Principles of Lateral Craniofacial Reconstruction

Steven J Wang
Kevin Fung
Editors

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Editors
Steven J Wang
Otolaryngology – Head and Neck Surgery
University of Arizona
Tucson, AZ
USA

Kevin Fung
Otolaryngology – Head and Neck Surgery
Schulich School of Medicine and Dentistry
London, ON
Canada

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Preface

Aims

Extirpation of tumors of the lateral craniofacial region can be associated with many important and challenging reconstructive issues. Patients may suffer major functional and cosmetic consequences associated with facial nerve paralysis, facial contour deformity, and soft tissue loss (i.e., skin, ear, temporal bone, mandible, orbit, cranial base).

Scope

This textbook will provide an overview of reconstructive principles ranging from facial nerve and facial contour problems to complex defects of the lateral craniofacial region. The scope of this textbook will include basic concepts, a practical anatomical defect-based approach, and will highlight specific technical challenges that are commonly encountered in the contemporary era of intensive chemoradiation therapy, the aging population, and global health.

Tucson, AZ, USA — Steven J Wang
London, ON, Canada — Kevin Fung

Contents

Part III Special Considerations

Contributors

Arnaud F. Bewley University of California, Davis Department of Otolaryngology Head and Neck Surgery, Oakland, CA, USA

Steve B. Cannady Hospital of the University of Pennsylvania, Philadelphia, PA, USA

Jason Cohn Department of Otolaryngology and Facial Plastic Surgery, Philadelphia College of Osteopathic Medicine, Philadelphia, PA, USA

Abel P. David Department of Otolaryngology-Head and Neck Surgery, University of California, San Francisco, San Francisco, CA, USA

Yadranko Ducic Otolaryngology and Facial Plastics Associates, Fort Worth, TX, USA

Atson Carlos de Souza Fernandes State University of Bahia and Bahian School of Medicine and Public Health, Salvador, Bahia, Brazil

Gregory R. D. Evans Department of Plastic Surgery, The University of California, Irvine, Orange, CA, USA

Johannes J. Fagan Division of Otorhinolaryngology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa

S. Farooq Oral and Maxillofacial Department, University Hospital Birmingham, Birmingham, UK

Marco Ferrari Department of Otolaryngology – Head and Neck Surgery/Surgical Oncology, University Health Network, Toronto, ON, Canada

Unit of Otorhinolaryngology – Head and Neck Surgery, University of Brescia, Brescia, Italy

Techna Institute, University Health Network, Toronto, ON, Canada

Matthew M. Hanasono Department of Plastic Surgery, The University of Texas MD Anderson Cancer Center, Houston, TX, USA

Austin Hembd Department of Plastic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

Marc H. Hohman Facial Plastic and Reconstructive Surgery, Madigan Army Medical Center, Tacoma, WA, USA

Jonathan Irish Department of Otolaryngology – Head and Neck Surgery/Surgical Oncology, University Health Network, Toronto, ON, Canada

Techna Institute, University Health Network, Toronto, ON, Canada

Marjorie Johnson Anatomy Cell Biology, Schulich School of Medicine and Dentistry, Western University, London, ON, Canada

Stephen Y. Kang Department of Otolaryngology – Head and Neck Surgery, The Ohio State University, Columbus, OH, USA

Michael Kinzinger University of California, Davis Department of Otolaryngology Head and Neck Surgery, Oakland, CA, USA

P. Daniel Knott Division of Facial Plastic and Reconstructive Surgery, Department of Otolaryngology-Head and Neck Surgery, University of California, San Francisco, San Francisco, CA, USA

Seung Ah. Lee Department of Plastic Surgery, The University of California, Irvine, Orange, CA, USA

N. Mahon Oral and Maxillofacial Department, University Hospital Birmingham, Birmingham, UK

Wayne Manana Specialist Oral & Maxillofacial Surgeon, Harare, Zimbabwe

E. Mustafa Oral and Maxillofacial Department, University Hospital Birmingham, Birmingham, UK

Matthew O. Old Department of Otolaryngology – Head and Neck Surgery, The Ohio State University, Columbus, OH, USA

S. Parmar Oral and Maxillofacial Department, University Hospital Birmingham, Birmingham, UK

Krupal B. Patel Head & Neck/Endocrine Oncology, Moffitt Cancer Center and Research Institute, Tampa, FL, USA

P. Praveen Oral and Maxillofacial Department, University Hospital Birmingham, Birmingham, UK

Margaret S. Roubaud Department of Plastic Surgery, The University of Texas MD Anderson Cancer Center, Houston, TX, USA

Shai Rozen Department of Plastic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

Axel Sahovaler Department of Otolaryngology – Head and Neck Surgery/Surgical Oncology, University Health Network, Toronto, ON, Canada

Guided Therapeutics (GTx) Program, Techna Institute, University Health Network, Toronto, ON, Canada

Rahul Seth Division of Facial Plastic and Reconstructive Surgery, Department of Otolaryngology-Head and Neck Surgery, University of California, San Francisco, San Francisco, CA, USA

Tom Shokri Division of Otolaryngology, Penn State Milton S. Hershey Medical Center, Hershey, PA, USA

Fiyin Sokoya Otolaryngology – Head and Neck Surgery, University of Arizona, Tucson, AZ, USA

W. Walsh Thomas Oregon Health Sciences University, Portland, OR, USA

K. Ubayasiri Oral and Maxillofacial Department, University Hospital Birmingham, Birmingham, UK

Ottie (JE) Van Zyl Groote Schuur Hospital, Cape Town, South Africa

Aurora G. Vincent Otolaryngology, Head and Neck Surgery, Madigan Army Medical Center, Tacoma, WA, USA

Mark K. Wax Department of Otolaryngology-Head and Neck Surgery, Oregon Health Sciences University, Portland, OR, USA

Part I

Basic Concepts/Principles

1 Lateral Craniofacial Anatomy

Marjorie Johnson and Atson Carlos de Souza Fernandes

Overview

The lateral craniofacial region of the skull consists of both neurocranial and viscerocranial (facial) bones. The frontal, parietal, temporal, and greater wing of the sphenoid merge together to form the pterion, a thin-walled congruence of the suture lines of these four bones, deep to which runs the middle meningeal artery. The zygomatic bone, which forms the prominence of the cheeks, articulates with the frontal, maxilla, temporal, and sphenoid bones. The zygomatic, sphenoid, and maxilla also form part of the boney orbit. The maxilla and mandible complete the facial boney structure (Fig. 1.1) Superficially, the lateral craniofacial region is covered by muscles of mastication, and/or facial expression, the parotid gland and duct, facial artery and vein and the facial nerve. The facial nerve emerges through the parotid gland to innervate the very superficial muscles of facial expression. The superficial veins of the face converge into the retromandibular vein, which drains into the jugular system Fig. 1.2).

M. Johnson (✉)
Anatomy Cell Biology, Schulich School of Medicine and Dentistry, Western University, London, ON, Canada
e-mail: marjorie.johnson@schulich.uwo.ca

A. C. de Souza Fernandes
State University of Bahia and Bahian School of Medicine and Public Health, Salvador, Bahia, Brazil

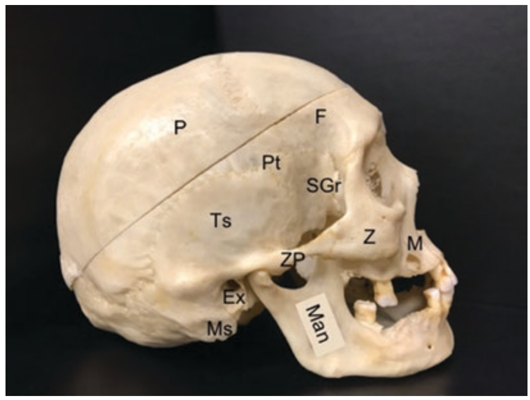

Fig. 1.1 The bones of the lateral cranial facial region of the skull. The labeled bones are the *parietal (P), frontal (F), squamous part of the temporal (Ts), and greater wing of the sphenoid (SGr)*. The sutures of these bones meet at the *pterion (Pt)*. In this lateral view, also note parts of the temporal bone, namely the *mastoid process (Ms), external auditory meatus (Ex), and the zygomatic process (ZP)*, which articulates with the *zygomatic bone (Z)* to form the zygomatic arch. Anteriorly sits the *maxilla (M)* and most inferior and lateral is the *mandible (Man)*

Specific Anatomical Regions

The following sections will describe some of the anatomical features of the lateral cranial facial region in more detail.

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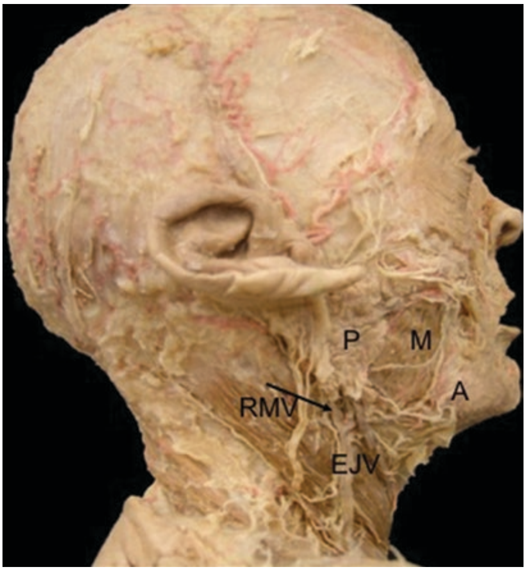

Fig. 1.2 Superficial soft tissue of the lateral cranial facial region. Note the branches of the facial nerve emerging and coursing anteriorly from the substance of the *parotid gland (P)*. Deep from the parotid gland, part of the *retromandibular vein (RMV)* can be followed inferiorly where it drains into the *external jugular vein (EJV)*. The *facial artery (A)* is winding over the mandible just anterior to the *masseter muscle (M)*

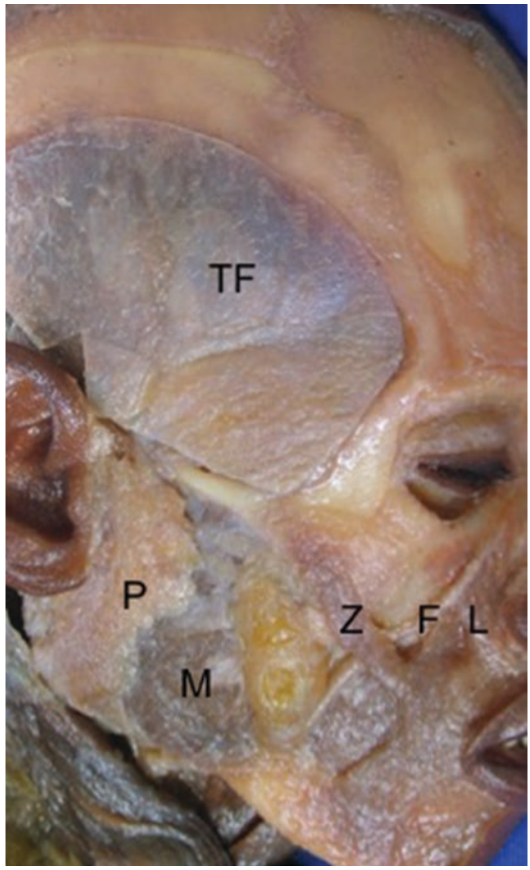

Fig. 1.3 The superficial soft tissues of the lateral cranial facial region. Covering the pterion region and squamous temporal bone is the temporalis fascia of the temporalis muscle. The area just anterior to the external auditory meatus is covered by the *parotid gland (P),* through which emerges the facial nerve (not shown). The angle of the mandible is crossed by the *masseter muscle (M)* and the torturous *facial artery (F).* Two muscles of facial expression are shown anchoring on the zygomatic bone, the *zygomaticus major (Z)* and *levator labii superioris (L). (With permission* Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil0

Zygomaxillary Region

The zygomatic bones are located on either side of the facial midline at the lateral borders forming the cheeks. The zygomatic bone possesses a frontal, maxillary, temporal, and orbital process about which the zygomatic body is centered. Slight asymmetry has been noted in normal zygoma [3]. The malar convex surface of the zygomatic bone faces anteriorly and laterally and the temporal concave surface faces posteriorly and medially. The malar surface contains the zygomaticofacial foramen for the nerve and vessels of the same name, whereas the temporal surface houses the zygomaticotemporal foramen. Both the zygomaticofacial and zygomaticotemporal nerves are branches of the maxillary nerve (CN V2) and relay general sensory input from the skin over the prominence of the cheek and temple respectively [8].

Two muscles of mastication, the masseter and temporalis (which will be described in detail with the mandibular region), and two muscles of facial expression, the zygomaticus (major and minor) and levator labii superioris, originate from the zygomatic bone. The zygomaticus muscles originate from the body of the bone whereas the levator labii superioris originates in part along the maxillary process of the zygomatic bone just superior to the infraorbital foramen located within the maxilla (Fig. 1.3).

The maxilla is part of the viscerocranium, consisting of the main body and four processes: the frontal process (joins with the frontal bone), the zygomatic process (joins with the zygomatic bone), the palatine process (joins with the palatine bone), and the alveolar process (contains the upper teeth). Within the maxilla lies the infraorbital foramen. It is found just below the margin of the orbit and houses the infraorbital nerve, a branch of the maxillary division of cranial nerve V. This nerve primarily supplies sensory innervation to maxillary teeth, gums, skin covering the maxilla, and the maxillary sinus [22].

In addition to providing structure and protuberances or processes for muscle attachment and foramina for passage of vessels and/or nerves, these bones protect the underlying soft tissue. Deep to zygomatic process is the infratemporal fossa, a region that houses muscles of mastication, vascular branches of the maxillary artery, pterygoid plexus of veins, and nerves arising from the mandibular division of cranial nerve V. The infratemporal fossa is continuous with several areas of the cranium via the pterygomaxillary fissure, which leads to the pterygopalatine fossa (Fig. 1.4). The pterygopalatine fossa is an important passageway [23] due to the following connections:

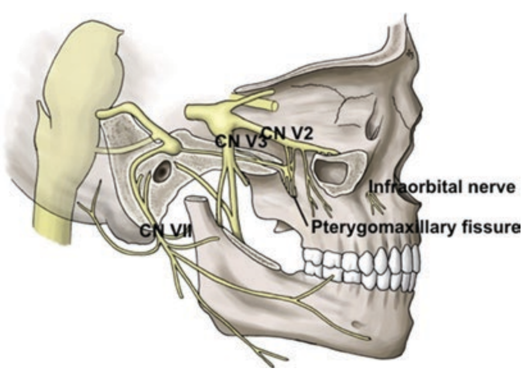

Fig. 1.4 Portions of the maxilla, mandible, zygomatic, and temporal bone have been removed to reveal the path of *cranial nerves V3 (mandibular division of the trigeminal nerve*) and *VII (the main trunk of the facial nerve).* Also exposed is the *pterygomaxillary fissure* which leads to the pterygopalatine fossa (PPF). The illustration hints at some of the connections through the PPF. One of the terminal branches of the *maxillary division of cranial nerve V (CN V2)* is shown at the infraorbital foramen, the *infraorbital nerve*. (With permission from Dr. Gian-Marco Busato, University of Toronto Otolaryngology)

- Anteriorly to the orbit via the inferior orbital fissure.
- Laterally with the infratemporal fossa.
- Medially with the nasal cavity through the sphenopalatine foramen.
- Posteriorly to the middle cranial fossa via the foramen rotundum and pterygoid canal.
- Inferiorly to the hard palate via the greater and lesser palatine canals.

Temporal Region

The temporal bone has an irregular shape due to its various processes and articulations. It is divided into 4–5 primary parts depending on your source: a flat or squamous portion anterosuperior; petrous; mastoid; tympanic and styloid process. The outer squamous surface is covered by the temporalis muscle and the anterior aspect articulates with the zygomatic bone via the zygomatic process. This process is an attachment point for the masseter muscle. Just posterior to the zygomatic process sits the mandibular fossa of the temporal bone. The zygomatic process has an anterior and posterior root. The anterior root is broad and strong and terminates as the articular eminence (tubercle). The eminence forms the anterior boundary of the mandibular fossa. The posterior root progresses posteriorly above the external acoustic meatus. The mandibular fossa is bordered anteriorly by the articular eminence and posteriorly by the tympanic part of the temporal bone, separating the fossa from the external meatus (Fig. 1.5). The anterior and posterior aspects of the mandibular fossa are separated by the narrow slit petrotympanic fissure. A very important branch of the facial nerve, the chorda tympani, passes through a canal separated from the edge of the fissure in an angle between the squamous and petrous portion of the temporal bone [8].

The petrous portion fuses with the squama and mastoid process and is wedged between the sphenoid and occipital bone. It contains the middle and inner ear and several openings, such as the internal acoustic meatus, carotid canal, auditory tube, and a portion of the jugular foramen.

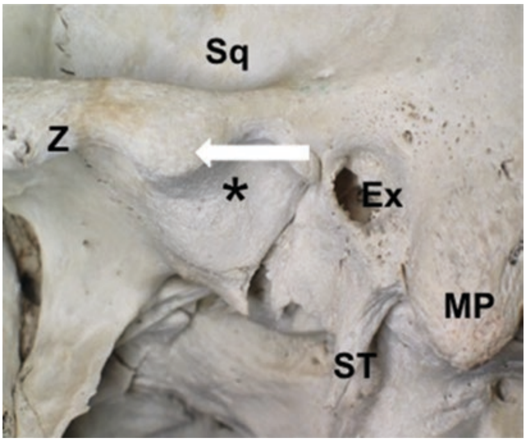

Fig. 1.5 A lateral-inferior view of a portion of the temporal bone. Several of the parts are shown, namely the *superior squamous portion (Sq)* and its *zygomatic process (Z)* anteriorly. The *articular eminence* is indicated by the *white arrow* just above the *mandibular fossa (*)*. The petrotympanic fissure (not labeled) can be seen separating the mandibular fossa from the *external acoustic meatus (Ex)* and the *styloid process (ST)*. Posteriorly sits the *mastoid process (MP)*. *(With permission, [21])*

The mastoid process is often associated with the petrous bone and referred to as the petromastoid part. The mastoid is a prominent landmark sitting posteriorly just behind the ear. It contains the tympanic antrum and mastoid air cells. The outer surface is rough due to attachments of the sternocleidomastoid and posterior belly of the digastric muscles, splenius capitis, and longissimus capitis. There are several foramina associated with the mastoid, the largest is the mastoid foramen which transmits a branch of the occipital artery to supply the dura, and a vein to the transverse sinus. Anteriorly the mastoid fuses with the squama above and below it helps form the external acoustic meatus and tympanic cavity.

The styloid process extends as a slender, pointed jut of bone from the under surface of the temporal bone. There is a considerable anatomical variation of the styloid process [6] and this may have clinical implications since this process is used as a palpable landmark. A number of small muscles, ligaments, and nerves are associated with the styloid process. Externally, the stylopharyngeus, stylohyoid, and styloglossus muscles originate from the process as do the stylohyoid and stylomandibular ligament. From within the pharynx, the styloid process is located between the carotid arteries and the internal jugular vein. Cranial nerves, glossopharyngeal, facial, accessory, hypoglossal, and vagus all have trajectories associated with the process. A very prominent opening, the stylomastoid foramen, which transmits the main motor root of the facial nerve, is found on the inferior surface of the temporal bone between the styloid process and mastoid process [18].

The final part of the temporal bone, the tympanic part, is a curved plate or ring of bone just inferior to the squama and anterior to the mastoid process. The tympanic part forms part of the external acoustic meatus (the anterior wall, floor, and a portion of the posterior wall), medially it provides an attachment for the tympanic membrane and anterio-inferiorly it contributes to the posterior aspect of the mandibular fossa as described above.

Temporomandibular Joint (TMJ)

The TMJ is a bilateral, bicondylar synovial joint. In the resting position the condyle or head of the mandible (convex) articulates with the mandibular (concave) fossa (Fig. 1.6). However, with the mouth open we observe a bicondylar joint formed between the mandibular head and the articular eminence of the temporal bone. Therefore, bicondylar is a morphological and functional classification of the TMJ. The morphology of the TMJ differs in adults and children, particularly, the shape of the condyle and depth of the mandibular fossa indicating the degree of joint movement will vary with age [15].

The head of the mandible (condyle) has medial and lateral poles to which the articular disc inserts [9]. The articular eminence is positioned anterior to the mandibular fossa and acts as a transverse resistant bone structure that prevents excessive anterior translation of the condyle. The articular surface of the condyle and the mandibular fossa of the temporal bone are covered by articular cartilage and, unlike other synovial joints, fibrocartilage [21]. The articular

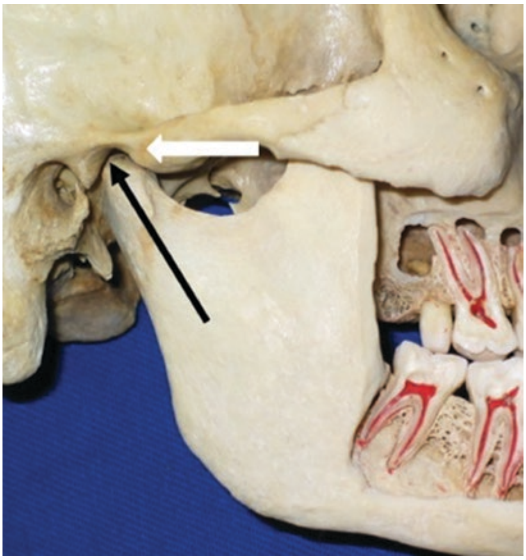

Fig. 1.6 A lateral view showing the *head or condyle of the mandible (black arrow)* articulating with the mandibular fossa of the temporal bone. The *white arrow* indicates the *articular eminence* or tubercle, the anterior extension of the TMJ. (With permission, Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil)

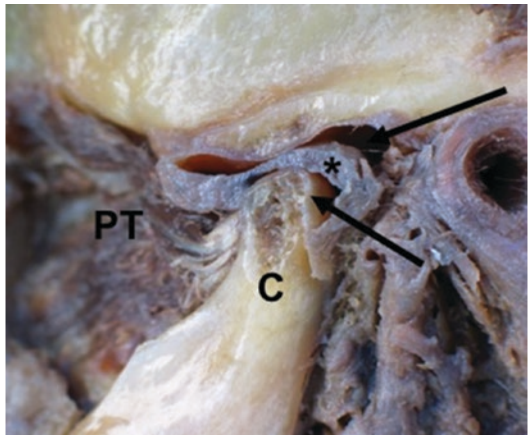

Fig. 1.7 An inner view of the TMJ illustrating the *supra and infra disc spaces of the joint (black arrows)* on either side of the *articular disc (*)*. The tendon of the *lateral pterygoid muscle (PT)* is shown merging with the disc anteriorly. (With permission, [21])

cartilage in the TMJ presents thickness differences according to the forces acting on the surfaces. The greater thickness of the articular cartilage occurs in the ostero-inferior slope of the articular eminence and in the supero-anterior slope of the mandible head, places of greater functional relationship during mastication [7].

The articular disc consists of fibrocartilaginous tissue. Its thickness is greater in the periphery, diminishing considerably in its center. The peripheral collagen fibers are arranged circularly (concentrically arranged), which increases the ability to resist compression forces during mastication [21]. The disc completely isolates the supradiscal and infradiscal compartments, making them independent both morphologically and functionally (Fig. 1.7). The articular disc is inserted at the lateral and medial poles through the ligamentous tissue.

In this type of insertion, the disc remains immobile during the rotational movements of the mandible head. However, the disc always accompanies the jaw in the translation movements. Changes of insertion between the disc and the mandible are often accompanied by joint noises. The peripheral edges of the disc are inserted in the joint capsule, and its border also inserts with muscle fibers of the superior head of the lateral pterygoid muscle and, with a bilaminar retrodisc cushion that is rich in elastic fibers and sensory nerve fibers.

The TMJ articular capsule is formed of loose fibrous tissue capable of allowing large joint movements. The capsule boundaries are the same as those of the articular bone surfaces. In the mandible it extends anteriorly to the upper limits of the pterygoid fovea, laterally and medially it inserts just below the ligament insertions of the disc in the poles, and finally, its posterior insertion occurs in a lower level of the mandible's neck. Articular ligaments are formed by collagenous connective tissue and are important in a synovial joint since they limit the amplitude of the movements, avoiding injury or disarticulation between the bones.

Three ligaments are defined at the TMJ: lateral, sphenomandibular and stylomandibular. The lateral ligament covers almost the entire lateral surface of the articular capsule and is continuous therein, extending obliquely downward from the lateral projection of the lateral articular eminence to the neck of the mandible immediately below the insertion of the articular capsule.

Facial Nerve

The facial nerve gives off three branches before exiting through the stylomastoid foramen. These are the motor nerve to the stapedius muscle of the middle ear, the chorda tympani, which carries both secretomotor fibers to the submandibular and sublingual salivary glands and taste signals from the anterior two-thirds of the tongue.

The chorda tympani joins the lingual branch of cranial nerve V to reach the tongue and salivary glands (Fig. 1.4) The third nerve branch communicates with the auricular branch of the vagus nerve (cranial nerve X) at or near the stylomastoid foramen. This branch conveys pain from the posterior external acoustic meatus and the tympanic membrane [18].

The main trunk of the facial nerve leaves the skull via the stylomastoid foramen running between the styloid process, stylohyoid muscle, and posterior belly of the digastric muscle. Here it gives off a posterior auricular branch that supplies the small auricular muscles and occipitalis. The facial nerve then splits into temporofacial and cervicofacial divisions, from which arise five main terminal branches (Fig. 1.8). The temporal and zygomatic nerves arise from the former division and the buccal, mandibular, and cervical branches from the later division. All these branches will form interconnecting loops referred to as the parotid nerve plexus [18]. The temporal branch runs superficially over the zygomatic arch, where it is at risk of injury. The buccal branch usually runs parallel to the parotid gland. The marginal mandibular branch courses obliquely, inferiorly, and anteriorly. It often arises from the main trunk behind the posterior border of the mandible, crossing the ramus at its lower border. This allows good access with relative safety between the buccal branch and the marginal mandibular nerve.

