A common practice is 3 months of observation before considering exploration. Figure 41.30 outlines a decision tree for unexpected pain or numbness during PNF.

Post-procedure Care

A light gauze or adhesive bandage is all that is needed. The patient may change bandages as described in the patient instructions. Splinting or hand therapy is optional and generally unnecessary. Follow up in 1 week and then every 6 months.

Collagenase *Clostridium histolyticum* Injection

CCH injection for Dupuytren works as an enzymatic fasciotomy. CCH injection primarily degrades type I and III collagen, the main structural components of skin, fascia, cord, ligaments,

and tendons. These structures are temporarily weakened, lowering their mechanical thresholds to rupture under tension. *The safety of CCH depends on anatomy and mechanics*. Passive extension selectively ruptures the tightest tissues, and the tightest tissues are the cords limiting extension. The procedure is technically simple, with a short learning curve. CCH progressively weakens tissues for hours before its effect plateaus; injection and manipulation are performed on separate days. Patients may have one or two fingers treated every 30 days.

Documentation

Use this checklist: https://dupuytrens-contracture.xiaflex.com/public/pdf/xiaflex-dc-chart-documentation-guide.pdf

"What I need you to do during the procedure."

- "*If I ask, gently wiggle just your fingertips as if you are scratching.*" (tendon monitoring)
- "*While I'm working, relax your fingers. Don't grip or pull against me. Try straightening them out instead.*" (cords taut, tendons lax)

Drug Preparation

Strictly follow the package instructions for reconstitution. Keep the drug continuously refrigerated until immediately before use and use immediately after reconstitution. Immediate use is critical because *CCH rapidly degrades at room temperature*. The reconstituted solution is viscous, making it difficult to tap bubbles out of the syringe once drawn up. Swirl but don't shake the vial to mix, and keep the needle tip at the bottom of the vial to avoid bubbles while drawing up the injectate.

Planning Injection Sites

Guidelines for PNF portal choices also apply to CCH injection sites. Seek areas of maximum cord bowstringing where the cord is palpably closest to the dermis. With CCH, use a greater number and more closely spaced injection sites. Because the cord tissue is dense, the injectate from any injection site may track back through the needle path or out other paths rather than remain localized in the cord tissue. Multiple injection locations counter this possibility and distribute the injectate for maximum overall effect.

Anesthesia

CCH injection is painful. Anesthetize the planned injection sites before injection using nerve blocks rather than local infiltration. Local infiltration makes cords difficult or impossible to feel.

Dose

CCH preparation recommendations were formulated to use the same dose of CCH reconstituted in 0.25 ml for a single MCP cord and 0.20 ml for a single PIP cord. This dose is less than the full vial. Some authors have used the entire CCH vial contents to inject one [116, 117] to five cords [123]. Two vials are Food and Drug Administration (FDA) approved for same-day treatment of two cords. Larger doses increase the risk of pain requiring narcotics, itching, lymphadenopathy, blood blisters, and skin tears [124].

Injection

- *Equipment*. Injection requires greater pressure than typical solutions. Use a hubless or Luer-lock needle and syringe to prevent the needle from popping off the syringe during the injection.
- *Secure the cord*. Use two steps to stabilize the cord during injection to reduce the chance of extra-cord leakage. The first is to *maintain passive extension on the digit during the injection*. The second is to *hold the cord through the skin*. If cords bowstring enough, pinch between finger and thumb, use the "pinch-and-poke" technique [125]. Alternatively, have an assistant isolate and stabilize the cord between the ends of two tongue depressors during the injection [126].
- *Safe zone*. The "safe zone" refers to both the maximum depth of needle penetration and the maximum distal point of injection site recommended to avoid inadvertent tendon or tendon sheath injection and subsequent tendon rupture. The maximum recommended depth of needle insertion is *5 mm in the palm and 3 mm in the digit* [127]. The most distal recommended injection site is *4 mm distal to the proximal finger flexion crease* [125].

Consciously avoid inadvertently advancing the needle while injecting.

- *Needle feel*. Needle penetration of a cord under tension typically feels crisp or gritty. If not or if the needle meets rubbery resistance, remove the needle and move to a different site.
- *Injection feel*. With a properly positioned needle tip, there should be obvious resistance to injection. If not, remove the needle and move to a different site. If resistance to injection is suddenly lost, stop injecting, remove the needle and move to a different site. Lack of resistance means extravasation outside the cord with worst-case scenario of leakage into the flexor tendon sheath. Avoid multiple needle passes in the same area, which can create tracks for extravasation.

Post-injection Care

A light gauze or adhesive bandage is all that is needed. The patient may change bandages as described in the patient instructions.

Manipulation

- *Schedule*. CCH remains biologically active for about 4 days after injection [127]. Manipulation is performed 1–7 days after injection [128–130]. Perform manipulation maneuvers as described above.
- *Anesthesia*. Manipulation is painful. Use generous local or block anesthesia prior to manipulation.

Post-manipulation Care

A light gauze or adhesive bandage is all that is needed. The patient may change bandages as described in the patient instructions. Splinting or hand therapy is optional. Follow up in 1 week and then every 6 months.

Conclusion

Dupuytren disease is a chronic medical disease with a wide range of clinical disease patterns. The correction of Dupuytren-related hand deformities is often partial and temporary. Minimally invasive treatments such as collagenase injection or percutaneous needle fasciotomy can delay but may not prevent the need for fasciectomy or dermofasciectomy. Complications of open surgery and repeat procedures for recurrence are more likely than for other common hand diagnoses. The surgeon should consider this in planning to reduce the lifetime risk of permanent complications from both Dupuytren disease and its treatment. The most common Dupuytren procedure is fasciectomy, which is technically demanding. Procedures work best for mild deformities before secondary changes develop in tendons and ligaments. The surgeon must educate the patient early on about the nature of the disease and the need for ongoing follow-up. To do this, the surgeon must be familiar with Dupuytren-related patient perspectives, short- and long-term treatment results, and all available Dupuytren procedures.

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Thumb Reconstruction

42

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Introduction

Forty percent of the function of the hand relies on the thumb; loss of the thumb leads to devastating disability due to loss of pinch and grasp functions [1]. This has significant implications for both employability and simple activities of daily living. The thumb's importance and lack of satisfactory reconstruction options in the 1960s drove Harry Buncke's early experiments for digit transfer in rhesus monkeys and development of microsurgical techniques and instruments, which contributed to the birth of the field of microsurgery [2–4].

Approximately, 800–1000 thumb amputations are reported in the United States each year to the National Trauma Data Bank, which underestimates the frequency of injury requiring thumb reconstruction, as incomplete amputations are not captured [5]. The majority of injuries occur in working-age males involving the use of machinery. Thumb reconstruction leads to large quality of life gains for patients [1, 6], and in the absence of compelling contraindications, reconstruction should be offered to all patients.

Assessment of the Patient

Standard history and physical examination should be performed, including patient occupation and handedness. In acute trauma, nature of the injury (e.g., sharp, crush) should be discussed. Patient comorbidities and traumatic injuries outside the hand must be evaluated; despite the importance of the thumb, thumb reconstruction is elective, and limb should not be placed over life. Social history, including capturing smoking history, is paramount.

Radiographic examination including posteroanterior, lateral, and oblique views of the hand should be obtained. Radiographic views of amputated parts are also helpful in operative planning for attempted replantation.

In delayed presentations or in congenital defects, operative reports from any prior surgeries should be obtained, as this may inform on what structures are left and available for use. In adult patients, formal angiograms may be performed if there is questionable vascular anatomy.

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Choice of Reconstruction

Deconstructing the thumb into its two integral functions can be helpful when planning reconstructive modalities [7]:

- *Sensation*. Protective sensation (at minimum) to avoid noxious stimuli and a nonlimiting level of pain to allow activity are crucial. Lack of satisfactory sensation is the most consistent reason for thumb disuse after reconstruction; thus, predictable methods of innervation for the reconstruction should be preferred [8].
- *Opposition*. Length, mobility, and stability to provide a post against other digits are characteristics of the useful thumb. Amputations or tissue loss distal to the interphalangeal (IP) joint are often tolerable for functional grip, though fine dexterity may suffer [9]. Amputations proximal to this level typically require lengthening procedures. Motion at the IP joint or metacarpophalangeal (MP) joint is not mandatory to fulfill function. However, circumduction provided by the carpometocarpal (CMC) articulation is critical [10].

A patient's occupation may also affect the reconstructive decision; someone utilizing fine motor skills such as a jeweler or surgeon may require a different reconstructive technique compared to a manual laborer. The patient's toleration for potentially multiple surgeries and prolonged therapy must also be assessed before embarking on complex reconstruction.

Acute Injuries

Despite the ingenuity of reconstructive techniques, there is no true substitute for the thumb that can replace native tissue. Therefore, attempted replantation of the thumb should be performed whenever possible.

Replantation

Successful replantation of the thumb offers excellent results to regain function and sensation without morbidity of a donor site. At any amputation level, replantation should be attempted whenever medically and anatomically feasible. Given the potential functional, sensation, and aesthetic benefits, any amputated part warrants examination under magnification to assess if replantation is possible. Crush and avulsion injuries have historically been considered contraindications for replantation, but utilizing vein grafts to allow vascular anastomoses outside of the zone of injury increases survival for these types of injuries [11, 12]. Artery-only replantation is also possible for patients willing to tolerate prolonged postoperative admission [13]. Outcomes in elderly patients and for delayed presentation up to 24 hours are also favorable. Thus, absolute contraindications to replantation are few, and attempted replantation of the thumb should be the default first-line option [14, 15]. Pinch and grip strength, range of motion, achievement of protective sensation, and return to work are all favorable after replantation in large patient studies [16–18].

When a thumb amputation occurs, the amputated part should be wrapped in a sponge moistened with saline, placed in a plastic bag, and then placed on a bed of ice. The amputee should be evaluated primarily as a trauma patient, and care of the hand injury should proceed after life-threatening injuries are stabilized. Amputated stumps should preferably be treated with pressure dressings and elevation, with avoidance of tourniquet application or vessel ligation if possible. Radiographic analysis of the stump and the part should be performed, and tetanus prophylaxis should be administered if indicated. Consultation with a replantation center should occur expediently, and receipt of photographs of the part and stump can aid in the decision of transferring a patient. Transfer should occur swiftly, and at our center patients are routinely flown from the point of origin if ground transportation would exceed 4 hours of travel. Ischemia time for thumb replantation is typically not limiting, as the structures of the thumb tolerate ischemia well, and replantation can reliably be performed in excess of 24 hours of cold ischemia time [15]. Successful replantation of a thumb has been reported after 94 hours of cold ischemia time [19]. It is recommended that warm ischemia

time not exceed 12 hours. For very proximal thumb amputations where the part contains intrinsic musculature, replantation should proceed in less than 6 hours after amputation to limit muscle necrosis. Overnight delay of replantation has been shown to be safe with comparable outcomes to immediate replantation [20], though at our center all replantations are performed on an immediate basis (Fig. 42.1a–c).

Efficiency of replantation is critical, and steps to maximize efficiency are made as soon as the patient enters the emergency room or as soon as notification that a devascularized thumb is being transferred for care. The operating room should be notified, and a sterile end table with microdissection instruments and a microscope should be prepared. Consent for the procedure should be obtained when the patient arrives, and the patient must understand that despite maximum medical efforts, replantation of the thumb may ultimately fail and revision amputation may be performed. After consent is obtained, the thumb can then be taken to the operating room for preparation. This allows the surgeon to effectively begin the procedure while other arrangements, such as patient consultation with anesthesia, are being made. The thumb should be washed gently with dilute betadine and placed on the end table. The structures to repair in the part can then be identified. If the surgeon is working alone, the part can be tied to a sterile towel with 4-0 nylon to facilitate dissection. Midaxial- or Bruner-type incisions can be used to allow exposure of the tendon sheath and neurovascular bundles. The digital nerves and arteries can be dissected beyond the zone of injury, appropriately trimmed, and clipped for later identification. The flexor tendon can be prepared with two double opposing locking stitches to allow later repair to the hand; our preference is to use 3-0 FiberWire. The dorsum of the thumb can then be explored and the extensor tendon dissected for later repair and veins identified and

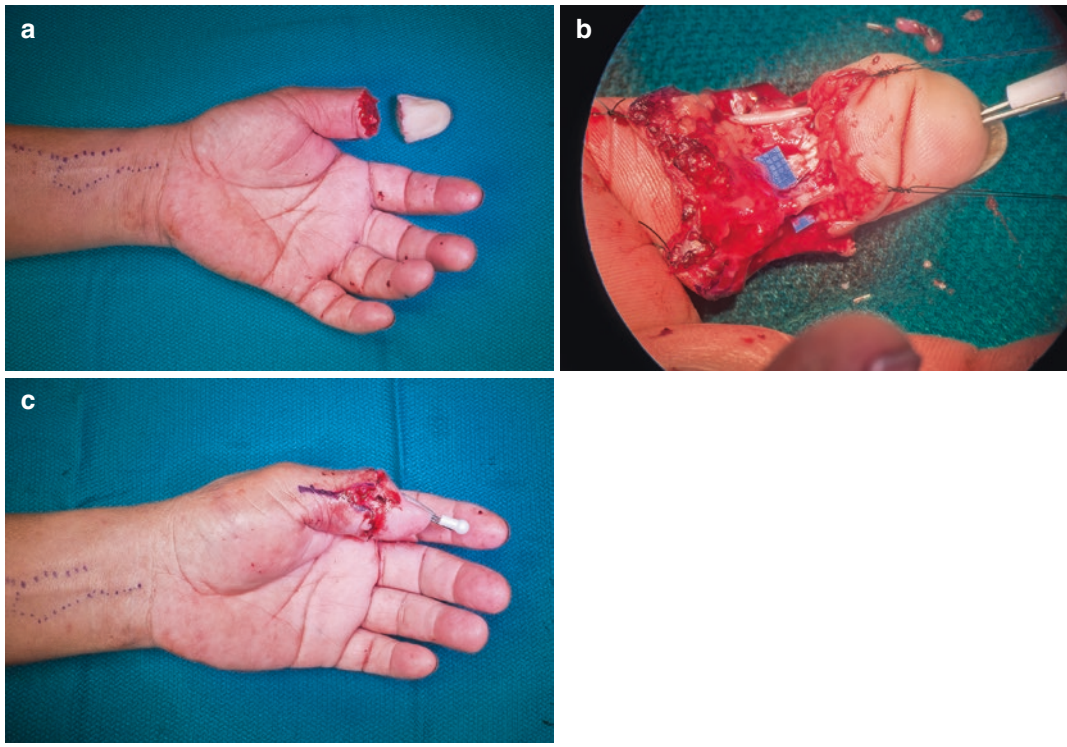

Fig. 42.1 Thumb replantation. (**a**) Amputation distal to the IP joint. Note that volar veins are marked in case vein grafts are necessary. (**b**) Repair of neurovascular bundles after bone and tendon repair. Note the use of nerve allografts. (**c**) Final on-the-table result

clipped. Finally, two Kirschner wires (.045 or .035 depending on level of amputation) can be passed anterograde through the part to allow for osteosynthesis. The part is then delivered to scrub tech for later use. By preparing the thumb in this manner, a large portion of the case can be completed before the patient even arrives in the operating room.

Our preference is for patients undergoing replant to obtain general anesthesia; movement during microscopic portions of the case is unacceptable. After patient arrival into the operating room and induction of anesthesia, a brachial tourniquet is placed, and the injured extremity is prepped and draped. Volar wrist and forearm veins are tagged in case vein grafts are necessary. The extremity is exsanguinated and the tourniquet is insufflated, and the injured hand is then explored. Bruner's incisions are often the most convenient way of exploring the injured thumb stump, though depending on prior lacerations and avulsions, these may be extended. The surgeon should keep all flaps broadly based to maximize skin viability; it is also key to note in designing incisions that the base of the Bruner's flap will often provide wider exposure of the neurovascular bundle than the tip side. For most patients, the ulnar digital artery of the thumb will be larger and easier to repair. The digital arteries and nerves can be identified and trimmed out of the zone of injury. In our experience we do not deflate the tourniquet to check for inflow; examination of the vessel for signs of damage and intimal injury under loupe magnification is often sufficient to allow debridement to an adequate level. Venting of flexor sheaths may be necessary, and the oblique pulley should be preserved if possible. If the flexor pollicis longus (FPL) is difficult to retrieve, it can often be found at the carpal tunnel and retrieved with a tendon passer. A 25-gauge needle can be passed through soft tissue and tendon to keep in place, and two double opposing locking stitches are placed in the tendon for later coaptation to the part. The dorsum of the hand should then be explored to identify the extensor tendon and target veins, and the veins are clipped for later identification. At this point, the surgeon should know whether primary repair for the neurovascular structures is possible or if vein grafts and/or nerve grafts will be required.

The thumb is then brought into the field. Osteosynthesis is performed with the pre-placed K-wires. After confirmation of adequate reduction by fluoroscopy, the flexor tendon is then repaired with the pre-placed double opposing locking sutures.

The microscope can now be brought into the field, and attention is turned to the digital arteries. Arteries should be mobilized to the point of allowing repair under reasonable tension. Tethering or obstructing side branches must be clipped and ligated. If the zone of injury is wide, reversed vein grafts should be taken from the volar wrist. After arterial repair, attention is turned to the digital nerves. It is critical for nerve repair to be under minimal tension, as even stretching of 8% of the resting nerve length causes ischemia that may limit regeneration [21]. At our center, nerve allografts are used if necessary, as they have demonstrated excellent outcomes and obviate the need for a secondary surgery with nerve autografting [22]. After neurovascular repair, the volar side of the thumb is closed with 4-0 chromic loose sutures to protect the microanastomoses, and attention is turned to the dorsal veins. As many vein repairs as possible are performed. The tourniquet is then deflated and perfusion of the tip confirmed. Instillation of papaverine 1 mg/ml into the anastomotic sites and warming may aid with confirmation of inflow. Patience is often required and rewarded; in the case of a pale part, exploration of the arterial anastomoses should not be performed until at least 10 minutes of warming and vasodilatory measures. The repaired veins can also be visualized directly to confirm perfusion.

The replantation of a thumb should not require more than one tourniquet run. In the event of multiple digit replants being performed, we advocate for a structure-by-structure approach for efficiency [23]. Venous repairs can be saved for last, as engorgement of the veins may even facilitate repair.

After confirming inflow and outflow, the dorsal skin is closed loosely with chromic and the

patient is placed in a spica splint. Aspirin is started postoperative day 1, and occasionally heparin at 500 units/hour or a therapeutic rate is administered, depending on degree of vessel damage. At our center, patients remain on bed rest for 3 days, are allowed up to chair on postoperative day 4, and are allowed to ambulate on postoperative day 5. The operative splint is replaced by a hand therapy custom splint on postoperative day 5, and the patient continues daily aspirin for 1 month. In the case of artery-only replants, hospitalization requires prolonged coagulation, and often a 10-day or longer hospital stay; given the importance of the thumb, this investment is worthwhile [13]. Pins are removed after clinical and radiologic evidence of bony healing, usually at 6 weeks after discharge. Hand therapy for the operated thumb is started immediately.

Subtotal Amputation with Insufficient Soft Tissue Coverage

Often amputations occur without recovery of a replantable part. In instances of amputation at the IP joint or distal, the injury may be well tolerated if length is preserved. In almost all circumstances, remnant bony length should be preserved by any means possible; function and future reconstruction options both suffer as amputation occurs more proximally. Bony structures must be covered, and pain-free and sensate soft tissue coverage must be provided.

Healing by Secondary Intention

When loss of tissue involves skin only, and adequate subcutaneous tissue remains without exposure of bone or tendinous structures, often healing by secondary intention provides an excellent result. The advantage of this method is that the healed area will retain a higher level of sensation in contrast to skin grafts or noninnervated local flaps [24]. However, the downside to this method is that patients must tolerate prolonged daily wound care, and coverage of larger wounds may take weeks.

Local Flaps

Palmar Advancement Flap/ Moberg Flap

The palmar advancement flap is the workhorse for skin loss of the thumb pad. Deficient pulp skin is replaced by innervated sensate palmar thumb skin, effectively replacing like with like. There are many variations to this technique, which may be performed with or without a proximal releasing incision (creating an island-type flap) and/or skin grafting [25–27]. With the most aggressive techniques, up to 2 cm of a thumb defect may be covered.

To raise a Moberg flap, midaxial incisions are made extending from the proximal portion of the defect, and the volar thumb skin is raised with advancement of the underlying neurovascular bundles. The thumb can be flexed at the IP joint to facilitate advancement. If a proximal incision is performed to islandize the flap, skin grafting of the resultant defect with a full-thickness graft is recommended. Raising the flap in a V–Y-type design may reduce the need for back grafting, though it must be ensured that the flap is adequate to cover the initial defect. Nonabsorbable sutures, such as 4-0 nylon, are recommended, as there will likely be some degree of tension in the advanced flap. A spica splint is placed for 2 weeks postoperatively; afterward, with adequate tissue healing, the patient may start hand therapy to maximize thumb motion.

We agree with other centers reporting contractures at the IP joint, and final overall motion is impaired with this technique [28]. Neuroma formation, cold intolerance, and dissatisfaction with pulp stability have also been reported for this flap [29], and in our experience many patients have long-term symptoms with this technique. Thus, while it is a reliable pedicled flap with sensate tissue, it is not always our first-line treatment, even with acceptable wound sizes (Fig. 42.2a–c).