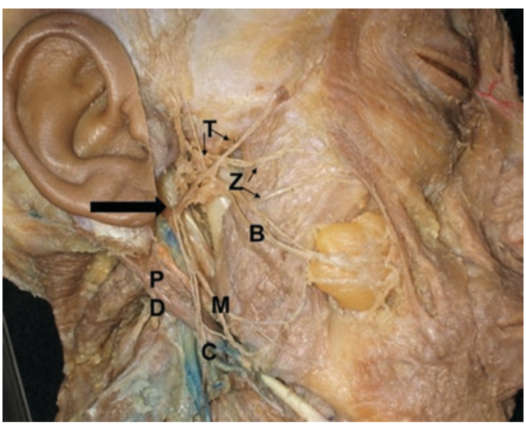

Fig. 1.8 The main motor trunk of the *facial nerve (thick black arrow)* has emerged from the stylomastoid foramen just above the *posterior belly of the digastric (PD)*. The terminal branches are noted: *temporal (T), zygomatic (Z), buccal (B), mandibular (M), and cervical (C). (With permission* Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil)

As the facial nerve crosses the external carotid artery and retromandibular vein, it pierces the posterior-medial surface of the parotid gland. It is within the parotid gland that the nerve splits into its two main divisions.

Retromandibular Vein

The retromandibular vein (RMV) courses through the parotid gland, retro to the ramus of the mandible and superficial to the external carotid artery. The superior and lateral face drains into the retromandibular system via the superficial temporal, maxillary, and posterior auricular veins. The RMV is formed by the junction of the maxillary and posterior auricular veins. The union of the posterior auricular vein and the posterior division of the retromandibular vein forms the external jugular vein, which empties into the subclavian vein. There is a great variation in the venous drainage [19].

The veins in the central region of the face and the deep structures of the head and neck drain into the internal jugular vein. More specifically, the central region of the face is drained by the facial vein (anterior facial vein). This vein ends by passing in front of the submandibular gland to join the anterior branch of the retromandibular vein (posterior facial vein). The union of these two veins forms the common facial vein. The common facial vein, in turn, usually empties into the internal jugular vein (Fig. 1.9).

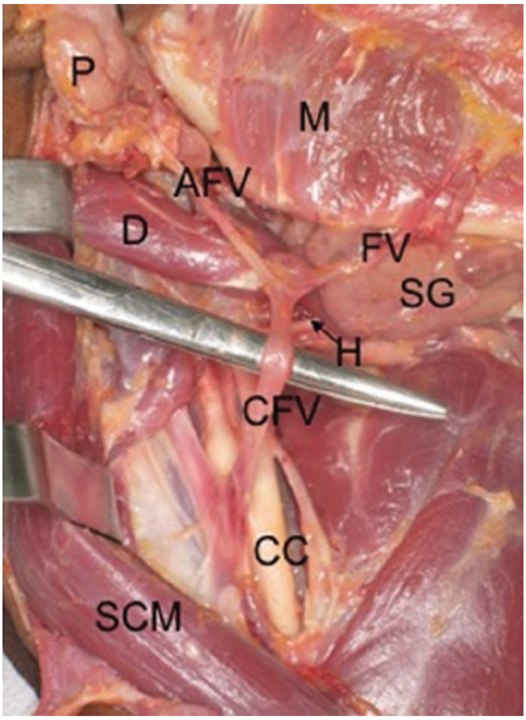

Fig. 1.9 The region just inferior to the *masseter (M) and parotid gland (P)* are depicted. Passing over the *submandibular gland (SG) is the facial vein (FV)*. It is continuous with the anterior division of the *retromandibular vein (AFV)* just superficial to the *digastric muscle (D)*. The facial vein drains into the *common facial vein (CFV)*, which drains into the internal jugular system. Note the position of the *common carotid artery (CC)* and the retracted *sternocleidomastoid muscle (SCM)*. (With permission, Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil)

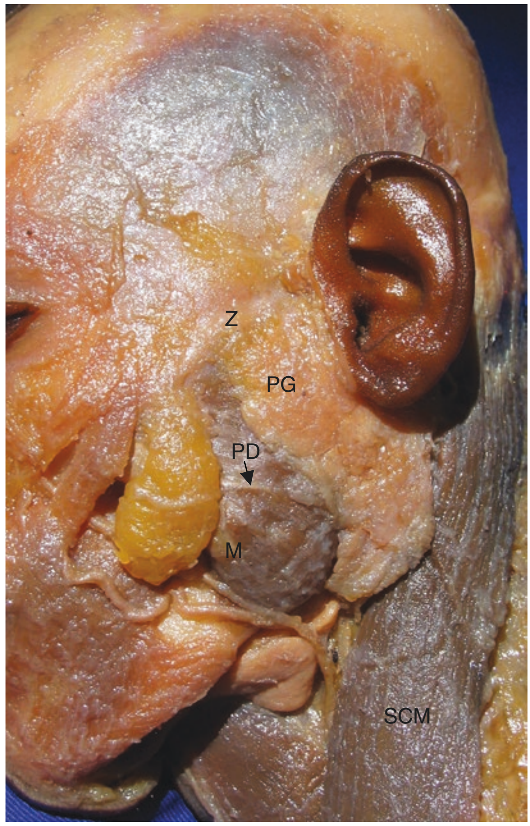

Fig. 1.10 The superficial part of the *parotid gland (PG)* is shown bound by the *zygomatic process (Z), masseter muscle (M), and the sternocleidomastoid muscle (SCM)*. Note the *parotid duct (PD)* traversing the masseter to pierce the buccinator muscle (not shown) deep to the buccal fat pad (not labeled). (With permission from Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil)

Parotid Gland

The parotid gland, the largest of the salivary glands, is located in the retromandibular fossa, anterior to the ear, and sternocleidomastoid muscle. It is wedged between the mastoid and styloid process posteriorly and below by the angle of the mandible (Fig. 1.10). The superior limit is usually defined by the zygomatic arch. Parts of the superficial lobe cover the ramus of the mandible and the posterior part of the masseter muscle, over which runs the main parotid duct (Fig. 1.11). The parotid duct (also known as Stenson's duct) [8] pierces the buccinator muscle to open opposite the upper second molar in the oral vestibule. The parotid duct may be surrounded by a small portion of parotid glandular tissue termed the *accessory lobe* and is closely associated with the buccal branch of the facial nerve (refer to Fig. 1.17b).

The deep component of the parotid is defined as deep to the plane of the facial nerve. It is defined by the posterior border of mandibular ramus and medial pterygoid anteriorly, the inferior surface of the petrous temporal bone superiorly, the styloid process and associated muscles medially, and mastoid process with associated muscles inferoposteriorly.

The muscles attached to the mastoid and styloid process separate the deep glandular tissue from the carotid sheath containing the internal

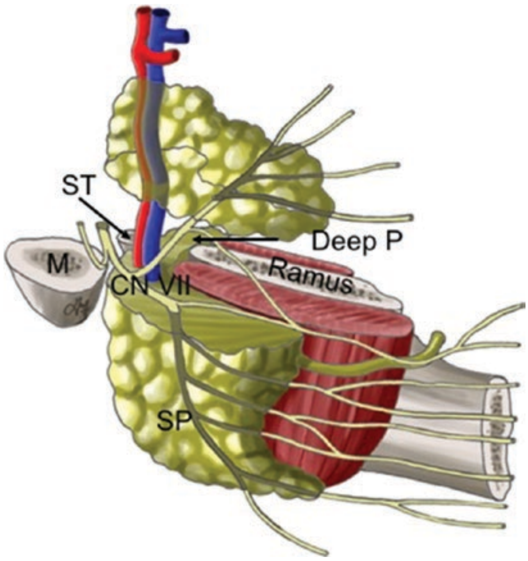

Fig. 1.11 An illustration of the *superficial (SP) and deep parotid (DeepP) gland* in relationship to the branches of the *facial nerve (CNVII)*, *mastoid (M), styloid (ST), and ramus of the mandible (Ramus)*. (With permission from Dr. Gian-Marco Busato, University of Toronto, Otolaryngology)

carotid artery, internal jugular vein and vagus nerve, and the cranial nerves IX, XI, and XII. The terminal branches of the external carotid artery pass through the deep gland. The auriculotemporal nerve, a sensory branch of cranial nerve V3, emerges from the upper aspect of the gland. Superficially, the parotid is surrounded by skin and fascia and parotid lymph nodes.

The parotid gland is vascularized by the superficial temporal artery and the transverse facial artery and serviced by the retromandibular vein, which passes through the gland. Secretomotor innervation to the gland is from postganglionic parasympathetic fibers from cranial nerve IX via the otic ganglion. Sympathetic neurons from the superior cervical ganglion produce vasoconstriction resulting in dry mouth [2].

External Ear and Relationships

Divided into external, middle, and inner portions, each ear extends from the auricular pavilion, located posteriorly to the temporomandibular joint, to the petrous part of the temporal bone called the labyrinth. The external ear is formed by the auricle, or auricular pavilion, or pinna, and acoustic meatus, responsible for capturing, amplifying, and conducting the ambient sounds toward the middle ear.

The external ear is sensible to touch, pain, and temperature, receiving branches from several nerves including the auriculotemporal branch of trigeminal, auricular branch of vagus, greater auricular branch of cervical plexus, and lesser occipital from the cervical plexus. Its vascularization occurs from collateral branches of the superficial temporal and posterior auricular arteries, which are terminal and posterior branches of the external carotid artery. Immediately in front of the auricular pavilion it is possible to perceive the pulse of the superficial temporal artery by pressing it against the zygomatic-temporal arch during its passage.

The auricle also maintains a functional relationship with superior, anterior, and posterior superficial auricular muscles innervated by cranial nerve VII. The origin of these muscles occurs in the superficial muscular aponeurotic system (SMAS) and in some people are developed enough to provide small movements of the auricle.

The more lateral portion of the auricle is located immediately postero-superiorly to the TMJ and parotid gland, and antero-superiorly to the mastoid process of the temporal bone. It is composed by a thin cartilaginous structure of fibrocartilage nature covered by skin containing fine hairs, sebaceous, and sweat glands. A series of reliefs and depressions define its external surface: helix; anti-helix; scaphoid fossa; fossa triangularis; superior and inferior roots of antihelix; tragus; antitragus; intertragic notch; root of helix; superior and inferior concha; and lobule (Fig. 1.12). The auricle is responsible for capturing and conducting sound through the acoustic meatus, and provides a small functional gain of amplification of the air acoustic pressure that will affect the tympanic membrane.

The external acoustic meatus is defined as a permanently open channel of rigid walls with an adult, extending approximately 25 mm from the auricular pavilion (laterally) to the tympanic

Fig. 1.12 A schematic of the external with the major external features labeled. (With permission Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil)

membrane (medially). The acoustic meatus is divided into two parts: a lateral cartilaginous skeleton and medial bone skeletal, being responsible for amplifying the sound by up to 15 dB during its resonance in the inner walls of the canal.

In the lateral half of the acoustic meatus, which is elastic and sinuous-shaped, the superficial epidermal coat (stratum corneum) is composed of dead keratocytes layers, offering a waterproof and flexible surface barrier important for the protection of the underlying tissues to potential harmful effects such as dryness, moisture, abrasion, chemical substances, and invasion of microorganisms.

Also found in this lateral portion of the meatus are hypodermis adipose tissue, hair follicles, and sebaceous and ceruminous glands, providing an environment of greater protection to the invasion of microorganisms [7].

In the medial half of the acoustic meatus, the bone portion, the skin is thin, smooth, and dry. It has no hairs or glands and is closely adhered to the bone. At the inner end of the meatus the skin extends to form the outermost layer of the tympanic membrane.

Tympanic Membrane

The tympanic membrane, also known as ear drum, is thin, whitish, and generally translucent in appearance, which often allows us to observe part of the structures present in the tympanic cavity. It has a slightly oval shape with an approximate mean diameter of 9–10 mm and 0.1 mm of thickness. Its disposition is conical with a very obtuse apex, facing toward the interior, and its structure is formed by layers of epidermis (ectoderm), laterally, fibrous tissue (mesoderm), and mucous membrane (endoderm), medially [7].

The tympanic membrane consists of two parts, the most extensive being the tense part (pars tense) which is supported by a fibrocartilage ring fixed to the tympanic sulcus of the U-shaped temporal bone, which maintains a certain tension, allowing the vibration of the membrane to the shock of the acoustic waves. The other portion of the membrane, anterosuperior, smaller, thinner, and loose, constitutes the upper pole of the membrane and is known as the flaccid part (pars flaccid). This portion of the membrane is composed only of skin and mucosa.

The center of the membrane is called the umbo. The manubrium of the hammer is attached to the medial surface of the tympanic membrane, which is closely related to the tympanic cord, a branch derived from the facial nerve, which has gustatory sensory fibers coming from the anterior 2/3 of the tongue, besides containing secretomotor (parasympathetic) fibers for submandibular and sublingual glands. The free end of the manubrium impinges on the obtuse apex of the tympanic cone. The incisions through the membrane are often made in the postero-inferiorly quadrant, thus avoiding the ossicles and chorda tympani nerve. The tympanic membrane is highly sensitive, the V and X pairs of cranial nerve (trigeminal and vagus nerves, respectively) innervate its lateral surface and the IX cranial nerve (glossopharyngeal nerve) innervates its medial surface.

Mandibular Region

The mandible is a mobile, high-strength bone that articulates with the temporal bones and is responsible for the greater composition of the lower third of the face. Structurally, its greater cortical thickness compared to the other bones of the face reflects the insertion of the powerful mastication muscles. Bilaterally, the upper, posterior part of the mandible consists of the condyle (Fig. 1.13), responsible for the articulation with the temporal bone forming the temporomandibular joint. Anterior to the condyle we find the coronoid process, the insertion site of the temporalis muscle tendon.

In the upper part of the mandible we find the alveolar process that is responsible for supporting the teeth. With the loss of teeth and reabsorption of the alveolar process the height of the mandible body decreases, generating a prognathous appearance in the patient, since there is a higher jaw elevation due to the excessive rotation of the TMJ [11].

The base of mandible (lower portion of the body) extends posteriorly to meet the posterior border of the branch, forming the angle of the mandible, which is the insertion site of the masseter and medial pterygoid muscles. The height of the angle (gonial angle) varies with individuals and there is evidence to indicate those with higher gonial angles are at greater risk of mandibular angle fractures [20]. The anterior border of the branch continues laterally in the body of the mandible in the form of reinforcement to the skeletal structure called the oblique line.

On the medial aspect (Fig. 1.14) of the mandible's body is the mylohyoid line, the site of insertion of the mylohyoid muscle, which divides the sublingual region into the superior and inferior parts. Below the mylohyoid line, in the region of molar teeth, there is a bone depression called the submandibular fossa, where the submandibular salivary gland is located, whose secretory duct extends anteriorly until it opens into the sublingual caruncle.

Anteriorly, the central region of the bone between the mental foramina experiences the greatest bone resistance due to the concentration of forces between the right and left sides during chewing. In addition to the mental tubercles and the mental protuberance anteriorly, in the lower and posterior part of the chin we find the genial tubercles (area of muscle insertion) and the digastric foveas where digastric muscles are inserted.

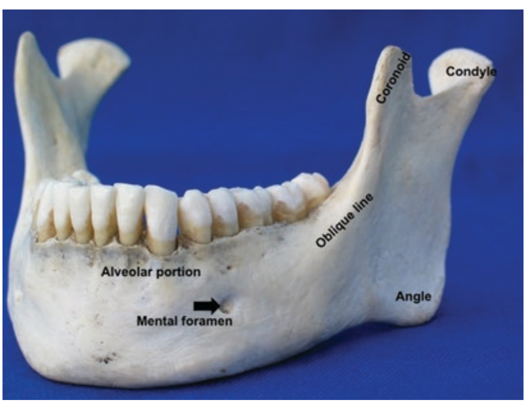

Fig. 1.13 An anterior view of the mandible. Labeled are some of the major boney landmarks. (With permission, Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil)

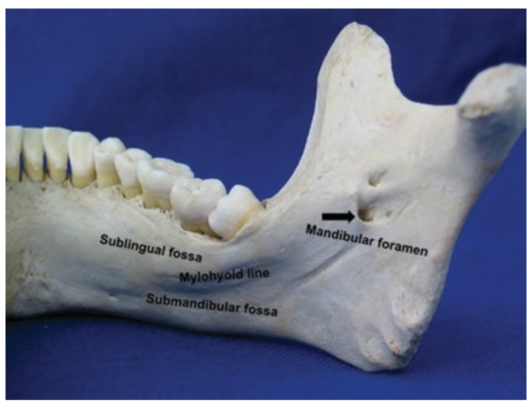

Fig. 1.14 A medial view of the mandibular ramus and body illustrating the relationship of the *mylohyoid line* to the *fossa* above and below. Also indicated is the *mandibular foramen* through which passes the inferior alveolar nerve and vessels. (With permission, Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil)

Being a bone with great cortical thickness [16], the mandible houses important foramina that give passage to the neurovascular structures. In roughly the middle of the medial aspect of the ramus and body sits the mandibular foramen, which gives passage to the inferior alveolar nerve (IAN), a branch of the mandibular nerve (third branch of cranial nerve V), responsible for the sensitive innervation of the bone, teeth, and lower lip. The inferior alveolar artery and vein also travels through this foramen. In the lateral portion of the mandible's body, between premolars, we find the right and left mental foramen, responsible for the passage of the vasculo-nervous structures of the same name.

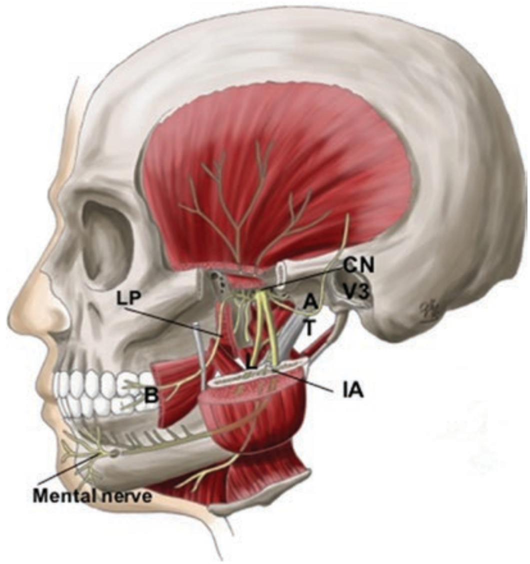

Fig. 1.15 An illustration of the infratemporal region with the sensory branches of cranial nerve V, *mandibular division CN V3*. The *inferior alveolar nerve (IA)* is emerging from the mandibular foramen and its terminal branch, the *mental nerve*, is seen at its corresponding foramen. The other branches of V3 are also indicated, *auriculotemporal (AT), buccal (B),* and *lingual (L)*. The *lateral pterygoid (LP)* muscle has been removed to expose these nerve branches. (With permission from Dr. Gian-Marco Busato, University of Toronto, Otolaryngology)

Muscle Relationships

The muscles of mastication consist of four bilateral pairs of muscles, being three elevators (masseter, temporalis, medial pterygoid) and one protrusor (lateral pterygoid) of the jaw. All these muscles insert on the mandible and originate from the neurocranium. These attachments enable muscular contractions that move the mandible in diverse planes and directions with their fulcrum being the temporomandibular joint. The mastication muscles exert great forces on the mandible resulting in thick cortical bone compared to the other facial bones.

The muscles of mastication are innervated by the motor root of the trigeminal nerve (cranial nerve V), which emerges in the exocranium through the foramen ovale at the base of the skull, as part of the mandibular division of the trigeminal nerve. Just inferior to the foramen ovale, the motor root divides into branches named according to the muscle which it innervates. The motor root is accompanied by the sensory branches of the mandibular division of the trigeminal nerve. In addition to the mastication muscles, the motor root also supplies the mylohyoid muscle, anterior belly of the digastric muscle, tensor veli palatini of the soft palate, and tensor tympani of the middle ear. The sensory component of the mandibular division (Fig. 1.15) branches into a long buccal, inferior alveolar, lingual and auriculotemporal branch, providing sensory supply to the skin of the lower lip and jaw, external ear and temporal region, mucus membranes and floor of the oral cavity, mandibular teeth, and gingiva.

The is some variability in the vertical position of IAN and the mandibular canal relative to the alveolar ridge and basal margin of the mandible, and its path from the lingual aspect of the mandible toward the buccal aspect as it passes anteriorly from the molar region to the mental foramen [1, 14].

Temporalis Muscle

Temporalis is a fan-shaped muscle easily palpated on the lateral aspect of the skull over the temporal, sphenoid, and parietal bones (Fig. 1.16a). Its fibers spread superiorly filling most of the entire temporal fossa and then converge inferiorly to a tendinous insertion on the coronoid process of the mandible. The upper limit of the muscle extends to the inferior tempo-

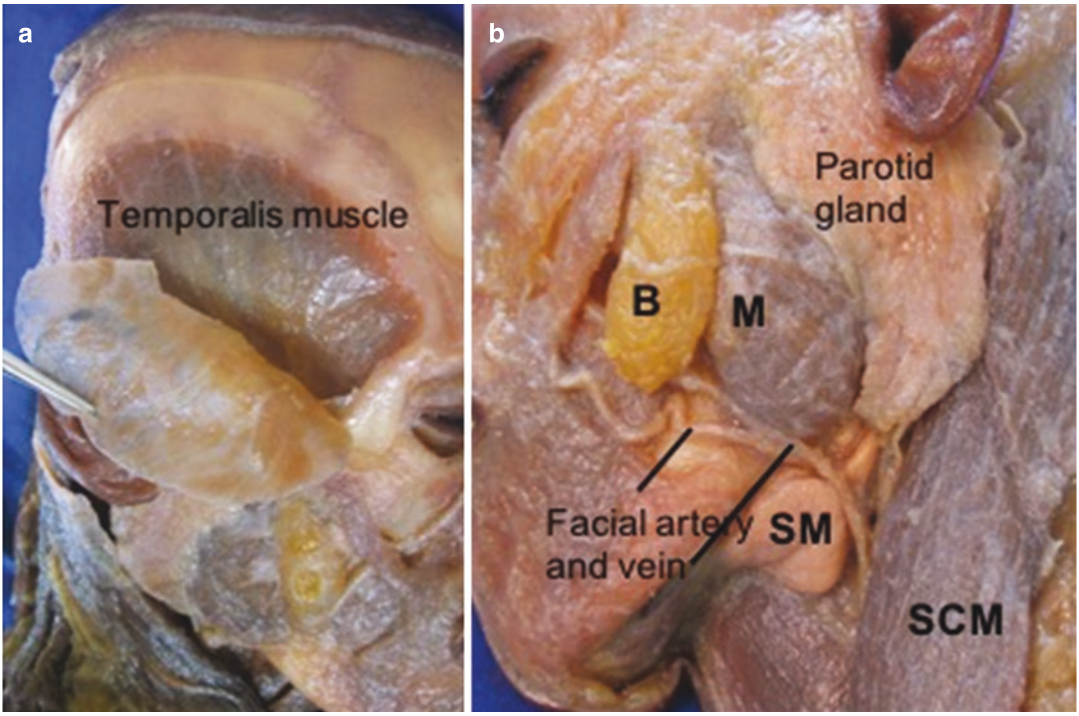

Fig. 1.16 (**a**) The *temporalis muscle* is exposed under its reflected fascia. (With permission from Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil) (**b**) The relationships of the *masseter muscle (M)* are indicated: anterior the *buccal fat pad (B)* and *facial artery and vein*, posterior the *parotid gland*, inferiorly the *submandibular gland (SM)* and the *sternocleidomastoid muscle (SCM)*

ral line, which runs from the frontal bone, passing through the parietal to the squamous part of the temporal bone. The fan-like arrangement of the muscle can be described as three functional groups: the vertical anterior group, oblique middle group, and horizontal posterior fiber group. This arrangement of fibers allows the muscle to elevate and retract the mandible.

Masseter Muscle

The masseter is a thick, rectangular-shaped muscle that can be palpated along most of its length, except for the posterior third of the muscle that is covered by the parotid gland. The parotid duct courses over the lateral side of the muscle as it disappears beneath the buccal fat pad. The masseter originates from the zygomatic arch and is inserted at the angle of the mandible and lateral portion of the lower third of the mandibular ramus. The fibers run primarily vertical, with a posterior slant, making this muscle a strong elevator of the jaw. The muscle can be described as having a superficial and deep portion. The superficial fibers are the more posteriorly arranged muscle. Just anterior to the masseter runs branches of the facial artery and vein (Fig. 1.16b). Despite the close relationship of the facial artery and vein, the masseter also receives vascular supply from branches of the deeper maxillary artery and transverse facial artery (a branch of the superficial temporal artery).

Lateral Pterygoid Muscle

The lateral pterygoid differs from the other mastication muscles because it is short, horizontal in orientation and maintains a direct continuity with the temporomandibular joint (TMJ). The arrangement of the muscle means it is the only one of the four that is not an elevator of the jaw.