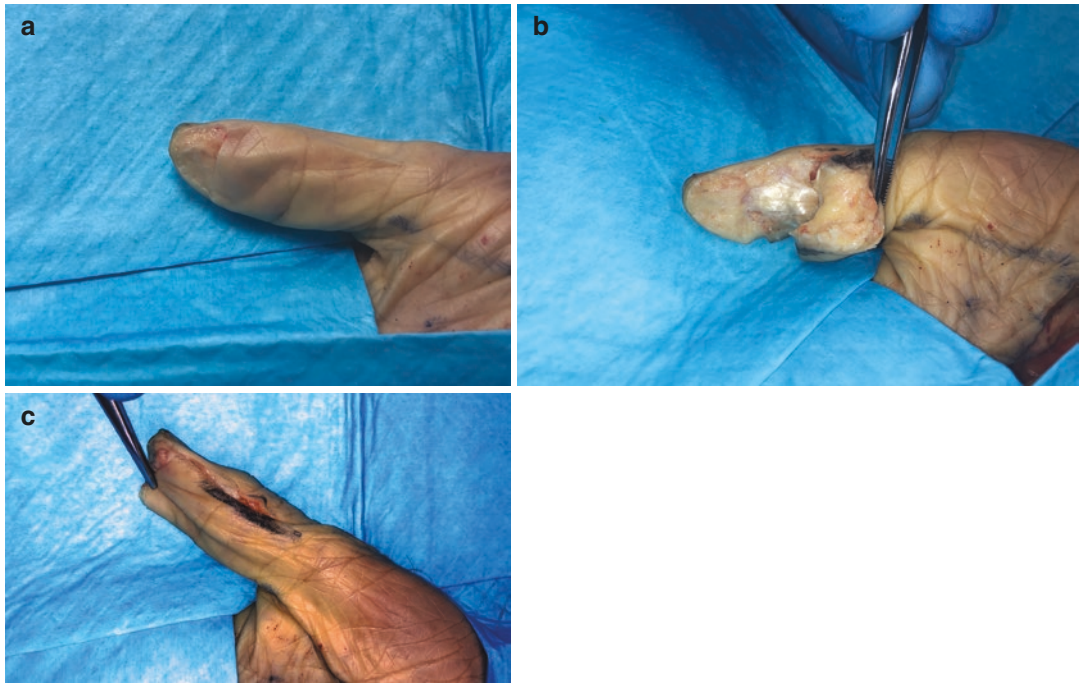

Fig. 42.2 Volar advancement flap. (**a**) Volar thumb wound of 1–2 cm dimensions. (**b**) Elevation of flap leaving flexor tendon and paratenon with elevation of subcutaneous tissue. Note that neurovascular bundles must be included in the flap. (**c**) Advancement of flap prior to inset

Cross-Finger and Innervated Cross-Finger Flaps

For wounds of the thumb pulp, the use of tissue from other fingers provides an attractive option for durable skin coverage. While originally designed for use in finger defects [30], a cross-finger flap from the proximal phalanx of the index finger can be used for volar thumb soft tissue loss. For this flap, conversion of the wound of the thumb into a rectangular shape will facilitate design and inset. The wound shape and size can be templated on the dorsum of the index finger with suture packaging or blotting from a piece of paper. Because of the palmar abduction of the thumb, the base of the flap needs to be placed volar to the midaxial line, in contrast to the standard cross-finger flap [28]. Incisions are made on the distal, ulnar, and proximal borders of the flap, sparing the paratenon of the underlying extensor tendon. As dissection continues radially, Cleland's ligament must be incised to allow optimal reach of the flap. The flap is inset using nonabsorbable suture, and a full-thickness skin graft is placed in the harvest site. The thumb and index finger should be immobilized in a splint for 2–3 weeks, and then division and inset of the flap may be performed (Fig. 42.3).

Some studies have cited adequate sensory return, though this is less likely in older patients [31–34]. Cross-finger flaps may be innervated by including a branch of the sensory radial nerve as part of the transposition. This additional dissection requires tracing of the nerve proximally and dissection through the first web space to allow nerve transposition, which may lead to unfavorable contractures.

While cross-finger flaps are reliable, they require a significant period of immobilization for the patient, which may be poorly tolerated, especially in elderly patients.

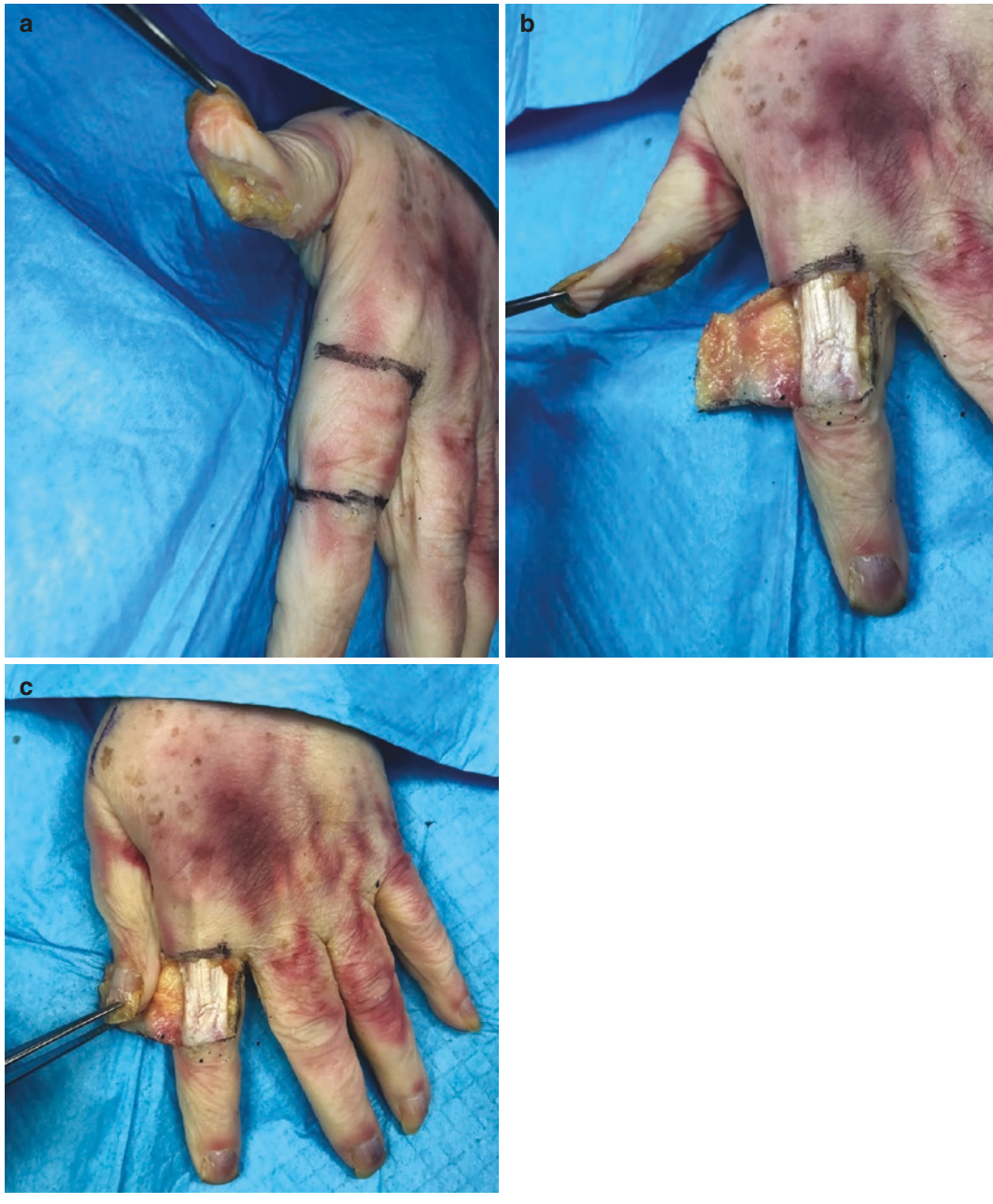

Fig. 42.3 Cross-finger flap to thumb. (**a**) Design of cross-finger flap for thumb defect. Note that volar extent of incisions of the donor site extends beyond the midaxial plane. (**b**) Elevation of cross-finger flap, leaving paratenon and elevating subcutaneous tissue of finger dorsum. Cleland's ligament must be divided to allow adequate mobilization. (**c**) Positioning of thumb to allow inset of flap

First Dorsal Metacarpal Artery (FDMA) Flap

Popularized by Foucher as a pure island flap (kite flap), this flap is often cited as a workhorse of thumb reconstruction for defects that exceed those that can be covered by a volar advancement flap [35]. The theoretical benefits of this flap are many; the flap allows transfer of skin and subcutaneous tissue as well as branches of the radial sensory nerve in a single stage. It must be noted, however, that the reach of the flap will not reliably provide coverage distal to the IP joint.

The thumb defect can be templated on the dorsum of the index finger proximal phalanx. The path of the first dorsal metacarpal artery can be mapped using a Doppler probe from the radial aspect of the index MP joint to the proximal pivot point, which is located near the junction of the thumb and index metacarpals. The flap is elevated above the extensor paratenon, and a curvilinear incision is made proximally. Care must be taken to avoid injuring the vessel, as the FDMA enters the subcutaneous plane at the radial border of the index MP joint. Typically, the pedicle to this flap is not skeletonized, and the pedicle is raised by incising the interosseous fascia radially and a portion of the index metacarpal periosteum ulnarly. Capture of the relevant vessels should be confirmed with Doppler intraoperatively (Fig. 42.4).

The pedicle is dissected to its pivot point. For inset of the flap, the flap must be tunneled under the dorsal skin of the thumb, or an incision may be made to facilitate placement of the pedicle subcutaneously. It must be ensured that excessive tension is not placed on the pedicle with inset. The donor site must be grafted with a full-thickness graft. The patient should be placed in a spica splint with a bolster over the graft site; after 5–7 days the splint and bolster may be removed, and the patient can start gentle motion.

Neurovascular Island Flap

Neurovascular island flaps (Littler flaps) are uncommonly performed, and we do not recommend acute reconstruction of the thumb with this flap. This procedure carries significant morbidity to the donor digit, with loss of palmar sensation, and requires extensive palmar dissection. Additionally, many patients will attain a functional level of sensation of the thumb even without innervated flaps. However, this flap may have use in select patients with insensate scars of the thumb or prior reconstructions without sufficient sensation for their occupational duties or avocations. Surgeons employing this technique should realize and counsel their patients that there is a significant risk of hyperesthesia of the flap and paresthesia in the donor finger over the long term [36].

The status of the median and ulnar nerve must be assessed preoperatively. If the median nerve is intact, a preferable donor site is the ulnar aspect of the long finger. If median nerve function is absent, the ulnar aspect of the ring finger would be the next preferred site. The concept of the operation is to sacrifice sensation to the side of the donor finger that does not participate in pinch.

The size of the thumb defect will mandate the size of the flap, but in many cases the entire length of the donor digit will be necessary. The ulnar aspect of the donor digit is outlined from the MP crease to the tip. The palmar skin to the middle of the finger in the sagittal plane should be used for the flap to maximize harvest of glabrous tissue, and posteriorly the harvest site may need to be extended just past the midlateral line. Dissection begins in the palm with Bruner incisions to identify the common digital arteries and nerves in the web space. The radial digital artery to the finger ulnar to the donor finger must be ligated to allow mobilization of the flap. The digital nerve of the flap must be isolated, and internal neurolysis may be necessary to allow adequate reach of the flap while preserving innervation to the adjacent ulnar finger. After isolation of the neurovascular bundle in the palm, dissection then proceeds in the finger to elevate the flap, with inclusion of the digital artery and nerve. Small vascular branches will be encountered around the interphalangeal joints that must be electrocauterized or clipped.

After elevation of the flap, the flap must be tunneled to the thumb. Great care must be taken

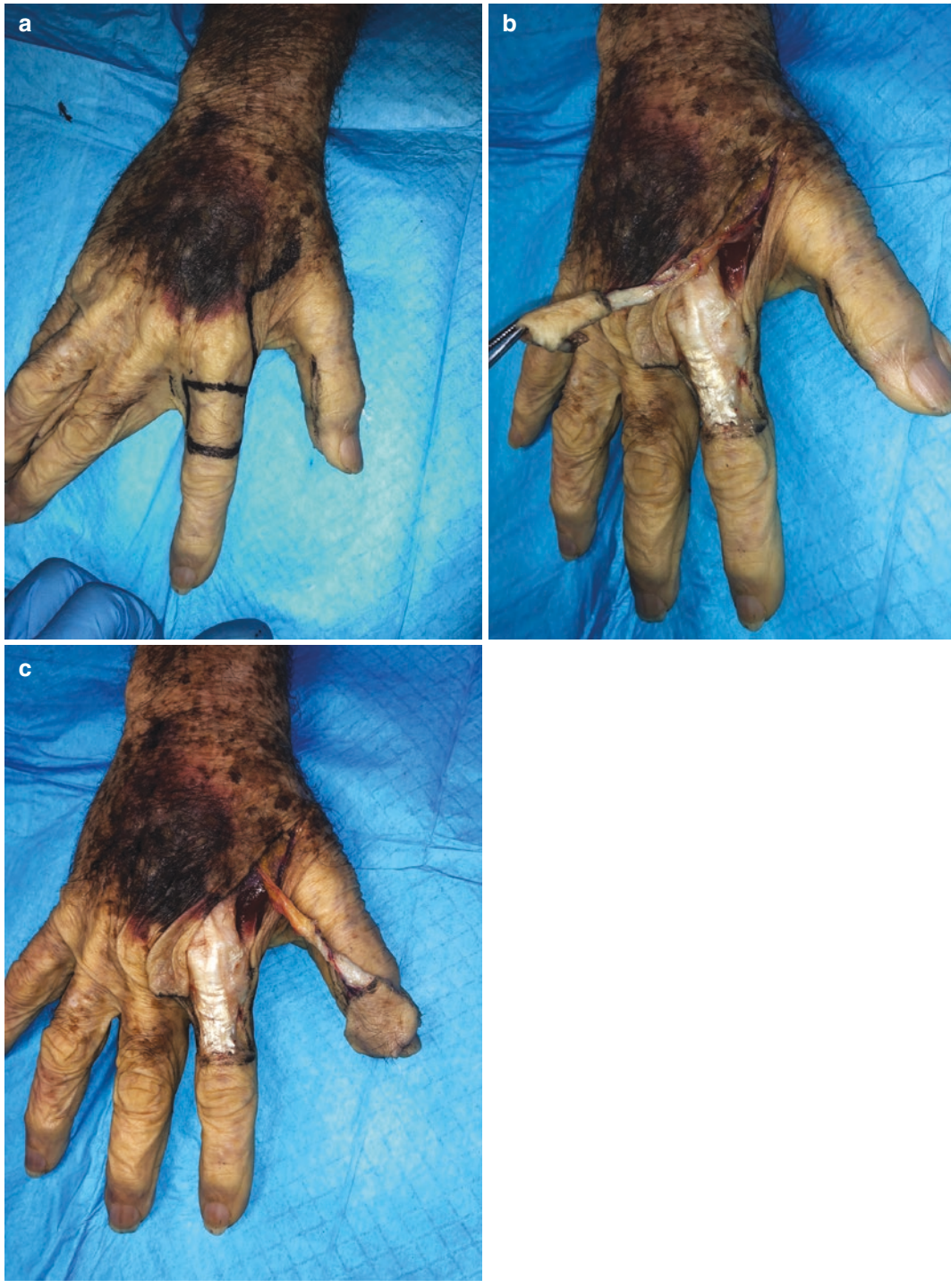

Fig. 42.4 FDMA Flap. (**a**) Design of FDMA flap over index proximal phalanx dorsum. (**b**) Dissection of FDMA pedicle along border of index metacarpal. Note that the pedicle is raised with interosseous fascia and periosteum and is not skeletonized. (**c**) Demonstration of reach allowed by FDMA pedicle

to prevent twisting or compression of the pedicle. The donor site must be grafted with a full-thickness graft. Nonabsorbable sutures are recommended, and bolsters and a spica splint should be used to protect the repair for 5–7 days.

Free Flaps

The techniques described above are the classic pedicled flaps for soft tissue augmentation of a thumb stump. However, all of the pedicled flaps of the hand borrow tissue from the already injured hand, leading to at least some degree of impairment or stiffness involving the donor site. Free tissue allows taking tissue from areas that are less functionally important, often leading to less donor site morbidity.

Venous Flaps

Free venous flaps are an attractive option for thumb soft tissue defects. Venous flaps are incredibly customizable and allow for placement of thin, pliable tissue that matches well to the native tissue of the hand. The feasibility and viability of arterialized venous flaps in covering vital structures are well described in many series [37–40]. The ipsilateral volar wrist or forearms are attractive donor sites and carry little morbidity with harvest; primary closure is usually attainable, and if not, skin grafting from the dorsal forearm can be performed easily. Flap design may be artery–vein–artery (flow-through) in acute revascularization cases that also require soft tissue reconstruction, or may be artery–vein–vein in cases where only soft tissue volume or surface area is needed. Innervation through a cutaneous nerve of the arm is also possible. Similar to cross-finger flaps, many patients are satisfied with resultant sensation even without direct innervation.

Prior to tourniquet insufflation, veins on the ipsilateral forearm and wrist should be marked. The thumb defect should then be explored, and potential inflow and outflow vessels should be identified. Templating the defect and vessel requirements on a piece of Esmarch bandage will help facilitate flap design. The venous plexuses of the forearm that fit the vessel requirements can then be identified, and the flap can be designed accordingly. With elevation of the flap, it is critical that the initial incision only cuts through skin and the underlying veins are preserved. The flap is then raised on the suprafascial plane, preserving the necessary veins and clipping branching vessels. For a flow-through flap, revascularization of the thumb tip is paramount, and a direct inflow and outflow vein is appropriate. For an artery–vein–vein-type design, a direct inflow and outflow path through the flap should be avoided; by directing flow throughout the flap, blood will be "shunted" to more areas of the flap and overall survival will be enhanced (Fig. 42.5).

The venous flap should be inset loosely; venous flaps swell significantly. Microanastomoses must be performed as with any other free flap, and the flap perfusion should be checked. In the recovery period, the flap may initially appear quite congested; in the vast majority of cases, this swelling resolves without further intervention. For flaps that are not done in the revascularization setting, these procedures may be performed as outpatient or with a short hospital stay. The patient should be immobilized for a 2-week period without pressure on the flap; after soft tissue healing, mobilization and therapy may begin immediately. Our group typically places patients on aspirin for 1 month after the surgery.

Traditional Flaps

In mutilating hand injuries, often bony structures of the thumb may remain but a pedicled or venous flap will be insufficient to cover exposed structures. As discussed previously, a core tenant of thumb reconstruction should be preservation of native length; the reconstructive surgeon should not hesitate to perform free tissue transfer to provide coverage if necessary. The surgeon must keep the next steps of reconstruction in mind as well. After sufficient soft tissue coverage, further procedures can be performed to optimize functional length. The free radial forearm flap is a

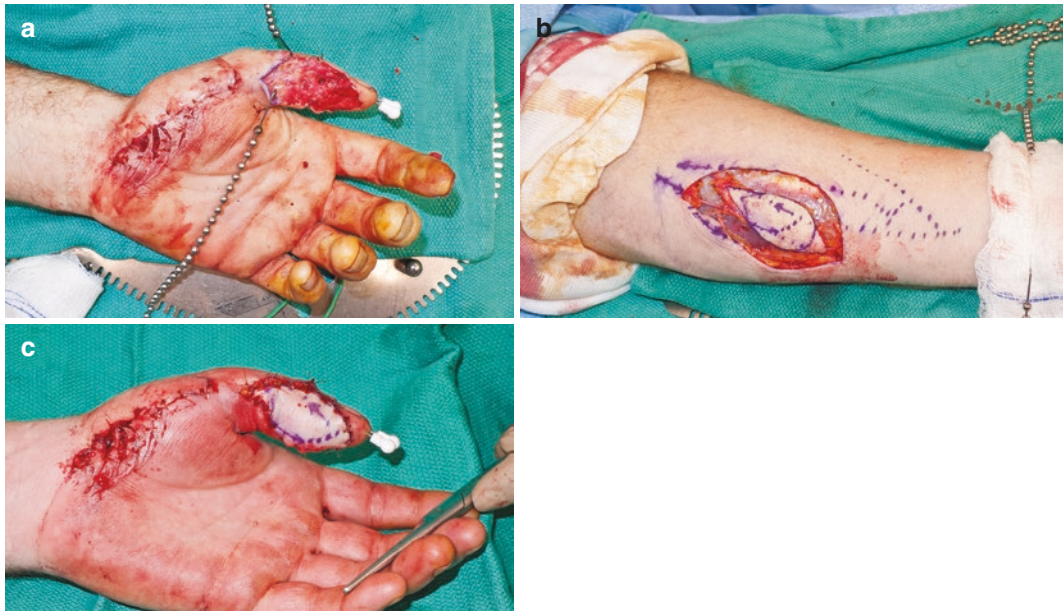

Fig. 42.5 Thumb reconstruction with a free venous flap. (**a**) Traumatic degloving of thumb involving the working surface. (**b**) Elevation of free venous flap from the ipsilateral volar forearm designed in artery–vein–vein fashion. A cutaneous nerve was raised with the flap. (**c**) On-the-table inset of flap. Inflow was provided with ulnar digital artery; outflow was provided by a dorsal vein. Innervation was through a branch of the ulnar digital nerve

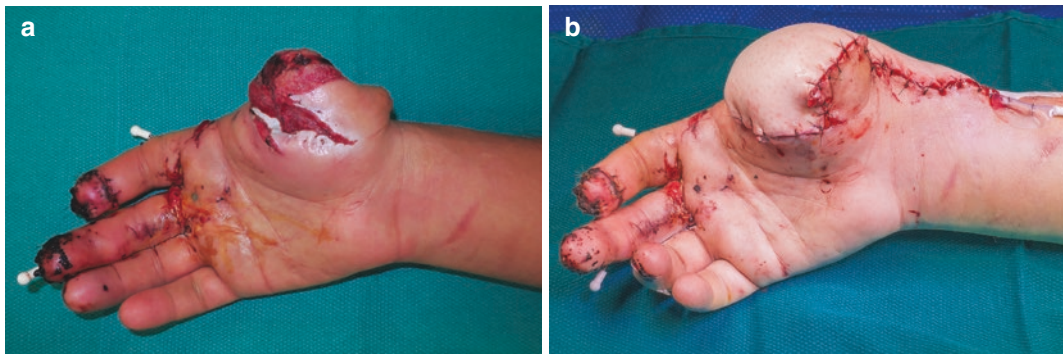

Fig. 42.6 Tissue transfer for thumb amputation stump coverage. (**a**) Patient after firecracker injury to the right thumb, with exposed metacarpal. (**b**) A free anterolateral thigh flap was utilized to provide coverage and maintain bone length. Excess tissue will be utilized for later toe-to-thumb reconstruction

workhorse for resurfacing large defects of the hand; while a pedicled reverse radial forearm flap is often possible, this may complicate need for further flaps to the hand in the future. Available inflow and outflow sites must be considered when undergoing staged reconstruction. Free anterolateral thigh flaps also provide generous soft tissue. While flaps may initially be bulky, they can be debulked in future stages, and often this soft tissue is useful if further bony reconstruction is necessary (Fig. 42.6).

Thumb-Lengthening Procedures

Multiple options for soft tissue reconstruction have been described thus far, but often the reconstructive surgeon is presented with a patient who

had inadequate bony length for the thumb to fulfill its function. These circumstances must be tailored to the patient's needs and willingness to participate in care. As previously noted, bone loss up to the IP joint is often well tolerated, even in manual laborers. Loss past the IP join will decrease hand span, reducing the capability to grasp large objects and grip strength. For moderate and high-demand patients, this is often a source of distress. The aggressiveness of treatment must take the deficit and patient into account. Though a toe-to-thumb transplant offers excellent outcomes and can restore a significant amount of length and soft tissue, not all patients can tolerate the prolonged immobilization and therapy. Simpler procedures, such as web space deepening, may not fully restore functional anatomy but may be the wiser choice in less reliable patients.

Web Space Z-Plasty

This technique is used to effectively extend the functional length of a remnant thumb. Z-plasties, originally described for scar lengthening in the eyelids by Horner [41], can be effective in lengthening the web space to allow for increased span of the thumb in relation to the remaining fingers. A web space Z-plasty is most effective if at least half of the proximal phalanx remains, the web space is not significantly scarred, and the first metacarpal is mobile. Partial adductor release may be necessary if the web space musculature is tight from trauma or disuse.

Z-plasties can be simple, with two limbs, or more complex. In the case of a simple Z-plasty, the first web space ridge acts as the central limb, and 60-degree limbs are designed to be the same length of the central limb. Care should be taken to avoid incisions on the ulnar thumb or radial index finger. The incisions are carried down to muscular fascia, and the flaps are transposed.

A four-flap Z-plasty can be carried out similarly, with each apex of the resultant flaps ranging between 45 and 60 degrees. The advantage of using multiple flaps is that inset without resultant tension and dog ears is easier with multiple flaps; while a 90-degree simple Z-plasty has the same theoretical gain as a four-flap Z-plasty with 45-degree limbs, the real-world contractile and three-dimensional properties of the skin diminish the a priori result [42]. When the four-flap Z-plasty is transposed, it is helpful to label the flaps (i.e., A, B, C, D) to ensure the correct transposition has been performed (i.e., the flaps should then lay in a C, A, D, B configuration). For these web space procedures, we recommend the use of nonabsorbable sutures and temporary use of a web spacer splint to maintain the gain in depth.

Variant local tissue rearrangements, such as the jumping man flap or V-to-Y flaps, may also be used for web space deepening; these flaps may be more facile to design in areas of irregular scarring [43]. For very scarred beds and in cases of extensive adduction contracture, increased web space length can be achieved with rotational flaps from the dorsal hand after contracture release [44]. The flap is randomly based and should follow standard 3:1 principles. Backgrafting may be necessary for large flaps. Regional flaps, such as the pedicled radial forearm flap or posterior interosseous flaps, may also be used for this purpose [45, 46]. Distant pedicled flaps, such as cross-arm flaps or groin flaps [47], are also possible, but given the awkwardness of positioning/immobilization and the inconvenience preventing even activities of daily living, we would not advocate these flaps unless all other options are exhausted; in areas where microsurgical capabilities exist, these are almost never indicated. Free tissue transfer may play a useful role in web space reconstruction; small fasciocutaneous flaps, such as the lateral arm flap, provide nontraumatized, supple tissue for web space deepening (Fig. 42.7).

Bony Reconstruction

Amputation with Preservation of the Basal Joint

When there is insufficient proximal phalanx remnant or a transmetacarpal amputation of the thumb, often web space deepening will not suffice for thumb function. In these cases, bony augmentation is necessary. The majority of patients

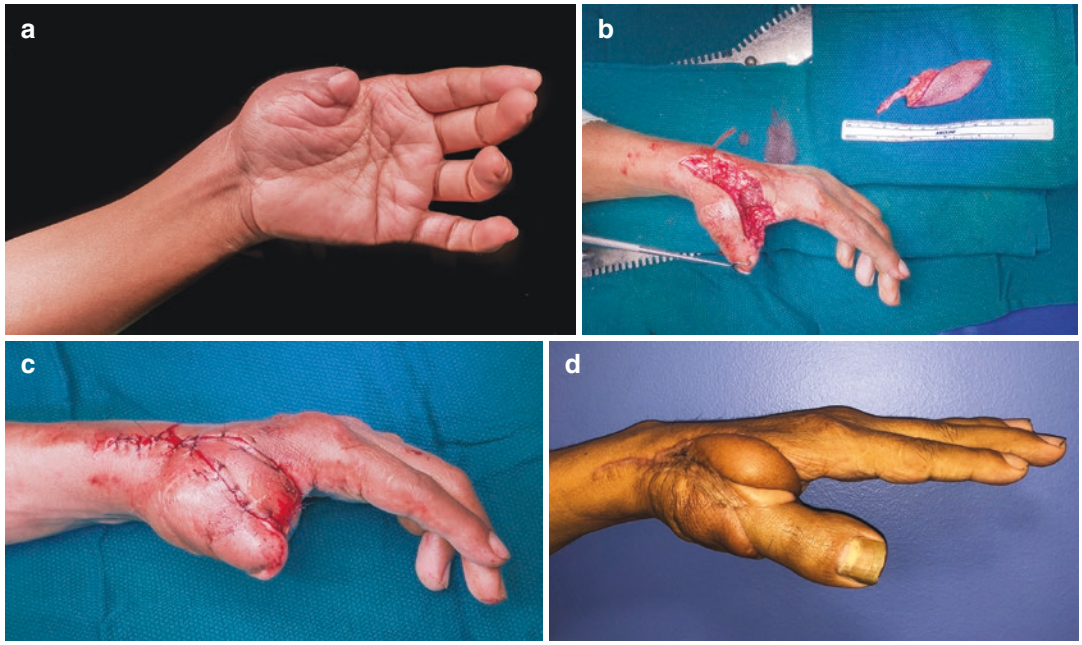

Fig. 42.7 Free tissue transfer for web space deepening. (**a**) Patient after remote thumb amputation with contracted web space, which prevented opposition. (**b**) A free lateral arm flap was utilized to augment the web space. (**c**) On-table inset. The increased web space allowed opposition to the thumb stump, though length was still lacking. (**d**) This patient ultimately underwent a free toe transfer, demonstrating the role of staged reconstruction in thumb reconstruction with significant soft tissue and bone loss

are candidates for free toe transfer, which offers excellent outcomes in objective hand function and in patient-recorded outcomes [1]. Other methods include osteoplastic reconstruction through other means or distraction osteogenesis.

Osteoplastic reconstruction utilizing soft tissue transfer with a bone graft or vascularized bone flap has largely been supplanted by toe-to-thumb transfer, but this technique has situational applications. There are many options, and the type of defect and creativity of the surgeon will determine the reconstruction. However, the overall principle to follow is to establish a stable post with durable soft tissue with functional length, that is., to the mid-proximal index phalanx. Some examples are discussed, though operative details will not be discussed here. When microsurgical options are not available, a pedicled reverse radial forearm flap with cortical cancellous graft from the iliac crest can provide bone and soft tissue in a single stage. If a large and lengthy amount of bone is required, free fibula may be used with or without a soft tissue flap to provide a large post. In the mutilated hand, there may be situations where a lesser finger is nonviable and is amputated, but the remnant metacarpal can be used as a bone graft with a soft tissue flap to provide a thumb post. A large disadvantage of these reconstructions is that innervated skin is not provided; a neurovascular island flap from the ulnar middle finger or a subsequent toe/toe pulp transfer can be used to overcome this if necessary (Fig. 42.8) [48].

Distraction may have a role in selecting patients who are adamant against another donor site and can provide 3–4 cm in optimal conditions. However, the technique is technically demanding, and the distraction period can easily last over 1 month, and potential morbidity to the injured hand from prolonged external fixator placement has not been well described [49]. This technique is not utilized in our practice.

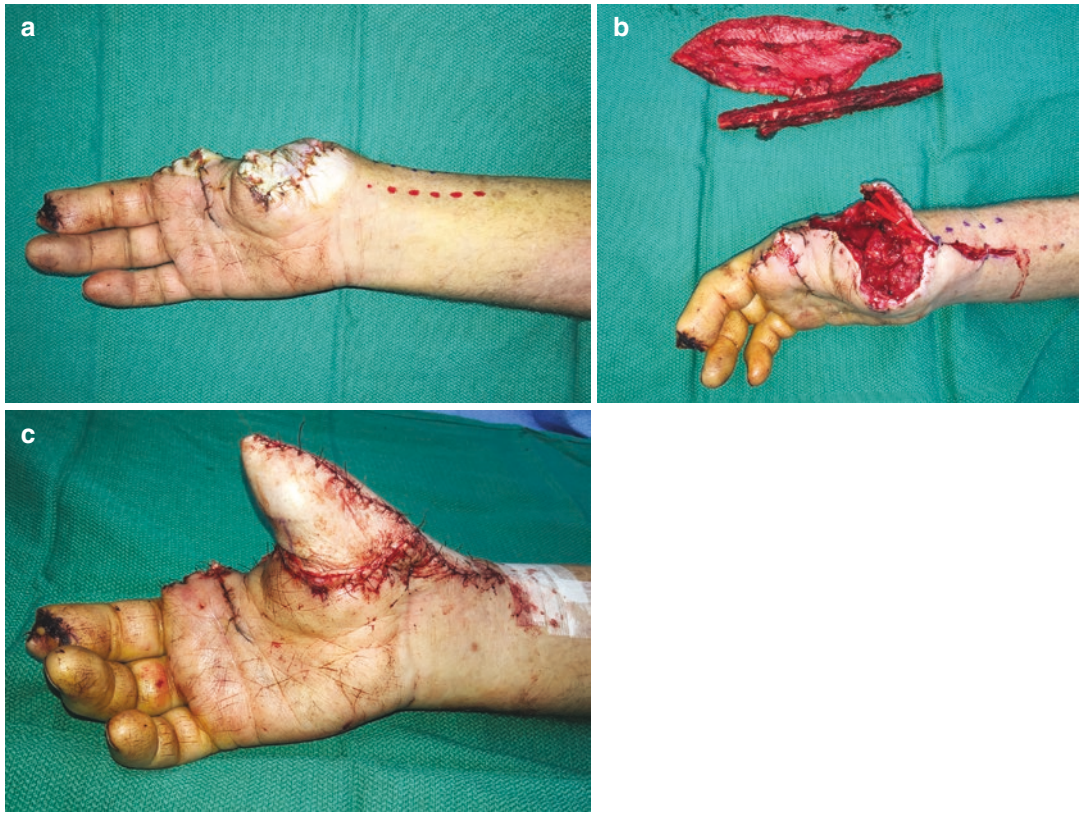

Fig. 42.8 Osteoplastic reconstruction. (**a**) Amputation of thumb down to the CMC joint. (**b**) Free fibula flap raised to provide opposable post for remnant fingers. (**c**) Inset of fibula flap. Adequate soft tissue was provided by the associated skin paddle for coverage

Toe-to-Thumb Transfer

The first report of a toe-to-hand transfer was by Nicoladoni in the nineteenth century as a pedicled transfer [50]. The first documented free transfer of a toe to the hand was performed by Yang in 1966, who transferred the second toe for thumb replacement [51]. Cobbett performed the first free great toe transfer to the thumb in 1968 [52]. For thumb reconstruction, toe transfer is now widely accepted for both pediatric and adult populations and provides a functioning digit with sensitivity [53–55]. While many patients may express anxiety about the donor deficit, studies have suggested that donor site morbidity does not significantly affect patient-reported outcome measures [1]. The excellent outcome with toe transfer for thumb reconstruction thus makes it the gold standard for amputations of significant length that are not replantable.

Evaluation for potential toe transfer should begin at the time of the initial trauma, if possible. As noted above, replantation should be attempted for the majority of thumb injuries; however, the possibility for future reconstruction with a toe should be explained to the patient should replantation fail. In the acute case where replantation has failed or is not feasible, extensor and flexor tendon lengths should be preserved for future use. The digital arteries and veins should be tagged with clips and preserved as long as possible. Similarly, the nerves should be kept long for future coaptation. Skin may often be a limiting factor in toe reconstruction, as toe transfer will not offer additional skin beyond the bony length that is taken. In these cases, we recommend refraining from local tissue use, as this will com-

plicate dissection in the hand for the thumb reconstruction. In these cases, we recommend staging reconstruction with a free flap such as a radial forearm or anterolateral thigh (ALT) to provide adequate tissue to reconstruct the web space and soft tissue length of the thumb. It is integral that the surgeon be conscious of the choices of inflow and outflow to the flap to allow for future toe transfer; in many cases the pedicle of the flap can even be used to support the toe.

When possible, acute toe-to-thumb transfer should be performed, as these patients have a higher chance of returning to their original occupation [56, 57], though this may not be possible for all patients. In the setting of significant soft tissue deficit, performing concurrent free flap coverage with a toe is possible, though this is technically demanding and complicates perioperative monitoring. Failure of a toe transfer due to underappreciation of the zone of injury or technical mistakes in an aggressive reconstruction plan is inexcusable. In the majority of cases involving mutilating hand injuries, we recommend staged reconstruction, allowing at least 3 months after soft tissue reconstruction before proceeding with toe transfer.

As noted above, amputations at the level of the IP joint and distal are often well tolerated, but there is a cosmetic defect, and fine manipulation may be affected. A modified toe transfer or toe wraparound flap can be offered to these patients. A full toe can be offered for amputations through the proximal phalanx. If the amputation is through the metacarpal, thenar musculature will be affected and opponensplasty at the time of toe transfer or as a secondary procedure should be considered [58]. When a significant portion of the metacarpal is lost, toe transfer alone is insufficient to provide adequate length and function. Taking a portion of the great toe metacarpal is possible, but this greatly increases donor site morbidity. In these cases, osteoplastic reconstruction of the thumb metacarpal should be considered before toe transfer [59].

In our practice, we use great toes for transfer, as we find they have the most desirable donor aesthetic and function. The toe initially may appear large for the hand, but over time atrophies to resemble a native thumb. Harvest of a full toe will be described here. A two-team approach, with one surgeon preparing the structures in the hand and another surgeon harvesting the toe, will greatly decrease the operative time. The ipsilateral great toe should be harvested with the defect, as this will most easily allow vascular anastomosis to the ulnar digital artery or the dorsal radial artery in the hand. The dissection can be fully done under tourniquet. Dissection should start from the dorsum of the foot and first web space to identify the dorsalis pedis artery in continuity with the first dorsal metatarsal artery (FDMA). The FDMA will be the dominant inflow in approximately 70% of cases. The FDMA branch point into the lateral digital artery of the great toe and the medial digital artery of the second toe should be identified over the intermetatarsal ligament. The plantar vessel can then be inspected; if it is in equal caliber or smaller than the dorsal vessel, we recommend utilizing the dorsal system, since dissection is much easier. The plantar vessel can be ligated and the dissection continued dorsally and proximally. If a plantar dominant system is noted, we recommend dissection of the first plantar metatarsal artery (FPMA). This artery will extend to the middle of the metacarpal shaft; we recommend only taking the vessel to an adequate caliber for anastomosis and vein grafting if there is insufficient length, as extensive dissection in the plantar foot can lead to significant morbidity. Both inflow systems can be preserved until final division if the dominant supply is not visually apparent.

After the dominant arterial supply is identified, the artery is traced proximally to obtain sufficient caliber and/or length. Skin incision should be in a V-shape configuration with a proximal extension, with care to prevent a scar on the direct plantar surface of the metacarpal head. At least one dorsal vein is preserved, and the extensor tendon is taken to the necessary length. Dissection can then be performed on the plantar surface to identify the neurovascular bundles and flexor tendon. Nerves may be taken to length, but we leave the arterial inflow and venous outflow until final division of the toe. If the necessary tendon length is beyond the access of the harvesting incision,

counter incisions should be made to avoid excessive dissection. Tenting the tendons with flexion or extension of the toe will allow identification of incision sites. Initial dissection should be circumferential down to the joint capsule of the MP joint. The MP joint is then incised with great care to protect the neurovascular bundles and tendons. The collateral ligaments can be harvested if use of the toe hemi-joint is planned. Eburnation of the remnant metacarpal head has not been necessary for our practice. At this point, the toe is secured in place with an Esmarch wrap and the tourniquet is deflated. We allow 20 minutes of reperfusion to the toe before transfer. At this time the smaller inflow tract can be clamped to confirm adequate perfusion if the dominant supply was in question. After reperfusion and preparation of the hand, the vascular supplies of the toe are ligated, and the toe is brought to the hand. Closure of the donor site is performed with layered sutures such as 3-0 Monocryl for deep sutures and 4-0 nylon for skin. We do recommend nonabsorbable suture for the donor site, as these wounds may be slow to heal. A Penrose drain is placed in the donor site. A soft dressing with an elastic wrap is then applied.

For dissection of the recipient site, skin flaps must be designed to allow tension-free inset of the thumb. Bone, tendon, and nerves must be adequately mobilized. For recipient artery, the ulnar digital artery is our first choice if not traumatized; otherwise, the dorsal radial artery is used. An acceptable vein must also be identified. The usable lengths of these structures in the hand will dictate lengths necessary for harvest in the toe. For bony fixation, a reciprocating saw can be used to craft flat surfaces of the toe and hand bones for osteosynthesis if similar in size. If the native thumb bony remnant is smaller than the toe proximal phalanx, a "ball in a cup" design can be made by burring a hollow in the toe proximal phalanx. Two crossing or longitudinal K-wires will be adequate for fixation. If using the toe as a hemi-joint, collateral ligament repair can be performed. Repair of the remaining structures is done as in a standard replant. The patient is kept in house for 5 days for monitoring. The Penrose drain in the foot is removed prior to discharge. We keep the patient with the operated leg elevated and non-weight bearing for 2 weeks after discharge; wound complications of the donor site can be very bothersome to both surgeon and patient. The thumb is immobilized in a spica for 6 weeks, and pins are then removed. The patient then starts aggressive hand therapy (Figs. 42.9 and 42.10).

Special consideration should be taken for pediatric cases. While Lister has reported performing toe-to-thumb transfer in patients 6 months of age, the small anatomy of these patients will make the procedure more difficult. It is, however, recommended to perform transfer before 2 years of age before adaptive behavior dominates [60]. It is critical that the hand is explored before toe harvest to identify vascular pedicles, nerves, and tendons, as this is variable between patients. Nerve or tendon transfers may need to be performed. The transferred toe may not grow to be the same length as the contralateral toe if present, and parents should be counseled on this [61].

Total Loss of Thumb with Basal Joint Destruction

Amputations that involve the basal joint limit the options for thumb-lengthening procedures. One option is to create a post in a static opposed position through osteoplastic techniques described above. The other alternative is pollicization of a finger of the same hand or through free digit transfer. This is the more attractive option, as the transposed MP joint, while lacking the same mobility as the native CMC joint, will allow for some mobility of the neothumb.

Most of the techniques for pollicization in the traumatized hand are borrowed from the pediatric thumb hypoplasia literature. Long-term studies for pediatric pollicization patients show robust outcomes [62, 63]. However, long-term studies for outcomes for the adult population are on the order of case series, and while many patients become facile with grabbing large objects, many still struggle with fine pinch [64]. Without a functioning CMC joint, however, this may be the best option to restore semblance of a thumb.

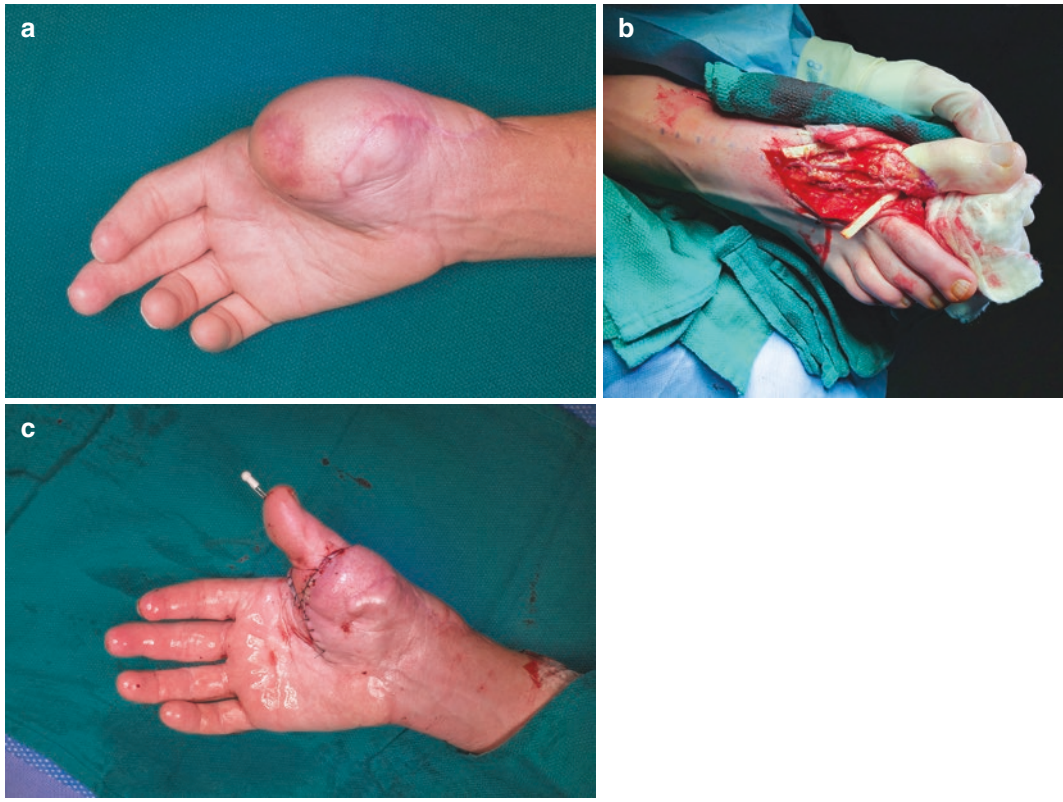

Fig. 42.9 Toe-to-thumb transfer. (**a**) Patient with toe amputation status post-first-stage reconstruction with a free ALT (see Fig. 42.6). (**b**) Circumferential dissection of the toe completed. Tourniquet has been released, and dorsal blood supply to the toe is dominant. (**c**) Toe inset after ALT flap debulking

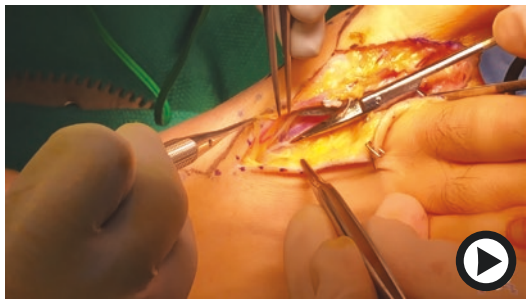

Fig. 42.10 Video demonstrating the technique of great toe to thumb free tissue transfer (▶ https://doi.org/10.1007/000-3vj)

The index finger is most commonly selected for pollicization. An elliptical incision at the base of the index finger with an extension to the site of vindex finger is incised first, and the neurovascular bundles to the finger are identified. The proper digital nerves must be isolated and mobilized to their takeoff; occasional vascular leashes may be identified that require ligation and division. The digital arteries and as many veins as possible must be preserved. The A1 pulley of the index finger is incised to prevent flexor tendon buckling after bone shortening, and the intermetacarpal ligament must also be divided. The flexor and extensor tendons are not shortened. The interosseous muscle insertions onto the extensor hood should be released and tagged. A metacarpal osteotomy is performed, and the remnant metacarpal is shortened to the metaphyseal flare. The index finger length can be tailored to the patient's hand, using the mid-proximal phalanx of the middle finger as a desired length. The metacarpal of the index finger can be arthrodesed to the remnant trapezium if available. Kirschner wire fixation is our fixation method of choice. The

index finger should be rotated 160 degrees into pronation to allow opposition against the remaining fingers [65]. The MP joint of the index finger should be set in hyperextension when inset to the carpus; this will prevent unwanted extension of this joint with attempted opposition [66]. The first dorsal interosseous tendon should be transferred to the radial lateral band and the first palmar interosseous tendon into the ulnar lateral band around the index proximal interphalangeal joint. Excessive skin should be judiciously excised. The patient should be kept in a spica for 6 weeks, pins should then be removed, and aggressive hand therapy should be performed.