This muscle has a triangular shape, whose apex is positioned at the TMJ (Fig. 1.17a). Anteriorly, the muscle has two distinct parts known as the upper and lower heads. The upper head originates on the infratemporal crest of the

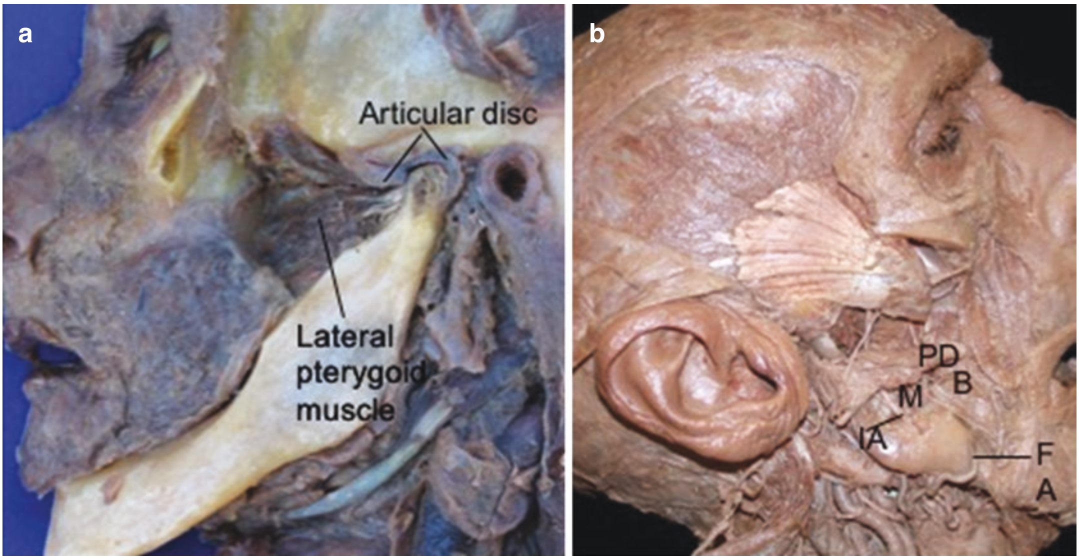

Fig. 1.17 (**a**) The tendon of the *lateral pterygoid* is seen attaching in common with the *articular disc* at the TMJ. Anteriorly the lateral pterygoid arises from the lateral pterygoid plate (not labeled). (With permission from Dr. Atson Carlos de Souza Fernandes, Bahiana School of Medicine and Public Health Brazil) (**b**) The ramus of the mandible has been removed to reveal a portion of the *medial pterygoid muscle (M)* seen deep to the *parotid duct (PD),* which is piercing the *buccinator muscle (B).* Within the bone the *inferior alveolar nerve (IA)* is exposed in the mandibular canal. The *facial artery (FA)* is winding over the mandible

greater wing of the sphenoid. The upper head courses posteriorly to attach on the anterior portion of the TMJ capsule and articular disc. Therefore, the lateral pterygoid has a direct connection to the articular joint and may significantly influence the path of the articular disc. The lower head is larger and originates from the outer surface of the lateral pterygoid plate. Its fibers are more horizontal in orientations running posteriorly to insert into the pterygoid fovea.

Medial Pterygoid Muscle

The medial pterygoid, as well as the lateral pterygoid, is located in the infratemporal fossa and therefore is not palpable during examination. The medial pterygoid, although smaller than the masseter, has similar orientation characteristics. Its fibers, parallel to those of the masseter, are short, tendinous, and intertwined, resulting in strong contractions. This muscle originates in the pterygoid fossa of the pterygoid process of the sphenoid bone. Thus, it is located between the lateral pterygoid and tensor veli patatine muscles. Its fibers travel obliquely, inferiorly, and posteriorly to insert into the medial portion of the lower third of the ramus and angle of the mandible (Fig. 1.17b).

Facial Artery

The typical description of the facial artery describes it as a branch of the external carotid artery in the carotid triangle, just above or in congruence with the lingual artery at the level of the hyoid bone. It hooks over the mandible medial to the ramus and takes a tortrous route to the face. At this point it is usually deep to the superficial part of the submandibular gland (refer to Fig. 1.17b) and then winds a path that enters the face anterior to the border of the masseter muscle.

Variations in the path of the facial artery and vein with respect to its depth, branching, or relationship to the submandibular gland [24] should always be considered (Fig. 1.18). Facial artery morphology is described as either Type I–Type VI [12] with variations in asymmetry and point

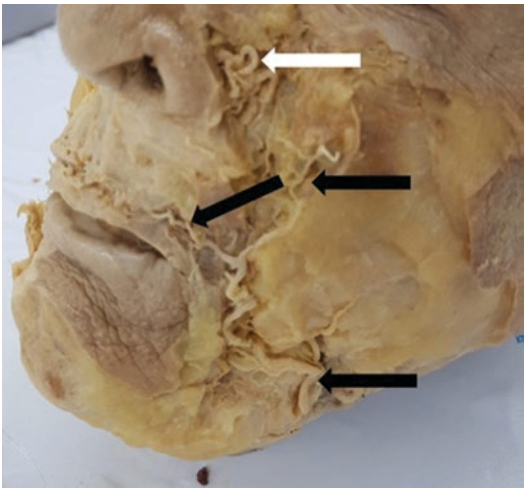

Fig. 1.18 The left side of the face is depicted with the *facial artery indicated by the black arrows*. Note its course over the mandible, anterior to the masseter and parotid gland. This vessel branches medially to form the superior labial artery and laterally giving a branch to the zygomatic region. A *winding artery, white arrow,* is seen emerging from the infraorbital foramen to supply the nasal ala. It was not determined if this branch anastomoses with the facial artery or acts separately. (With permission from Dorota Klubowicz, University Western Ontario)

of termination. Even if the bilateral facial arteries are symmetrical in their path they may differ in depth and diameter [10] .

The most common facial artery pattern (Type 1 according to Lohn et al. classification, [12]) presents with the artery entering the face from the neck, then proceeding to the medial angle of the eye to terminate as the angular artery. As it travels across the face, the facial artery can travel either near or directly underneath the nasolabial fold where it gives off several branches including: inferior labial artery, superior labial artery, and lateral nasal artery [4]. The facial vein, although more direct than its accompanying artery, also shows variability in its path with respect to the submandibular gland and mandibular angle [5].

Lymph Nodes

The lymph nodes of the lateral cranial facial region are closely aligned with the vasculature of the area but named according to the area they drain. In broad terms, the lymph nodes can be grouped into a horizontal circular ring grouping that extends from the occipital area anteriorly to the submental region, and a vertical chain grouping along the anterior and lateral neck including tracheal, retropharyngeal, deep, and superficial cervical nodal groups [8, 2].

The horizontal circular ring is composed of several nodal groupings with varying nomenclature (Fig. 1.19):

- Occipital – follows the occipital artery and drains the posterior scalp and neck.
- Posterior auricular or mastoid – a few nodes on the mastoid drain the posterior temporoparietal region, posterior pinna, and external acoustic meatus.
- Superficial parotid or pre-auricular – few in number found in front of the tragus and auricle, and drain superficial temporal region.
- Parotid or deep parotid and facial – a small group superficial to the gland and those deep within the parotid gland. They drain the nasal area, external acoustic meatus, infratemporal region, orbit, lateral eyelid and upper teeth, and cheek. This group includes the buccal, maxillary and parotid nodes.
- Submandibular – found between the mandible and submandibular gland these drain the tongue, teeth, anterior nasal cavity, and upper lip. The submental and facial nodes drain into the submandibular nodes.
- Submental – on the mylohyoid and drain tip of tongue, floor of mouth, and lower lip and chin.
- Superficial cervical – follow the external and anterior jugular veins and drain the corresponding area.

The efferent flow of lymph from all but the superficial parotid group drains into the deep cervical nodes. The superficial parotid nodes drain into the superficial cervical group.

The vertical or deep cervical chain of nodes (Fig. 1.19) are associated superiorly with the internal jugular vein and carotid artery and extend laterally and inferiorly to just above the clavicle (supraclavicular nodes). These nodes are usually large in size and more numerous than the circular

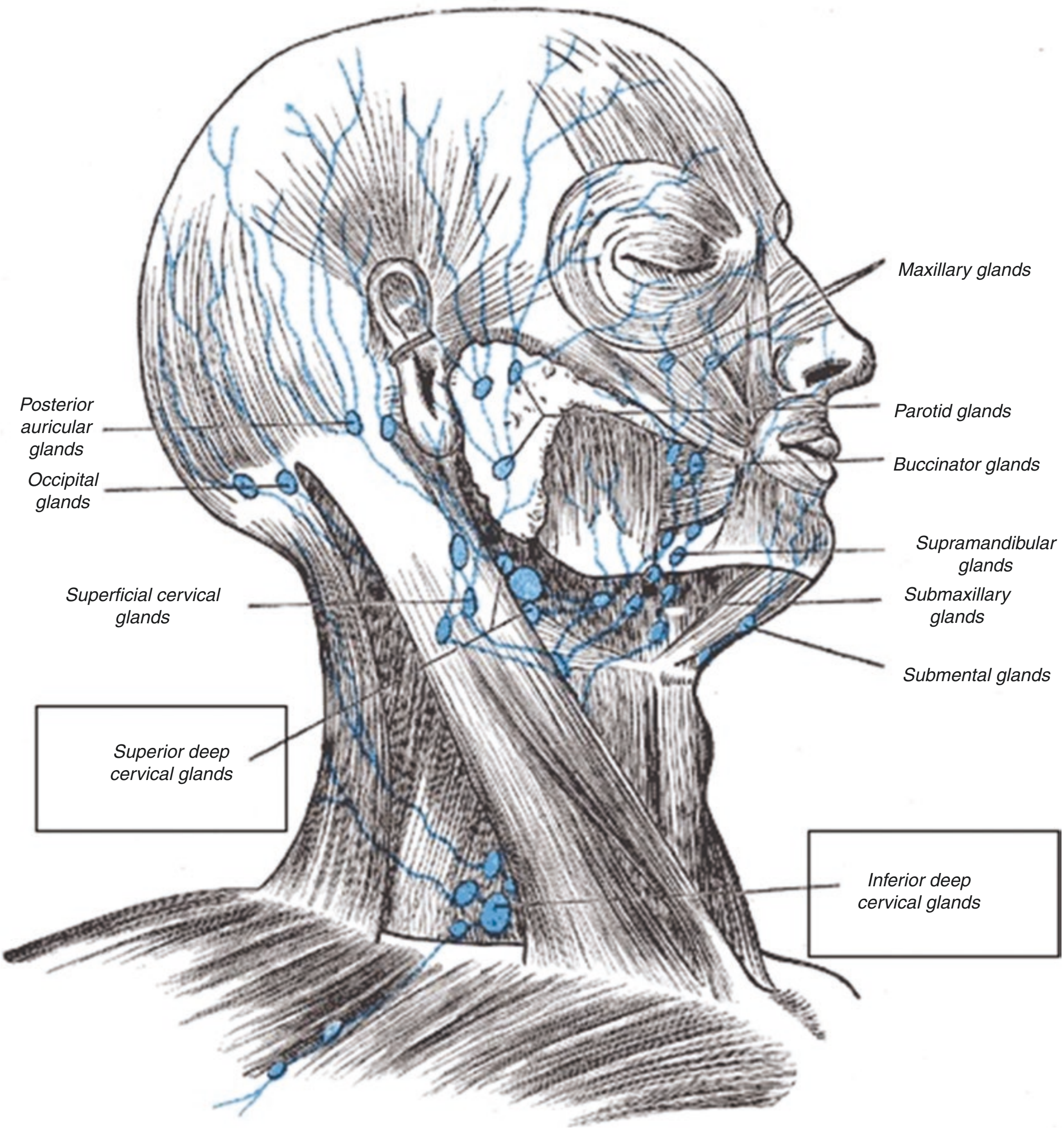

Fig. 1.19 Classic illustration of the lymph nodes of the head and neck. The deep lymph nodes are indicated by the *boxed text*. By Henry Vandyke Carter – Henry Gray (1918) Anatomy of the Human Body. Bartleby.com: Gray's Anatomy, Plate 602, Public Domain, https://commons.wikimedia.org/w/index.php?curid=566193

chain. The deep cervical nodes converge to form the jugular lymphatic trunks. The deep chain nodes are classified as:

- Jugulodigastric – found posterior to the mandible and drains the lateral tongue and tonsils.
- Jugulo-omohyoid – found between the superior belly of the omohyoid and internal jugular vein these drain the tongue via the submental and submandibular nodes.
- Para and pretracheal – these are numerous and lie along the inferior thyroid vessels draining the thyroid and trachea region. The efferent vessels are continuous with mediastinal tracheobronchial nodes.

In addition to draining most of the circular ring, the deep cervical nodes receive lymph from the salivary and thyroid glands, tonsils, tongue, nose, pharynx, and larynx as stated above. After the efferent vessels have formed the jugular lymphatic trunk, this trunk joins the thoracic duct on the left and the right lymphatic trunk on the right.

The left supraclavicular node near the jugulo-subclavian venous junction where the thoracic duct terminates is referred to as the Vichow's node. It has clinical significance due to its connection to lymph vessels from the abdomen [17]. Gastric cancer that has spread through the lymphatic vessels may present with an enlarged left supraclavicular node before other symptoms appear.

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2 Principles of Lateral Craniofacial Reconstruction: Anatomic Defect-Based Approach to Reconstruction

Krupal B. Patel, Stephen Y. Kang, and Matthew O. Old

Basic Concepts/Principles

Irish et al. reviewed 77 patients with skull base tumors and classified the defects based on the origin and growth of tumor, and the anatomical boundaries [1]. Region II corresponds to the lateral skull base defect as per their classification. These tumors arise from lateral skull base and extend into the infratemporal fossa and pterygopalatine fossa along with involvement of middle cranial fossa. Memorial Sloan-Kettering group also described a classification system for anterior and middle cranial fossa defects [2]. This classification as it relates to middle cranial fossa is similar to that proposed by Irish et al. Mount Sinai group described another classification system taking into consideration the individual anatomic elements of the defect [3].

Broadly, the lateral craniofacial skeleton includes the external auricle, skin and underlying soft tissue, temporalis muscle, parotid gland, bones – coronoid, temporomandibular joint, zygoma, temporal bone, calvarium, and dura. Approach and resection of the individual structures will depend on where the tumor is located and which structures it involves. For example, a skin cancer of the auricle will involve only the resection of the part of the auricle, a cancer of the external auditory canal may require a lateral temporal bone resection, a tumor involving parotid gland may require a parotidectomy and/or mandibulectomy and/or maxillectomy and/or lateral temporal bone resection and/or temporal craniotomy.

An important concept in any reconstruction is to consider the characteristics of the structures that will be removed after extirpation of the tumor and require subsequent reconstruction. It is equally important to consider different aesthetic subunits and plan incisions either at the border of the aesthetic units to camouflage them or parallel to the relaxed skin tension lines to provide a tension-free closure and minimize contractures. As advocated by Pusic et al., reconstructive ladder does not necessarily hold true in the case of complex skull base resections and thus the simplest method is the one which gives the highest degree of success and in most cases this is local or free flap tissues [2]. This is especially true in cases of salvage surgery or persistent cerebrospinal fluid leak where patients have undergone prior surgery and/or radiation as multiple reports have indicated [4–9]. One of the largest series reported by Neligan et al. of 90 flaps in 87

K. B. Patel (✉)
Head & Neck/Endocrine Oncology, Moffitt Cancer Center and Research Institute, Tampa, FL, USA
e-mail: krupal.patel@moffitt.org

S. Y. Kang · M. O. Old
Department of Otolaryngology – Head and Neck Surgery, The Ohio State University, Columbus, OH, USA
e-mail: stephen.kang@osumc.edu; matthew.old@osumc.edu

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patients showed that patients who underwent skull base reconstruction using free tissue transfers had lower complication rates compared to those who underwent local flaps [10].

Anatomy

Important aesthetic regions for lateral facial region include: ear, lateral aspect of the forehead subunit, temple, cheek subunits – zygomatic and mandibular, and neck.

The ear is externally lined by skin and the superior two-thirds is made up of cartilage that is thin and pliable, yet maintains its structure. The cartilaginous components include conchal, antihelical, antitragal, helical, and lobular complexes [11–13]. Each of these is important for consideration of reconstruction.

The cheek is the largest aesthetic region of the face and has a broad slightly convex contour. It is bound by the inferior bony orbital rim, nasofacial sulcus, line from lateral canthus to the root of the helix, preauricular crease, melolabial crease, labiomandibular crease, and inferior border of the mandible [14]. The cheek can be further subdivided into zygomatic, medial, lateral (mandibular), and buccal units. Zygomatic and mandibular subunits are relevant in the reconstruction of lateral defects [15]. Several suspensory ligaments also provide the support for overlying the soft tissues to the underlying bony structures. McGregor's patch anchor the soft tissue to the zygoma, mandibular retaining ligament attaches soft tissue to the lower lip forming the labiomandibular crease [16]. The malar fat pad overlies malar region and along with the maxilla provides the convexity of the mid face. Muscles of facial expression also support and provide the structure of the face, most notable being zygomaticus major which is deep to the malar fat pad and is invested by the superficial musculoaponeurotic system.

Deep to the skin is the subcutaneous tissue and as discussed above, the composition varies depending on the subsite. Deep to the subcutaneous tissue is the superficial musculoaponeurotic system (SMAS). SMAS extends over the cheek, inserting anteriorly at the melobial crease and is contiguous with the platysma in the neck. It is discontinuous at the zygomatic arch but forms the temporoparietal fascia over the temporal region and then galea of the scalp [17, 18]. TPF is distinct from and should not be confused with the fascia of the temporalis muscle which is deep to the TPF and covers the temporalis muscle.

Deep to the SMAS is the parotid gland. The parotid gland provides the majority of the volume in the preauricular region primarily over the mandibular subregion of the cheek. Temporalis muscle fills the defect of the temporal fossa. Superficial to the temporalis muscle is the temporoparietal fascia which can be used to harvest the temporoparietal flap. Removal of either the parotid or the temporalis muscle leaves a significant soft tissue defect that is noticeable.

Lateral craniofacial skeleton includes the zygomatic process, zygoma, temporal bone, mandible – coronoid, condyle, temporomandibular joint, ramus, angle and posterior body, maxilla [15]. A detailed discussion on the temporal bone anatomy is beyond the scope of this chapter, however this should be reviewed prior to any surgical procedure. Temporal bone houses the auditory and vestibular systems along with the facial nerve that courses through it.

Special consideration should be directed toward facial nerve which has an intracranial, an intratemporal, and an extratemporal course [15]. The extratemporal course exits from the stylomastoid foramen and courses through the parotid gland and branches at the pes anserius. Facial nerve branches run deep to the muscles of facial expression except buccinator, levator anguli oris, and mentalis which are innervated from the superficial side. The motor nerve to the frontalis muscle – temporal branch of the facial nerve – is the most likely nerve at risk of injury. This is especially the case over the zygomatic arch and in the temporal area. Below the zygomatic arch the SMAS is superficial to the nerve and temporalis fascia is deep to the nerve; at the level of the zygomatic arch, SMA is superficial to the nerve and the temporalis fascia and muscle are deep to the nerve; above the zygomatic arch, the nerve is deep to the frontalis muscle.

Specific Considerations

Auricle

Auricular defects can involve skin only, skin and cartilage, or full-thickness defects. If oncologically feasible, every effort should be made to preserve the upper third of the auricle to provide support for eye glasses. Lateral skin defects, given that the skin is tightly adherent, can rarely be closed primarily without excision of excess cartilage to avoid distortion. If the perichondrium can be preserved, a skin graft can be used for closure. Medial skin defects typically can be closed primarily without excision of excess cartilage, as the skin is more loose and abundant in this region. Defects of the skin and cartilage can be reconstructed either excising a full-thickness wedge followed up primary closure or using a composite graft or flap. Cartilages of the concha, fossa triangularis, and scapha are not critical to the structural support of the ear and thus can be excised to create windows and use posterior auricular subcutaneous tissues for reconstruction.

Small defects of the helix or antihelix (less than 1.5 cm) can be reconstructed using full-thickness wedge excision followed by primary closure. Medium-sized defects (1.5–2 cm) can be reconstructed using a composite graft from the contralateral ear [14, 19]. Several local flaps have been described for repairing auricular defects [19–31]. Local flaps to repair full-thickness helical auricular defects include: chondrocutaneous composite advancement flaps, interpolated tube flaps, postauricular island advancement flaps, and postauricular interpolated flaps. Postauricular island advancement flaps and postauricular interpolated flaps can be used for reconstruction of concha, fossa triangularis, and scapha defects. For more extensive defects that have major structures missing, a three-dimensional autologous rib cartilage framework and soft-tissue coverage, can be used for reconstruction. In these cases, postauricular skin and/or temporoparietal fascia flap can provide the soft tissue component [32–34].

Cutaneous Defects

Depending on the size and location of the cutaneous defects multiple options exist for reconstruction. Local flaps remain the mainstay for the reconstruction of small or even moderate size cutaneous defects providing excellent results [14]. For a small defect granulation, a primary closure, primary closure with asymmetric skin undermining, advancement with M-plasty, skin graft and rhombic flaps can be undertaken. If moderate size cutaneous defects are present transposition, rotation flaps including uninpedicle advancement flaps, rotational cheek advancement flaps or cervicofacial rotation flaps can be utilized. If a significant cutaneous defect is present, one must look at either pedicled flaps or free flaps to manage the defect. Pedicled flaps with cutaneous component or myofascial only that can be skin grafted include fasciocutaneous supraclavicular flap, infraclavicular flap, submental, temporoparietal, temporalis, latissimus, trapezius, and pectoralis flaps. Free tissue transfer options include lateral arm, radial forearm, scapular system including parascapular fasciocutaneous or latissimus, rectus, anterolateral thigh, a fasciocutaneous supraclavicular or radial forearm free flap being the most commonly utilized for this given its pliability, bulk, and long pedicle length.

Contour with or without Cutaneous Defect

Contour of the lateral face is the most obvious cosmetic change that affects the patients after resection of the neoplasms. This does not necessarily have to be a skin defect and can involve the underlying soft tissue defect in the cases of total parotidectomy where there is a significant lack of the underlying volume. Another important consideration is that flaps with a significant muscle component atrophy over time and thus the contour cannot be accurately predicted.

Both regional and free tissue transfer options are available in this case. Regional options include fascia only supraclavicular flap, fascia only infraclavicular flap, pedicled submental, temporoparietal, temporalis sternocleidomastoid, latissimus, trapezius, and pectoralis flap.

Free tissue transfer options include lateral arm, radial forearm, scapular system including parascapular or latissimus, rectus, and anterolateral thigh.

Extended Contour Defects:

In the event, that part of the mandible or maxilla requires resection, one can reconstruct the bone defect along with the soft tissue volume loss. Purely lateral zygoma defects do not require a bony reconstruction, as once the volume is replaced the defect is not as noticeable. In these circumstances, either a fibula with a large skin paddle or scapular system can be utilized for reconstruction. If the defect involves the anterior maxilla, a bony reconstruction would be required as a soft tissue only option would result in significant volume loss over time. A fibula or scapula tip can be utilized for this. Scapula tip can be positioned in many different orientations depending on the goals of the bone reconstruction. It is also an excellent choice for orbital support.

Reconstruction

Cervicofacial Rotation Flap

Cervicofacial rotation flap is based on random blood supply and does provide an excellent choice in patients who cannot tolerate prolonged anesthesia. Although first used by Conley in 1960, the name "cervicofacial flap" was first used by Kaplan in 1978 [35, 36]. The advantage of cervicofacial is the ability to cover large defects, excellent skin match, pliability, and ability to reconstruct at the same time (Fig. 2.1). Careful incision planning is required. The flap can be extended over the clavicle and upper chest if the flap is to be used to reconstruct a superiorly based defect. Depending on the size of the defect, location of the defect and cosmesis, cervicofacial flaps can be anteriorly based or posteriorly based flap and it can be designed based anterior or

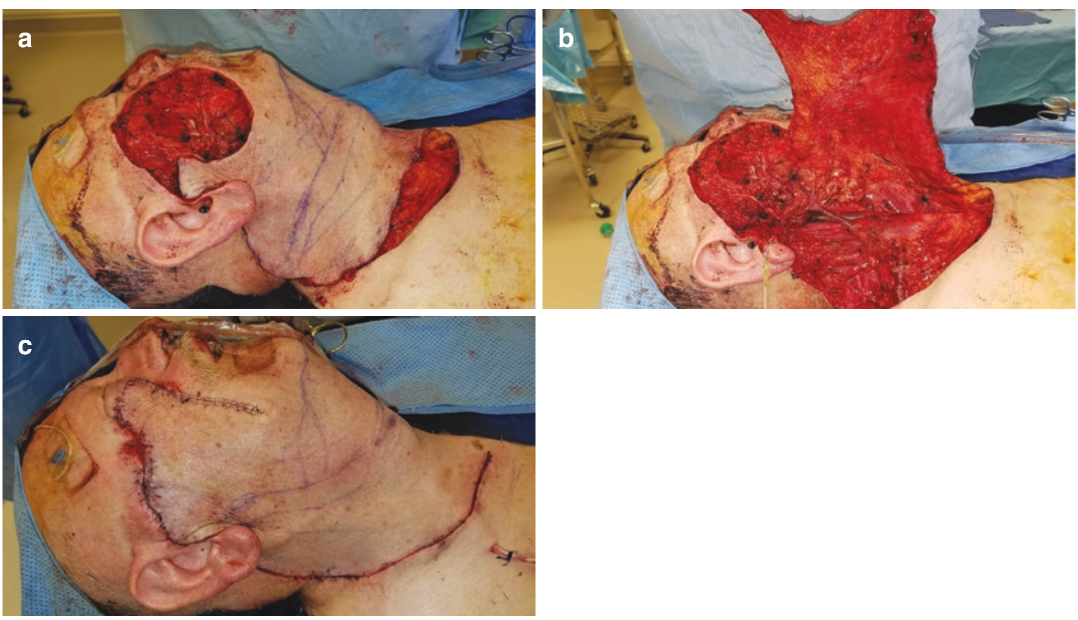

Fig. 2.1 (**a**) A large cheek defect is showcased following excision of cutaneous squamous cell carcinoma and parotidectomy. (**b**) The elevated cervicofacial rotation flap is shown. Note the large base of the flap to avoid ischemia of the flap. (**c**) Final inset and closure of the defect

posterior base. Given its random blood supply, the biggest risk is blood flow to the distal tip, in patients who are smokers. Cervicofacial flaps do not provide any significant bulk and thus cannot be used to reconstruct defects that require the volume.