Conclusion

The optimal method of thumb reconstruction is highly dependent on the level of amputation and needs of the patient. There are principle tenants of reconstruction, however. Bony length should be preserved by whatever means necessary for acute trauma, and soft tissue coverage with durable, sensate tissue should be achieved.

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Tumors

43

Busayo Irojah, Donna Lynn Mullner, Craig Moores, Manoucher Lance Tavana, and Milton B. Armstrong

Introduction

A wide array of benign and malignant tumors occur in the hand and upper extremity. Management of each tumor differs, consequently it is important for the hand surgeon to be able to recognize and manage hand and upper extremity lesions appropriately. This chapter describes the presentation, risk factors, and treatment of benign and malignant hand and upper extremity tumors. A video demonstrating various approaches and incisions for tumors of the hand is included in the chapter (Fig. 43.1).

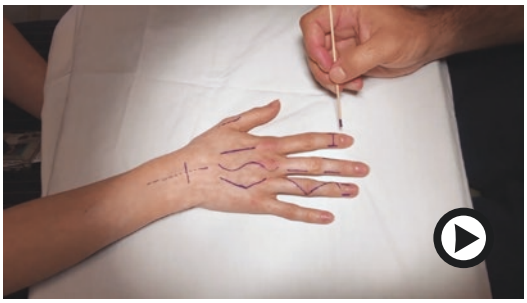

Fig. 43.1 Video reference outlining various approaches and incisions when planning surgical intervention for hand lesions (▶ https://doi.org/10.1007/000-3vk)

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-78028-9_43) contains supplementary material, which is available to authorized users. The videos can be accessed by scanning the related images with the SN More Media App.

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Benign Tumors

Ganglion Cysts

Ganglion cysts are the most common lesion of the hand, representing 60–70% of all benign hand lesions [1, 2]. They are most commonly found next to a joint capsule, tendon sheath along the dorsum of the hand. The most common involved location is the dorsal wrist at the scapholunate joint [1, 3]. When the lesions are present on the palmar aspect of the hand, they usually arise from the radioscaphoid or scapholunate joints. The radial artery is often abutting the mass or intimately related when on the volar aspect [3]. Cysts can also be found along the flexor tendon sheaths of the fingers (retinacular cysts) and along the distal interphalangeal joints (mucous cysts) (Fig. 43.2a, b) [2, 3]. They may also

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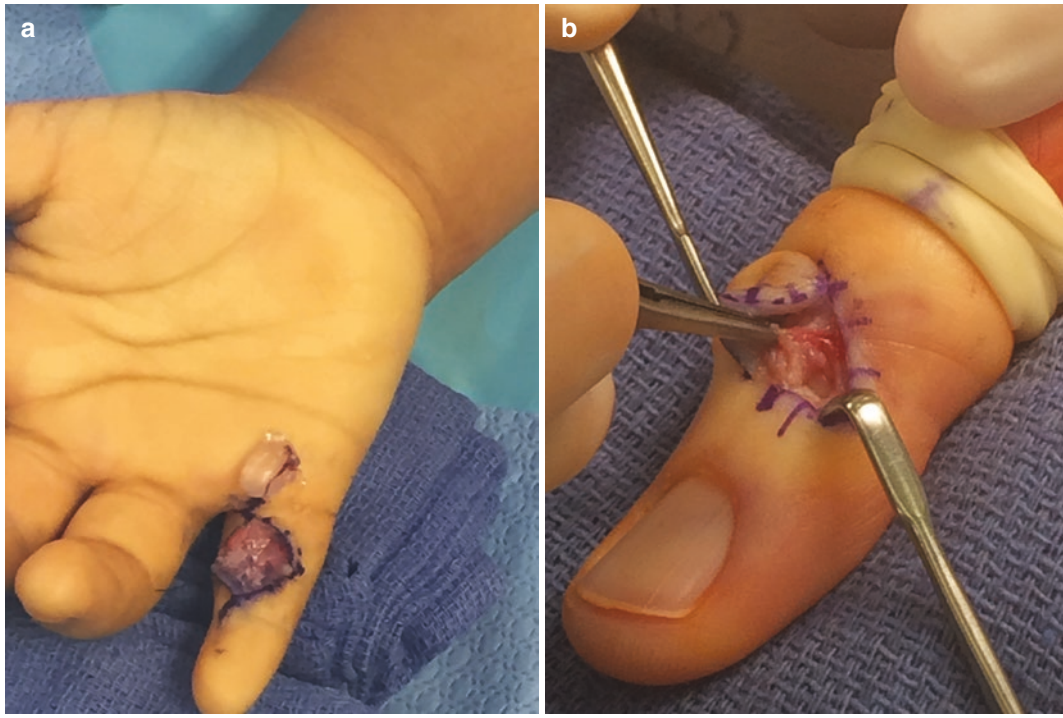

Fig. 43.2 (**a**) Ganglion cyst located on the flexor tendon sheath excised through a Brunner incision. (**b**) Mucous cyst located at the distal interphalangeal joint

arise from the radioulnar or ulnocarpal joints [3]. Presentation usually is a woman in her late 20s–40s, with a smooth, firm, but fluctuant mass that is able to transilluminate [1–3]. History may include symptoms of paresthesia or tendinous involvement related to the variation in size or pressure of the involved area [1]. Diagnosis is mainly clinical; however, imaging such as MRI may be necessary if location is suspect or history unreliable [2]. Treatment may involve observation, aspiration, or excision. In children, approximately two-thirds of cysts will involute over the next several years [1]. Aspiration may be performed to offer diagnostic and therapeutic benefits; however, recurrence is high and if the mass is on the radial, volar aspect of the wrist should not be attempted [3]. Surgical excision is the most effective treatment if the stalk of the cyst is excised, as well as a small portion of the joint capsule from which it arose [1]. Immobilization with splinting postoperatively is important to avoid capsulodesis from postoperative scarring [3].

Giant Cell Tumors

Giant cell tumors are the second most common lesions of the hand and wrist, at about 3–9% of lesions [1, 3]. This lesion is benign despite the ominous nomenclature. These tumors may also be referred to as localized nodular tenosynovitis, fibrous xanthomas, xanthomas of the synovium, benign synoviomas, and sclerosing hemangiomas [1]. Typical presentation is a patient in their 30s–50s with a slow-growing, nonpainful, nodular lesion adjacent to the DIP joint of the index or long finger (Fig. 43.3a–c) [1, 3]. The patient may have secondary effects of the mass such as pain, paresthesias, or triggering of the afflicted digit. The lesion is thought to form from a hyperplastic, inflammatory process [1]. Rare instances of pathologic fractures and intraosseous expansion of the lesion have been reported [1, 3]. Radiographs may be normal, from showing some associated erosion of cortex to the aforemen-

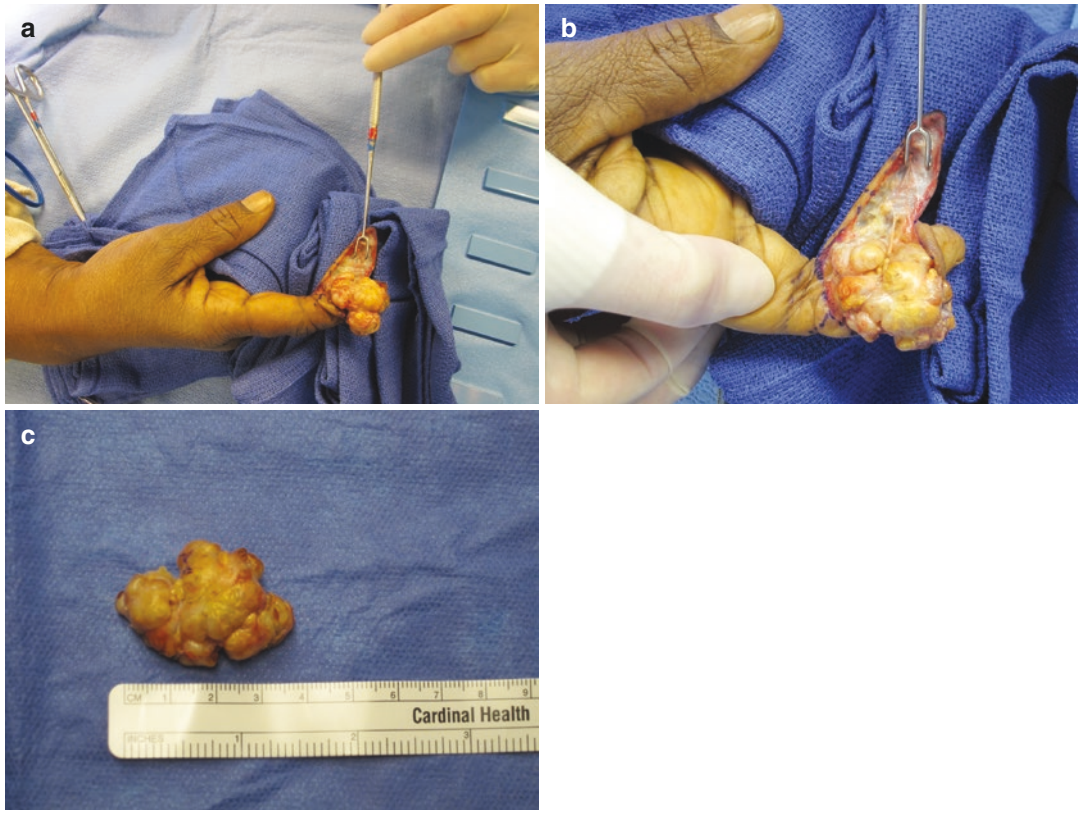

Fig. 43.3 (**a**–**c**) Giant cell tumor adjacent to the distal phalangeal joint of the index finger, which is the typical location for these tumors

tioned, albeit rare, pathologic fracture [1]. Treatment of choice is local excision. If the lesion exhibits communication with the involved joint, the component within the joint must also be excised [1, 3]. Recurrence rate ranges broadly between 10% and 50% and is related to location at the DIP or IP joint, presence of erosion, and adjacent degenerative joint disease [1].

Epidermal Inclusion Cyst

Approximately, 4–14% of hand tumors are comprised of epidermal inclusion cysts, making them the third most common mass of the hand [1, 3]. Usually presentation is that of a painless, round or dome-shaped protuberance on the volar surface of the hand or fingers, and the patient may endorse a history of drainage associated with waxing and waning in the size of the lesion [1, 2]. A punctum may also be able to be visualized on examination. Unlike ganglion cysts, these lesions are unable to transilluminate and can be associated with a remote history of trauma. One theory on formation is that cysts are likely formed from traumatic implantation of epidermal cells into the dermis. Once within the dermis, epithelial cell-lined cysts may form a capsule, and this is filled keratin debris [1]. It is also possible for cysts to erode into bone on the distal aspect of the phalanges where skin is adherent to bone [2]. Formation involves occlusion of pilosebaceous follicles or keratinocyte trapping within the periosteum [1, 2]. For this reason, cysts can mimic malignancy on plain films as a lytic lesion in the distal phalanx [2]. Typically cysts do not require treatment unless they exhibit secondary effects due to size, causing pain and pressure or infection. Treatment is operative and involves excision of the cyst en bloc, making sure to remove the entirety of the

surrounding capsule. If the bone is involved, the curettage, with bone graft if necessary, can be performed of the affected area [2, 3]. Incomplete excision can result in reoccurrence of the lesion.

Verruca Vulgaris

Warts are commonly caused by the HPV virus types 1, 2, 4, and 29 [1]. They are most commonly found on sites with associated trauma. Most warts undergo spontaneous regression after 2 years [1, 4]. However, in the immunosuppressed, they may persist for longer periods of time and become more numerous [1]. While malignant transformation is rare, 90% of squamous cell carcinoma (SCC) in the hand is infected with HPV [1, 4]. Diagnosis is clinical, based on examination and history [4]. The key to management of lesions is diligent, continuous use of topical irritants, such as salicylates, to stimulate immunity to the virus [1]. Cryotherapy may also be used, although with caution along the lateral portion of digits overlying neurovascular bundles and periungual regions, to protect the nail matrix [1]. For refractory cases, immunotherapy such as with imiquimod has been reported with some success.

Seborrheic and Actinic Keratosis

Actinic keratosis are commonly found on the dorsal surface of the hand and associated with high sun exposure in aged individuals. The present as pink/red, scale-like macules that are often rough in texture [1]. Diagnosis is clinical. There is approximately a 5% risk of malignant transformation to commonly squamous cell carcinoma over a 10- to 25-year period [1]. Treatment is recommended to reduce the transformation risk to malignancy. Physical findings concerning for transformation include a hyperkeratotic appearance with indurated surrounding skin, inflammation, and ulceration of the lesion, as well as a sudden change in size. Typically treatment is topically based via cryotherapy or curettage with or without the addition of electrosurgery. If multiple lesions are present, 5-fluorouracil or photodynamic therapy with aminolevulinic acid or imiquimod can be used. Other agents such as diclofenac and dermabrasion or chemical peels have shown either delayed (former) or variable results (later) [1]. Biopsy should be considered of lesions that are recurrent or unresponsive to treatment. Ultimately, preventative treatment focuses on regular sunscreen use to protect and prevent the development of actinic keratosis.

Keratoacanthoma

This is a rapidly growing cutaneous tumor that presumed to arise from hair follicles. In the upper extremity, they occur most commonly in the forearm and dorsum of the hands [6, 7]. They share many similarities to squamous cell cancer and can be difficult to distinguish. Histologically keratoacanthoma have a sharp demarcation between the tumor and stroma, while SCC are more likely to have ulceration, increased mitotic rate, and marked pleomorphism [7]. Two important subtypes are subungual keratoacanthoma and giant keratoacanthoma (>2 cm in size). Sun exposure and fair skin are risk factors for occurrence. Its peak incidence is the fifth and sixth decades of life [6, 7]. They go through three distinct phases: a proliferative phase, maturation phase, and involution. It takes 4–6 months from onset to resolution [7]. Mature keratoacanthomas are dome-shaped, skin-colored or pink, with a central keratin plug [6–8]. During involution, the keratin plug is expelled, leaving behind a depressed scar. Ten percent of lesions thought to be keratoacanthomas are actually squamous cell cancer. Intervention is therefore recommended for all keratoacanthomas. Wide local excision or Mohs surgery is recommended for management. Topical agents such as imiquimod and 5-FU can be used to treat keratoacanthomas, but these are considered second-line agents [1]. As noted earlier, keratoacanthomas can occur subungually. Subungual keratoacanthomas that invade the underlying distal phalanx may require amputation [7, 8].

Desmoid (Aggressive Fibromatosis)

This is a benign, locally aggressive tumor with an infiltrative growth pattern arising from fas-

cia, deep muscle, and aponeurosis [9, 10]. The most common presenting complaint is a painful mass, and 70% of patients recall prior trauma to the area [10]. Desmoids in the extremity tend to be sporadic and not associated with familial adenomatous polyposis [11]. Desmoid tumors have no metastatic potential, but cause morbidity due to their infiltrative nature. In the upper extremity, the peak incidence is between the ages 25 and 30 [9]. MRI is the best imaging modality for these lesions. On T2-weighted images on MRI, they are well circumscribed, predominantly hyperintense, heterogenous masses. Surgical excision with negative margins with or without radiation was the mainstay of treatment; however, several recent studies call this to question, advocating an initial period of observation, as many tumors stabilize after an initial period of growth [11]. A period of observation therefore helps to identify patients whose tumors have a favorable pathology. Patients whose tumors progress during observation undergo resection [11]. Radiation is used in the adjuvant setting for those having positive margins and also for palliation when the tumor is unresectable. A number of systemic and local therapies are also available for desmoid. These include NSAIDS, antiestrogen medication (tamoxifen), tyrosine kinase inhibitors, anthracyclines, and other chemotherapy medications. Antiestrogen medications and anthracyclines have the best therapeutic effect. Isolated limb perfusion has also been used with good results in patients in whom resection would result in severe functional impairment [11].

Glomus Tumor

A glomus tumor is a benign lesion that contains modified perivascular smooth muscle cells [2]. A glomus body is commonly found in the subungual areas, lateral aspects of distal digits, and palm, and plays a role in regulating blood flow and temperature [2, 3]. Glomus tumors are more frequently found in women, who present with a triad of symptoms that is often diagnostic—cold intolerance, severe and paroxysmal pain, and pinpoint tenderness [1]. In addition, the lesion in question is usually solitary, blue to red in coloration, blanching in nature, and associated with nail ridging when it is located subungually [1, 2]. Diagnosis is clinical, based on presentation and history; however, local maneuvers to elicit pain responses may also be diagnostic, such as Hildreth sign [1]. Radiographs may show a lytic lesion of the distal phalanx, and MRI is only necessary if the clinical picture is ambiguous [1, 2]. Treatment is surgical excision by shelling out the lesion from the surrounding tissue [1]. If the lesion is subungual, removal of the nail plate may be performed and then replaced [2].

Arterial/Aneurysm

A true vascular aneurysm is defined by the presence of all three layers of the arterial wall—endothelium, tunica media, and tunica adventitia—and are the result of repetitive blunt trauma [3]. A false aneurysm has a wall that only contains the endothelium [1]. Trauma causes the wall of the vessel to weaken, which then allows progressive dilation. It is also possible for aneurysms to result due to infection, atherosclerosis, arteritis, tumor, and metabolic disorders [1, 3]. The usual involved vessel in the hand is the ulnar artery in the hypothenar aspect of the palm, commonly in those who use a hammer (hypothenar hammer syndrome) [3]. Presentation is initially a painless mass, but not necessarily always pulsatile, that may eventually cause compressive nerve symptoms or embolic phenomenon of the finger tips [3]. Angiography is the best method of diagnosis. Resection is the recommended treatment due to the possibility of distal emboli and thrombosis locally [3]. It is important to determine the presence of collateral flow before ligation of proximal and distal ends intraoperatively. If no collateral flow is present, or it is inadequate, the artery must be repaired either end to end or via an interpositional graft [3].

Hemangioma

Hemangiomas of the hand are often identified in childhood and are more common in females than males (5:1) [3]. Hemangiomas consists of rapidly proliferating blood vessels that last up to 1 year, followed by an involutional phase [2]. Ninety percent of the lesions are resolved by 9 years of age [3]. Etiology of these lesions is unknown. Presentation is often within the first month of life, and clinical appearance is variable, depending on location and depth within the tissue, presenting as a reddish-purple or flesh-colored lesion that is rapidly growing and poorly defined [1, 3]. The growth pattern and involution are diagnostic of these lesions; however, MRI is the current imaging modality of choice if there is difficulty in distinguishing from a vascular malformation [1]. Glut-1 and WT1 are two immunohistochemical markers found in hemangiomas and not vascular malformations, and offer another way of distinguishing the two [1].

Most hemangiomas do not require treatment because they are benign lesions and they involute [1, 2]. Beta blockers can help accelerate the involution process [2]. The lesions can often outgrow the infant, resulting in bleeding and ulcerations, and this can be treated with antibiotics and local wound care, unless there is impaired functioning [1, 3]. Surgical excision under tourniquet becomes necessary if the lesion impedes function, is esthetically displeasing, or persists into adulthood (Fig. 43.4a, b) [1–3]. Recurrence is reported low, with incidence of 2% [3].