Pedicled Flaps

Pedicled Submental

Submental island flap (SMIF) was first described by Martin et al. in 1990 as a cutaneous, myocutaneous, and osteocutaneous pedicled rotation flap based off of the submental branch of the facial artery [37]. There have been reports of using submental flap as a hybrid submental flap – part pedicled, part free, where the venous system is anastomosed for a better arc of rotation and longer pedicle length [38, 39].

Submental flap has been utilized for reconstruction of the parotid/cheek skin and lateral temporal bone defects [37, 40–43]. In the largest of the series by Thompson et al. describing the use of submental flap for reconstruction of the lateral temporal bone defects, increased soft tissue coverage was provided by harvesting bilateral anterior bellies of the digastric and mylohyoid muscles. Compared to the free anterolateral thigh flap, the submental group had shorter operative time and hospital stay than the anterolateral flap group with fewer debulking revisions.

Submental flap has also been described as an osteocutaneous and as a reverse flow through flap by ligating the facial artery proximally to the root of the submental artery and thereby increasing the arc of rotation of the flap [37]. Both of these modifications have been utilized to make the SMIF more versatile in the reconstruction of the maxillary defects [44, 45].

Advantages of the submental flap include short harvest time, within the operative head and neck field, ability to harvest as cutaneous, myocutaneous and osteocutaneous flap, good skin color match and bulk and ability to close the donor site primarily.

Submental flap does its limitation. Even though largest skin paddle used by Howard et al. was 11 cm × 17 cm, this is not always possible [37]. In young patients or patients with previous neck irradiation, the ability to harvest a large skin paddle can be limited due to decreased skin laxity with increased flap loss. This can also affect the ability to close the donor site in a primary fashion and result in wound dehiscence [46]. There is also a risk to the marginal mandibular nerve when the flap is harvested in a subplatysmal plane.

Supraclavicular Flap

Supraclavicular flap (SCAIF) is a fascicocutaneous flap that is pedicled off the supraclavicular artery – a branch of the transverse cervical artery [47]. Although previously described, Pallua et al. in 1997 discussed its use, first in cases of mentosternal burn contracture release, and then subsequently in head and neck reconstruction [48, 49]. Cadaveric studies have shown that the pedicle can supply angiosomes ranging in size from 10 × 22 cm to 16 × 30 cm [49]. The flap can also be harvested with no skin island for the reconstruction of contour defects [50].

SCAIF has been described to reconstruct the various head and neck defects including oral cavity, oropharynx, parotid/cheek skin, laryngectomy, and lateral temporal bone defects [50–55]. Epps et al. utilized SCAIF for the reconstruction of the contour defects left behind after radical parotidectomies by de-epithelializing the SCAIF flap [50].

SCAIF has limited donor site morbidity. Shoulder function following SCAIF was evaluated by Emerick et al. Although, the study included only 10 patients, they did measure both objective and subjective shoulder function. Patients undergoing SCAIF appeared to have limited postoperative morbidity with some limitations in the shoulder range of motion.

Advantages of the supraclavicular flap include short harvest time, within the operative head and neck field, ability to harvest as fasciocutaneous or fascial only flap, good skin color match, and ability to close the donor site primarily. It also can be a sensate flap when the cervical plexus nerves are preserved.

SCAIF does have some disadvantages. By its virtue of being a fasciocutaneous flap, it tends to be pliable but lacks the bulk that is often required for the reconstruction of parotid defects. Although head and neck irradiation field excludes the donor site of SCAIF, there is higher risk to the flap as the tunnel where the flap is brought into the neck can be tight due to excessive scar tissue [56]. Su et al. also found higher rate of both donor site and partial and total flap loss when using the SCAIF in a vessel depleted previously irradiated patients [57]. Additionally, given that the pedicle of the flap comes off the transverse cervical artery, a previous neck dissection or nodal disease in the area can result in the vascular compromise of the pedicle.

Pedicled Latissimus

Latissimus can be used as either a pedicled or a free flap. As a free flap it can be combined with other components of the scapular system as well. It is based on the thoracodorsal artery. This flap generally is raised as a myofascial flap due to the excessive bulk of the skin and adipose tissue.

Pedicled Trapezius

Lower island trapezius flap is based on the transverse cervical artery [58, 59]. The advantage of the flap is that it is in the operative field and will easily reach the lateral skull base. Care must be taken to avoid inadvertent injury to the transverse cervical artery during posterior neck dissection.

Temporoparietal Flap (TPF)

TPF is an extension of the SMAS and is deep to the subcutaneous tissue over the temporal region. It is supplied by temporalis artery and vein [15]. TPF flap can be used for the reconstruction of significant auricular defects by embedding three-dimensional cartilage templates or provide soft tissue coverage over the temporal bone defects [60]. Skin grafts can be placed on top of the vascularized TPF flap.

Temporalis Flap

Temporalis muscle can be rotated over the temporal bone resection [10, 59]. It does result in a hollow over the temporal fossa. The blood supply to the temporalis muscle is from the anterior and posterior deep temporal arteries which can be inadvertently injured during resection of mandibular condyle and coronoid process [10].

Pectoralis Major Flap

Pectoralis major flap (PMF), based on the thoracoacromial vascular pedicle, has been the workhorse of the head and neck reconstruction. It was first described in 1968 by Hueston, but Ariyan was first to describe its use in head and neck reconstruction in 1979 [61, 62]. PMF can be used as a musculocutaneous flap or as a muscle flap only with a split-thickness skin graft for the external component. PMF has been used for the reconstruction of temporal bone and skull base defects [63–71].

Advantages of the PM flap include predictable pedicle, rich vascularity, large skin territory, primary closure of the donor site and bulk with muscle that can provide coverage for the great vessels and protection against fistula. Additionally, it tends to be outside the primary head and neck radiation field thus providing non-irradiated healthy tissue for coverage.

Disadvantages of the PM flap include its bulkiness – when the defect is small and requires a smaller, more pliable tissue for reconstruction, PM flap is not ideal, cosmetic effect on donor site – distortion of the breast tissue occurs in female patients in addition to the loss of muscle tissue over the chest, and limited arc of rotation. Although there are techniques that help with each of these issues, they cannot be completely addressed – especially bulk and reach of the flap. Arc of rotation can be improved by detaching the humeral attachment of the PM, however it does limit its reach. Excess bulk of the PM flap can be an issue if it used in areas where pliability is more preferred. To decrease the bulk, skin island can be harvested over the sternum or harvest the flap as muscle only flap [72–74].

Free Tissue Transfer Options

Lateral Arm

There are several key advantages of the lateral arm donor site [75–77]. If used for resurfacing of skin defects of the head and neck, the lateral arm has excellent color match to surrounding skin, providing outstanding cosmesis (Fig. 2.2). In addition to the color match, the fat in the lateral

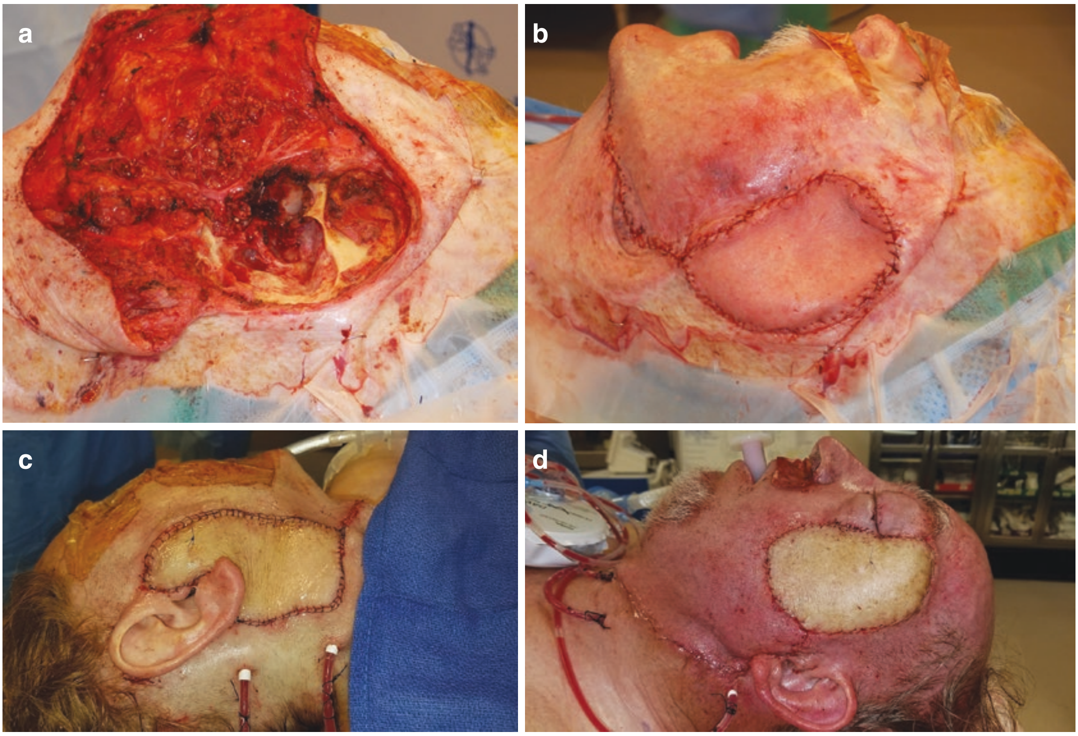

Fig. 2.2 (**a**) Example of a defect from parotidectomy and temporal bone resection due to parotid malignancy. (**b–d**) Inset of lateral arm free flap

arm is well compartmentalized and resists ptosis, making it an excellent choice for skin resurfacing of facial and neck defects. The lateral arm also provides access to the donor nerves such as the posterior cutaneous nerve of the forearm, which can be utilized as a vascularized nerve graft. The donor site is able to be closed primarily in many cases, without the use of a skin graft. Finally, the donor site permits a two-team approach.

Radial Forearm Free Flap

The radial forearm donor site is a workhorse donor site frequently utilized in head and neck reconstruction [4–7, 78]. Radial forearm donor site is thinner, more pliable, with larger vessel caliber and a long pedicle. This donor site also permits two-team surgery. In patients with high body mass index (BMI), the radial forearm donor site may be preferred over the lateral arm. Lack of adipose tissue on RFFF is a disadvantage in cases where contour or increased volume is required. However, a “beavertail” modification including the subcutaneous fat in the proximal forearm connected to the flap through the subdermal plexus permits rolling this tissue into the defect to increase the volume of the flap (Fig. 2.3) [79]. Unlike the lateral arm, most radial forearm donor sites require skin graft for closure. One of the advantages of RFFF is the ability to harvest bone – osteocutaneous RFFF (OCRFF). OCRFFF can be used in instances where either a mandible, maxilla, zygomatic, or orbital floor defects need to be reconstructed [4].

Rectus Abdominis

Rectus abdominis can be utilized for lateral skull base defect [8, 9]. The main advantage of this donor site is the ability to center the skin paddle around one or two periumbilical perforators and a long pedicle that is useful for skull base reconstruction. These flaps may be harvested in a perforator-based fashion to avoid excessive bulk and ptosis and to maximize pedicle length. Donor

Fig. 2.3 (**a**) Recurrent squamous cell carcinoma of the forehead is outlined with the resection margins. (**b**) Cutaneous paddle of the radial forearm free flap (outlined) along with adipose ("beaver tail") tissue tail (hashed area) is elevated. (**c**) The cutaneous paddle addresses the forehead defect and the adipose tissue tail provides contour to the defect resulting from the parotid defect

site morbidity is also decreased when harvested based on a perforator and the anterior rectus sheath is preserved. However, in cases where dural defect is present, the fascia and a cuff of rectus muscle can be helpful. The perforator-based rectus donor site can be used for many complex soft tissue defects [80]. The donor site can be closed primarily.

Anterolateral Thigh

The anterolateral thigh (ALT) free flap donor site has been utilized in the reconstruction of lateral skull base defects (Fig. 2.4) [76, 81]. The donor site can have variable volume and thickness of the adipose tissue. ALT most commonly has musculocutaneous perforators [82]. Thus, unless septocutaneous perforators are present, a perforator-based ALT must be harvested in cases where adipofascial flap is desired. The ALT donor site permits two-team surgery and can be closed without a skin graft. While the vascular anatomy may vary this flap may be harvested with relative ease [82]. Color match to facial skin is very poor and not as ideal as the lateral arm.

Scapular System

Scapular system is one of the most versatile systems that allows the reconstructive surgeon the ability to harvest tissues with multiple characteristics and freedom for rotation (Fig. 2.5) [83]. Lateral border or scapular tip for bone can be combined with either a latissimus muscle, teres major muscle, parascapular fasciocutaneous component or serratus muscle or any combination of the above to provide coverage for the missing components. Scapular system is especially helpful when the defect has both an external skin and mucosal components missing along with the bone, the main advantage being the degrees of freedom the surgeon can have during reconstruction. For the reconstruction of the lateral skull base, the thoracodorsal artery scapular tip free flap is particularly useful [84]. This flap can be harvested in the supine position and permits a limited two-team approach. This flap provides scapular tip bone-based off of the angular branch of the thoracodorsal artery as well as a latissimus dorsi skin paddle which is independent of the bone. Additionally, this approach provides a long pedicle that often avoids the need for vein grafting.

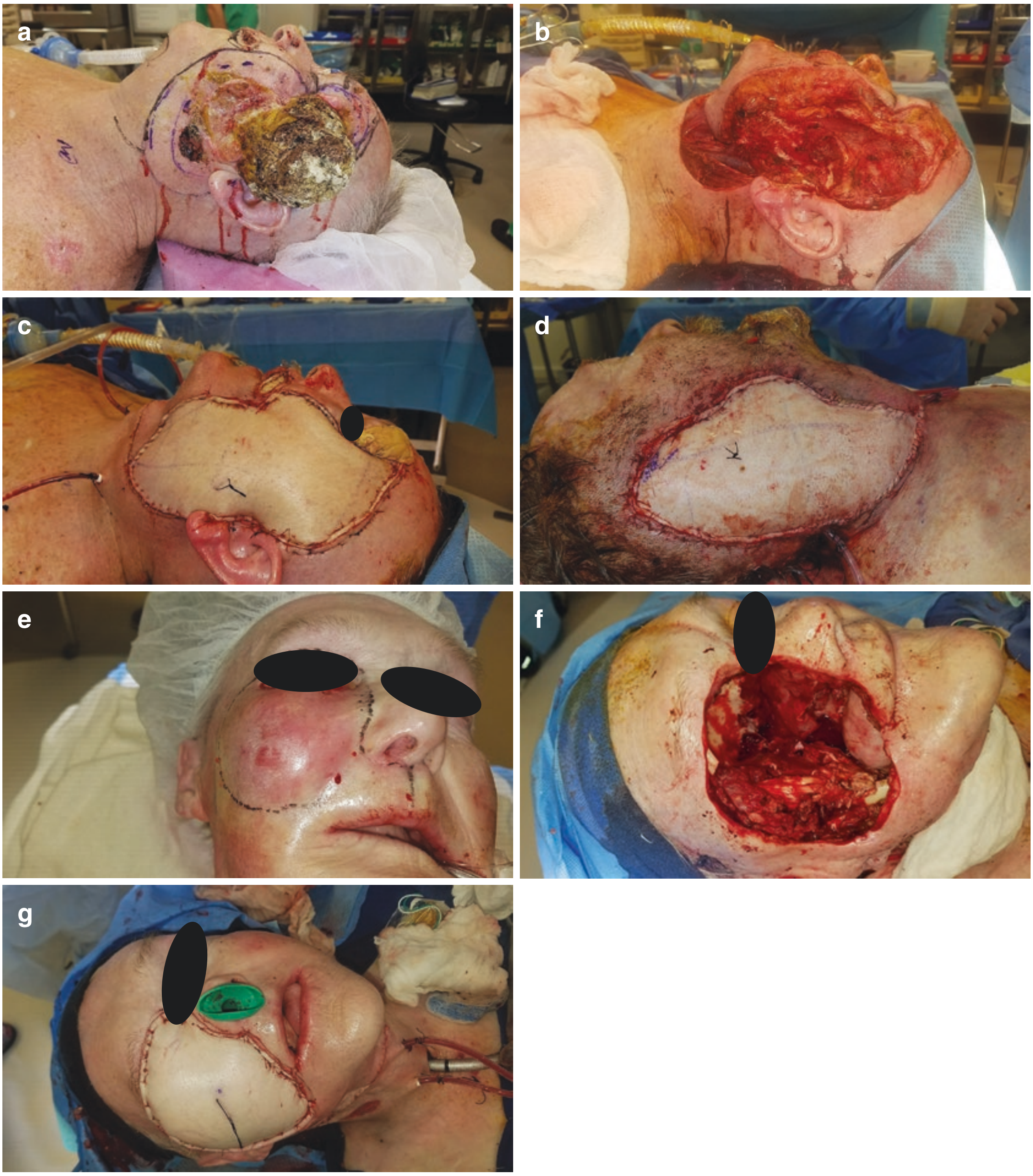

Fig. 2.4 (**a**) Large cutaneous malignancy involving the entire lateral aspect of the face. (**b**) Resultant defect after extirpation of the skin and the parotidectomy missing the cutaneous skin and contour. (**c**) Large anterolateral thigh flap was raised and final reconstruction of the defect following the inset of the flap (**d**) Another example of anterolateral thigh flap to reconstruct lateral craniofacial defect following total auriculectomy, parotidectomy, and temporal bone reconstruction. (**e**) Sinonasal malignancy involving the cheek skin and orbit and maxilla. (**f**) Extirpation resulted in a total maxillectomy defect with orbital exenteration. (**g**) The defect was reconstructed with anterolateral thigh flap to reconstruct the cheek skin, volume defect, and finally intraoral hard palate defect. Part of the flap was de-epithelialized to allow for both cheek and hard palate defects

Parascapular adipofascial or fasciocutaneous is an excellent free flap to reconstruct contour defects with/without cutaneous defects. The advantage of this flap is the long pedicle, large pedicle artery, and minimal morbidity of the donor site. However, in patients with significant subcutaneous adipose tissue, this flap may be too bulky.

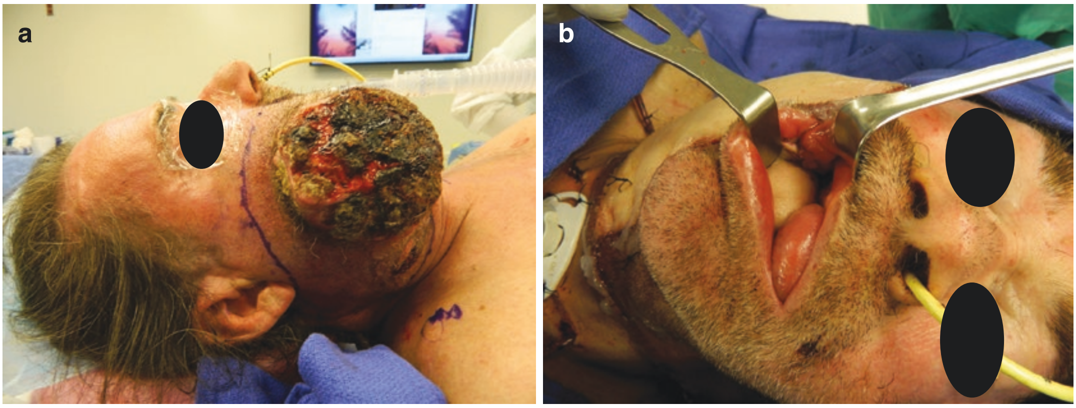

Fig. 2.5 (**a**) Large cutaneous squamous cell carcinoma is shown. The defect required resulted in large cutaneous defect, underlying mandible and a through and through defect of the buccal mucosa intraorally. (**b**) Scapula free flap was used for the reconstruction of the defect with parascapular component, lateral border, and latissimus dorsi skin paddle

Fibula with Skin Paddle

Fibula free flap can also be utilized for the reconstruction of the maxilla or mandibular defect. Preoperative planning and bending of the plates can provide excellent contour of the midface with long pedicle length. The accompanying soft tissue can be used for oronasal separation or to line the nasal cavity if required.

Rehabilitation of the Paralyzed Face

Finally, any discussion about lateral skull base defect would not be complete without techniques in managing the facial nerve. This is an expansive topic and will be addressed here briefly. If possible, primary neurorrhaphy should be undertaken [85, 86]. If interpositional cable grafts are required, common donor nerves include great auricular nerve, sural nerve, and medial antebrachial cutaneous nerve [87].

Management of the Eye

The most important consideration in a paralyzed face is to address the eye. Neglecting the eye can cause significant injury to the cornea resulting in corneal abrasions and potential blindness [88]. Paralyzed or injured temporal branch which innervated the upper division of the orbicularis oculi muscle can result in the following manifestations: brow ptosis, upper lid retraction, lagophthalmos and incomplete closure, lower lid laxity, weakness, or ectropion. Bell's phenomenon is a physiologic protective mechanism where the eye rolls upward and outward upon closure of the eye. In cases where Bell's phenomenon is weak, corneal symptoms can present in cases with even mild weakness.

Non-surgical procedures include taping the eye shut at night or humidity chamber [89]. Ophthalmic ointments and drops should also be utilized – drops during the day to prevent clouding of the vision and ointment at night for maximal lubrication. Surgical options to address the lower eyelid include lateral tarsorrhaphy and canthoplasty. For upper eyelids, surgical options include brow lift or upper eye lid weights. While lateral tarsorrhaphy, canthoplasty, and upper eye lid weights help in eye closure, brow lift aids in improving cosmesis and vision that is impaired from weak frontalis [89]. In the author's experience, upper division should be preferentially innervated to facilitate eye closure – either with a cable graft or primary neurorrhaphy.

Static Slings

Static slings are helpful in facial nerve reanimation as well [90]. Options for slings include tensor fascia lata, or palmaris longus and temporalis tendon. These can be attached at the modiolous and at the lateral nasal wall.

Dynamic

Several dynamic procedures are also an option [90]. These include temporalis tendon transfer, primary neurorrhaphy, cable neurorrhaphy, masseter to facial nerve neurorrhaphy, hypoglossal to facial nerve transfer, cross face nerve grafts, and free tissue transfer. Free tissue transfers can be undertaken as a single-stage or in two-stage approach. If the two-stage approach is required, a cross face nerve graft must be utilized. Gracilis has been the most widely reported free flap for this given the thin pliability with the ability to have multiple neurotized sections of the muscle. Other free tissue transfer option includes pectoralis minor.

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Part II

Defect-Specific Reconstructive Issues

3 Cutaneous Considerations in Lateral Craniofacial Reconstruction

Seung Ah. Lee and Gregory R. D. Evans

Introduction

Regions and Subunits of Face

The face consists of seven principal aesthetic regions, which are the forehead, eyelids, cheeks, nose, lips, chin, and auricles. These areas are covered by skin that shares common characteristics, such as color, thickness, texture, fascial adherence, and hair growth. These regions can be divided into smaller subunits. For example, the forehead is divided into central and temporal units. The cheek is divided into zygomatic, infraorbital, and mandibular subunits. The concept of regions and subunits is critical for facial reconstruction in that a flap is often designed from within the same region or subunit, and incision lines are also often placed along the borders of the subunits.

Relaxed Skin Tension Lines

The extensibility of skin determines the tension for wound closures. This extensibility can vary depending on which direction strain is applied. This is how the lines of maximum extensibility (LMEs) are defined. Relaxed skin tension lines (RSTLs) correspond to the natural direction of collagen and elastin fibers in the dermis. Relaxed skin tension lines are generally perpendicular to the direction of the lines of maximum extensibility and the fibers of the mimetic muscles of the face. Therefore, orienting of wound repair parallel to relaxed skin tension lines puts the tension of wound closure to a minimum level.

Skin Grafts

Skin grafting is a useful tool for superficial facial defects especially when a local flap cannot be utilized for the reconstruction. Skin grafts can be harvested either as full thickness or split thickness. The graft survival depends on several factors such as vascularity and contact between the graft and recipient site. When there is limited contact with a vascular source, a thin graft is more likely to survive compared to a thick one. One should avoid choosing skin grafting as a reconstruction option when the recipient site is previously irradiated or badly scarred, or if periosteum, perichondrium, or peritenon is not intact.

S. A. Lee · G. R. D. Evans (✉)
Department of Plastic Surgery, The University of California, Irvine, Orange, CA, USA
e-mail: gevans@hs.uci.edu

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Full-Thickness Skin Grafts

Full-thickness skin grafts (FTSGs) include both epidermis and the entire thickness of dermis. Therefore, they have better pigmentation, texture, and contour match, but have a higher rate of graft failure compared to split-thickness skin grafts. The ideal surgical candidate is an individual with fair complexion and thin facial skin who acquires a superficial wound, which is confined to one facial subunit, without underlying muscle loss. Full-thickness skin grafts can also be a practical reconstruction choice for wounds involving concavities on the face (e.g., temple or medial canthus). Donor sites are chosen carefully to hide scars and to avoid hair-bearing areas. Commonly used donor sites are pre- and postauricular skin, concha, upper eyelid, neck, submental, and supraclavicular skin.

Split-Thickness Skin Grafts

Split-thickness skin grafts (STSGs) include epidermis and dermis of a variable thickness. They "take" better to the wound bed as they incorporate vascularity more expeditiously. Despite these advantages, split-thickness skin grafts are chosen more carefully for facial reconstruction because they tend to contract significantly and pigment unpredictably, thus producing aesthetically less favorable outcomes (Table 3.1).