Vascular Malformations

Vascular malformations are the result of errors in development during the fourth through tenth fetal weeks [3]. While these lesions are present at birth, they may not be clinically apparent until adulthood. Venous malformations are the most common malformation of the hand. These malformations have a blue to purple hue in coloration and are dependent in that they decompress with elevation and engorge upon lowering [1, 3]. High-flow arterial lesions may present with thrills, bruits, or ulceration on the distal digit [1]. Capillary malformations are present as pink macules that progress with time to darker, nodular tumors (port-wine stains) [1]. Patient symptoms are dependent on the type of lesion and the involved tissues, but usually involve cosmetic deformity, heavy/dependent feeling of the hand, local compressive symptoms, or thrombophlebitis [3]. MRI and MRA can help in diagnosis and to reveal the extent of the lesion (Fig. 43.5a) [1, 3]. Treatment varies according to the extent of the lesion and the type. Observation and conservative management with compression garments is appropriate initially [3]. Surgery is recommended when compression does not relieve or control symptoms, or better aesthetics are desired

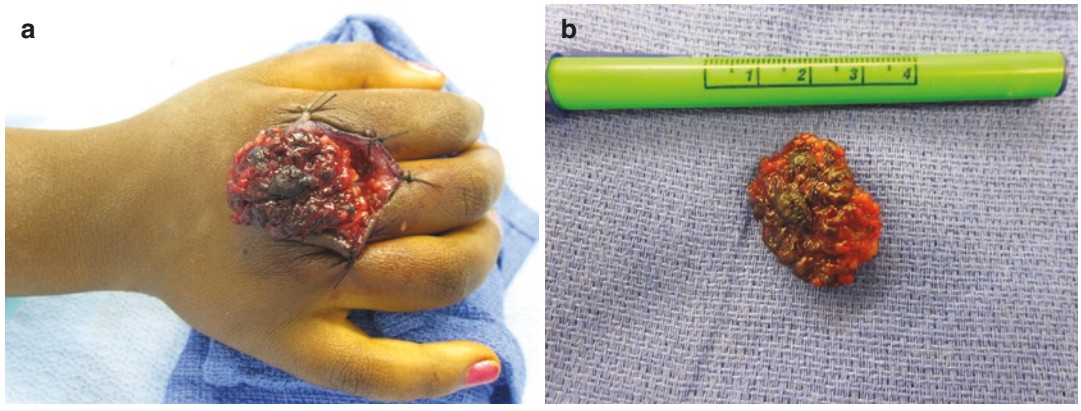

Fig. 43.4 (**a**, **b**) Large exophytic hemangioma on dorsum of the hand

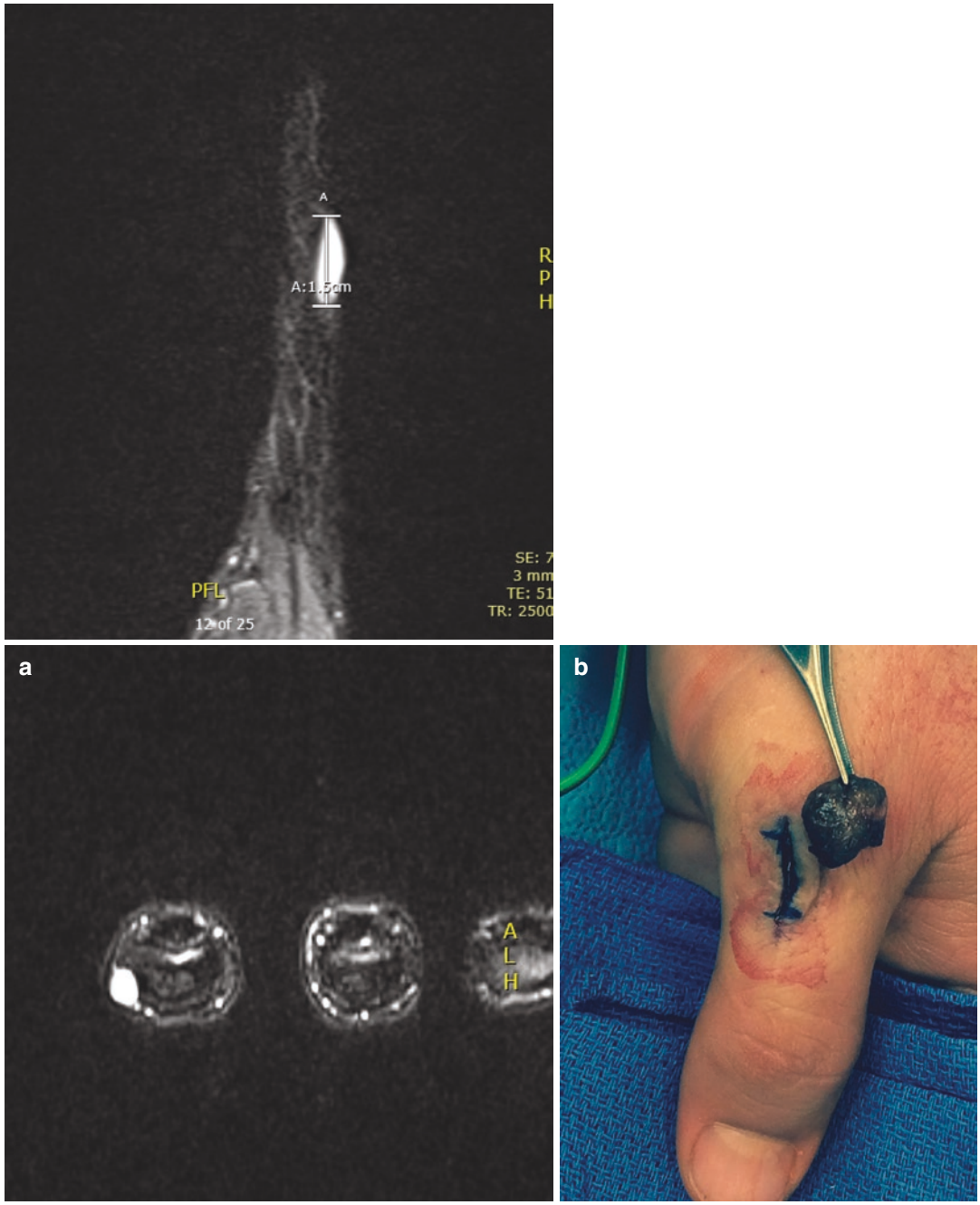

Fig. 43.5 (**a**) MRI imaging of vascular malformation showing characteristic hyperenhancing T2-weighted mass. (**b**) Vascular malformation on dorsal thumb being surgically excised

(Fig. 43.5b) [1, 3]. However, if the lesion is large, resection may be incomplete and may have to be performed in a staged manner, and in severe cases, amputation is necessary [3].

Pyogenic Granuloma

Pyogenic granulomas are friable, dome-shaped, pedunculated lesions that are commonly found

on the digits of the hand [1]. They are red in color and have a base surrounded by a collarette of scale equated to an appearance similar to that of raw hamburger meat [1, 5]. They are most common in children and pregnant women, associated with various pharmaceuticals, and are the result of trauma [5]. Presentation is that of a patient with the lesion appearing as described, plus a history of a finger that easily bleeds [1]. Diagnosis is clinical; however, some argument exists for biopsy due to similar malignant lesions that may mimic pyogenic granulomas [1, 5]. Treatment consists of surgical excision, with silver nitrate cautery on any remaining tissue [1].

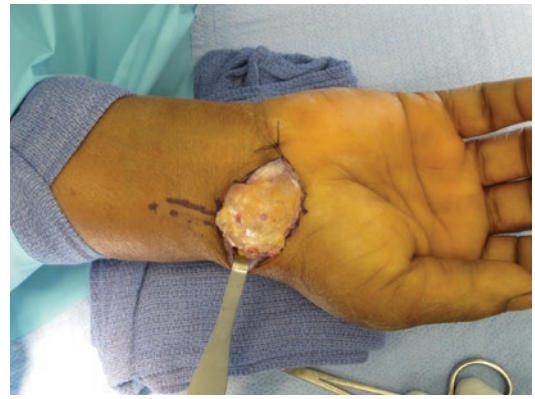

Fig. 43.6 Lipofibroma of the volar wrist

Lipoma

Lipomas are the most common benign soft tissue mass in adults; however, they only make up about 1–3% of hand tumors [1]. They typically present as soft, nontender nodules over palmar or dorsal aspects of the hand, often with indistinct borders [1, 3]. If symptoms are present, they are compressive symptoms with paresthesias related to location or size of the mass [1]. History and physical examination are not always a diagnostic entity for these lesions. Further imaging such as MRI will show a homogenous, well-circumscribed mass with signal intensities similar to that of surrounding subcutaneous fat [3]. MRI can also assist in surgical planning if the lipoma is in close proximity to surrounding neurovascular structures. Surgical excision is the current recommendation for treatment [1]. Often, these lesions are easily removed with blunt dissection from the surrounding structures, and recurrence is rare (Fig. 43.6) [3].

Lipoblastoma

Lipoblastoma is a rare, benign neoplasm that arises white embryonic fat in the extremities and neck and trunk of infants and children. They may also be congenital [12, 13]. It typically presents as a rapidly growing painless mass [12]. Because of the young age at presentation and rapid growth of the lesion, it is important to rule out the differential diagnosis of a liposarcoma with ultrasound, MRI, cytology, and cytogenetics [12, 13]. Imaging will visualize a fatty tumor with possible invasion into local structures, but lipoblastoma never metastasizes [13]. Fine-needle aspiration may be diagnostic of lipoblastoma with typical cytologic features such as lipoblasts, plexiform capillary networks, and myxoid stroma, with lipoblasts being the distinguishing feature from other benign adipose tumors [13]. Chromosomal abnormality associated with the lesion is a rearrangement of 8q11-13 [12]. These tumors are thought to arise due to a developmental aberration with associated overgrowth of tissue in the region [13]. If the lesion becomes symptomatic, it is due to compressive symptoms caused by the rapidly growing size [12, 13]. Ultimately, surgical excision is the treatment of choice, given the predilection of the lesion to be large and for resemblance to other lesions that are more ominous in nature [13].

Nerve Tumors

Lipofibromatous Hamartoma

These are rare, infiltrative lesions occurring in the peripheral nerves of the upper extremity [2]. They are characterized by expansive proliferation of fibrous and adipose tissues within nerves. They occur in patients in the third and fourth decades of life. The median nerve in the wrist and forearm is the most commonly affected nerve, but they may also occur in the brachial plexus and other nerves.

The most common presenting symptom is paresthesia. When they involve the digital nerves, they may also cause macrodactyly (Fig. 43.7a–c) [2]. Treatment is indicated for tumors causing pain or a cosmetic deformity. When they affect the median nerve, they are managed with a carpal tunnel release. Limited surgical debulking is performed for brachial nerves and other peripheral nerves to prevent neurologic compromise [2].

Neurofibroma

These are benign tumors that consist of Schwann cells, neuroblasts, perineural cells, and mucoid material [2]. They are intimately attached to involved nerves and cannot be separated from the nerves easily. They may occur in the subcutaneous tissue or involve the peripheral nerves. Patients with neurofibromatosis or Recklinghausen's disease have multiple neurofibromas and are

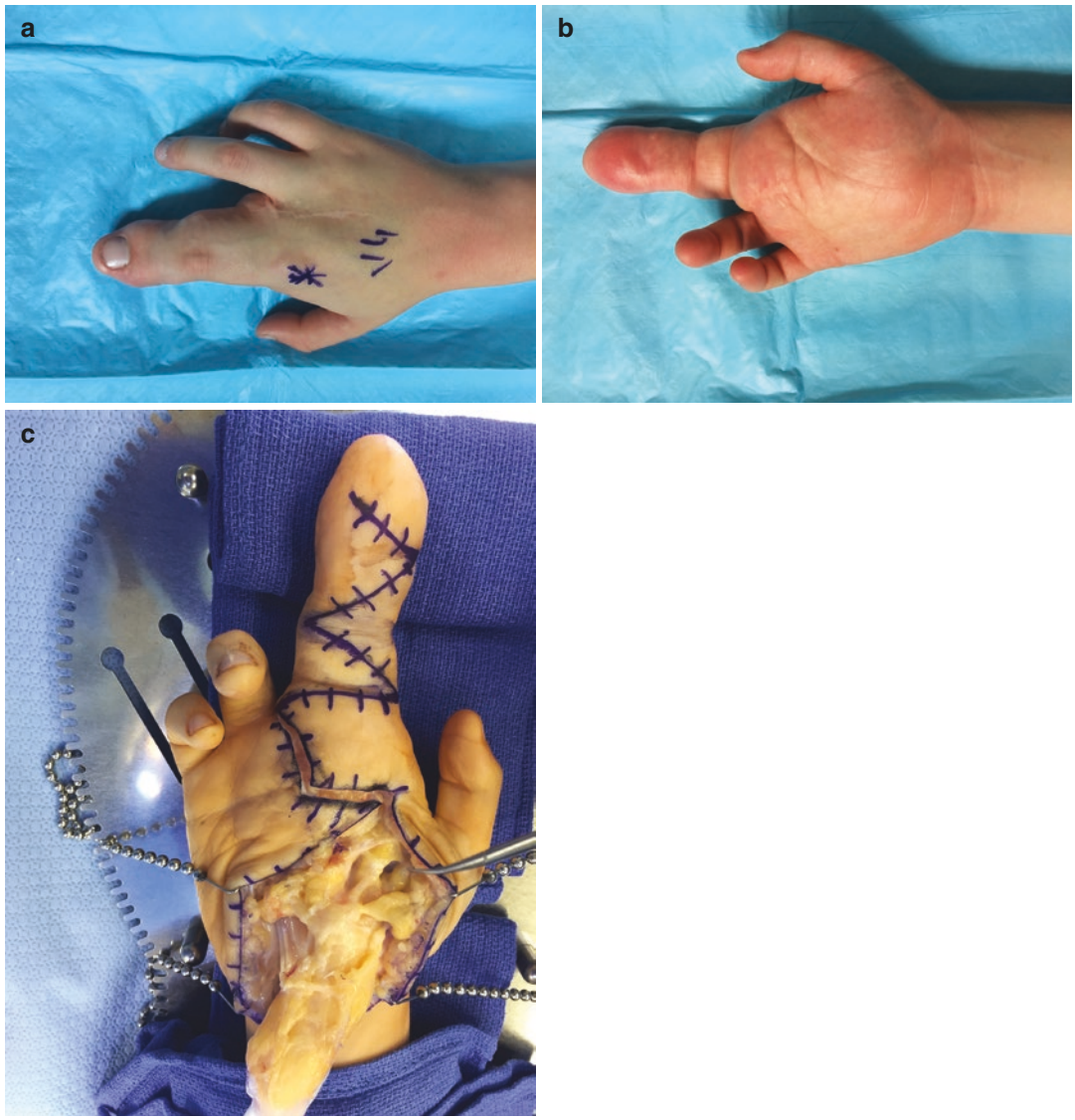

Fig. 43.7 (**a**–**c**) Large lipofibromatous hamartoma causing macrodactyly of the index finger. Median nerve involvement is common and can be seen during surgical excision

at higher risk of malignant transformation. Subcutaneous lesions are managed with excision (Fig. 43.8). Tumors involving the peripheral nerves are excised only when extremely symptomatic or exhibit behavior concerning for malignant transformation. They are resected en bloc with the involved peripheral nerve followed by repair or interposition nerve grafts [3].

Neurilemmoma (Schwannoma)

This is a benign, well-circumscribed tumor consisting of only Schwann cells. The tumor does not invade the nerve, but is located eccentrically, and the nerve fibers travel around the tumor. They can cause nerve compression leading to neurologic deficits. Superficial tumors may be palpable and patients have a positive Tinel sign over the tumor. Histologically the nuclei of the spindle cells are arranged in palisading manner called Verocay bodies. Management is excision under magnification (Fig. 43.9) [3].

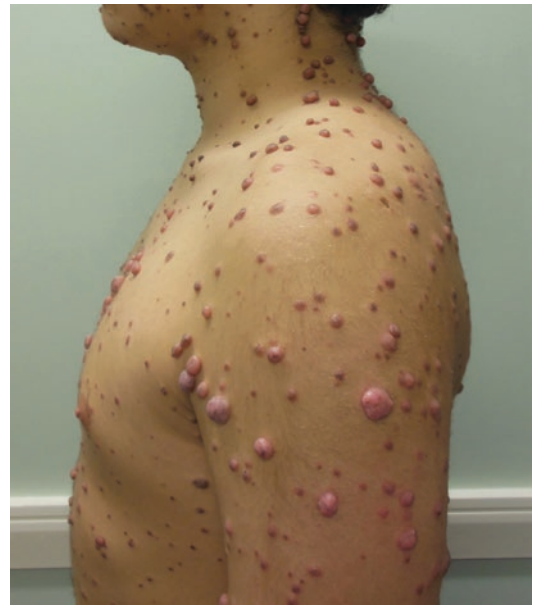

Fig. 43.8 Cutaneous presentation of numerous neurofibroma

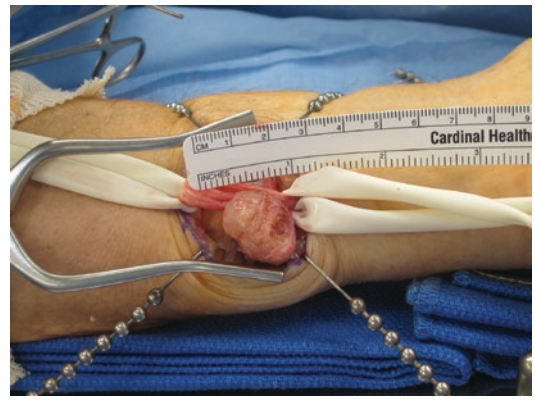

Fig. 43.9 Schwannoma excision from the distal forearm

Cartilage-Producing Tumors

Enchondroma

These are the most common primary bone tumor of the hand. In order of decreasing frequency, they are found in the proximal phalanx, metacarpal, and middle phalanx. Radiographically these are well-circumscribed, radiolucent, centrally located tumors with punctuate calcifications (Fig. 43.10). They may present with pathologic fractures. Enchondromas are managed with curettage and bone grafting. When an unstable pathologic fracture exists, it is best to wait several weeks until the fracture is stable prior to excision [3].

Osteochondroma

This is a common benign tumor with a cartilaginous cap that arises in continuity with the medullary canal of bone. They most commonly occur in children and adolescents. They may present as a painless mass near the joints or cause discomfort with movement if they are located near tendons. In the hand, they may also interfere with function of the digits. Resection is reserved for symptomatic lesions [14].

Periosteal Chondroma

In the upper extremity, these cartilaginous tumors typically occur in the humerus and the cortical surface of the phalanges of young adults. They arise on the surface of cortical bone and erode the underlying cortex without invading the marrow cavity [14]. They present with mild pain and

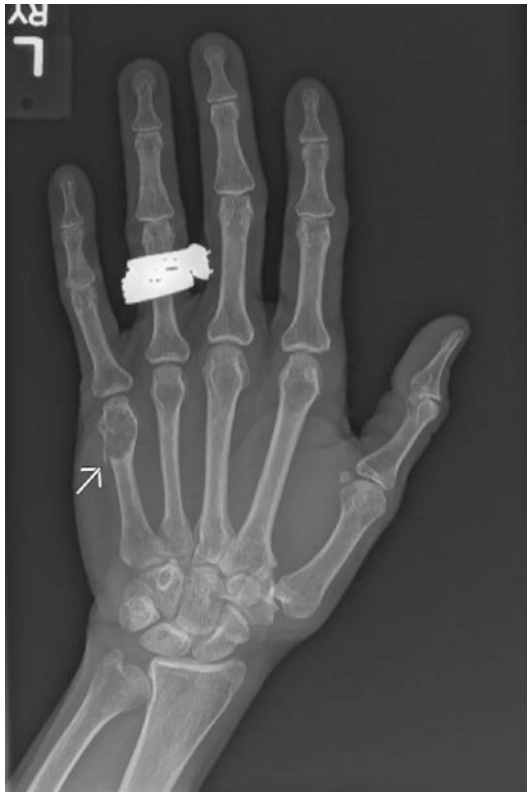

Fig. 43.10 Endochondroma of the fifth metacarpal with characteristic appearance of well-circumscribed, centrally located lesion with surrounding punctate calcifications

swelling. Radiographically these tumors have a well-defined sclerotic margin with cortical scalloping [3, 15]. These are managed by en bloc resection with a rim of underlying bone c.

Simple Bone Cyst

These can occur in the carpal bones, metacarpals, phalanges, distal radius, and ulna. Individuals younger than 20 years are most likely to be affected, but they can occur in any age group. Radiographically these appear as lucent centrally located lesions. Grossly they contain serous fluid and are lined by a thin membrane. Surgical intervention is only necessary when the cysts are symptomatic or associated with a pathologic fracture. They are managed with curettage with or without bone grafting [2].

Aneurysmal Bone Cyst

These are the second most common cystic lesion of the hand and wrist. They are benign locally aggressive tumors with a propensity for the metacarpals and the distal radius. They are most common in adolescents and young adults. Radiographs show an expansible, lytic lesion with cortical destruction with elevation of the periosteum. Management is dependent on the location of the tumor and the amount of bone destruction. When the cortical shell is intact, curettage and bone grafting are appropriate. Curettage of these lesions involves mechanical curettage with curettes and burs as well as chemical or thermal curettage [2]. In lesions of the phalanx where the cortical shell has been destroyed, amputation may work best [3].

Osteoid Osteoma

These are small, benign, bone-forming tumors that occur in the second and third decades of life. Patients usually present with pain that is worse at night and is relieved by nonsteroidal anti-inflammatory agents. On radiographs, they are small (<1 cm) radiolucent lesions surrounded by an area of reactive sclerosis. In the hands, they are most commonly found in the proximal phalanges. Swelling is a typical complaint in lesions of the hands. They are typically managed with excision or curettage of the radiolucent nidus. Alternatively, observation is a good option for patients who respond well to NSAIDS, as most lesions resolve spontaneously with time [3].

Osteoblastoma

Similar to osteoid osteomas, they are bone-forming tumors that occur in the second and third decades of life and present with pain [16]. However, they are larger in size (>2 cm), grow over time, and do not respond to nonsteroidal anti-inflammatory medications. They can arise in any bone of the body. Radiographic findings are variable, but most tumors have a well-defined border with a rind of sclerotic bone. They may

also have a radiolucent nidus similar to osteoid osteomas. Histologically they consist of a woven bone within a fibrovascular stroma [15]. They are managed with resection [3].

Nora Lesion

Nora lesions are also known as bizarre periosteal osteochondromatous proliferations (BPOPs). They present as a calcified mass apart from the bone. They have a predilection for the proximal phalanges, middle phalanges, and metacarpals of patients in their third and fourth decades. They may interfere with function of the hand. Excision with removal of the capsule and periosteum is recommended to rule out malignancy [2].

Brown Tumor

This is a locally destructive bone tumor that occurs due to bone resorption by osteoclasts mediated by parathyroid hormone. They occur in patients with hyperparathyroidism, chronic renal failure, and vitamin deficiency. They are treated by addressing the underlying endocrine abnormality [2].

Malignant Tumors

Malignant Lesions of Epidermal Origin

(a) *Basal Cell Carcinoma* (*BCC*): Basal cell carcinoma is the second most common malignant skin lesion of the hand and upper extremity [17]. These present as well-defined nodules with pearly translucent borders. With time, some tumors become ulcerated. Most lesions are slow growing and occur in sun-exposed areas [8, 17]. Treatment is by excision with 3–4 mm borders [8]. They may also be managed by electrodessication, curettage, laser, or cryotherapy. Recurrence is common, so close follow-up is necessary [8].

(b) *Squamous Cell Carcinoma* (*SCC*): This is the most common malignant skin tumor of the hand. Risks factors include chronic sun exposure, fair complexion, immunosuppression, and radiation and chemical exposure [8]. Presentation is varied; some lesions present as scaly, crusty lesions, while others present as exophytic masses [8, 17]. SCC has a high propensity for lymphatic spread and invading surrounding tissue. In elderly men, they may occur subungually in the thumb and index finger. Subungual squamous cell carcinomas present as slow-growing erythematous lesions [8]. Management for subungual SCC is amputation at the distal interphalangeal joint. SCC in other areas can be managed with excision with 1 cm margins (Fig. 43.11a–c).

(c) *Melanoma*: Pigmented lesions not involving the nail complex can be evaluated using the ABCDE system. *A*symmetric *b*orders, *c*olor variation in the lesion, *d*iameter >6 mm, and *e*volution over time are concerning for melanoma. Definitive diagnosis is made by biopsy. Risk factors for cutaneous melanoma include UV radiation and early sun exposure/sunburn. UV radiation is not a major contributive factor to melanoma along the palmar surface of the hand. Some studies suggest previous trauma and acral nevi are risk factors [18]. Management is by excision and sentinel node biopsy. Table 43.1 shows excision margins for melanoma based on depth [18]. Sentinel node biopsy is indicated for clinically node-negative tumors >1 mm in diameter and tumors <1 mm that have concerning features such as ulceration, mitotic rate >1, and satellitosis.