Table 3.1 Differences between full-thickness skin graft versus split-thickness skin graft

	Full-thickness skin graft	Split-thickness skin graft
Structure	100% of epidermis and 100% of dermis	100% of epidermis and parts of dermis
Contracture	Minimal secondary contracture	Maximal secondary contracture
Cosmesis	Excellent	Moderate
Survival	More resistant to trauma and shearing Higher chance of survival	Less resistant to trauma and shearing Lower chance of survival
Donor site	Must be surgically closed	Does not require surgical closure

Lateral Forehead Reconstruction

Surgical Principles

The important goals of forehead reconstruction are to preserve motor and, possibly, sensory nerve functions; to protect the aesthetic borders of the forehead and hairline; to maintain position and symmetry of the eyebrows; and to hide the scars in or near hairline, eyebrow, and relaxed skin tension lines (RSTLs). The temporal branch of the facial nerve is at high risk for injury during flap elevation over the zygomatic arch and the temporal area because the nerve courses immediately deep to the temporoparietal fascia–superficial muscular aponeurotic system (SMAS) layer. The area most susceptible to injury (also known as the facial danger zone) is a triangle outlined by a line drawn 0.5 cm inferior to the tragus to a point 2 cm superior to the lateral eyebrow, a second line on the zygoma to the lateral orbital rim, and a third line connecting the previous two lines. The injury to this nerve will result in ipsilateral eyebrow ptosis and facial asymmetry by paralyzing the frontalis muscle.

Reconstruction Options

A variety of reconstruction options are available for lateral forehead and temporal region due to excellent skin elasticity and contour that is flat and/or concave. These characteristics often allow primary closure when the orientation of the repair lies parallel to the relaxed skin tension lines (RSTLs). In fact, the transverse wrinkles on the forehead provide an excellent space for hiding scars. When primary closure is not feasible, advancement, rotation, and transposition flaps can be utilized.

An advancement flap is the simplest local flap option. It is created by advancing tissue into a defect unidirectionally (Fig. 3.1). The skin is slid into the defect without rotation or lateral movement. A defect adjacent to eyebrow or lateral hairline can be reconstructed with bilateral advancement flaps, which conceal the incision along the hairline. Care must be taken to avoid hair follicle damage by making the incision beveled to the surface and 1–3 mm posterior to the anterior border of hairline.

For a defect away from a hairline, a rhomboid flap is most commonly used for reconstruction. A classic rhomboid flap, a type of a transposition flap, is designed with two 60-degree and two 120-degree internal angles to fill a rhombic defect with similar internal angles (Fig. 3.2). Multiple modifications exist in the rhomboid flap designs. For example, a rhomboid flap can be designed to fill a circular defect (Fig. 3.3). The flap is transposed into the original defect with a couple of key stitches, which evenly distributes the tension. The secondary defect can be closed primarily with undermining if necessary. A standing cone deformity can occur at the base of the flap, which may be excised to achieve an aesthetically pleasing contour. This modified rhomboid flap is extremely useful because the flap can be placed anywhere along the circumference of the defect ultimately allowing a scar to be made as inconspicuous as possible (Fig. 3.4).

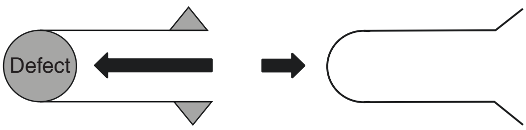

Fig. 3.1 Advancement flap

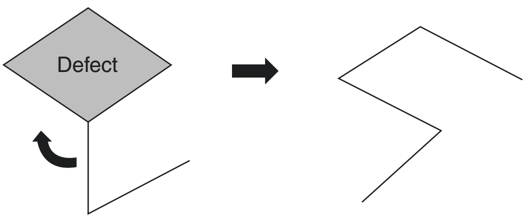

Fig. 3.2 Rhomboid flap

Lateral Cheek

Surgical Principles

The cheek plays a key role in mastication, facial manifestation of emotion, and the support of adjacent primary structures. Therefore, the goal of cheek reconstruction should be to preserve these functions while achieving adequate cosmesis. Extreme visibility and limited local tissue supply make the cheek reconstruction a challenging task. The cheek is divided into multiple subunits such as the medial, lateral, buccal, and

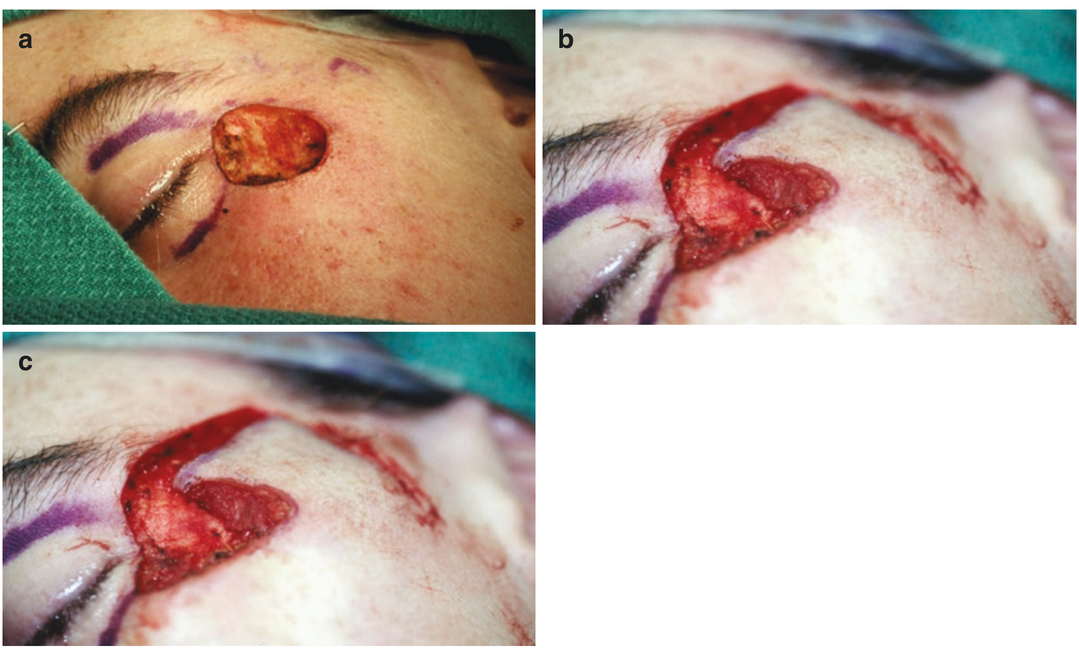

Fig. 3.3 Modified rhomboid flap. (**a**) Circular defect. (**b**) Flap raised. (**c**) After reconstruction

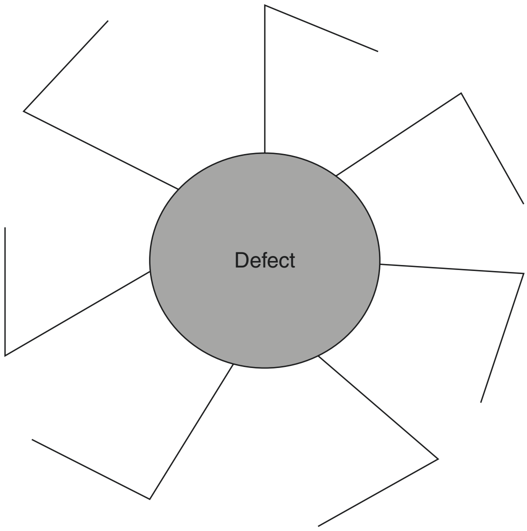

Fig. 3.4 Rhomboid flap allows incision to be placed in anywhere along the circumference of the defect

zygomatic units. This section, however, will focus on the lateral and zygomatic units of the cheek. It should be noted that the skin in these two regions adheres to the underlying fascia more strongly, making it less mobile and less redundant compared to the skin on the medial cheek. Potential radiation therapy and lymph node dissection should be taken into consideration when planning for major reconstruction.

Reconstruction Options

A small lateral cheek defect can be repaired with primary closure or with transposition flaps such as a rhomboid flap. One should plan to place the incision lines in the preauricular crease, or other preexisting folds, the resting skin tension lines, or along the beard edge in order to effectively hide the scars and to respect the borders of aesthetic subunits. Medium-sized defects can be repaired with transposition or advancement flaps. In this case, care should be taken to avoid distortion of the anatomy of the lower eyelid. For example, tissue movement should be based laterally rather than inferior in order to avoid development of lower eyelid ectropion. In fact, when it comes to the reconstruction that involves periorbital area, a thorough understanding of the complex anatomy

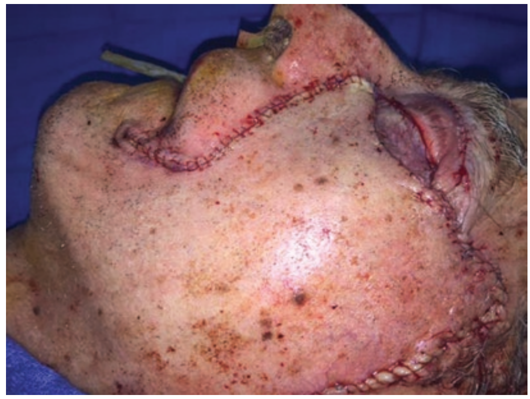

Fig. 3.5 The cervicofacial flap

is crucial to achieve optimal surgical outcome with the proper restoration of eyelid function. Periorbital relaxed skin tension lines (RSTLs) orient horizontally over both upper and lower eyelids. When tension is applied parallel to these lines, cicatricial scars or ectropion can occur. Therefore, it is preferred to create horizontal tension by orienting the long axis of the excision perpendicular to the eyelid margins. The tension can also be placed parallel to the relaxed skin tension lines over the medial and lateral canthi.

Large-sized defects can be repaired with cervicofacial, deltopectoral, or pectoralis major flaps. The cervicofacial flap is one of the most useful options for a large reconstruction for lateral cheek defects because it transposes submandibular skin, which provides excellent color and texture match (Fig. 3.5). The incision of the flap begins from the lateral border and extends along the preauricular crease. As stated above, the need for neck lymph node dissection should be taken into consideration while planning the surgery. If the neck dissection is necessary, it is recommended to raise the flap first and then to proceed with the dissection. The pectoralis major flap is another useful option for lower lateral cheek defects. This flap is based on the pectoral branches of the thoracoacromial vessels, and is reliable with low necrosis rate. This flap, however, can be bulky and, therefore, it is mainly used for complex reconstruction involving multiple structures such as skin, subcutaneous tissue, muscles, and parotid gland. The trapezius flap can also be used for complex lower lateral cheek defects. This flap is based on the transverse cervical artery and vein, which are branches of the thyrocervical trunk. The trapezius system provides three different musculocutaneous flaps – superior, lateral, and lower. Because of their arc of rotation, the lower and lateral flaps are more useful for cheek reconstruction. It should be noted, however, that the trapezius flap often has poor blood supply and should be utilized with caution.

A large, complex defect may require free flap reconstruction such as the radial forearm, anterolateral thigh, and scapular flaps. The radial forearm free flap is a fasciocutaneous flap based on the perforators from the radial artery (Fig. 3.6). It is widely used as a workhorse flap in head and neck reconstruction due to its many advantages such as reliable vascularity, easy dissection, good aesthetic results, and low flap loss rate. The radial forearm free flap can be used not only for coverage of cheek defects but also for reconstruction of the mandible or oral lining.

The anterolateral thigh (ALT) flap is a fasciocutaneous flap based on perforators of the descending branch of the lateral circumflex femoral artery (Fig. 3.7). It has gained popularity for head and neck reconstruction because it can provide large areas of well-vascularized skin. The vastus lateralis muscle can also be taken when extra bulk is required.

The scapular flap, based on the circumflex scapular artery, is another popular choice due to its reliable anatomy and large pedicle, which makes harvesting relatively easy. Its large skin paddle makes it an ideal choice to cover big defects. Although it is most commonly described as a fasciocutaneous flap, it can be raised as an osteocutaneous flap based on the osseous branches of the circumflex scapular artery. This is a reliable alternative for mandibular or maxillary defect reconstruction when the free fibular flap is not available. Based on the multiple axes of the subscapular artery system, it can be designed as a chimeric flap with multiple independent soft tissue flaps.

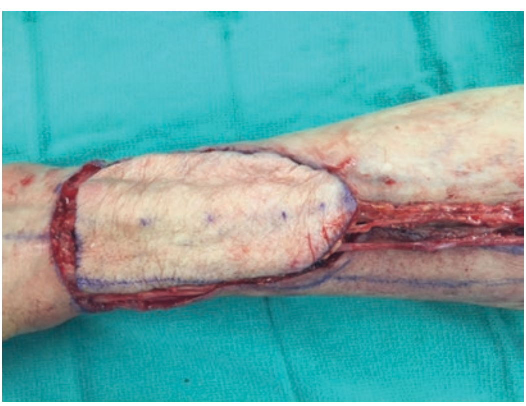

Fig. 3.6 Radial forearm free flap

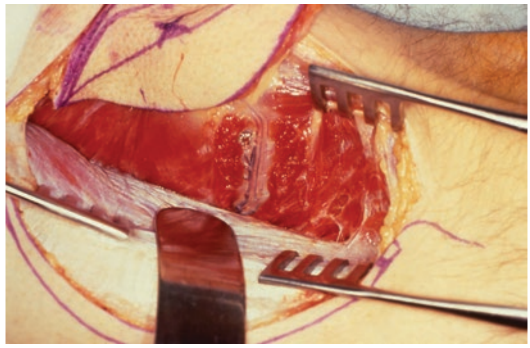

Fig. 3.7 Anterolateral thigh (ALT) flap

Lateral Skull Base Defect

Surgical Principles

Reconstruction of a lateral skull base defect can be a challenging task because it is often associated with exposure of vital structures and major vasculatures. A cancer ablative operation often encompasses lateral, subtotal, or total parotidectomy along with extensive soft tissue dissection. The pursuit of clear margins may lead to the exposure of the dura, often over the temporal lobe or posterior fossa. Extensive infratemporal fossa dissection may lead to pharyngotomy and/or the great vessels exposure. Therefore, the goal of reconstruction should be to (1) establish support for the CNS and facial skeletons, (2) protect the aerodigestive tract, (3) reconstruct the nasal and oropharyngeal cavities, (4) provide adequate volume for dead space, and (5) restore the three-dimensional appearance of the face and head.

The complete reconstruction is a multidisciplinary endeavor with involvement of the neurosurgical, head and neck, and plastic surgical teams. This section will focus mainly on cutaneous soft tissue restoration.

Reconstruction Options

Reconstructive options for lateral skull base defects are often limited to free tissue transfer. The skin in this region lacks laxity and mobility. Therefore, primary closure or small local flaps may not be always feasible even for a relative smaller defect. Free flaps cover the exposed bone and dura, eliminate dead space, and provide cutaneous coverage. For a relatively small defect, the radial forearm free flap is a great option because of its reliability and malleability (see the previous section for details). For a large defect, the anterolateral thigh (ALT) or the latissimus dorsi (LD) flaps are commonly used due to their excellent outcomes and minimal morbidity. The anterolateral thigh flap, based on the descending branch of lateral circumflex femoral artery, can be raised as a fasciocutaneous flap, musculocutaneous flap, or chimeric flap. This flexibility in flap design has made it a popular choice for head and neck reconstruction (see the previous section for details). The latissimus dorsi myocutaneous flap, based on the thoracodorsal artery, is equipped with a long pedicle and a large vessel diameter. The latissimus dorsi is the largest muscle in the body with less than 1 cm thickness, therefore making it a perfect option to drape defects with an irregular contour (Fig. 3.8).

The rectus abdominis flap is another workhorse flap for complex head and neck reconstruction that requires multiple layers of tissue. The pedicle vessels, the deep inferior epigastric artery and vein, are highly reliable. The flap may be bulky, particularly in obese patients, therefore, secondary revisions with liposuction or direct excision may be necessary in some cases. The rectus flap is often raised as a musculocutaneous flap, but it can also be designed as muscle flaps or fascial flaps.

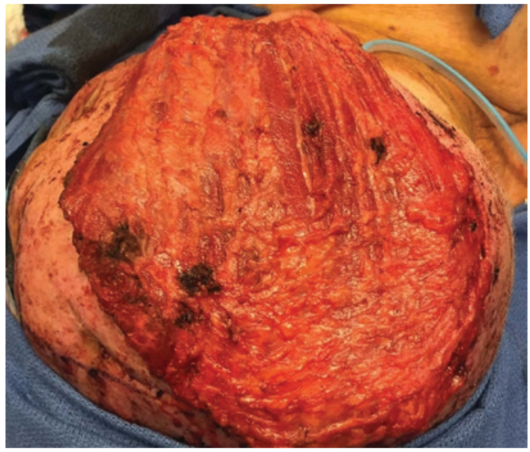

Fig. 3.8 Skull defect reconstructed with Latissimus dorsi flap

Burn Reconstruction

Almost half of burn injuries occur in the head and neck regions. Burn injury can not only severely affect the critical functions such as breathing, hearing, vision, speech, and eating, but also cause severe psychological distress such as social embarrassment, depression, anxiety, and/or post-traumatic stress disorder (PTSD). Therefore, the reconstruction of facial burns often requires multistaged operations, which aim to restore the vital functions with careful considerations for aesthetic results. As a general rule, the reconstruction should wait until scars mature, but early interventions can be necessary to release the scar around the neck, eyes, and mouth for functional reasons.

Scalp Burns

Cicatricial alopecia is a common sequela of head and neck burn injury. The reconstruction of the burn defect on scalp often depends on the size. In general, small areas can be excised and primarily closed by advancing adjacent hair-bearing scalp. On the other hand, serial excisions may be necessary for a moderately sized wound to achieve the best possible results. Care should be taken to avoid excessive tension in order to avoid secondary stretching over the scar. For a medium-sized defect, skin grafts or local flaps may be used. For up to 50% defect, the ideal method is to use a tissue expander. Using a tissue expander yields better color and texture match to the surrounding tissue while maintaining sensation with minimal donor site morbidity. However, it requires multistage procedures prolonging treatment duration, and is associated with temporary disfigurement and a higher complication rate. For a larger burn, free flaps are often chosen. Common free flaps for scalp reconstruction include the radial forearm free flap, parascapular flap, rectus abdominis flap, latissimus dorsi flap, and anterolateral thigh flap.

Forehead Burns

Small burn scars on the forehead can be excised and closed primarily. Similar to the scalp, skin grafts, tissue expansion, or flaps can be used. Forehead burns that involve skull exposure without intact periosteum require a flap for reconstruction. Care should be taken to preserve facial nerve when operating in the forehead region.

Eyelid Burns

A priority for eyelid reconstruction is to restore its function as much as possible. The upper eyelid reconstruction can be accomplished with skin graft from the opposite lid or distant donor sites such as the inner arm. A Fricke flap can also be useful for upper eyelid reconstruction. The lower eyelid is thicker than the upper lid, and therefore retroauricular skin grafts yield the best match. A Tripier flap, originating from the upper eyelid, can also be used for the lower lid reconstruction. If all local tissue was destroyed by a complex burn injury, a temporoparietal fascia pedicled flap or other free flaps may be necessary (Fig. 3.9).

Fig. 3.9 Tripier flap. (Photo courtesy: Dr. Wendy K. Ng)

Cheek Burns

In general, the burn defect in the cheek area is repaired with a full thickness skin graft or local flaps. Care should be taken to respect the aesthetic units of the cheek. If the cervical skin is intact, a cervical advancement flap may be used. If the beard area is affected, a submental flap can be used to bring the hair-bearing skin.

Conclusion

Craniofacial reconstruction is one of the most challenging fields in plastic surgery. It requires profound understanding of anatomy, careful planning, and meticulous execution. Effective reconstruction of this region is essential in achieving proper facial aesthetics. Color and texture match as well as contour are important factors that can affect the results. The goal of the reconstruction, however, should focus on maintaining and restoring of the functions and care must be taken to preserve the facial nerve functions.

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4 Soft Tissue Considerations in Lateral Craniofacial Reconstruction

W. Walsh Thomas, Steve B. Cannady, and Mark K. Wax

Introduction

Reconstructing defects of the lateral craniofacial structures – skin, soft tissue, and bone – involves replacing composite soft tissue with composite soft tissue. Caveats to this paradigm are the additional constraints that the reconstruction must separate intra- and extracranial compartments, fill empty cavities, prevent cerebrospinal leaks, replace soft tissue bulk to create contour, and provide integumentary coverage. These additional wound constraints can rapidly move a reconstructive surgeon up the reconstructive ladder [1]. When considering surgical defects of the lateral head and neck, a common paradigm, illustrated by Drs. Rosenthal and Wax, divided wounds into three categories. Class one defects involve a parotidectomy with skin loss and possible mastoidectomy, but maintaining the external auditory canal. Class two and class three defects involve a lateral temporal bone resection (LTBR) with middle ear obliteration and either partial (class 2) or complete auriculectomy (class 3) [2] (Table 4.1).

However, wounds of the lateral craniofacial region can be much more nuanced when considering the most appropriate reconstruction. Dermatologic malignancies, often long-neglected, can create unique and complex cutaneous loss involving preauricular and postauricular skin as well as hair-bearing scalp or loss of lateral and posterior cervical skin [3]. Neurovascular considerations regarding the facial nerve, ocular, otologic, and masticatory considerations require a complete understanding of the limits of reconstruction capabilities of each potential modality. Metastatic or deeply invasive cutaneous disease, primary parotid malignancies, or otologic malignancy create defects with considerable composite tissue loss that requires replacement in addition to complicating wound requirements as mentioned above.

With regard to soft tissue considerations in reconstructing lateral craniofacial skeleton, each defect will be discussed in turn with a variety of reconstruction options.

Skin/Cranium

The primary concerns for soft tissue reconstruction of cutaneous defects of the lateral craniofacial region involves coverage to ensure cosmesis

W. W. Thomas
Oregon Health Sciences University, Portland, OR, USA

S. B. Cannady
Hospital of the University of Pennsylvania, Philadelphia, PA, USA

M. K. Wax (✉)
Department of Otolaryngology-Head and Neck Surgery, Oregon Health Sciences University, Portland, OR, USA
e-mail: waxm@ohsu.edu

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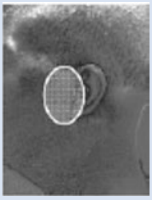
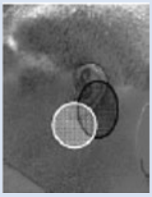
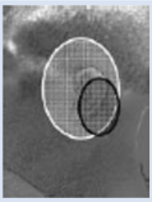
Table 4.1 Classification of preauricular defects

	Class I	Parotidectomy with skin loss EAC preserved ±mastiodectomy	Cervicofacial rotation flap RFFF
	Class II	Lateral temporal bone resection; middle ear obliteration; most of auricle preserved	ALT flap RFFF
	Class III	Lateral temporal bone resection; total auriculectomy; middle ear obliteration ± parotidectomy	ALT flap rectus

Note: While shaded circle represents cutaneous loss; dark shaded circle represents bone loss
Abbreviation: *RFFF* radial foream free flap, *ALT* anterdateral light, *EAC*, external auditory canal
Credit: Rosenthal et al. [2]

and color match of the resected skin along with sufficient tissue volume to maintain cosmesis. The subunits of the lateral craniofacial region can be defined as hair-bearing scalp, preauricular skin, auricle and attendant skin, postauricular skin, and cervical skin. Thin/wide local excisions or Mohs resections in these various areas present different considerations in an aesthetic reconstruction. Cutaneous considerations regarding reconstruction of these defects is discussed in detail previously in this text; however, cutaneous malignancy of the H-zone of the face often presents with larger tumors with deeper depth of invasion [4]. These tumors will require soft tissue volume reconstruction in addition to cutaneous coverage.

Given the hidden or neglected nature of cutaneous malignancies in the hair-bearing scalp, patients can present with large volume defects, whose depth of invasion can extend to the cranium and below. For simple defects of the cutaneous scalp, many reconstructive options are available including secondary intention, primary closure with linear repair, or a primary closure with a local rotation–advancement flap. Rotation–advancement flaps such as the O-to-Z closure are an excellent option for scalp defects that do not have deep soft tissue loss because the scalp lacks resting tension lines; wide undermining of adjacent tissue can provide wide well-vascularized skin flaps and outside of the forehead, incision lines and distortion of hair placement is clinically insignificant. Defects that do not extend below the periosteum of the scalp can be covered with a split- or full-thickness skin graft or acellular collagen matrix such as Integra™ (Integra LifeSciences, Plainsboro, NJ). Galeal scoring can increase the arc of rotation of scalp rotational flaps and reduce the time of expansion of scalp tissue expanders. Tissue expansion of the scalp requires placement of the expanders between the galea and pericranium and at least 4–6 weeks of lead time. It may be longer depending on size of defect. The scalp is an ideal location for tissue expansion given the firm deep surface of the cranium as well as the ability to minimize the cosmetic appearance of the tissue expander with hair [5].

For defects of the scalp that extend into the cranium, cranial reconstruction requires meticulous soft tissue management. Neurosurgical consultation is appropriate for reconstruction of dural and intradural defects. Dural defects are commonly repaired with pericranial flaps, non-autologous and bovine pericardial grafts [6], fascia lata, and synthetic or cadaveric dural patches. Following closure of the dura, cranial protection and contour considerations of the lateral skull will require soft tissue as well as implant reconstruction. Many techniques have been described for titanium mesh implantation to reconstruct the cranial vault (Fig. 4.1). With the advent of computer-aided design and its marriage to computed tomography scans, patient specific implants are available to improve the postoperative contour of the lateral skull (Fig. 4.2) [7]. Similar to virtual surgical planning for mandibular reconstruction of the head and neck debate regarding the utility versus cost considerations as compared to traditional methods exists in the literature [8]. In patients with concomitant large cutaneous defects, infected operative site, prior radiation, or the need for postoperative radiation, vascularized soft tissue augmentation of the cranial reconstruction is warranted to minimize postoperative complica-

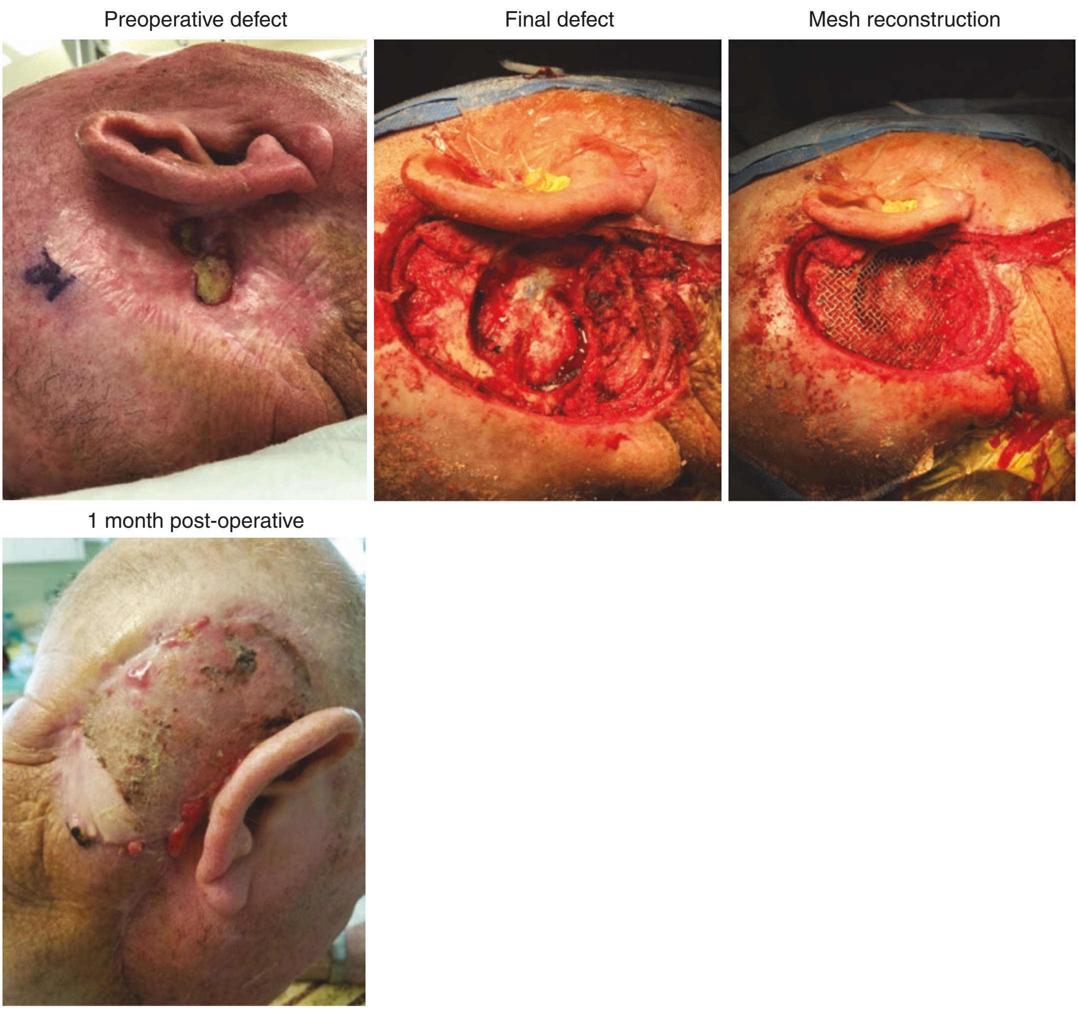


Fig. 4.1 Postauricular resection of temporal bone osteoradionecrosis with cranial mesh and serratus muscle free flap and skin graft

Fig. 4.2 Cranioplasty with implant and radial forearm free flap coverage. Note: STA superficial temporal artery, STV superficial temporal vein

tions. The local flaps most commonly utilized are the temporalis muscle flap based upon the deep temporal arteries or temporoparietal fasciocutaneous flap, based upon the superficial temporal artery (Fig. 4.3) [9]. These local flaps provided shorter operating times, less donor site morbidity, and minimal complications in reconstructing small lateral skull defects where the local arterial supply remains preserved and the local tissue has not been irradiated. In Hanasono's series of 27 patients with temporal bone defects, temporalis flap reconstruction required significantly less operative time (6.9 vs. 11.2 hours) and shorter hospitalization times (4.1 vs. 8.6 days); fewer major complications (4/27 vs. 14/90) occurred in the regional reconstructive group, though this difference was not statistically significant and the cutaneous

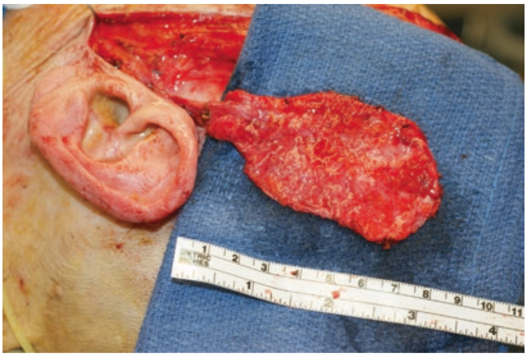


Fig. 4.3 Temporoparietal fasciocutaneous regional flap pedicled on superficial temporal artery and vein

defects reconstructed were significantly smaller with the temporalis flap as compared to all free flaps (15 vs. 31 cm^2) [10]. Additionally, the parietal branch of the superficial temporal artery can be traced with a Doppler probe and a scalp island rotational flap can be utilized to transpose hair-bearing scalp to the lateral forehead, temporal scalp, or parietal scalp. In the referenced series, this galeo-cutaneous flap utilized an perivascular fascial pedicle cuff (2–3 cm) when a branch of the superficial temporal vein was not available to provide venous drainage with 15/18 flaps suffering at least slight venous stasis [11]. Regional options for soft tissue coverage of the lateral skull base include the trapezius, suprascapular, pedicled latissimus, pectoralis, sternocleidomastoid, and submental island flaps, among others.

The submental island flap (SIF) has been studied retrospectively in comparison to free and regional tissue transfer for temporal bone cutaneous and soft tissue reconstruction. Retrospective series by Hayden and Zender discussed 37 patients with temporal bone defects reconstructed with the SIF. Both authors concluded that these patients required less operative time, shorter hospitalizations, minimal donor site morbidity without oncologic compromise, and significantly fewer subsequent debulking procedures for contour refinement. The Hayden series reported 1 free vein graft in 16 flaps with a maximum cutaneous paddle of 99 cm^2; additionally, both anterior digastric muscles as well as bilateral mylohyoid muscles were transposed, allowing for sufficient soft tissue bulk for temporal bone reconstruction [12]. The Zender series does quantify defect size and similar to the previously discussed Hanasono series regarding temporalis muscle flaps, the submental island flap size averaged 32.4 cm^2 with a maximum of 72 cm^2 as compared to an average free tissue flap area of 105.2 cm^2 [10, 13].

For larger defects with considerable scalp and soft tissue loss, free tissue transfer is warranted. One common example for free tissue scalp reconstruction is the muscle-only latissimus free flap with split-thickness skin graft. This flap has a large surface area with limited bulk as well as a long pedicle capable of reaching the neck when the superficial temporal vessels are not available [14, 15]. Perforator dissection of the ALT flap allows for thinner flaps that can be utilized for skin-only defects. For defects requiring more bulk, the traditional ALT flap or rectus free flap can be utilized. Increasing utilization of the ALT flap has decreased the use of the rectus flap due to donor site morbidity. However, the rectus flap can reconstruct the extremely large defect that may not be possible with an ALT [16]. No significant differences are found in postoperative complications, defect size constraints, or calvarial considerations in comparing the ALT to latissimus flap in complex scalp reconstruction [17]. The location and size of the scalp defect can influence the type of free flap utilized. In a series by Sweeny et al., forehead and frontal defects were most commonly reconstructed with radial forearm free flaps while larger defects in the occipital and parietal regions more frequently required a latissimus flap with a skin graft. Their conclusions report that although the radial forearm is uncommonly reported in the literature for scalp reconstruction, for defects of appropriate size, its ease of harvest, considerable pedicle length, and reliability make it a free flap to consider regularly [18].

One caveat to reconstructive surgical management of the temporal region are complications and soft tissue changes induced by the bicoronal approach to the upper face for any indication. The most worrisome complication of a bicoronal approach to the upper one-third of the face is, outside of rare catastrophic complications, a facial nerve palsy of the frontal/temporal branch. This nerve is known to run under the temporoparietal fascia (superficial temporal fascia), which places it immediately above the superficial temporal fat pad. In an effort to protect the frontal branch of the temporal nerve, the approach to the inferior/lateral limb of the coronal approach is performed through the superficial temporal fat pad and deep to frontal branch to approach the zygoma [19]. This technique while ensuring safety of the facial nerve can induce temporal hallowing as a sequela. In a prospective randomized trial comparing deep (transtemporal fat pad), subfascial, and suprafascial dissection planes to the zygoma, it was noted that the suprafascial approach had significantly less temporal hollowing relative to the median hollowing of the entire cohort. Additionally, the amount of temporal hollowing was also related to a decrease in BMI postoperatively and no patient suffered a facial nerve paresis [20]. Approaches to reconstruct lateral skull base defects have their own risks and complications in addition to the deficits induced by the traumatic on malignant insult.

Periauricular/Parotid

Periauricular and parotid reconstruction is a very diverse topic in head and neck reconstruction as defects range from mild contour deformities, which can be reconstructed with a multitude of techniques ranging from local flaps to contouring adipofascial free flaps. Alternatively, the total parotidectomy may include facial nerve (to be discussed elsewhere in this text), lateral mandible or maxilla, temporomandibular joint, and infratemporal fossa considerations.

Soft tissue considerations in lateral craniofacial resections with specific focus to the parotid region are defined by three main variables: amount of soft tissue loss with the resultant contour deformity, the incidence of Frey's syndrome and management or rehabilitation of the facial nerve. All three variables when incorrectly managed can have significant detriment to the patient's quality of life [21]. The first two considerations will be discussed in this chapter at length and the third consideration is discussed elsewhere in this text. Superficial parotidectomy or extracapsular dissection for parotid resections routinely generates a defect centered on the tail of parotid that does not require formal reconstruction. It is a routine practice to attempt to decrease tissue dead space with sutures through remnant superficial parotid tissue at the time of wound closure. For complete superficial parotidectomy defects or limited total parotid defects, a variety of methods have been reported. Acellular dermal matrix, Alloderm (LifeCell Corporation), can be placed to improve the contour defect and ingrowth of fibroblasts is noted to stabilize the facial contour at 6 months after surgery. However, it should be noted that considerable acellular matrix is resorbed in the first 6 months necessitating overcorrection and subsequent cost considerations [22]. Biologic options for these defects utilize a single modality or combination of sternocleidomastoid (SCM) flap, superficial musculoaponeurotic system (SMAS) flap, and/or free fat graft. These typically de-innervated muscle grafts provide initial bulk to contour defect, but long-term results are in debate. In a head-to-head retrospective survey of the SCM to SMAS flap, the SCM flap was found to be better able to eliminate contour defects by visual–analog scale greater than 3 cm in diameter; both the SCM and SMAS flaps were equivalent at defects less than 3 cm in diameter at 24 months follow-up [23]. Free fat grafts are typically harvested from a periumbilical or lower abdomen donor site and most patients have sufficient extra-abdominal adiposity to overcorrect the defect by 30% in order to correct for reabsorption. Free fat grafts in association with a SMAS flap, unlike SMAS flap alone, was noted to improve contour deformities in post-parotidectomy defects with an average size 21.6 cm^3 at an average of 27-month follow-up [24].

For defects of the periauricular and parotid region that are primarily cutaneous loss, cervicofacial advancement flaps are the workhorse closure method as skin color match, skin flap perfusion, and access to lymphatics of the neck are advantages of this approach. Given the size and height of the defect, from temple and forehead superiorly to below the auricle, the inferior limbs of advancement of this sub-SMAS, subplatysmal, and subcutaneous (with preservation of deltopectoral fascia) flap can be extended inferiorly onto the chest. Medial dissection is halted 2 cm from the sternum to preserve the internal mammary perforators, but addition of the incisions to the chest for larger incorporation of skin did not increase complications in the series of 33 patients by Moore et al. While one-third of patients in this series developed wound issues at the distal most aspect of their rotational flap, no patient suffered delays to initiation of radiation therapy [25]. The cervicofacial–thoracic rotational flap is ideal for medically fragile patients, who are not candidates for free tissue transfer or live in a resource-poor environment.

A more complex reconstructive option in the quiver for contour deformities in total parotidectomy defects is buried free tissue transfer with or without facial nerve considerations. For total parotidectomy, contour defects with or without mastoidectomy considerable soft tissue bulk will need to be replaced, potentially without skin loss. Free flaps containing significant amounts of vascularized fat are ideal for this purpose; unlike de-epithelialized myocutaneous flaps, they will not undergo de-innervation atrophy. The work horse flap for this purpose is the ALT free flap with alternatives being lateral arm flaps, deep inferior epigastric perforator (DIEP) flaps, and radial forearm free flap (RFFF). A series by Cannady et al. utilized buried ALT FF in 72% (13/18) of patients. A single lateral arm flap was utilized for the largest recorded defect (168 cm^2) and four RFFFs were utilized in this series. De-epithelializing the flap and harvesting significant subcutaneous tissue fat in proximity to the cephalic vein allowed the authors to reconstruct a large defect of 70 cm^2 [26]. In this series, there was no loss of cutaneous tissue; however, the RFFF has an additional advantage of similar sun exposure of the cutaneous paddle to the lateral face allowing for a better aesthetic match in low Fitzpatrick scale patients. A significant advantage of the ALT against the RFFF and lateral arm FF is the decreased donor site morbidity and abundant adipose and muscle tissue available for harvest; furthermore with an endoscopic harvest of a free rectus femoris flap, the length of the cutaneous incision is approximately 5 cm [27]. Utilizing the adipofascial flaps from the anterior thigh allows the surgeon to alter the surgical plan based upon the patient's anatomy if suitable lateral perforators are nonexistent, which is one of the theoretical drawbacks to the ALT FF [28]. While specific facial nerve rehabilitation procedures will be discussed in length in other areas of this text, it is pertinent to note that upon harvesting the ALT FF, the motor nerve to the vastus lateralis is easily harvested for cable grafting of the facial nerve and when static slings or temporalis tendon transfer are employed, the tensor fascia lata can be harvested without compromise to the harvested ALT FF. Utilizing the combined static and dynamic facial nerve reanimation procedures allows for a single-stage facial nerve reinnervation and facial contour reconstruction at the time of tumor extirpation [29]. A recent development in the reconstruction of total parotidectomy defects is the utilization of innervated vastus lateralis, as a single or dual functional muscle units, for functional muscle rehabilitation of blink and oral commissure elevation at the time of tumor removal with adipocutanous components of the ALT FF being utilized for the concomitant contour defect as well as static sling placement. This technique has yet to be evaluated in a large series, but case report examples show functional facial movement following radiation therapy. This innovation could potentially obviate the need for secondary gracilis free tissue transfer for dynamic midface reanimation in radical parotidectomy defects [30, 31].

Any consideration of parotidectomy must include a discussion of Frey's syndrome, which is characterized by gustatory sweating and skin erythema and is hypothesized to occur from regeneration of previously parotid postganglionic parasympathetic secretomotor nerve fibers to the skin and associated sweat glands. This phenomenon occurs approximately 6–12 months following parotidectomy and the primary treatment paradigm is to interpose tissue, local flap (SMAS, platysma, or SCM), acellular dermis, or fat, to prevent the aberrant reinnervation to the skin. Debate exists concerning the incidence of Frey's syndrome following parotidectomy as qualitative reporting is considerably lower (40–60%) than objective Frey's syndrome as demonstrated by the Minor starch–iodine test (80–100%) [32]. A literature review by the International Head and Neck Scientific Group found that the current literature is insufficient to draw definitive conclusions regarding interposition of SCM, acellular dermis, or other reconstructive techniques due to the heterogeneity of the data, lack of randomized controlled trials, and methodological weaknesses of the single meta-analysis previously published to this series. However, single meta-analysis reported odds ratios of 3.88 and 3.66 for the protective impact of any interposition method on subjective and objective Frey's syndrome respectively [33, 34]. In light of conflicting views of the published literature, surgeons are encouraged to treat the patients to the best of their abilities with cost and patient morbidity considerations being made on an individual patient and defect basis.

Lateral Temporal Bone Resection and Reconstruction

Resection of advanced tumors of the lateral craniofacial skeleton and skull-base require management of the auricle, external auditory canal (EAC), and Eustachian tube. The malignancies that involve this region are often advanced-stage parotid malignancy, EAC primary tumors, periauricular cutaneous malignancy, or rarely tumors of the middle ear or internal auditory canal (IAC). Periauricular cutaneous malignancy is found more commonly on patients' left side, as attributed to driving patterns, and this subset of cutaneous squamous cell carcinoma is found to be much more aggressive with a higher rate of local recurrence (4–7%) and nodal metastasis. These tumors, when presenting at later stages with involvement of the external ear canal (EAC) can be accurately staged with the Pittsburgh Staging System [35]. These larger tumors require lateral temporal bone resection, subtotal temporal bone resection, or total temporal bone resection with petrosectomy. In the MD Anderson series from 2000 to 2010, in all patients requiring at least a temporal bone resection for malignancy (n = 117), a cutaneous primary (57.3%) was more common than EAC primaries (20.5%) or parotid primaries (14). The survival outcomes from this series trended but did not meet significance with stage 1 and 2 carcinomas (Pittsburgh staging system), having shorter survival than stages 3 and 4, which was again shorter than recurrent carcinomas. The shortest surviving cohort were the sarcoma patients with a median survival of 30.7 months. Carcinoma patients had a median survival of 61.9 months for all patients, with squamous cell carcinoma being the most common diagnosis (53.8%). 92.3% of this cohort underwent adjuvant or neoadjuvant radiotherapy and 35% underwent adjuvant chemotherapy [10].

The necessity of adjuvant radiotherapy in the management of advanced-stage lateral craniofacial tumors increases the importance of adequate soft tissue coverage and closure. There are numerous deleterious sequelae following lateral skull base radiation including sensorineural hearing loss, otitis media, and osteoradionecrosis (ORN). Osteoradionecrosis has a delayed onset in the lateral skull base of between 4 and 10 years post-radiation therapy and is anecdotally associated with cumulative radiation doses above 50 Gy. ORN of the temporal bone initially presents with bone exposure of the EAC, if present, and can spread to include mastoid abscess, skull base osteomyelitis, or brain abscess. The temporal bone is at risk for ORN due to its thin skin coverage, poor blood supply, bacterial colonization via the Eustachian tube, and potentially chronic trauma due to ill-fitting hearing aids or cerumen disimpaction [36].

Osteoradionecrosis is associated with parotidectomy defects that include a mastoidectomy in approximately 12.5%; however the utilization of a soft tissue reconstruction was associated with 0 cases of ORN. Vascularized soft tissue reconstruction provides well-perfused tissue to the lateral skull base defect, which can withstand the microvascular thrombosis and inflammation induced by radiation therapy [37]. With regards to the risk of ORN with bone-anchored hearing aid (BAHA) placement following radiation therapy, there is considerable evidence from the dental literature with regards to dental implants to suggest BAHA implantation will increase the risk of ORN [38]. However, the BAHA can be placed further from the radiation field following reconstruction allowing for non-radiated bone to promote osseointegration. One series of 11 patients who underwent nasopharyngeal and neck radiation reported 0 cases of ORN at mean follow-up of 39.8 months. The BAHAs for these patients were placed in a two-staged procedure with a 3-month integration period prior to heading device loading; additionally, with the utilization of the BAHAs and removal of traditional intra-aural hearing aids, there was a significant decrease in reported otorrhea rates indicated less intra-aural trauma and inflammation [39].

Lateral temporal bone resections with auriculectomy, class 3 defects in the Wax/Rosenthal nomenclature, are typically reconstructed with free tissue transfer. As previously mentioned, these flaps are likely ALT or DIEP flaps as a large skin paddle is typically required. It is important when possible to preserve the superior auricular helix for support of eye glasses (Fig. 4.4). These flaps have improved cutaneous appearance rela-

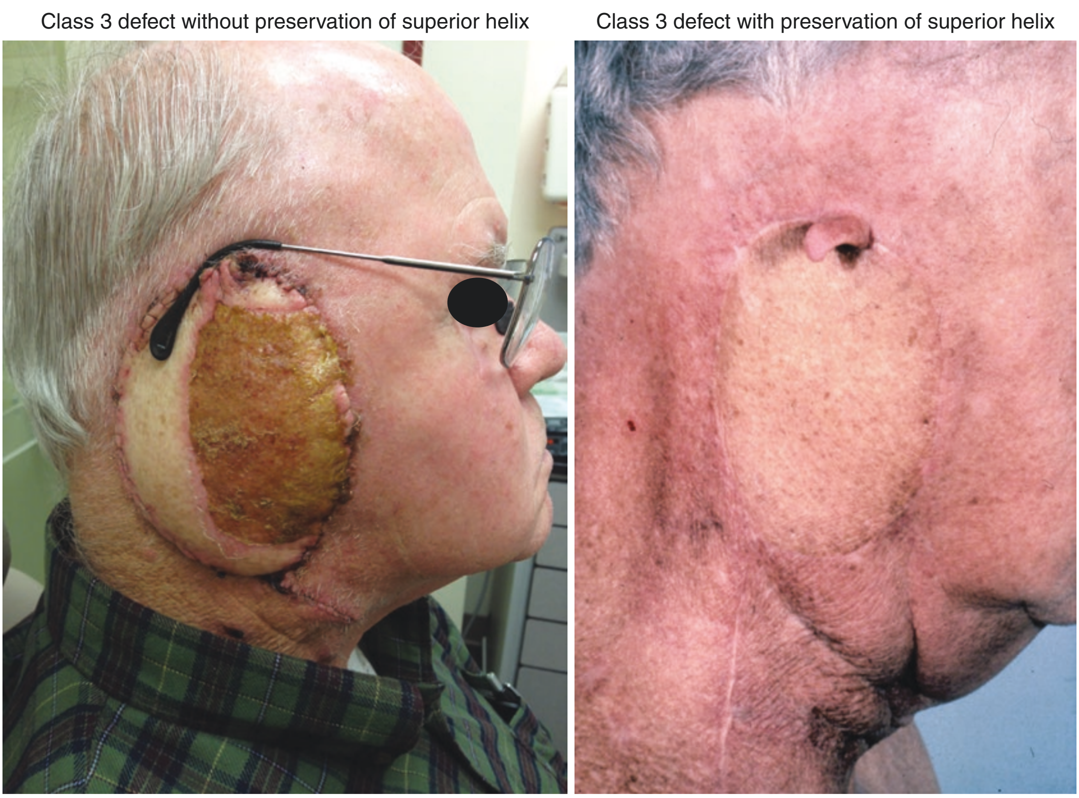


Fig. 4.4 Lateral temporal bone resection and reconstruction with and without preservation of the superior helix

Class 2 defect with revision free flap reconstruction of inferior auricle

Fig. 4.4 (continued)

tive to a free muscle flap, such as a latissimus dorsi free flap, covered with a skin graft. Unless harvested in a perforator fashion, these flaps typically contain a large amount of subcutaneous bulk and patients may elect to undergo aesthetic debulking of the free flap. At the time of debulking, additional functional and cosmetic procedures related to facial nerve loss, such as rhinoplasty, browlift, or blepharoplasty can be performed. Procedures to immediately protect the eye such as upper lid weight placement, tarsal strip, and static sling procedures are done at the time of tumor ablation [27] (Fig. 4.5). The incidence of aesthetic revision varies significantly with regards to patient age, frailty, and prognosis of primary tumor. Most reconstructive surgeons wait at least 6 months following the end of radiation therapy prior to considering revision surgery as this time period allows for a stabilizing of tissue edema and wound contracture to ensure accurate parameters for revision. Free flap reconstruction of the lateral skull base is typically oversized to allow for radiation contracture and adequate wound coverage. Subsequent, liposuction or powered debridement tools in addition to skin elevation and tightening have been utilized to refine aesthetic features of lateral skull base free flaps (Fig. 4.5) [40].

Typical contour deformity of Class 3 defect; sequela of facial nerve deficit

Revised Contour deformity of Class 3 defect with concomitant brow and midface lift to address facial nerve palsy – Photos courtesy of Dr. Steven B Cannady

Contour defect following ALT free flap reconstruction for skin loss secondary to cutaneous neoplasm

Revised contour with direct excision debulking of ALT free Flap

Fig. 4.5 Aesthetic revision of lateral craniofacial reconstructions to improve contour deformities

Conclusion

Soft tissue aspects of lateral craniofacial reconstruction are a diverse topic with many constraints unique to each individual patient. While ablative defects, as classified by Rosenthal and Wax, are usually amenable to typical reconstructive techniques in the reconstructive quiver, each individual patient warrants full consideration of all available reconstructive options to achieve the optimal outcome. Factors such as postoperative radiotherapy, patient frailty, disease lethality, and even demographic influences, such as distance travelled, can all impact the optimal reconstructive modality for a specific patient. Free tissue transfer allows for improved reconstructive outcomes for the largest subset of defects, without which soft tissue deficiencies, both functional and aesthetic, would be immediately evident. Generally, a larger reconstruction, free or regional flap, is preformed to ensure adequacy of initial reconstruction with the option for secondary revision as desired by individual patients. Management of the facial nerve is a critical component of lateral craniofacial reconstruction that is intimately tied to soft tissue considerations and this topic will be further delineated in subsequent chapters.