Subungual melanomas arise from the nail matrix. They more commonly affect darker skin individuals in the fifth to seventh decades of life [8, 18]. The diagnosis of subungual melanoma is typically delayed, as they are amelanotic and are frequently confused with fungal infections [8]. Delayed diagnosis leads to a more advanced stage at the time of diagnosis. Treatment is amputation through the proximal phalanx of the thumb and the proximal interphalangeal joint of other digits [8]. Recent studies have shown partial amputation of the distal phalanx in T1 and T2 subungual melanomas does not result

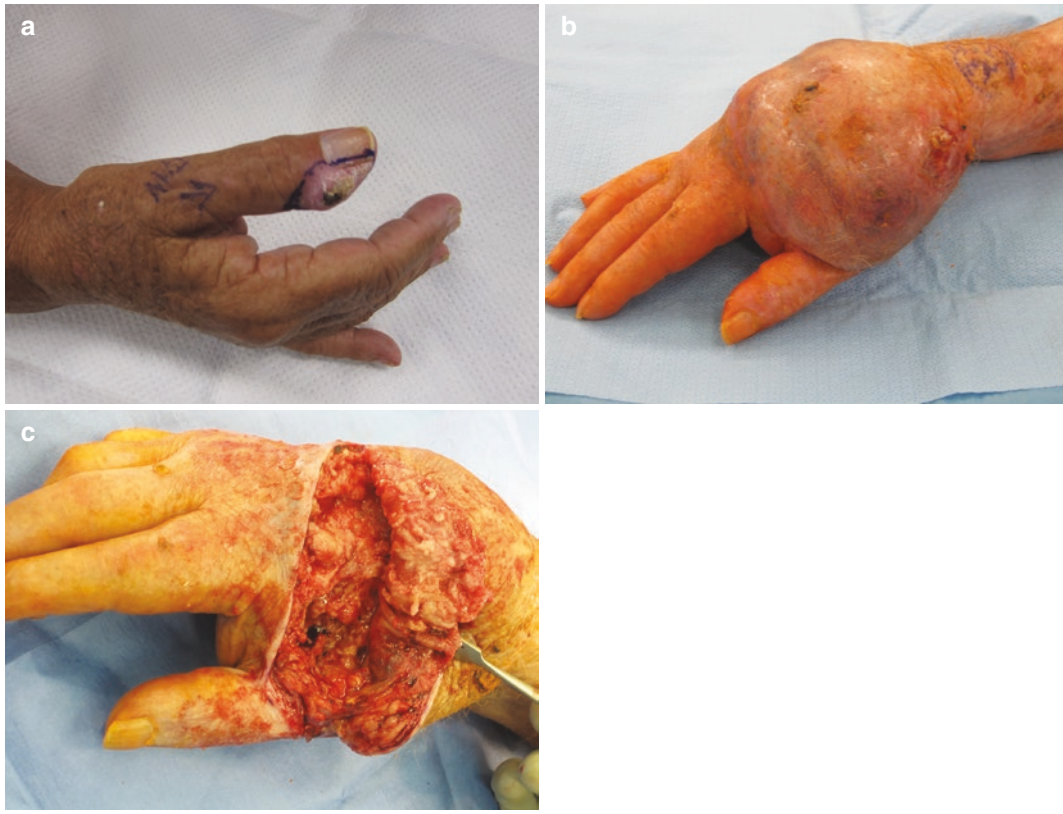

Fig. 43.11 (**a**–**c**) A large dorsal hand squamous cell carcinoma of the hand excised via wide local excision with margins

Table 43.1 Excision margins for melanoma based on depth

Depth of lesion	WHO	Australian trial	Dutch trial	UK trial
In situ	5 mm	5 mm	5 mm	5 mm
<1 mm	1 cm	1 cm	1 cm	1 cm
1–2 mm	1–2 cm	1 cm	1 cm	1–2 cm
2.1–4 mm	2 cm	1 cm	2 cm	2–3 cm
>4 mm	2 cm	2 cm	2 cm	2–3 cm

in a poorer prognosis, but the standard of care remains amputation [19].

(d) *Merkel Cell Carcinoma*: Merkel cell carcinoma is an aggressive tumor arising from Merkel cells located in the basal layer of the epidermis. They occur on the upper extremity as well as the dorsum of the hand. They present as painless, dome-shaped, skin-colored, or violaceous lesions. Risks factors include immunosuppression, HIV, fair skin, and male gender. They are managed by surgical excision with 1–2 cm margins to fascia and sentinel lymph node biopsy. Mohs may also be used for excision. Adjuvant radiation is standard of care, as these tumors are radiosensitive. Chemotherapy is indicated for advanced and metastatic disease, but its use in local disease is controversial [20, 21].

(e) *Eccrine Cell Carcinoma*: These arise from sweat glands in the palm. They present as slow-growing subcutaneous nodules in elderly patients. They are managed with sur-

gical excision. A lymphadenectomy is performed in patients with clinically positive lymph nodes [18, 21].

Soft Tissue Sarcoma

Of soft tissue sarcomas, 15–25% affect the upper extremity and only 5–10% involve the hand and wrist [21]. Ultrasound is useful for initial workup of these masses, but MRI is the gold standard for soft tissue sarcomas of the upper extremity [22]. For tumors with features concerning for malignancy on MRI, biopsy is recommended. CT- or US-guided biopsy can be performed for tumors in the arm and forearm, but surgical biopsy is recommended for tumors in the hand [23].

(a) *Angiosarcoma*: Angiosarcomas are rare but aggressive tumors. In the upper extremity they occur in areas of chronic lymphedema, radiation, and chronic inflammation. They have also been reported to arise from AV fistulas. The majority of lesions affect the skin and superficial subcutaneous tissue, but they may also involve soft tissue and bone [24]. They are treated with surgical resection, systemic chemotherapy, and locoregional chemotherapy. Prognosis is poor [25].

(b) Dermatofibrosarcoma Protuberans: This is a low-grade malignant tumor that arises from the dermis. They usually arise as painless nodules, but often become ulcerated. Treatment is wide local excision with a 3-cm margin. Radiation or rescission can be performed for positive margins [18].

(c) *Epithelioid Sarcoma*: Epithelioid sarcomas are aggressive tumors, spreading along lymphatics, tendons, and fascial planes. They present as a painless mass on the volar surface of the digits and on the palms of men between the ages of 10 and 35. They progress to ulceration. Aggressive treatment with wide local excision or amputation is required for these sarcomas. A sentinel node biopsy should be performed in patients with clinically negative nodes [18].

(d) *Clear Cell Sarcoma* (*CCS*): This is an aggressive rare tumor with clinical and pathologic similarities to melanoma and sarcomas. Most CCS tumors are characterized by a recurrent chromosomal translocation resulting in fusion of the EWS gene on 22q12 and with the ATF1 gene on 12q13. The hand is the second most common location after the foot. These tumors are treated with surgical resection to obtain negative margins, plus radiotherapy and chemotherapy [26].

(e) *Fibrosarcoma*: Fibrosarcomas frequently arise from tendon and deep fascia, although they may also arise in bone. They may arise from scar tissue or around foreign material such as joint endoprosthesis. They are rare in the upper extremity. Resection with negative margins is the mainstay of therapy. Chemotherapy and radiotherapy are also used, although they typically have low sensitivity to these modalities [27].

(f) *Liposarcoma*: The upper extremity is the third most common site for liposarcomas, following behind the lower extremity and the retroperitoneum. They commonly arise within muscles, but they may be subcutaneous or intermuscular [26]. Well-differentiated tumors typically present as painless slow-growing masses. On contrast-enhanced MRI, well-differentiated tumors are predominantly adipose with enhancing septa. Well-differentiated tumors may be difficult to differentiate from lipomas. Well-differentiated liposarcomas are managed with excision with negative margins. The recurrence rate is low for subcutaneous lesions, but >40% for deep tumors. Other subtypes of liposarcomas include myxoid liposarcomas, pleomorphic liposarcoma, dedifferentiated liposarcoma, and primary liposarcoma of bone. Myxoid liposarcomas have a similar presentation to well-differentiated liposarcomas, but on MRI they are multilobulated and intramuscular. Management of myxoid sarcoma is surgical excision. Radiation can be used when nega-

tive margins cannot be obtained due to the tumors' proximity to vital structures. pleomorphic sarcoma are more aggressive than well-differentiated and myxoid sarcomas. Treatment of pleiomorphic sarcomas is multimodal and includes surgical resection, chemotherapy, and radiation [28].

(g) *Hemangiopericytoma*: Hemangiopericytoma arise from uncontrolled proliferation of pericytes and typically arise in the fifth to sixth decade of life. Occurrence in the hand and upper extremity is extremely rare, but it has been reported. The tumor presents as a slow-growing painless mass. Most tumors are benign, but carry a high risk of recurrence following resection. Malignant tumors are managed with surgical resection. Adjuvant radiation and chemotherapy have been used in malignant tumors, but with limited success [29, 30].

(h) Malignant Fibrous Histiocytoma: These typically occur in the forearm, but have been known to occur in the hand. Management includes wide local excision or amputation, radiation, and sometimes chemotherapy [18].

(i) *Rhabdomyosarcoma*: Of the three histologic types of rhabdomyosarcomas, the alveolar type is the subtype seen most frequently in the hand. Embryonal-type rhabdomyosarcomas may also occur in the bones of the hand of children, but these are more frequently metastatic [18]. Surgical resection, chemotherapy, and radiation all play a role in the treatment of these tumors [18].

(j) *Synovial Cell Sarcoma*: These typically occur in the hand and wrist, but may occasionally occur in the fingers. They originate from the para-articular tissue (tendons, sheaths, and bursa). Similar to epithelioid carcinomas, these are aggressive and should be managed with wide excision or amputation and sentinel node biopsy [18].

(k) *Malignant Peripheral Nerve Sheath Tumor* (*MPNST*): These make up 3% of all malignant hand tumors. They typically occur in men between the ages of 30 and 50, and arise from peripheral nerves. Fifty percent of patients with MPNST have von Recklinghausen's disease. Patients with MPNST are usually treated with chemotherapy and radical resection; there are, however, no standardized guidelines for treatment. Prognosis is poor [18].

(l) *Myxoid chondrosarcoma*: This is a rare hand tumor originating from tenosynovial structures like the tendon sheaths of digits. These present as multilobulated gelatinous tumors and can be mistaken for a hematoma. These are managed by ray resection.

(m) *Leiomyosarcoma*: These rarely occur in the hand, with less than 1% found in the wrist and hand. They arise from smooth muscle cells. They present as painless mobile masses and can be confused with a benign lesions. They are managed with resection and radiation [18].

Bone Sarcomas

(a) *Osteosarcoma*: Osteosarcomas are rare in the hand. They usually arise in patients in the sixth decade of life. Radiographically they appear as masses with sclerosis, periosteal elevation, and areas of bone destruction (Fig. 43.12a). Treatment of tumors in the phalanx is with ray resection. Tumors arising in a metacarpal may require resection of two rays. If involvement of the forearm or upper arm, excision with bony reconstruction may be necessary (Fig. 43.12b–e). Neoadjuvant and adjuvant chemotherapy may also be of benefit [18].

(b) *Chondrosarcoma*: Chondrosarcomas are the most common malignant tumor originating from bones of the hand. They are usually found in the metacarpals and proximal phalanges. They may arise de novo or from malignant transformation of endochrondoromas in patients with multiple endrochromatosis. They typically present as painful lesions in patients in the fifth to seventh decades. On imaging, cortical expansion with destruction and extension into soft tissue is seen. In the hand, these tumors are

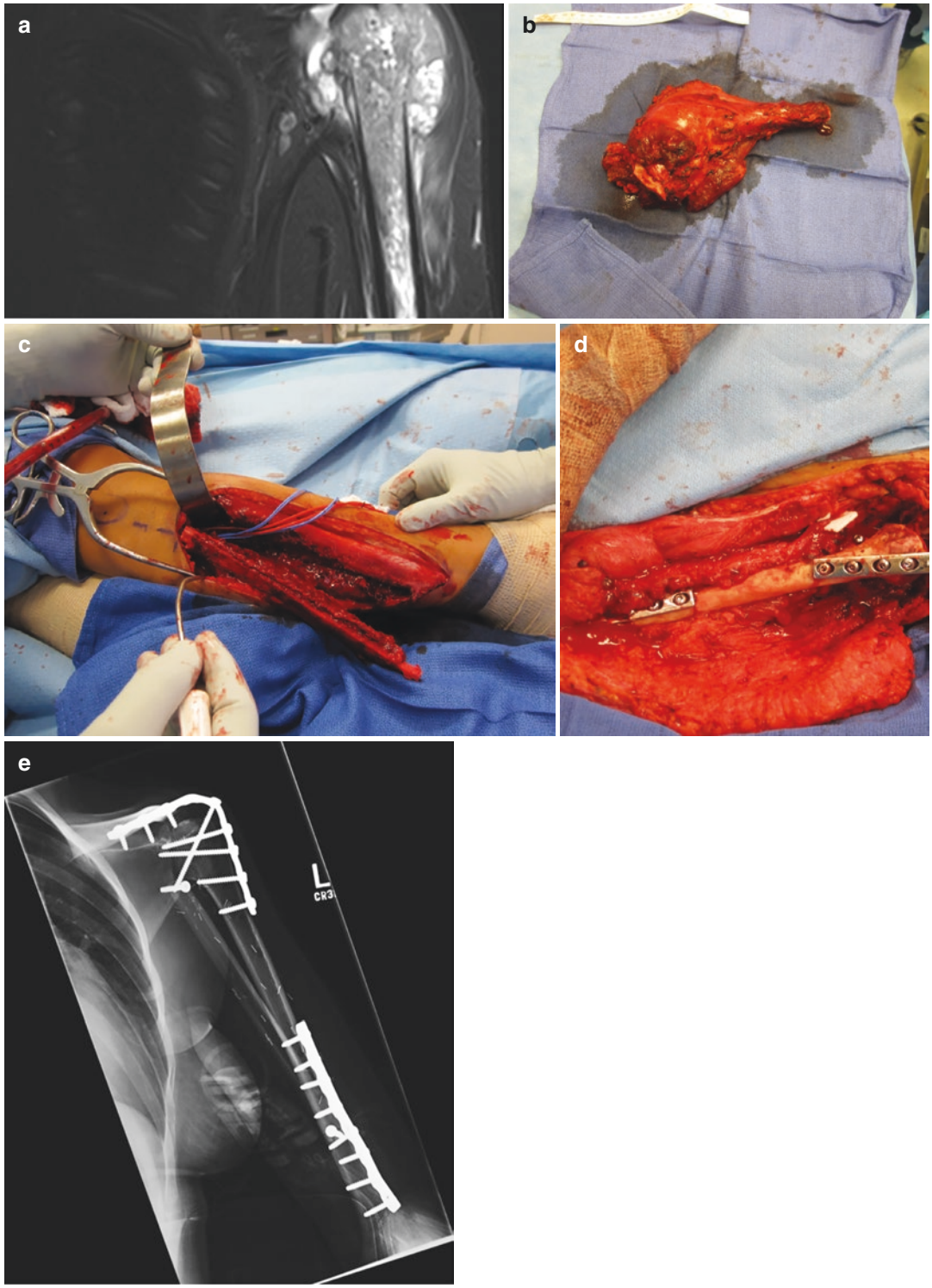

Fig. 43.12 (**a**) X-ray appearance of osteosarcoma of the shoulder visualized as a large mass with periosteal elevation and local bone destruction. (**b**–**e**) Surgical resection of glenoid of humerus for osteosarcoma, with fibula harvest and anastomosis for reconstruction

managed with ray resection. In the rest of the upper extremity, resection with negative margins is the standard of care. Chondrosarcomas are radioresistant and chemoresistant, but some studies report use of radiation in patients with positive margins. Adjuvant radiation therapy remains controversial [18, 30].

(c) *Ewing Sarcoma*: Although 20% of Ewing sarcoma involves the upper extremity, involvement of the hand is rare. These present with systemic symptoms such as fever, as well as localized symptoms including pain, edema, and erythema. On X-rays they appear as destructive mottled lesions similar to osteomyelitis. The presenting symptoms frequently lead these to be misdiagnosed as an infection. Neoadjuvant chemotherapy followed by resection is the best way to treat these lesions [18].

(d) *Primitive Neuroendocrine Tumor* (*Neuroepithelioma*): Neuroepithelioma are another rare tumor of the hand. Histologically they appear very similar to Ewing sarcoma and can only be distinguished with electron microscopy and immunohistochemistry. These are treated with neoadjuvant chemotherapy followed by resection [18].

(e) *Primary Liposarcoma of Bone*: This is a rare tumor that arises in long bones. In the upper extremity, it occurs in the humerus. Treatment is surgical resection. Radiation may be used in palliative cases and in the adjuvant setting to reduce local recurrence [28] (Fig. 43.1).

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Soft Tissue Coverage for the Hand and Upper Extremity

44

Jason D. Wink, Rikesh A. Gandhi, Ines C. Lin, and L. Scott Levin

Introduction

The hand is an external structure that allows an individual to interact closely with their environment. The ability of the hand to perform complex motor movements is a collaboration between the sensory structures within the skin itself, the nerves that manage these critical signals, the vascular structures that supply the required nutrients, and the intrinsic and extrinsic muscles that create the movements of the hand and digits. The soft tissue of the upper extremity plays a critical role in protecting all of these structures and allows them to function as they were intended. There are no other regions in the body where both the aesthetic and functional aspects of reconstruction are so closely connected. The hand not only has a physical function but has unique psychological, societal, and aesthetic components that must be addressed when planning for reconstruction.

The ability to provide well-vascularized soft tissue to the hand is essential to restore function after injury. This often cannot be achieved through the use of skin grafting or other off-the-shelf modalities. Healing by secondary intention in the hand can be troublesome, as scar contracture can result in limited motion. These factors may lead to the use of the reconstructive elevator instead of the reconstructive ladder when thinking about reconstruction and hand salvage [1].

There are a number of reliable local and regional flaps that can be utilized to treat the hand requiring soft tissue coverage. The "reconstructive ladder," originally described by Mathes and Nahai, is based on the principle of using the simplest approach that adequately restores form and ideally optimizes function [2]. In cases where the simplest techniques prove to be inadequate, local and regional flaps and ultimately microsurgical free tissue transfer should be considered.

Wound Preparation

Before any final reconstructive procedure is undertaken, the wound must be prepared. Devitalized tissue must be debrided and any sources of infection must be removed. The surgeon must be confident that the wound is clean

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and ready for reconstruction [3]. The operating surgeon must not be afraid to debride away devitalized tendon, nerve, muscle, or bone. It is likely that without adequate preparation of the recipient wound, the reconstruction will fail. This may require multiple trips to the operating room for wound irrigation and debridement to assure that the wound is ready for reconstruction. In practice, we prefer the use of nonpressurized irrigation using cystoscopy irrigation tubing, as there is little evidence to suggest that pressurized irrigation has any clinical benefit [4].

At this point, cultures and tissue biopsies may be performed to ensure that the wound is clean. It is also common for infectious disease specialists to be involved in the patient's care to ensure that appropriate antibiotic regimens are chosen. It cannot be emphasized enough that these complex patients require a team of physicians, nurses, and therapists working together to achieve a successful outcome. This only reinforces the idea that a wound must be "ready for reconstruction." Performing a soft tissue reconstruction too early or with inadequate debridement can result in reconstructive failure, potentially making an already poor situation much worse.

Once the wound has been deemed "ready for reconstruction," an exam must be performed to identify "white structures" such as tendon, nerve, and bone devoid of periosteum. These structures must be covered by healthy, well-vascularized tissue. A skin graft will not work in these situations. The size of the wound must be assessed to determine if primary closure or a local flap option exists or whether the patient would benefit from a more complex reconstruction. Understanding the size of the wound is critical, as the hand is made to be in motion, where wound size can change based on joint position. If required, the hand can be temporarily fixated in the intrinsic-plus position to ensure that an adequate size flap is taken and that the hand remains in a safe position during the healing process. In a case involving multiple digits, the digits may be temporarily syndactylized so that a smooth wound bed can be created to aid in the reconstruction [5]. The fingers can then be divided at a later time once the flap has healed. The choice of flap must also be made with the depth of the wound in mind, in that a bulky flap will hinder the overall function and aesthetics of the extremity. Allowing a wound of the upper extremity to heal by secondary intention can be a grave error, as contractures of the wound can occur inhibiting the motion of the upper extremity.

Timing of Soft Tissue Reconstruction

In the upper extremity, the timing and sequence of reconstruction is often debated [6]. Soft tissue defects are usually associated with other injuries to critical structures of the upper extremity that must be addressed. Skeletal stabilization of fractures is mandatory to provide a foundation for soft tissue coverage, and new hardware should not leave the operating room without stable soft tissue coverage. Injuries to underlying nerve, blood vessel, or tendon require an overlying stable soft tissue covering. In certain scenarios where a scar-free bed for tendon gliding cannot be achieved without intervention, definitive tendon reconstruction can be delayed and silicone spacers placed until adequate soft tissue reconstruction has been performed. It is generally accepted that soft tissue coverage should be achieved within 48 hours and no later than 10 days after injury. This will limit the development of granulation tissue and the risk of infection.

Skin Graft

When thinking about the reconstruction of any soft tissue wound, one must not forget the lower rungs of the reconstructive ladder. In some locations, soft tissue wounds of the upper extremity in which critical structures are not present can be left to heal by secondary intention without further sequalae. This is especially the case in the fingertip when it is traumatically amputated distal to the lunula. Dressing changes and allowing the wound to heal by secondary intention can often result in a sensate fingertip with preserved length [7]. In many cases, a full-thickness skin

graft (FTSG) is a nice option that can be used in these scenarios to expedite healing (Fig. 44.1). These grafts are often taken from the hypothenar eminence, antecubital fossa, or groin crease. Grafts taken from the hypothenar eminence must be taken in a full-thickness fashion. Due to the glabrous skin, it is not possible to raise a full-thickness skin graft without incising all the way into the subcutaneous fat. It is often difficult to achieve primary closure in the hypothenar eminence. If this is the case, the wound can be allowed to close by secondary intention with little sequelae. In other areas of the body, it is our practice to raise a FTSG by not incising completely through the dermis, allowing the surgeon to maintain tension while harvesting the FTSG.

The use of skin substitute products in the upper extremity has also begun to gain further traction [8]. These products come in a variety of different forms and can be used for a number of different indications, including large burns or to cover small areas of exposed bone or tendon in preparation for skin graft. They are also used to provide added thickness to a wound bed or improved contour in preparation for eventual skin grafting. The use of these materials in some cases prevents surgeons from going directly to a more advanced reconstructive option to achieve stable soft tissue coverage. In our practice, these products are often also used to temporize and prevent the desiccation of a wound in preparation for a more definitive reconstruction that may happen in the near future.

Much like the preparation of any wound, the use of dermal substitute products requires a clean, adequately debrided wound bed to allow for incorporation without infection. Once the graft is placed, a period of immobilization is required to ensure that the graft adheres to the underlying wound bed. Shearing forces can prevent the graft from incorporating, much like a standard skin graft. In our practice, negative pressure wound dressing or bolster dressing and aggressive splinting are utilized to help graft incorporation.