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5 Maxillomandibular Considerations in Lateral Craniofacial Reconstruction

N. Mahon, S. Farooq, E. Mustafa, K. Ubayasiri, P. Praveen, and S. Parmar

Maxillary Reconstruction

The maxillary defect is a challenge to the reconstructive surgeon. This area is a six-sided geometric structure involving many anatomical structures with specialized functions [1]. The cranial surface comprising of the orbit supports the globe and the caudal surface supports the dentition playing an important role in vision and mastication [1, 2]. It also includes the palate and sinus facilitating speech, deglutition, and respiratory functions [1, 2]. From an aesthetic point of view it contributes to the height, width, and projection of the midface and supports the base of the nose [1]. The extent of the defect is important when considering reconstructive options, whether it includes the lips, nose, cheek, outer skin, orbital contents, zygoma, pterygoid plates, or soft palate [3]. Consideration of the external soft tissue defect, the bony insufficiency, and the mucosal deficit is important [1]. The aims of maxillary reconstruction must include (1) obliterating the dead space; (2) separating functional cavities, orbit, nasal, and oral; (3) restoring function of the midface (speech, mastication); (4) providing adequate structural support and projection to the midface; and (5) optimizing aesthetics [1, 4, 5]. A vascularized bone flap and the provision of osseointegrated dental implants is the gold standard for maxillary reconstruction [2].

The Classification of Maxillectomy Defects

Maxillary defects are complex. They encompass a variety of defects which can involve only minor defects of the alveolus/palate or major defects involving the skull base and orbit [3, 6] Multiple classifications have been proposed to describe these complex anatomical defects [3, 7–10]. However, no universal classification has been accepted among surgeons and prosthodontists [3]. A systematic review of these classification systems found that most systems describe superior–inferior extent of defects but only a small number described the anterior–posterior and medial–lateral extent of defects [3]. It also noted that the dental status or soft palate involvement was rarely mentioned [3]. The authors felt that the ideal classification should involve the following six criteria. (1) dental status, (2) oro-antral/nasal communication status, (3) contiguous structure involvement, (4) superior–inferior extent, (5) anterior–posterior extent, and (6) medial–lateral extent [3]. In the UK a commonly used classification is the Brown–Shaw classification of reconstruction of the maxilla

N. Mahon (✉) · S. Farooq · E. Mustafa
K. Ubayasiri · P. Praveen · S. Parmar
Oral and Maxillofacial Department, University Hospital Birmingham, Birmingham, UK
e-mail: nicola.mahon@nhs.net

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and midface [11]. It consists of six categories. Class 1–IV describes the increasing extent of the maxillary defect on the vertical dimension, class V the orbitomaxillary defect, and class VI nasomaxillary defects. The horizontal classification consists of four categories a–d referring to the increasing complexity of the dentoalveolar and palatal defect (Table 5.1 and Fig. 5.1).

Table 5.1 Brown et al. classification of vertical and horizontal maxillectomy and midface defects [11]

Brown's classification		
Class 1	Maxillectomy not causing an oronasal fistula	Vertical classification
Class II	Maxillectomy not involving the orbit	
Class III	Maxillectomy involving the orbital adnexa with orbital retention	
Class IV	Maxillectomy with orbital enucleation or exenteration	
Class V	Orbitomaxillary defect	
Class VI	Nasomaxillary defect	
Class a	Palatal defect only, not involving the dental alveolus	Horizontal classification
Class b	Palatal defect less than or equal to half unilateral	
Class c	Palatal defect less than or equal to half bilateral or transverse anterior	
Class d	Palatal defect greater than half maxillectomy	

Reconstruction

The reconstruction should be tailored to the individual patient [2]. This usually involves presurgical planning via a multidisciplinary approach including the surgeons, prosthetics department, and prosthodontist to achieve optimum results. Virtual surgical planning allows for the fabrication of cutting guides and preformed plates to optimize the reconstruction and reduce theater time. The reconstructive ladder may be used as a guide to decide which reconstructive method to use. For larger defects options include microvascular free tissue transfer and prosthetic implants [12]. Newer techniques include allograft transplants or tissue engineering [12].

The type of reconstruction depends on multiple factors including the fitness of the patient, availability of donor sites, and extent of the defect. There are numerous issues to consider: the extent of the maxillary defect, the composition of tissue loss, and the surrounding remnant anatomy available for reconstruction:

1. Size of the defect
2. Skin involvement
3. Orbital involvement
4. Soft palate involvement
5. The dental status of the patient
6. Skull base involvement
7. Zygoma present or absent

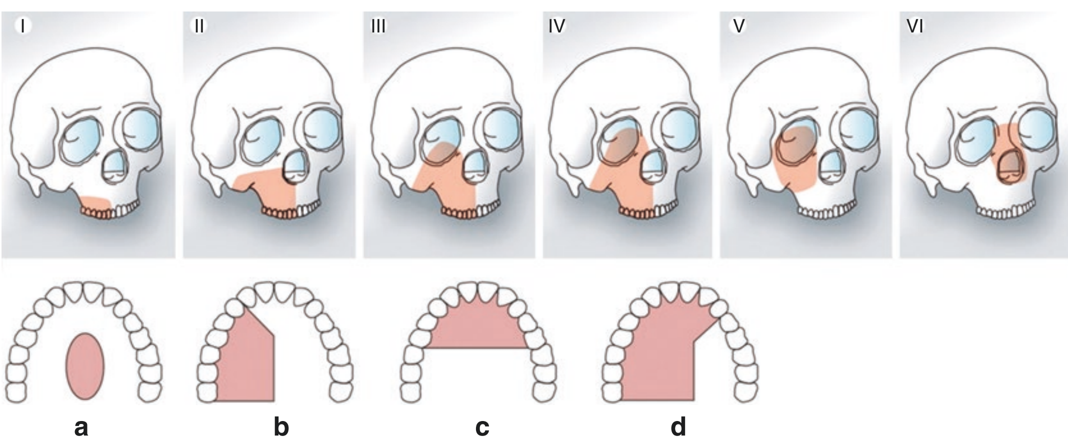

Fig. 5.1 Brown et al. classification of maxillectomy and midface defects [11]

8. Nasal collapse
9. Recipient vessels
10. Obturator versus tissue reconstruction

Soft Tissue Defects Only

The etiology of such defects include trauma, cutaneous tumors, burns, Romberg's disease, infection, radiotherapy, congenital deformities, and vascular malformations [2]. Full-thickness skin grafts can be used, but are prone to contraction and pigment changes. The best skin color matches are those of the postauricular, preauricular, or supraclavicular areas [2]. Superior results are gained from local flaps such as rotation, transposition, and advancement flaps. The nose is commonly reconstructed with nasolabial, bilobed, or paramedian forehead flaps. Rhomboid, island, or cervicofacial flaps are ideal for cheek reconstruction. When extensive soft tissue is required the radial forearm, anterolateral thigh, or scapula flaps are reliable options. The advantage of the radial forearm is that it is thin and reliable. The anterolateral thigh (ALT) flap is useful as it has a long, large vascular pedicle and can be thinned safely. If the soft tissue defect requires further bulk, the rectus, latissimus dorsi, or anterolateral thigh flaps can be used as they have long vascular pedicles but may require flap revision as a secondary procedure.

Parotidectomy Defects

Various options have been described in the literature dependent on the size of the defect. Free grafts, local muscle flaps, local fascial flaps, pedicled myocutaneous flaps, and free tissue transfer have been used successfully [13]. Free grafts include free autologous dermal fat or acellular human dermis [13–17]. They can be used for smaller defects. Their limitations include seroma formation, fibrosis, and loss of volume secondary to fat resorption [18, 19]. Local muscle and facial flaps include the sternocleidomastoid muscle rotation flap, superficial musculoaponeurotic system (SMAS) plication flap, and the temporoparietal fascial flap [20]. The disadvantage of these flaps is that they can leave a poor donor site cosmesis such as a neck contour deformity or temporal hollowing. The accessory and frontal branch of the facial nerve are also at risk when harvesting these flaps. Regional pedicled flaps include the pectoralis major, trapezius, latissimus dorsi, supraclavicular artery island flap, and submental island flap [21]. Free tissue transfer includes the radial forearm flap, rectus abdominis, and anterolateral thigh flaps. They are indicated for large defects, requiring bulk and can cover the dura in selected cases. They are more robust to withstand radiotherapy as they have their own blood supply [13]. Reconstruction of the sacrificed facial nerve is dealt with elsewhere in this book.

Reconstruction of Complex Three-Dimensional Defects Using Brown's Classification

Class I Defects

Smaller defects such as those involving an oronasal fistula can be reconstructed with an obturator, local pedicled flaps such as the temporoparietal and temporalis flaps, soft tissue flaps such as the fasciocutaneous radial forearm, or anterolateral thigh flaps [11].

Class II Defects

Class IIb defects which involve less than half of the lateral alveolus and palate can be reconstructed via an obturator or an osteocutaneous flap. Pedicled flaps such as the temporalis and temporoparietal flaps can repair oroantral or oronasal fistulas but will not facilitate a dental prosthesis like the osteocutaneous flaps. For larger defects, zygomatic implants can be placed to support a denture [11, 22]. If the defect involves the posterior alveolus only, a soft tissue flap may suffice such as the ALT, as long as the ipsilateral canine is present to support a denture. Class IIb defects can be reconstructed with a fibula flap. The deep inferior epigastric artery flap (DCIA) and scapula flap are also useful to reconstruct

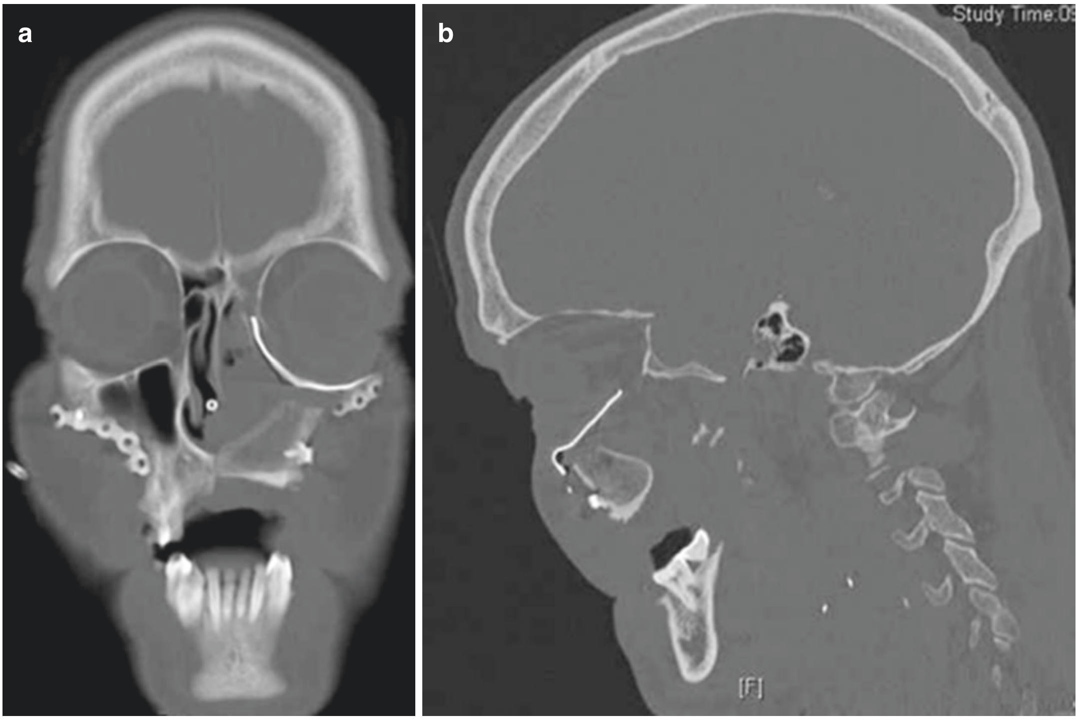

Fig. 5.2 Class III defect reconstructed with a DCIA flap and orbital prosthesis

these defects due to the muscle they provide resulting in a natural oral lining [11]. Radial and fibula flaps may not be strong enough to support the oronasal region in cases where there is a loss of alar support [11].

Class III Defects

In these types of defects, the support of the orbit and anterior support of the cheek are lost along with the dental arch [11]. The reconstruction needs to support the orbit and facial skin, close both the oral and nasal defects, and restore the alveolus for dental implants [11]. Muscle flaps can be used to obturate the fistulas and line the nasal wall as they epithelialize over time giving a natural appearance of the nasal and oral mucosa [11]. Soft tissue only flaps are another option such as the rectus flap but would need non-vascularized bone to reconstruct the orbital rim and floor which is not ideal [11]. The gold standard is to use an osseous or composite free flap such as the deep circumflex iliac artery (DCIA) flap, which will provide the best orbital support (Fig. 5.2). Other options include a fibula flap or a scapula flap [11].

Class IV Defects

Both the scapula flap and the DCIA are good options here [11] (Fig. 5.3). Both have sufficient muscle to fill the orbit, line the nasal cavity, close oral fistulas, and repair any dural tears if required. Skin coverage is also an option. The scapula is more reliable as in these cases orbital support is not required and the latissimus dorsi will provide adequate bulk [11].

Class V Defects

These orbitomaxillary defects can be reconstructed using soft tissue flaps only. The aim is to allow for subsequent orbital prosthetics to be fitted so bone is not required. Small defects may be reconstructed with a temporoparietal or temporalis flap. If there is a large area of skin loss, the anterolateral thigh (ALT) or radial

Fig. 5.3 Class IV defect reconstructed with a DCIA flap, orbital implants, and orbital prosthesis

Table 5.2 Recommended method of reconstruction according to the classification of midface and maxillary defects [11]

		I	II	III	IV	V	VI
Obturation		+	+	–	–	–	–
Local pedicled flaps							
	Temporoparietal, temporalis	+	+ (b)	–	–	–	–
Soft-tissue free flaps							
	Radial, anterolateral thigh	+	+ (a,b)	–	–	+	–
	Rectus abdominus, latissimus dorsi	–	–	–	+	–	–
Hard-tissue or composite flaps							
	Radial	+	+ (b,c)	–	–	+	+
	Fibula	–	+	–	–	–	–
	DCIA/internal oblique	–	+	+	+	–	–
	Scapula	–	+	+	+	–	–
	TDAA (with scapula tip)	–	+	+	+	+	+

forearm flap (RFF) are recommended. In cases where the lateral orbital wall needs reconstructing, a composite radial forearm flap may be used [11].

Due to the numerous available methods of treating maxillectomy defects, Brown et al. provided a recommendation of reconstructive options for each defect (Table 5.2).

In our opinion, osteotomized fibulas can be used for class III defects also. Obturation has also been used for Class III and VI defects but are not very successful.

Advantages and Disadvantages of Osseous Microvascular Free Flaps in Maxillary Reconstruction

Fibula Flap

This flap provides good bone stock and a large pliable skin paddle. Multiple osteotomies may be performed to shape the bone to fit the defect. The bone is suitable for dental implants and has minimal donor site morbidity [1, 2]. It provides 26 cm length of bone with adequate length and diameter of pedicle vessels [23–25]. Osteotomies can be performed safely with its reliable periosteal blood supply [1]. It allows for a two-team approach [1]. The disadvantages are that multiple osteotomies are required with severe angles between bone ends and planning the skin islands may be difficult in class III defects [11]. There is inadequate height in relation to the rest of the alveolus and it is contraindicated in those patients with peripheral vascular disease [23, 26].

DCIA and Internal Oblique

The advantages of this flap include the fact that it can be contoured and shaped to replace the orbital rim. It also provides enough bone for dental rehabilitation in the form of implant-retained prosthesis and full dentures supported by epithelialized muscle [11, 27]. There is good bone height to promote healing to the remnant maxilla [11]. It can be raised as a two-team approach. The internal oblique can fill the dead space, closing the oral fistulas and line the nasal airways [11]. However, its limitations include having a short vascular pedicle and a lack of segmental perforating vessels [23, 28]. The flap itself is difficult to raise, osteotomies are not easy, and the donor site may result in a weakened abdominal wall [2, 11] (Fig. 5.4).

Scapula Flap with Latissimus Dorsi

This flap provides adequate bone stock with surplus muscle, as the latissimus dorsi can be harvested as a chimeric flap [29]. It is an easier flap to raise compared to the DCIA, has adequate muscle to obturate the defects, and provide a natural nasal and oral lining once epithelialization has occurred [11]. It has a longer pedicle than the DCIA so is useful when options for

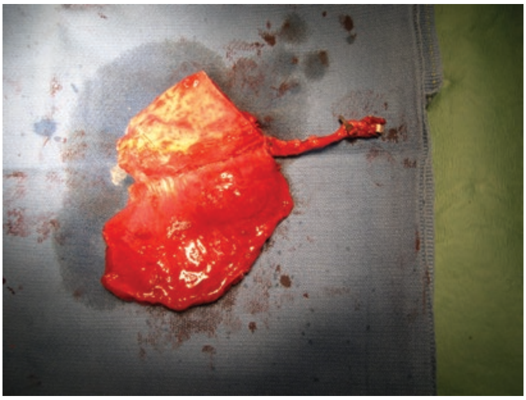

Fig. 5.4 DCIA flap showing the quality and quantity of bone and the versatility of the internal oblique muscle

anastomosis are limited [11]. A skin paddle is possible as a musculocutaneous or perforator flap [30]. The main limitation of this flap is that the patient requires turning during the procedure which lengthens the operating time and ischemic time.

Additional Points to Consider

The placement of osseointegrated implants may be immediate or delayed. In our experience implants placed 18 months post surgery and radiotherapy are successful. When an orbital floor defect exists without the need for an exenteration, a custom-made orbital floor plate or composite flap may be used. However, we have found that electing not to reconstruct the orbital floor could cause diplopia or enophthalmos. To overcome the challenge of a vessel-depleted neck, the temporal vessels may be used as recipient vessels. However, these vessels are often temperamental. No reconstructive technique can duplicate the functions of the soft palate satisfactorily [3, 31].

Obturator Versus Tissue Reconstruction

Obturators can provide extensive coverage and can compartmentalize the orbital, maxillary, and oral cavities. They do not require surgery which is ideal for patients where a lengthy operative time is contraindicated. An obturator will allow for direct oncological surveillance of the operative field, they are a custom-made reconstruction, the patient has an immediate new dentition and restoration of their appearance [2, 11]. The disadvantages include patient discomfort, pressure ulcers, infection, leakage from a poor seal, and the need for further refinement when the surgical cavity heals [2, 11].

Conclusion

The method of reconstruction should be selected on an individual basis, bearing in mind the medical situation, age and prognosis of the patient, the size, extension, and composition of the defect and the availability of local or distant tissues [2]. Obturation can be used for class Ia, IIb defects. Composite free flaps are advisable for Class IId, Class III–IV defects. The scapula flap is a good option if skin is required and the DCIA is the best flap if orbital support is required.

Reconstruction After Lateral Temporal Bone Resection

Primary temporal bone and lateral skull base malignancies comprise 0.2% of all head and neck cancers and consist of a range of pathologies at different sites. Cancers of the skin or parotid which invade the temporal bone are 10 times more common, comprising 2% of all head and neck cancers. Lateral skull base cancer includes [32]:

- Advanced skin cancer of the conchal bowl, pinna or periauricular skin. These can be squamous cell carcinomas (SCC), basal cell carcinomas (BCC), or melanomas.
- Advanced parotid cancers that invade the ear or temporal bone. These are generally high-grade malignant neoplasms or skin SCC metastasis to intraparotid lymph nodes.
- Infratemporal fossa temporomandibular joint sarcomas.
- External auditory canal (EAC) and middle ear malignancies, which are mostly SCC (80%), BCC, or skin adnexal tumors.

Temporal Bone Surgery

Lateral temporal bone resection should be regarded as the minimum oncological operation for T1 and T2 lesions [32]. This operation ideally entails en bloc excision of the ear canal lateral to the facial nerve. The conchal bowl should be resected as part of this. Resection boundaries should be from the mastoid to the tegmen of the middle cranial fossa, anteriorly into zygomatic air cells and temporomandibular joint (TMJ), and inferiorly to the hypotympanum and stylomastoid foramen [32]. In practice, depending on the pathology, a pinna sparing or pinna resecting approach can be used. This is followed by a cortical mastoidectomy and dislocation of the incus. This is then extended to the boundaries of the resection described above. An extended facial recess approach is used to enter the middle ear and separate the tympanic ring. The mastoid tip is drilled, and the bony and cartilaginous ear canal specimen is fractured anteriorly. The remaining soft tissue attachments anteriorly to the TMJ are finally cut, often with a monopolar. The soft tissue reconstruction is laid directly upon the stapes superstructure.

Extended temporal bone resection is required for tumors involving the middle ear. The additional steps are facial nerve sacrifice, total parotidectomy, posterior and middle craniotomy, labyrinthectomy, transection of the internal acoustic meatus, resection of the petrous apex, and exposure of the intrapetrous portion of the carotid [32].

Temporomandibular Joint/Mandible

The posterior wall of the TMJ is fractured during a lateral temporal bone resection, resulting in an inevitable disruption of normal TMJ function. In cases where the cancer specifically involves the TMJ or condyle, a partial mandibulectomy is recommended [32].

Reconstruction

The aims of reconstruction should address the following issues in descending order of importance: cerebral protection where the dura has been breached, the skin defect, the auricular defect, the tissue volume defect, any mandible defect, and facial nerve dysfunction.

Dural defects can be repaired with non-vascularized tissues, such as autologous fascia lata grafts, xenografts, or synthetic materials [32]. Smaller skin defects with smaller volume loss can be reconstructed with a radial forearm free flap, cervicofacial rotation flap, temporalis flap, supraclavicular flap, or submental island flap. Where the pinna is not involved, the posterior pinna skin may be used as covering for the defect after removal of the auricular cartilage. While these avoid a free flap, it does result in loss of an uninvolved pinna and will be cosmetically unacceptable to some. Most defects are generally larger than this and the anterolateral thigh (ALT) free flap is, thus, the workhorse for lateral skull base defect reconstruction. It provides a large quantity of skin, has minimal donor site morbidity, can be harvested with a vascularized nerve graft, and allows for harvest of fascia lata or the lateral cutaneous nerve of the thigh. ALTs also allow for simultaneous two team working. Where mandibular reconstruction is also required a chimeric flap, such as a scapular osteomyocutaneous flap combined with a thoracodorsal artery perforator (TDAP) flap, can be employed instead to reconstruct both large mandibular and lateral skull base defects.

The ear canal is not reconstructed after lateral temporal bone resection. Instead, the soft tissue reconstruction is laid directly onto the head of the stapes forming a Type III tympanoplasty.

Although an ALT flap may be more cosmetic than a radial forearm flap, it often requires a lot of thinning of the skin around the implants to prevent peri-implantitis.

Primary or secondary implant insertion should also be considered for ear prosthesis. Insertion of implants is the same as insertion of bone anchored

Fig. 5.5 Lateral temporal bone defect reconstructed with a radial forearm flap (requires minimal thinning to avoid peri-implantitis), implants and an auricular prosthesis

hearing aid (BAHA) implants and is, thus, widely available. Magnets or a bar can be secured on to the implants so that a prosthetic ear may be attached (Fig. 5.5).

Reconstruction of the Mandible

The extent to which speech and swallow is successfully restored is an important determinant of quality of life following treatment of head and neck cancer [33]. From a treatment planning perspective the following elements must be met to ensure adequate oral function:

1. Oral competence: the ability of the lips to form a tight seal preventing air and liquid escape
2. Adequate mouth opening: ideally at 35 mm and greater
3. Adequate mandibular excursions: lateral–medial of the mandible on the condylar axis and free movement of the condylar head to swing out of and into the condylar fossa
4. Stable path of closure: intact mandibular skeleton ensuring reproducible mandibular swing without dislocation
5. Ability to withstand masticatory load
6. Well-distributed occlusal load: the ability of the reconstructed mandible to support a dental prosthesis whether free or implant supported

Furthermore composite resections of the mandible including the floor of mouth or external skin require soft tissue coverage to seal the oral cavity and prevent oral–cutaneous or oral–cervical salivary fistulae. Irrespective of the quality of bone reconstruction, if the soft tissues are not adequately sealed, a salivary leak would contribute to wound breakdown, failure of the vascular pedicle (and thus the free flap), and exposure of the great vessels with life threatening consequences.

The quality of the bone reconstruction must also ensure an adequate tooth-bearing arch width and lower-facial or chin projection which impacts facial appearance and ensures optimal perioral muscular function because this contributes directly to the stability and retention of a dental prosthesis.

The form and dimensions of bone required to achieve these goals depends equally on the size and anatomical subsite of the bone defect. The functional requirements of the anterior mandible are typically very different to those of the lateral mandible. This functional difference was expressed in a recent classification of mandibular defects presented by Brown et al. [34] (Fig. 5.6).

Mandible defects are categorized into lateral defects (Class 1), extended lateral defects (Class II), anterior defects (Class III), and extended anterior defects (Class IV). Lateral defects include the body and the angle. “Extended” defects include the canine (i.e. ,extend into the parasymphysis) and defects that incur the loss of the condyle are classified as a separate subset denoted by the suffix “c.” This section concerns condyle-sparing lateral defects (i.e., Classes I, II, III, and IV). The canine is a keystone tooth that landmarks a dominant feature of the dental arch where the orientation changes from a coronal plane to an oblique sagittal plane. This has major implications on dental rehabilitation and the biomechanical stability of the mandible.