Local Flaps

There are a number of local flaps in the upper extremity that can be used for soft tissue coverage of the arm and hand. They can be divided into local flaps, local pedicled flaps (that require the maintenance of a tissue pedicle that must be subsequently divided in a second stage), or axial pattern flaps that are based on a named blood supply located in the hand or forearm. A flap reconstruction is required when critical structures are found at the base of the exposed area. Bone, tendon, nerve, blood vessels, and hardware must be cov-

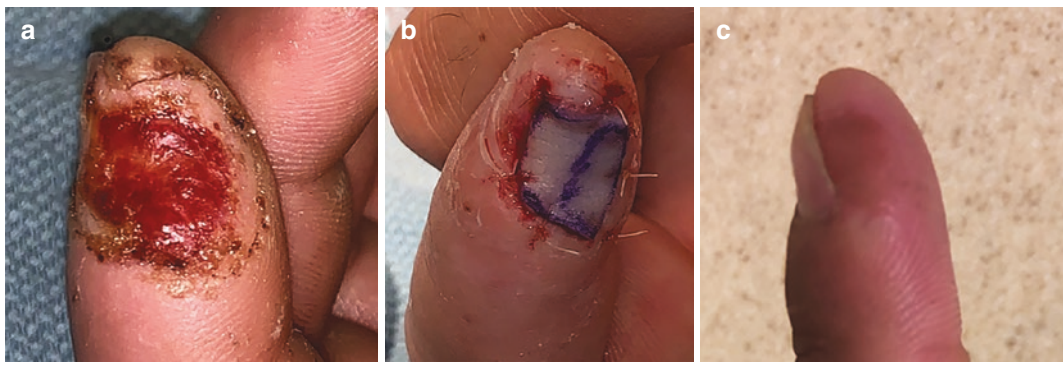

Fig. 44.1 This is an example of a case of partial index finger amputation due to a power saw. The wound has been kept clean with dressing changes prior to the presentation to the operating room. There is no exposed bone in the wound, and a bed of granulation tissue present, making it a good recipient site for a full-thickness skin graft. (**a**) A full-thickness skin graft was taken from the ulnar aspect of the hand and carefully inset over the defect. (**b**) Bulky soft dressings were applied to create compression at the graft site. The donor site was closed primarily. (**c**) This is the patient at about a 2-month follow-up. (Case courtesy of Benjamin Chang, MD)

ered by a well-vascularized flap. Flaps are also considered in areas where soft tissue contracture due to healing by secondary intention or skin grafting cannot be tolerated. This is often seen in the joint creases on the volar surface of the hand.

The V-Y flap is a random pattern local advancement flap frequently used for distal fingertip defects. V-Y advancement should be reserved for transversely oriented soft tissue defects and those with predominantly palmar rather than dorsal soft tissue loss. The V-Y advancement is performed with a proximally based V incision with its apex immediately at the distal interphalangeal flexion crease [9]. This flap is based on a lateral blood supply. We begin the procedure by incising the tip of the flap down to the periosteum; the lateral portions of the flap are incised through dermis until subcutaneous fat is present. A dissecting instrument is then used to carefully spread through the lateral incisions in a perpendicular fashion, taking care to free any fibrous septae without disrupting the laterally based blood supply. The flap is then advanced into the defect. The distal tip of the flap can be elevated off the periosteum to aid in distal advancement (Fig. 44.2). When the availability of a palmar donor site is limited, the Kutler V-Y advancement may be used by raising radial- or ulnar-based flaps, or both [10]. We perform this procedure rarely, as we feel laterally based flaps provide minimal advancement.

The thenar flap is an ideal tissue match between the thenar skin and the pulp of the fingertip, usually the index or ring finger. The thenar region has significant laxity, decreasing donor site morbidity and inconspicuous donor site [11]. The ideal case for a thenar flap remains one where the finger has lost the volar skin and pulp overlying the distal phalanx, but has the majority of the bone and nail plate intact. Like all pedicled flaps, the thenar flap requires a second stage for division and inset. We believe it takes about 3 weeks for the flap to grow an adequate blood supply from the underlying soft tissue bed. We recommend clamping the pedicle before inset to ensure that the flap will survive. The downside of this technique is the development of PIPJ flexion contractures that can occur in older individuals, but is less likely in a pediatric patient [11].

The cross-finger flap is useful for large palmar defects of the middle and distal phalanges (Fig. 44.3). Some surgeons favor the cross-finger flap as an alternative to the thenar flap to avoid PIPJ joint stiffness. The donor site is typically designed as a trapezoidal flap on the dorsal aspect of the middle phalanx of an adjacent digit to the defect. The base of the flap is the mid-axial line closest to the injured digit. A full-thickness flap is then elevated at the level of the extensor tendon paratenon with a hinge that spans the entire length of the middle phalanx to prevent compromise of the vascular network of the flap. It is criti-

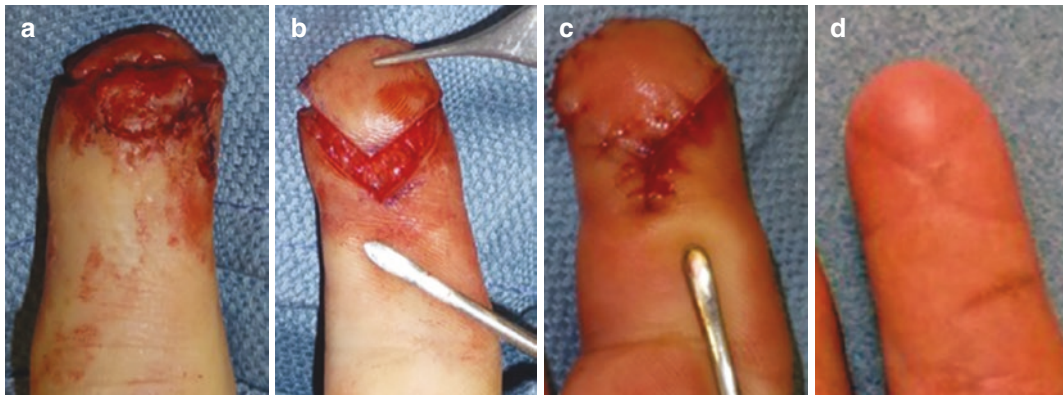

Fig. 44.2 This is an example of a patient who suffered a volar oblique amputation of the index finger. The part was replaced as a composite graft that did not succeed. (**a**) The resulting wound contained exposed bone that required coverage to preserve finger length. (**b**) A volar V-Y flap was designed, raised, and advanced to cover the exposed bone. (**c**, **d**) The flap was well healed at 3 months' postoperative. (Case courtesy of Ines C. Lin MD)

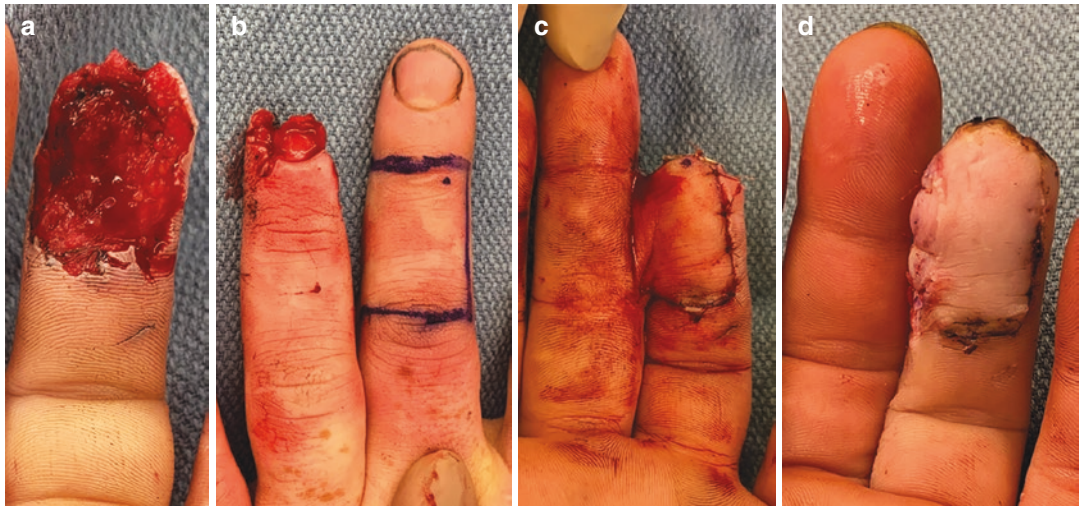

Fig. 44.3 This is an example of a patient who suffered a volar oblique amputation of the ring finger tip with exposed bone present at the base of the wound (**a**). The decision was made to perform a cross-finger flap from the dorsum of the adjacent long finger (**b**, **c**). The patient was brought back to the operating room in 3 weeks for definitive division and inset of the flap (**d**). (Case courtesy of Ines C. Lin, MD)

cal to raise the flap at the appropriate level and thickness to maintain the vascular supply to the tissue. After suturing the flap into the defect, a FTSG is applied to the donor site, usually from the ipsilateral medial arm, groin crease, or hypothenar eminence. The recipient digit is splinted in as minimal flexion as possible while maintaining minimal tension on the flap; the flap is typically divided and formally inset after a period of 2–3 weeks. The flap is not as thick as normal pulp skin and may result in pulp dystrophy. The lack of recovery of sensibility and donor finger morbidity caused by flap harvest are other common criticisms [12].

Intrinsic Axial Pattern Hand Flaps

The homodigital island flap [13] is a small digital fasciocutaneous flap that can be used for fingertip injuries. It can be raised in an anterograde [14] or retrograde fashion, based on a single proper digital artery, and can include the digital nerve as well. This involves either the isolation of a skin island and advancement of the neurovascular bundle, or rotation of the flap on the contralateral digital artery relying on the distal anastomoses between the two proper digital arteries. It is ideal to raise the flap off the ulnar side of the digit as to not effect sensation for finger opposition except for the small finger, for which a radial-sided flap would avoid a sensitive ulnar-side of the hand. You must also be confident that the contralateral digital artery remains patent. A digital Allen's test is used to determine if there is adequate blood supply [15]. No matter the donor site location, these often require skin grafting for definitive closure. For this reason, it is critical to leave a layer of paratenon on the donor site so that skin grafting can be performed. The heterodigital island flap [16] relies on the same anatomic principles, except the flap is taken from an adjacent digit to the defect.

The Moberg flap is a bipedicled fasciocutaneous advancement flap of the thumb based on both proper digital arteries. It is often used for coverage of thumb tip defects from 1.5 to 2 cm in size. Its reach can be lengthened by creating an island flap and placing a skin graft over the donor site. Both proper digital nerves are included in the flap and provide sensation to the new fingertip. The flap is limited by its inability to cover larger tip

defects and can result in some contracture of the thumb IP joint. It is important to note that this contracture is not functionally disabling.

Soft tissue flaps of the hand can also be based on the dorsal arterial supply. A Doppler exam can be performed to assess for the presence of a dorsal metacarpal artery between each metacarpal about which a flap can be based [17]. However, the presence of these vessels as you move from radial to ulnar becomes less reliable. The first dorsal metacarpal artery island flap, also known as the kite flap [18], is a fasciocutaneous flap based off the first dorsal metacarpal artery, a branch of the princeps pollicis artery. The flap is indicated for coverage of dorsal hand defects as well as large defects of the thumb tip. A dorsal radial sensory nerve and extensor indicis proprius can be included to create a chimeric flap. Many of these dorsal flaps can be designed in a propeller fashion to take advantage of skin laxity of the dorsal hand to enhance donor site closure.

Extrinsic Axial Pattern Hand Flaps

The reversed radial forearm flap is a fasciocutaneous, adipofascial, or osteocutaneous flap that can be raised on the radial artery for coverage of large defects of the hand. The flap can cover defects up to 10 × 20 cm and can reach to the PIP joints due to its long pedicle. The design of the flap on the forearm is critical, with the majority of skin perforators arising in the distal forearm. A wider fascial net can be taken with the desired skin paddle to ensure that enough perforators are captured during the dissection. This flap requires the sacrifice of the radial artery; thus, an Allen's test is required preoperatively. The ulnar artery perforator flap is another option for coverage of soft tissue defects of the hand. This flap is based on a consistent ulnar artery perforator that is found just proximal to the wrist, allowing a thin fasciocutaneous flap to be harvested in a free [19] or propeller fashion [20]. It does not require sacrifice of the often-dominant ulnar artery. The perforator is first identified with a doppler probe, and then, a subfascial dissection is performed to clearly identify the perforator and dissect it back to the ulnar artery.

The reverse posterior interosseus artery flap [21] is a third fasciocutaneous forearm-based option for reconstruction of the hand (Fig. 44.4). This flap, located over the dorsum of the forearm, is based on the perforators from the posterior interosseus artery, located between the extensor carpi ulnaris and extensor digiti minimi. A dermal leash can be taken with the flap to augment venous drainage. A fishtail can also be designed on the end of the flap to assist in rotation and closure of the flap and prevent the need for tunneling, which can compress the vascular pedicle. This flap pivots where the posterior interosseus artery anastomoses with the anterior interosseus artery, about 2.5–3 cm proximal to the distal radioulnar joint. This flap has gained prominence, as it allows for the use of a forearm-based flap without the sacrifice of one of the major blood vessels supplying the hand.

Free Tissue Transfer

In situations where local tissue options are inadequate, a free flap may be required to adequately reconstruct the soft tissue of the hand. The thickness of each flap available for an individual patient can vary greatly, and the operating surgeon must choose wisely. Free fasciocutaneous flaps are usually the best option, as they can be thin pieces of tissues that facilitate tendon gliding on the fascial undersurface of the flap. Fasciocutaneous flaps also have the ability to be easily elevated after they have healed to allow for further functional tendon reconstruction. Free muscle flaps are used less often, as they are often thicker pieces of tissue that are difficult to contour and are exceedingly difficult to elevate at a later time. Free fascial flaps are also a method of hand resurfacing that create a thin, pliable soft tissue construct that can be skin grafted [22]. The unique anatomy of the hand allows for the possible transfer of adjacent digits on their vascular pedicle for almost identical reconstruction. The foot can also be used as a donor site to create functioning digits in the upper extremity [23, 24].

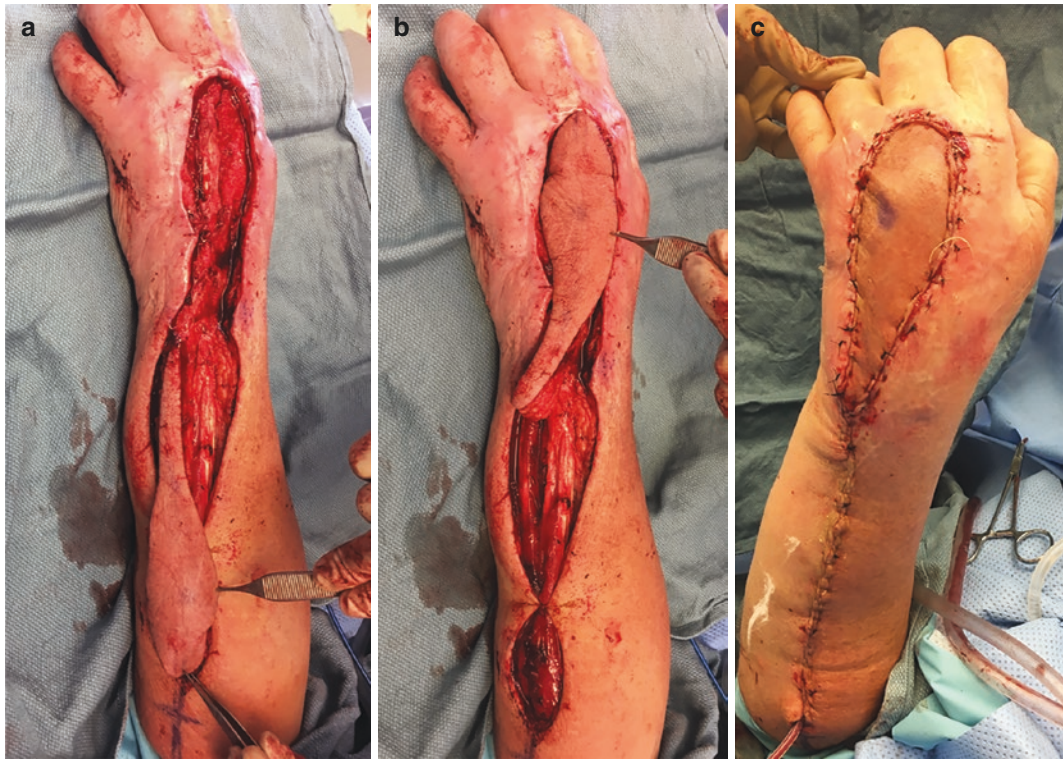

Fig. 44.4 This is a case of a dorsal hand wound requiring stable soft tissue coverage. A reverse posterior interosseus artery flap was designed and elevated (**a**) and rotated into position (**b**). Note the dermal leash that was maintained to augment venous drainage of the flap. The flap was definitively inset (**c**). The donor site was able to be closed primarily. (Case courtesy of Ines C. Lin, MD)

This ability is unique to fingers, as the body has 20 digits that can be thought of as a source for free tissue transfer. The goal of bringing distant tissue to the hand is to resurface the hand with pliable tissue of appropriate thickness.

Free fasciocutaneous flaps to the hand can provide a stable, healthy soft tissue covering to allow for adequate gliding of underlying tendon. The anterolateral thigh (ALT) flap and lateral arm flap have gained the greatest popularity for the use in the hand, where a thin flap is required. The concern with the use of the ALT flap is that it can be a thick flap in some individuals. It can be used to fill a large defect, as the donor site can be either skin grafted or closed primarily. Primary thinning of the flap is possible with extreme care, but is not without risk of vascular compromise to the flap [25]. The anterolateral thigh flap [26, 27] is based on the descending branch of the lateral femoral circumflex artery and can be used as a flow-through flap allowing for the reconstruction of the ulnar or radial artery at the same time [28].

The free lateral arm flap based on the posterior radial collateral artery is a thin fasciocutaneous option that can be harvested in a chimeric fashion for reconstruction of the hand (Fig. 44.5). It is commonly used for reconstruction of the first web space. The flap is thinner than an ALT flap in many patients. The flap can potentially include the posterior brachial cutaneous nerve for sensation, the lateral epicondyle as a bony component, and the triceps tendon if required [29]. The use of this flap has the benefit of keeping the surgical site located to a single extremity, which allows the case to be performed under regional anesthesia of a single limb [30].

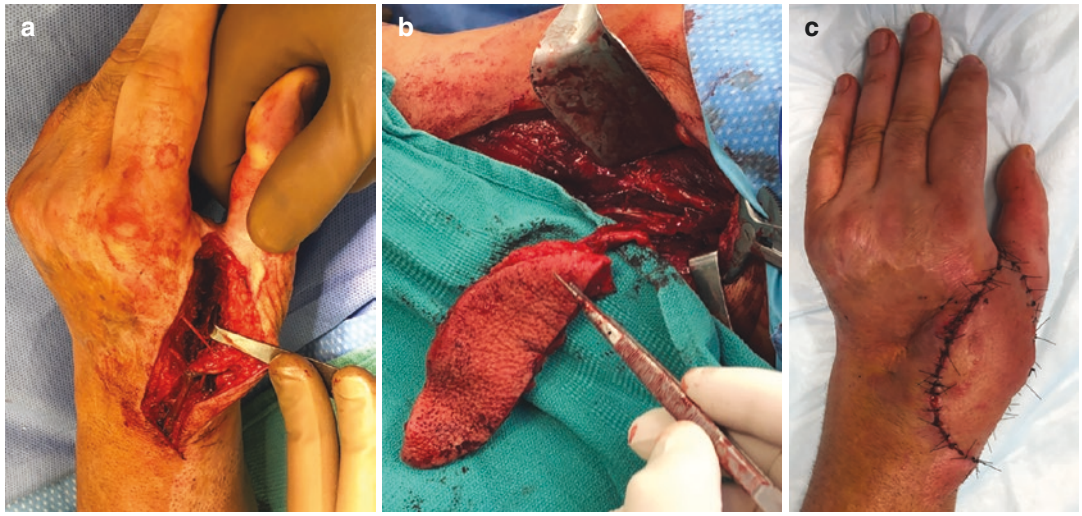

Fig. 44.5 This is a case of a patient who developed a contracture of the first webspace after crush injury. (**a**) Here, you can see the soft tissue defect that is present after debridement of scar tissue. Supple soft tissue is needed to untether the first webspace and help to enhance thumb function. (**b**) A lateral arm free flap was chosen to bring thin, healthy, and pliable soft tissue to the region. (**c**) Here, you can see the viable flap inset at the patient's initial postoperative visit. (Case courtesy of L. Scott Levin, MD, FACS)

Summary

Soft tissue reconstruction of the upper extremity is critical to maintain the function of the hand and upper extremity. The reconstructive ladder should not be abandoned, but a systematic approach is needed in order to maintain function of the injured upper extremity. The practicing upper extremity surgeon must be aware of the local reconstructive options that may be available, but be able to decide when a free tissue transfer may result in an improved outcome.

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Brachial Plexus Reconstruction

45

Jeremy Chang and Petros Konofaos

Introduction

Many factors can influence the success of brachial plexus repair and reconstruction. The age of the patient, the timing of nerve repair, the level of injury, the extent of the zone of injury, the technical skill of the surgeon, and the method of repair all contribute to the outcome after nerve injury [1, 2]. The basics of reconstruction include accurate preoperative assessment, properly executed surgical exploration, meticulous nerve repair, and intensive postoperative rehabilitation [3]. The aim of this chapter is to briefly review etiology of brachial plexus (BP) injuries and the options for repair, including direct repair, nerve grafts, end-to-side neurorrhaphy, and nerve transfers.

Etiology

Nerve injuries are caused by traction and compression, with traction accounting for 95% of injuries. As far as BP injuries are concerned, high-velocity motor vehicle accidents are the most common etiology [4]. Other common causes include industrial accidents, pedestrian vehicle accidents, snowmobile accidents, gunshot wounds, and other penetrating injuries [4]. The overall incidence of BP injuries in multitrauma patients secondary to motor vehicle accidents ranges from 0.67% to 1.3% [5]. This number further increases to 4.2% for motorcycle accidents.

Preoperative Investigation and Diagnosis

Preoperative investigation starts with a detailed history and physical examination of passive and active range of motion of all joints of the affected extremity. An appropriate sensory evaluation needs to be conducted, including the supraclavicular area, the arm, the forearm, and the hand. Grip and pinch strength are measured using a Preston dynamometer set on the "intermediate" level. Motor strength is evaluated by The British Medical Research Council (MRC) grading scale [6]. In cases of BP injuries, the presence of Horner's sign may be a strong indication of avulsion of the C8 and T1 roots. Furthermore, the absence of Tinel's sign in the supraclavicular area is an additional indication of root avulsion and an overall poor prognosis.

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The initial exam should also include electrodiagnostic evaluation of the upper extremity. Needle electromyogram should be postponed for a minimum of 3 weeks following injury, and preferably carried out at 6 weeks, allowing for physiologic degeneration processes to take place. Nerve conduction studies may occur sooner. The lamina test, a variation of nerve conduction study, may also be used. During the lamina test, tiny volleys of electrical stimulation are applied on each exiting root at the level of the foramina, with a positive response as evidence against avulsion [7].

Radiologic imaging can also have utility in diagnosis of BP injury. In cases of BP injuries, imaging studies (such as myelography, CT myelography, and magnetic resonance imaging) are used in order to detect abnormalities of the nerve roots. A combination of myelography with computed tomography of the cervical spine is used to confirm root avulsions. In cases of previous vascular injury or additional vascular comorbidity, angiography should be employed to investigate and identify any vascular compromise in preparation for reconstruction.

Important Tips

- Physical examination should include the contralateral upper extremity (noninjured) with which sensory and motor function of the ipsilateral upper extremity (injured side) should be compared.
- The same principle applies for the nerve conduction/EMG studies.
- CT/MRI myelography should be included in the preoperative management of acute brachial plexus injuries. In brachial plexus injuries with long denervation time (more than a year) or in injuries with avulsion of all roots of the brachial plexus, the use of the abovementioned studies is of little value, as prognosis is not favorable (especially for the hand function), and the function of shoulder and/or elbow can be restored with the use of extraplexus nerve transfers.

Treatment Options

Principles of Nerve Repair

The basic principles of nerve repair are the following: [7].

1. Preoperative assessment of motor and sensory function.
2. Adequate debridement of the proximal and distal nerve stumps in order to allow nerve regeneration to proceed across the repair site.
3. Utilization of microsurgical techniques.
4. Tension-free repair.
5. When a tension-free repair is not possible, use of other techniques for nerve repair.
6. Primary repair; when this is not possible, delay repair for approximately 3 weeks when the "zone of injury" is clarified.
7. Utilization of a nerve repair technique that allows early protected range of motion to permit nerve gliding.
8. Occupational and physical therapy in order to maximize the clinical outcome.

Timing of Nerve Repair

It is important to understand that BP injuries are often associated with additional fractures, vascular injuries, or soft-tissue injury. Current studies recommend early aggressive surgical intervention. Studies have shown that optimal functional outcomes occur when nerve repair is performed within 6 weeks of injury, and that primary repair is superior to secondary repair if the tissue bed is adequate [8–10].

In general, open wounds with associated nerve injuries necessitate immediate exploration. However, in cases of crush injuries with significant soft-tissue damage, a delayed repair after 2–3 weeks should be done, in which time the scar tissue becomes well demarcated.

In cases with closed or blunt trauma, initial management is close observation. If complete recovery is not observed within 6 weeks, electrodiagnostic studies should be obtained. Lack of signs of reinnervation (clinical or electrical) at

12 weeks' postinjury requires surgical exploration.

Techniques of Nerve Repair

Techniques for BP reconstruction include epineurial repair, group fascicular repair, fascicular repair, or a combination of those techniques in an end-to-end or end-to-side fashion. The goal is to achieve tension-free coaptation and in the proper alignment. Nerve grafts and transfers are additional options when tension-free reconstruction is not achievable.

End-to-End Repair

Repair in an end-to-end fashion can occur at the level of the epineurium, fascicle, and grouped fascicle, and it is most commonly used for nerve reconstruction. Epineurial repair should be utilized when one or only few fascicles are injured, whereby coaptation is achieved by single epineurial stitches in the epineurium along the circumference of the nerve using epineural vessels as a guide. Fascicular repair involves coaptation of individual in the internal epineurium surrounding individual fascicles. Lastly, in group fascicular repair, fascicular groups are coapted with sutures in the perineurium or perifascicular connective tissue which surrounds groups of fascicles.

End-to-Side Nerve Repair

End-to-side nerve repair is a technique which allows for additional muscle reinnervation with minimal detriment to donor-nerve function [11, 12]. Using this technique, a neurorrhaphy is created between the proximal end of an injured nerve and a side of an uninjured donor nerve by simple microsurgical attachment at the site of an epineurial or perineurial window. End-to-side neurorrhaphy has been utilized extensively to minimize morbidity from the various extraplexus donors [13]. For example, we have utilized end-to-side coaptation in combination with interposition nerve grafting in partial phrenic or hypoglossal nerve transfers to minimize donor nerve harvest.

Nerve Grafting

When local tension-free repair is not possible, alternatives must be pursued. Autologous nerve grafting is the current "gold standard" for repair of irreducible nerve gaps. Choice of donor nerves is dictated by availability and the functional and aesthetic deficits created by their harvest. Sunderland et al. describe four characteristics for the ideal donor nerve; it should 1) possess long, unbranched segments, 2) be easily accessible and reliably located, 3) possess large fascicles with little interfascicular connective tissue and few interfascicular connections, and, lastly, 4) sensory deficit from harvest should occur in a non-critical area of the body [14]. Most commonly used donor nerves for BP repair are the sural nerve, saphenous nerve, medial brachial cutaneous nerve, and lateral antebrachial cutaneous nerve.

After initial dissection, proximal and distal nerve stumps must be prepared prior to grafting. In cases of poly-fascicular nerve stumps, interfascicular dissection is done. The intraneural topography of both nerve stumps is obtained prior to suturing by means of intraoperative electrodiagnostic studies and carbonic anhydrase histochemistry [15, 16]. The authors advocate for use of a combination of microsutures and fibrin glue for neurorrhaphy.

Vascularized Nerve Grafts

Vascularized nerve grafts are particularly important for BP surgery, offering increased survivability for the nerve graft [17]. Vascularized nerve grafts are indicated in situations where there is scarred recipient bed that will not support a non-vascularized nerve graft [17, 18]. Vascularized nerve grafts can further be combined with non-vascularized nerve grafts to cover the cross-sectional area of long injuries. The following are common donor nerves:

- *Ulnar nerve*: Vascularized ulnar nerve grafts are specifically used in cases of global plexopathy with avulsion of the lower roots (i.e., C8 and T1) and rupture of the upper roots [17]. The vascularized ulnar nerve graft is harvested along the superior ulnar collateral vascular pedicle. If used

for ipsilateral BP reconstruction, the ulnar nerve is transected into segments to bridge the nerve defects while preserving the epineurial blood supply. This is done by folding the ulnar nerve and subsequent transection using a technique proposed by Terzis [17]. In distal lesions, vascularized fascia surrounding the donor nerve may be harvested and implanted with the graft to improve the blood supply of the underlying bed.

- *Sural nerve*: The sural nerve is harvested along with vascular supply from the sural artery or with an arterialized saphenous vein.
- *Saphenous nerve*: For BP injuries, the indications are the same as use of vascularized ulnar nerve graft as described earlier.

Nerve Transfers

A nerve transfer involves recruitment of redundant nerve fascicles from a donor nerve to innervate injured motor or sensory nerves close to their end target. Nerve transfers are utilized for BP injuries where there are limited proximal intra-plexus motor donors.

Indications for Nerve Transfers in BP Reconstruction

According to Dvali et al. [19], the indications for nerve transfers in the upper extremity are as follows:

1. Avulsion of BP root injuries.
2. Proximal nerve injuries which require a long distance for regeneration.
3. Major limb trauma with associated loss of nerve tissue.
4. In patients with long denervation time or in older patients.
5. Avoidance of re-exploring an area of previous injury because of potential damage to critical structures.

Clinical Pearls

- Choosing the indicated nerve repair type is based on several factors, including level and severity of the brachial plexus injury, if both nerve stumps are available, if tension-free repair is feasible or not, and the surgeon's experience.
- Immediate exploration and repair are keys for optimal functional outcomes.
- Fascicular and/or group fascicular repair along with proper fascicular alignment (e.g., motor-to-motor fascicle) are also related to optimal functional outcomes.

Intraoperative Diagnosis and Treatment

The precise level, type, and extent of the nerve lesion need to be fully determined during surgical exploration (Fig. 45.1). Intraoperative electrophysiologic recordings provide direct evidence of the extent of neural injury to determine the decision to repair, graft, or resect nerve tissue, as well as monitor nerve function, guide dissection, and distinguish nerve from scar tissue [20, 21].

Specifically, in cases of BP injuries, intraoperative electrodiagnostic studies are useful to verify a suspected avulsion of a root [20]. The presence of sensory action potentials and normal conduction velocities in a flail and anesthetic extremity implies root avulsion.

Terzis et al. developed an intraoperative assessment measurement tool of the severity of a BP injury, termed the "severity score" [22]. Avulsion of the BP roots always carries the worst prognosis and makes functional restoration in the paralyzed upper extremity much more challenging.

Clinical Pearls

- Intraoperative electrophysiologic recordings are of essential importance for the selection and execution of the indicated nerve repair.
- Knowledge of the brachial plexus' anatomy is important for proper exploration and assessment of the severity of the injury.

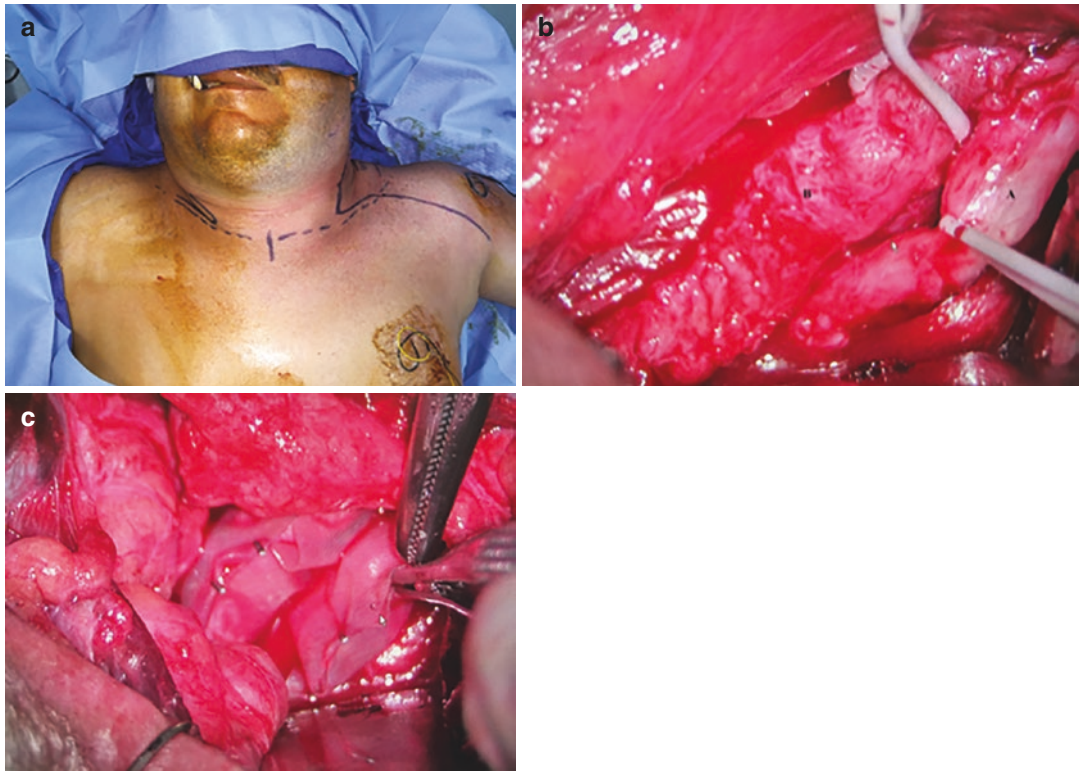

Fig. 45.1 (**a**) A male patient with left brachial plexus injury, due to a motor vehicle accident, involving C5–T1 spinal nerves with denervation time 1 year at the time of exploration. The patient at the time of the injury was advised to wait for a year before any exploration should be attempted. MRI myelography at the time of the injury was suggestive for rupture of C5–C7 spinal nerves and avulsion of lower plexus C8–T1 spinal nerves. The patient had very limited abduction of the shoulder (M2), limited elbow flexion (M2), and some minor sensory function at the ulnar nerve distribution. The aim of exploration/reconstruction was to augment shoulder/elbow function. (**b**) Marking of the incision. Upper (**a**) and middle with lower trunk (**b**) of the brachial plexus. Notice the scar tissue surrounding especially the middle and lower trunk of the plexus. Intraoperative nerve monitoring on the upper trunk enabled stimulation of deltoid and biceps muscles, but not on the lower plexus. Neurolysis of the upper trunk was performed. (**c**) The upper trunk after neurolysis and application of nerve wraps

Decision Algorithm for Brachial Plexus Reconstruction

Major clinical decisions for BP reconstruction are based on the extent of BP injury (i.e., number of nerve root avulsions) as well as the level of the injury (i.e., upper vs lower roots).

One- or Two-Root Avulsions

a. If the upper roots, C5 and/or C6, are avulsed, reconstruction of the shoulder and elbow function can be achieved by means of:
   1. Distal spinal accessory nerve transfer to the suprascapular nerve.
   2. Intraplexus donors (ipsilateral C7, nerve branch to the long head of the triceps) are used for biceps and deltoid neurotization.

b. If the lower two roots (C8 and T1) are avulsed, reconstruction can occur through:
   1. C5, C6, or C7 (in infants only).
   2. Vascularized ulnar nerve graft [17, 23].

Three-Root Avulsion

a. When the three upper roots (C5, C6, and C7) are avulsed, reconstruction is as follows:
   1. Distal spinal accessory nerve transfer to reconstruct the suprascapular nerve.
   2. Intercostal nerves transfer for reconstruction of the axillary and the nerve to triceps.

Fascicles of the ipsilateral ulnar nerve can be used for musculocutaneous nerve neurotization (i.e., Oberlin transfer) [10, 24].

b. If C7, C8, and T1 roots are avulsed, transfer of the distal part of the accessory nerve to the suprascapular nerve is performed. The ipsilateral ulnar nerve can be used as a vascularized free or pedicled nerve graft.

Four-Root Avulsion

In BP injuries with four-root avulsion (C6, C7, C8, and T1), reconstruction is as follows:

1. If the C5 root is well-developed (i.e., the BP is prefixed), the same reconstructive plan is used as with three-root avulsions. If C5 is small, it is usually dedicated to neurotization of the musculocutaneous nerve via sural nerve grafts.
2. Distal spinal accessory nerve transfer for the suprascapular nerve.
3. Intercostal nerves are used for neurotization of axillary and triceps nerves.
4. Selective contralateral C7 (cC7) root transfer [25, 26] with the following specifics: The anterior division is coapted to a vascularized ulnar nerve graft for neurotization of the median nerve on the affected side, while the posterior division is coapted to two saphenous cross-chest grafts which are "banked" for future free muscles for hand reconstruction.

Global Avulsion

In case of global avulsion plexopathy, all reconstructions must be carried out from extraplexus donors.

Surgical Techniques

Intraplexus Donors

Use of intraplexus motor donors is preferred over extraplexus motor donors, as studies have shown that intraplexus donors have a greater number of axons and less need of postoperative re-education, with overall superior results.

Ipsilateral C5-Root Transfer

Containing about 16,000 myelinated axons, the C5 root is the strongest motor donor, and if there is no avulsion, the proximal part of the ruptured root can be used as a motor donor for multiple neurotizations through interposition nerve grafting [15]. If the distal stump cannot be identified, the proximal stump should be used as a donor.

For the surgery, an initial curved incision should be made along the posterior border of the sternocleidomastoid muscle. The supraclavicular plexus, located between the anterior and middle scalene muscles and the phrenic nerve, may be identified. Dissection will proceed posteriorly until the C5 and C6 roots may be visualized. Care should be taken to isolate and preserve the C5 root unless it is ruptured.

Ipsilateral C7-Root Transfer

Due to extensive overlap among the nerve fibers derived from the upper and lower plexus, no muscle of the upper extremity is innervated solely by the C7 nerve root, allowing it to be a potential nerve transfer donor with minimal comorbidity [25–27]. In cases where the C5 and C6 roots are avulsed from the spinal cord, but C7 root is preserved, ipsilateral C7-root transfer may be used for reconstruction.

It is important to note that intraoperative mapping through electrical stimulation of each division of C7 is mandatory to isolate nerve bundles for reconstruction [25, 26]. Bundles that supply wrist extensors are never used for transfer, while bundles supplying the pectoralis major in the anterior division and the latissimus dorsi and triceps muscles in the posterior division are used [28, 29]. Anterior division bundles are used as motor donors for flexors, and posterior division bundles are donors for extensors [28, 29].

Extraplexus Nerve Donors

Extraplexus donor nerves include the cervical plexus motors, the spinal accessory nerve, intercostal nerves, the phrenic nerve, or the contralateral C7 (cC7) root.

Spinal Accessory Nerve Transfer

The spinal accessory nerve (XI) is a pure motor nerve that innervates the sternocleidomastoid and trapezius muscles. CN XI transfer is used for reinnervation of the suprascapular nerve due to its proximity. Compared with other extra-plexus donors, the distal XI has an advantage because it is a pure motor nerve with functional characteristics similar to that of the suprascapular nerve. In order to minimize trapezius muscle denervation, the nerve is transected distally after it gives off its two proximal branches. At this level, the XI contains about 1300–1600 myelinated nerve fibers [6].

The spinal accessory nerve may be identified as it emerges along the lateral border of the sternocleidomastoid muscle, cranial to the C4 spinal nerve. The transverse cervical vessels may be used as a landmark to identify the nerve on the anterior surface of the trapezius muscle. For transfer of the spinal accessory nerve to the suprascapular nerve, the terminal branches of the XI are divided deep posteromedially and moved to the supraclavicular fossa and directly coapted to the suprascapular nerve [6].

Intercostal Nerve Transfer

ICNs are the ventral rami of spinal nerves T2–T11. Lower ICNs from T7 to T11 supply the muscles and skin of the anterior abdominal wall, and theoretically carry a higher number of motor axons than the upper intercostal nerves. An ICN contains less than 1200–1300 myelinated fibers, of which only 40% are motor fibers. Lower ICNs are more commonly utilized for musculocutaneous, triceps, and axillary nerve neurotization, while T4 and T5 intercostals are used more often for neurotization of the thoracodorsal and long thoracic nerve [22, 30, 31].

Exposure of the ICNs is achieved by elevating the periosteum of the corresponding rib. Once all the ICNs are adequately dissected, they are passed through a subcutaneous tunnel to the ipsilateral axilla and coapted in an end-to-end fashion with the nerve of the target muscle.

Phrenic Nerve Transfer

Originating from C3 to C5 roots, the phrenic nerve has mainly been used for musculocutaneous nerve neurotization [32–34]. In obstetrical BP palsies, the phrenic nerve is used in an end-to-side manner through a perineurial window without compromising diaphragm function [33]. The phrenic nerve contains about 1300–1600 myelinated nerve fibers [34]. Pulmonary function must be evaluated before consideration of the phrenic nerve for transfer, as the phrenic nerve innervates the diaphragm. The entire phrenic nerve cannot be used in a patient who has concomitant intercostal nerve harvesting.

Surgically, the phrenic nerve is identified lying on the anterior surface of the anterior scalenus muscle. Interposition nerve grafts are coapted with the phrenic nerve in an end-to-side fashion to allow for nerve transfer.

Ulnar-to-Musculocutaneous Nerve Transfer

The ulnar-to-musculocutaneous nerve transfer, or Oberlin transfer, is performed to restore elbow flexion in patients who have an irreparable upper trunk injury or avulsion with an intact lower trunk [24, 35]. It involves transfer of one or more fascicles of the branch of the ulnar nerve to the flexor carpi ulnaris to the musculocutaneous nerve. Careful selection of nerve fascicles using intraoperative stimulation allows one to perform this transfer without a donor motor deficit. This technique allows for rapid motor recovery time because the transfer is performed so close to the target muscle that an interposition nerve graft is not necessary [35, 36].

During the surgery, the musculocutaneous nerve may be identified between the biceps and the coracobrachialis muscles. The nerve branches to the biceps are traced proximally where they usually coalesce into a single motor branch within the parent musculocutaneous nerve. Once the ulnar nerve has been dissected as well, intraoperative mapping of the components of the ulnar nerve is a mandatory step to identify the appropriate nerve bundles for transfer. The distal part of the branch to the biceps is then rotated medi-

ally toward the previously dissected ulnar nerve. Bundles supplying the flexor carpi ulnaris are isolated with vessel loops and separated. The fascicles are turned laterally and superiorly before being sutured to the musculocutaneous nerve.

Clinical Pearls

- Preoperative assessment of the severity of the brachial plexus injury is of critical importance regarding the choice of intraplexus versus extraplexus nerve donors.
- Intraplexus nerve donors are preferred, when available, due to larger number of axons and the less need for postoperative reeducation.
- The use of autologous nerve grafts is usually needed in order to bridge the gap between the nerve donor and the native nerves of the targeted muscles. Ideally, this gap should be less than 5 cm when possible.

Rehabilitation

Postoperative BP reconstructions require immobilization lasting 4–6 weeks, based on the location of the nerve injury and the type of the nerve repair that was performed. Immediately after completion of the nerve repair, a custom-made brace is applied to the patient to maintain the arm in anterior flexion and 45 degrees of abduction with the elbow flexed. The brace is removed after 4–6 weeks, after which, a sling is applied on the patient's operated extremity for four additional weeks. Physical therapy with passive range of motion can be initiated at 6 weeks immediately following removal of the brace, with the goal of full passive range of motion. Local therapies including ultrasound, massage, and slow-pulse stimulation are also initiated at 6 weeks, with the slow-pulse stimulation being continued for a period of 2 years. At each follow-up visit, axon elongation should be followed by advancement of Tinel's sign. Later-stage rehabilitation is focused on motor and/or sensory re-education. In addition, the patient should be counseled on the overall timeline of recovery, with the understanding that the process may be lengthy and take years.

Clinical Pearls

- Physiotherapy should not be initiated earlier than 6 weeks in order to avoid potential damage to the nerve repairs.
- Patient's motivation and compliance to the rehabilitation protocol is of outstanding importance for achieving optimum functional recovery.

Complications of Treatment

Though the majority of patients have positive outcomes following BP reconstruction, various complications can occur, depending on the type of nerve repair conducted [37]. Complications of an end-to-end neurorrhaphy include fibrosis in the repair site or misdirection of the nerve fibers due to improper alignment of the nerve stumps, causing functional deficits [4, 37]. With regard to nerve grafts, most common complications include sensory loss and scarring of the donor site, donor site neuroma formation, and graft failure [37]. Lastly, complications from nerve transfers include donor muscle atrophy and loss of function [37].

Conclusion

Advances in the field of peripheral nerve surgery have increased our understanding of the complex molecular and cellular events surrounding nerve injury and repair. The ultimate goal of any nerve reconstruction is the restoration of function as completely as possible, while minimizing comorbidities. There are several factors that influence recovery following a nerve injury: time elapsed, patient age, mechanism of injury, proximity of the lesion to distal targets, and associated soft-tissue or vascular injuries. Prompt repair of BP injuries leads to improved outcomes by allowing

for earlier distal motor end plate and sensory receptor reinnervation.

If end-to-end repair is not possible, several options for repair include interposition nerve grafting, nerve transfers, and end-to-side neurorrhaphy. Selection of each technique depends on the individual BP injury characteristics and the surgeon's experience.

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