Well lateralized (and typically distal/posterior) defects of the mandible may be suitably reconstructed without bone continuity. A large caliber reconstruction plate may be used to reestablish the mandibular arch without a bone flap. Soft tissue cover is still a necessity for defects that involve the floor of the mouth in order to form a barrier against salivary leak into the neck. This is an acceptable option particularly when no bone flap donor is suitable or if the patient is deemed physiologically unfit for a prolonged procedure. An important exception is when radiotherapy is either planned or in patients who have received previous radiotherapy even if that was for a different subsite such as the tongue base or radiotherapy. These patients are at a great risk of soft tissue avascular necrosis or wound breakdown, risking exteriorization of the metal plate or exposure of the great vessels. The least that would be required in these situations is a thick soft tissue cover (e.g., a regional pectoralis major, a forearm flap with adequate adipose tissue, or a thigh flap with a muscular cuff).

The anterior (labial) segment of the mandible that includes the canine and incisor teeth is subject to additional torsional forces during function in addition to the tension–compression forces that the lateral mandible is subject to. This means that the anterior mandible is inherently unstable and that the threshold for bone reconstruction should be much lower. The discrepancy in the functional requirements between the anterior and lateral mandible is such that smaller well-lateralized defects may function with minimal (e.g., plate only) reconstruction or, in select patients, patients may achieve acceptable oral function without bone reconstruction of a lateral defect. In contrast any anterior defect would require stability and bone continuity in most cases.

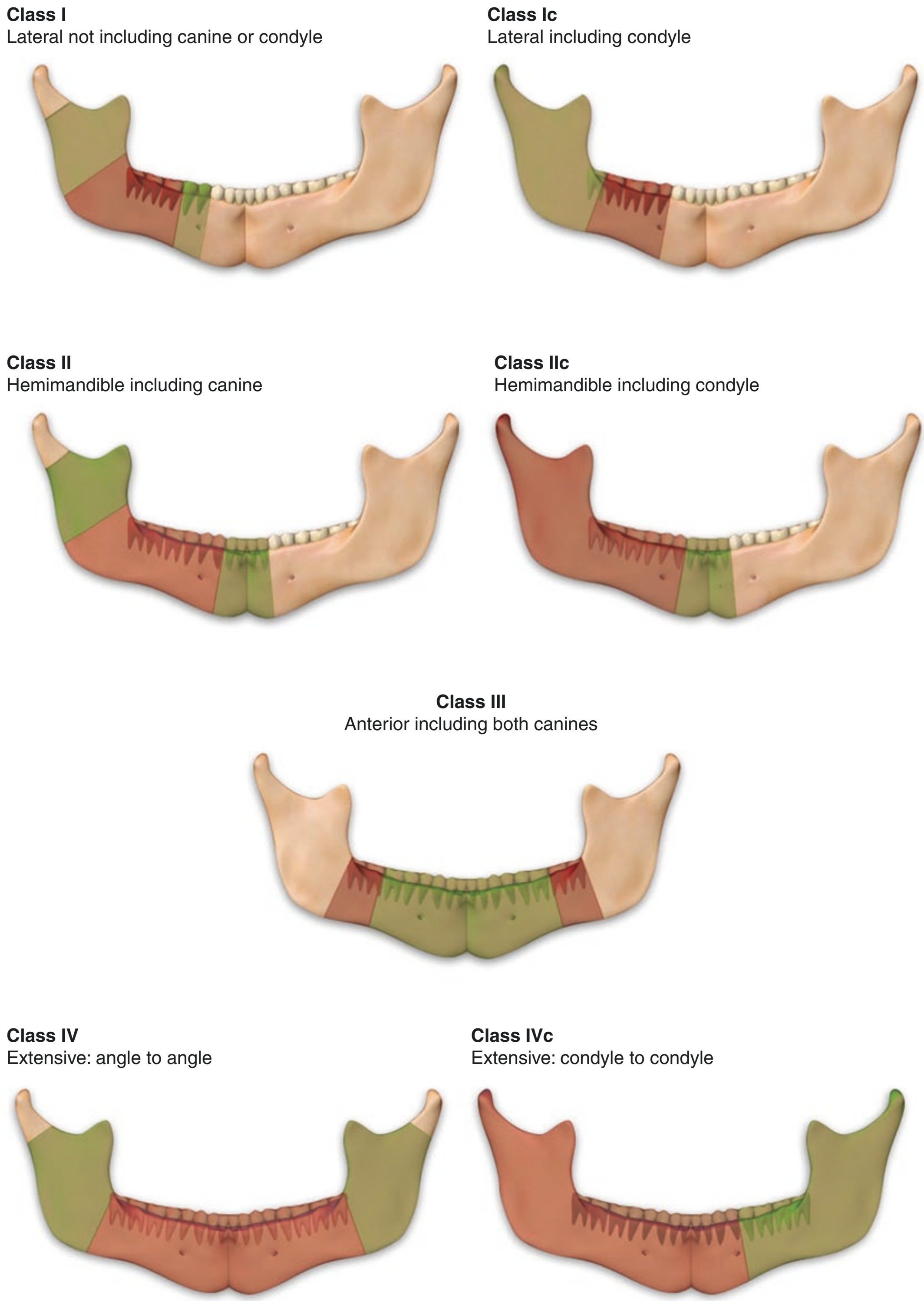

Fig. 5.6 Brown et al. classification of mandibular defects [34]

Figure 5.6: Classification of Mandibular Defects (James Brown)

- *Class 1* – lateral and not including condyle or canine
- *Class 1C* – lateral including condyle
- *Class 2* – hemimandible including ipsilateral canine but not the condyle
- *Class 2C* – hemimandible including ipsilateral canine and condyle
- *Class 3* – anterior mandible and includes both condyles
- *Class 4* – extensive defect, includes both canines and angles
- *Class 4C* – extensive defect, includes both canines, angles, and one or both condyles

Bone defects less than 5 cm may escape the need for bone flaps provided that the defect is bridged with bone grafts secured with osteosynthesis plates. In very select cases in pediatric patients, particularly where the bone resection was required for a benign pathology, short bone defects may ossify where the periosteal envelope is preserved.

Another important requirement for bone reconstruction in the anterior mandible is that osseointegrated implants in the lower jaw tend to be placed in the parasymphyseal segment (between the mental nerve foramina). This configuration provides optimal stability for implant supported dentures.

The native dental arch tends to follow what is referred to as the "curve of Spee" where the anterior teeth are set higher than the distal teeth. In addition to purely dental factors outside the scope of this discussion the higher set anterior teeth contribute to lower lip support. This must be borne in mind when selecting the bone flap to reconstruct an anterior defect. The fibula provides thick cortical bone that is ideal for primary stability of dental implants, but the bone height is much shorter than the native mandibular symphysis. Thus, the fibular bone flap must be set high so that the implants and dental prosthesis are appropriately set for a lip-supporting prosthesis. This may be achieved either by attaching the plate to the fibular bone deliberately high above the lower border of the fibular segment) or to osteotomize the fibula and fold one segment of bone over another thus creating a double-barreled reconstruction. A prerequisite for this to work is safe preservation of the periosteal sleeve as well as prevention of kinking or compression of the pedicle.

An alternative would be to use the DCIA flap. This provides good vertical bone height and larger volume of cancellous bone for implant osseointegration although primary stability is less favorable than the fibula flap given the relatively deficient cortical thickness. The scapula flap is another reliable bone donor and the same principles would apply to restoration of anterior defects as discussed for the fibula. A major advantage of the fibula over either the DCIA or scapula flap is that the fibula lends itself better to segmental osteotomies required to adapt the bone to the curvature of the reconstruction plate.

The plate itself may be either custom made to fit the curvature of the native mandible. Virtual surgical planning facilitates the use of custom-made plates and may also aid in the construction of cutting guides and orientation cleats. A stock plate may also be pre-bent on to the 3D model and then sterilized prior to the procedure. On-table bending of a straight reconstruction or adaptation plate is also possible, but it is time consuming. The bone flap is secured to the reconstruction plate and then onto the native mandible using locking screws which typically engage both the outer and usually the inner cortices.

The choice between the fibula, scapula, and DCIA is also dependent on many factors. Composite (bone, skin ± muscle) resections typically require composite reconstructions. The skin component is provided by the fibula and the scapula flaps but not reliably provided by the DCIA flap. The scapula flap may provide two skin paddles through its scapular (transverse) perforator and parascapular (descending) perforators. Multiple skin paddles are also possible in the fibula through the standard septocutaneous distal perforators and the proximal myocutaneous peroneal artery perforator.

A dual paddle is particularly suited to composite resections that remove facial skin (replaced by one skin paddle) and for separation of the oral cavity from the neck when the floor of mouth is removed during the surgical resection. The fibula or DCIA bone flaps may also be used with a separate soft tissue flap if dual paddles are not available. This could be achieved through free flaps, for example, the radial forearm or regional flaps including the pectoralis major and nasolabial flaps.

Finally, the required pedicle length is also an important determinant of bone flap selection. The fibula provides the longest pedicle length. The DCIA potentially provides equally long pedicles, especially if the iliac crest is harvested further away/distally from the anterior superior iliac spine as possible. The circumflex scapular pedicle provides greater vessel diameter (2.8 mm on average) compared to the peroneal artery (1.5 mm width on average) but the pedicle length is reduced. It may be the only option available should a preoperative study of the fibular vascular tree (e.g., magnetic resonance imaging or contrast CT angiography) reveal atherosclerotic narrowing or anomalous supply of the foot. The DCIA is also a good donor to consider in patients with peripheral vascular narrowing but the pedicle and its ascending branch tend to follow varying anatomical variations. The tip of the scapula gives a long pedicle avoiding the need for vein grafts.

The Mandible in Skull Base Tumors: Surgical Access and Reconstruction

The proximal mandible affords access to the lateral skull base through the lower infratemporal fossa and lateral pharyngeal spaces. Surgical division (e.g., vertical subsigmoid osteotomy) with immediate osteosynthesis allows for such access and preservation of the skeletal integrity of the mandible–masticator muscle matrix. En block resections may be indicated for tumors of temporal bone, salivary gland, or muscular origin, leading to immediate loss of lower facial height and lateral excursion of the lower jaw. This would disrupt the occlusal balance necessary for reestablishment of adequate oral function, including speech and swallow rehabilitation postoperatively. In addition, composite resections of overlying skin require reconstruction in all scenarios including post-pinnectomy defects (allowing primary placement of osseointegrated implants) and temporal bone defects with or without breach of the dura mater.

The type of reconstruction required is dictated by the extent of functional loss anticipated rather than mere replacement of an anatomical structure. A common example is loss of the condyle–ramus unit. This is by definition a composite resection because of the adherence of the pterygoid muscles. Establishment of a functioning temporomandibular unit is achievable with a reconstruction plate, with preferably a condyle component that is able to rotate freely within the glenoid fossa. This facilitates mouth opening up to the limit allowed by condylar rotation (approximately 25 mm inter-incisal opening). In practice a soft tissue component is necessary as a barrier against the oral cavity, preventing a salivary fistula and protecting the underlying tissues against radiotherapy should it be required. This would be well served by regional flaps (e.g., a temporalis or sternocleidomastoid flap) or free tissue transfer including the free composite fibula or scapula flap.

Each type of flap has benefits and limitations. The fibula is a long bone and has a good pedicle length albeit with a small vascular diameter (average 1.5 mm). More importantly, the vessels may be anatomically anomalous or deficient in peripheral atherosclerotic vascular disease. Clinical and angiographic assessment is necessary to determine whether the free fibula is an appropriate choice preoperatively. Alternatives include the scapula flap which provides a pedicle length up to 12 cm with larger arterial diameter (2.8 mm circumflex scapular artery). Unlike the fibula, the flap does not lend itself to a two-team approach. Further options include the deep circumflex iliac artery (DCIA) flap which in current practice tends to be used as a free osseous flap primarily. Reconstruction of the proximal mandible may also be achieved with costochondral bone grafts, although, in the context of aggressive lateral skull base tumors likely requiring adjuvant high-dose radiotherapy, they are less likely to be favored as a reconstructive choice.

TMJ Reconstruction Following Lateral Craniofacial Resection

Introduction

The aims of reconstructive surgery of the mandible are twofold: to restore form in terms of aesthetics and function. In mandibular defects this is particularly relevant in the reconstruction of the temporomandibular joint (TMJ). The aims are to preserve the preoperative occlusion and allow sufficient inter-incisal mouth opening [35].

Anatomy of the Temporomandibular Joint (TMJ)

The temporomandibular joint is described as a ginglymoarthrodial joint consisting of a superior and inferior compartment separated by an articular disc [36]. The superior compartment is responsible for allowing sliding or translational movements referred to as arthrodial, while the inferior compartment provides the hinge and rotational movements and is therefore called ginglymoid. The joint itself is also lined with synovium, which secretes synovial fluid providing nutrients and lubrication for the joint [35].

The subcomponents of the temporomandibular joint include the following: the glenoid fossa, this structure accepts the condylar process and has a fibrocartilage lining; the meniscus, which is an oval articular disc of variable thickness, and the fibrous capsule. Three ligaments are responsible for restriction of TMJ movements, which are as follows: the temporomandibular ligament forming the lateral portion of the anterior capsule, responsible for synchronizing movements of the condyle and disc. The sphenomandibular and stylomandibular ligaments support the mandible [37].

The facial nerve is the most common structure to be aware of when approaching the TMJ surgically. Once the main trunk exits the stylomastoid foramen and passes forward approximately 2 cm, it divides into two main branches – the temporofacial and cervicofacial divisions. The oblique line 0.5 cm below the tragus in the direction of the eyebrow passing 1.5 cm above the lateral extremity of the eyebrow estimates the path of the temporal branch in the soft tissue. It is this branch that is most susceptible to damage during approaches to the TMJ, the nerve itself lies under the surface of the temporoparietal fascia, the average distance from the external auditory meatus to where it crosses the zygomatic arch is approximately 2 cm (8-35 mm) [37, 38].

Reconstruction

Various options exist for reconstruction following surgical resection of the temporomandibular joint depending on the extent of the mandibular resection and whether the patient is likely to undergo radiotherapy as part of their treatment. The options are as follows.

No Reconstruction

A clinical decision may be made not to reconstruct the temporomandibular joint at all. The main disadvantage of this option is that the patient would ultimately experience a malocclusion. This is due to reliance on the contralateral TMJ to maintain stability and movement resulting in deviation of the mandible to the ipsilateral side and a malocclusion [39]. This is not so much of a problem if the patient is edentulous.

Soft Tissue Only

Soft tissue flaps alone have been used in reconstruction of posterolateral mandibular defects. These include radial forearm, anterolateral thigh, gracilis, rectus, and latissimus dorsi. Soft tissue only reconstruction adequately recreates the soft tissue contour and can camouflage the cut edge of the mandible. Soft tissue only reconstruction has been used successfully in a number of studies [40, 41]. Among these, one study found that the postoperative occlusion was better among those with vascularized bone grafts compared to soft tissue only free flaps. The use of soft tissue only reconstruction creates a "swinging defect" causing the mandible to shift to the affected side resulting in a malocclusion [41].

Reconstruction with Costal Cartilage Grafts/Non-vascularized Bone Grafts

This technique has been widely used in the reconstruction of TMJ defects, particularly in children, and is a useful technique in isolated condylar defects. This technique also provides a soft articular surface in patients providing coverage for the glenoid fossa [42]. Gilles first described it in 1920 in the reconstruction of the TMJ [43]. Subsequently, in 1974, Poswillo et al. were the first surgeons to identify its physiological compatibility with the TMJ [44]. Its biological properties show it has regenerative and growth potential, and while this is useful, it can also prove to be unpredictable. In addition, there is also potential for ankylosis of the joint [45, 46].

The costal graft has been deemed advantageous in the terms of favorability of the shape of the graft, it is relatively easy and quick to perform the procedure, and there is very little in the way of donor site morbidity.

The main disadvantages to this technique are among patients who will need postoperative radiotherapy. In addition, the size of the costochondral graft is limited to smaller defects and is prone to resorption [42]. Alternative non-vascularized bone that has been utilized for the same purpose include cancellous marrow with allogenic cribs [47, 48], free metatarsals [49, 50], or even sternoclavicular head grafts [51].

Reconstruction with a Prosthetic Joint

While there are many different types of prosthetic joints available, the most commonly used ones are TMJ Concepts or Biomet Total TMJ prosthesis. Depending on the extent of the resection it may be that a total joint prosthesis is required, a condyle-only prosthesis, or fossa-eminence prosthesis is needed [52]. There has been varying degrees of success reported with prosthetic joints; Marx et al. reported good stability and a low incidence of significant complications [53]. Two other studies also reported minimal complication but attributed this to preservation of the disc and TMJ capsule [54, 55]. Complications that have been reported include infection, plate fracture, extrusion, and erosion into the middle cranial fossa [42].

Plating of Native Condyle onto Vascularized Bone Flap

Another option for reconstruction is to affix the non-vascularized condyle to the end of the vascularized free flap. Varying degrees of success have been described with this technique. Hidalgo et al. reported some condylar resorption, but this didn't correlate with reduced function in their case series of 14 patients. In comparison, Wax et al. reported poor functional outcomes and condylar displacement in their case series of two patients [56, 57].

Replacement of Condyle with Fibular Head

The head of the fibula can be contoured and the end of the bony flap can be anchored from the periosteum of the fibula to the lip of the glenoid fossa [42]. The shape of the fibula and its cortical structure are similar to the native condyle and therefore a suitable replacement enabling a good fit into the glenoid fossa. Direct replacement with a fibula reconstruction is also advantageous in terms of its vascularity making it more resistant

Fig. 5.7 Reconstruction of the mandible and condyle resulting in a satisfactory interincisal distance (mouth opening) and occlusion

to irradiation compared to a non-vascularized bone graft. In favorable circumstances, the fibula free flap has been combined with a metal condyle. Complications from free vascularized fibula flaps to the condyle are rare, although ankylosis and dislocation have been reported [58].

Replacement with a Metallic Condylar Head into the Glenoid Fossa

The condyle is replaced with a condylar head attached to the plate used to hold the fibula flap in place. This is the author's preferred mode of reconstruction. It allows the occlusion, movements of the mandible, and the facial contour to be reestablished (Fig. 5.7). A theoretical disadvantage of this technique is the risk of the condylar head resorbing the bone of the glenoid fossa into the skull base. However, this risk is small as usually the pterygoid muscles and the masseter would have been resected, reducing the load on the reconstructed joint.

Reconstruction of the Disc

While so far we have considered reconstruction of the condyle and glenoid fossa, it is also important to consider reconstruction of the disc where preservation is not possible. Various options have been described, and these include temporalis fascia, fat graft, allogenic cartilage or dura, sternocleidomastoid fascia, and silastic sheet [53, 59]. However, the authors do not reconstruct the disc in any way.

Conclusion

Maxillomandibular lateral skull defects are complex and may include the temporal bone, maxilla, orbit, temporomandibular joint, and mandible.

Reconstruction aims to recreate the facial form aesthetics and restore the functional qualities of these three-dimensional, highly complex specialized structures. Optimum mastication, deglutition, speech, and cosmesis can be achieved through a multidisciplinary approach. Recent advances in microvascular free tissue transfer, virtual surgical planning, and implant retained prosthesis have revolutionized reconstruction in this area.

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6 Rehabilitation of Facial Palsy – The Brow

Austin Hembd and Shai Rozen

Introduction

A large portion of the reconstructive research, literature, and advances in the subject of facial nerve paralysis has dealt with ocular protection and dynamic reanimation of the smile. Surely, the protection of the globe, vision, and reparative efforts to restore an emotional and symmetrical smile cannot be understated. Nevertheless, it is a renewed interest in treatment modalities and pathophysiology of other aspects of facial palsy, such as synkinesis, that will inch the reconstructive surgeon's results toward the ultimate goal of normality with the contralateral, unaffected side. The rejuvenation and treatment of the periorbita and brow in the setting of CN7 palsy is one of these avenues. Independent from a dynamic smile, the proper animation, position, and shape of the upper horizontal facial third are crucial for facial recognition and emoting happiness. [1, 2]

In the field of cosmetic plastic surgery, it has long been noted that brow ptosis in the aging patient can mimic emotions of sadness, grief, or anger, and is a commonly reported reason for a patient consult for facial or forehead rejuvenation [3]. In addition, a ptotic brow position can lead to pseudoptosis or a pseudoexcess of upper lid skin, which can exacerbate an already present dermatochalasis and cause a worse superior visual field deficit [3]. Addressing the upper horizontal third as an aesthetic unit is standard of care in a patient undergoing a rhytidectomy. Incorporating this global treatment concept into the field of facial reconstructive surgery is imperative. A true understanding of the anatomy, aesthetic analysis, techniques, and normal facial aging processes all delineated in decades of cosmetic plastic surgery literature will greatly benefit the reconstructive surgeon [4–6]. Only when these principles and concepts are integrated into the specific pathophysiology of a denervated brow will we achieve the functional *and* aesthetic result our facial palsy patients deserve.

Anatomy

A firm understanding of the periorbital and forehead muscular and ligamentous anatomy is crucial to diagnosing and surgically intervening on the brow. The transverse head of the corrugator supercilii brings the brow medially to produce *vertical glabellar* frown lines, and its function is commonly associated with the appearance of grief and sadness [7]. The oblique head of the corrugator, the depressor supercilii, and the medial fibers of the orbicularis oculi all produce *oblique glabellar* rhytids and depress the medial brow along with the procerus muscle. The

A. Hembd · S. Rozen (✉)
Department of Plastic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA
e-mail: AUSTIN.HEMBD@phhs.org; shai.rozen@utsouthwestern.edu

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procerus chiefly creates *transverse glabellar* skin lines. The lateral brow is depressed by the actions of the lateral fibers of the orbicularis oculi muscle. This action, in addition to the transverse head of the corrugator supercilii sliding the entire brow complex medially, causes depression of the lateral brow, redundancy of brow skin at the superior orbital rim, and a relative excess of superior eyelid skin. This *pseudoexcess*, as Knize [3] described it, develops overtime with gravity and repeated muscle contract, thus further exacerbating an existing dermatochalasis or true eyelid skin redundancy.

The relative skin redundancy from brow ptosis and malposition is crucial to separate and recognize from dermatochalasis, as simply resecting this excess with a blepharoplasty could permanently fix the brow in ptosis.

The frontalis muscle creates *transverse rhytids* of the forehead. The frontalis hyperactivity to superior visual field obstruction by brow ptosis with or without dermatochalasis is important to understand, particularly in the setting of facial palsy. Unilateral ptosis may cause contralateral frontalis hyperactivity, thus masking a contralateral ptotic brow or worsening transverse rhytids. This should be delineated during physical examination, which will be discussed further in the following sections.

Fascial condensations are also an important part of understanding the pathology and the treatment in brow ptosis. The superficial temporal fascia, galea, and frontalis are continuous, but there are condensations along the temporal fusion line or temporal crest as well as the superior lateral orbital rim, often referred to as the orbital ligament. The latter are adherent with the bone and orbital septum. Besides these more rigid attachments to bone, there is a gliding areolar plane between the superficial temporal fascia and the deep temporal fascia and a fat pad between portions of the galea to the periosteum. There are, however, more firm attachments between the galea and superficial temporal fascia and the overlying dermis. This leads to a phenomenon with facial aging and facial paralysis where the superficial temporal fascia, galea, and overlying skin move caudally as a unit, driven by the contraction of the lateral orbicularis fibers and corrugators as described above. This occurs to the level of the junction of the middle and lateral thirds of the brow where the lateral frontalis fibers insert. Thus, the frontalis is the key muscle that counteracts the descending brow. This explains the profound effects of frontal branch palsy on the upper third facial aesthetic unit [8].

Sensation to the forehead and scalp is chiefly provided by the supraorbital nerve, which exits a foramen or notch lateral along a vertical line that connects with the medial limbus. This nerve divides into a superficial branch that enters the frontalis 2–3 cm above the rim and supplies the forehead and a deep branch that supplies the scalp posterior to the hairline [9]. This deep branch is typically located 0.5–1.5 cm medial to the temporal crest on its way to innervate the scalp. The supratrochlear nerve exits the orbit more medially: 1.5 cm lateral from midline glabella, and enters the corrugator before entering the frontalis to supply the forehead. It is typically division of this deep branch with a deep subgaleal dissection or coronal incision that can lead to postoperative scalp anesthesia or paresthesia.

The sentinel vein is the last anatomic structure of mention due to its anatomic relationship with the frontal branch. This vein is typically 1–1.5 cm lateral and superior to the lateral canthus, and Trinei et al. described the frontal branch coursing an average of 6.8 mm cephalad to the vein [10]. Thus, this vein marks the area of proximity to the frontal branch and excessive upward retraction and cautery should be limited. It also marks the caudal extent of necessary temporal fusion line release to achieve brow elevation during an endoscopic or coronal approach [11].

Aesthetic Analysis and Examination of the Brow and Upper Horizontal Facial Third

Aesthetic standards and norms are crucial in preoperative evaluation of a patient considered for repair of brow ptosis. The youthful appearance of the upper facial third is one with minimal transverse forehead and glabellar static rhytids, the absence of skin dyschromia, an appropriately positioned brow and hairline, and a pleasing brow shape (Fig. 6.1a).

The brow should start medially as a club shape and along a vertical line that connects the medial orbital fissure with the alar base (Fig. 6.1b). It then has a gentle arch with a peak at the middle and lateral third junction along a vertical line connecting roughly with the lateral limbus. The lateral brow gently tapers and ends along an oblique line that connects the alar base with the lateral orbital fissure. At the mid-pupillary line, the brow should sit 5 cm (in women) to 6 cm (in men) from the anterior hairline, 1.6 cm from the supratarsal crease, and 2.5 cm from the midpupil. If there is less than 2.5 cm between the midpupil and the top of the brow, brow ptosis is diagnosed [12] (Fig. 6.1b). Gender differences also exist in the position of the brow in relationship to the superior orbital rim. In women, it typically sits ~1 cm above this bony landmark, whereas in men it typically sits right at the rim itself [13]. If the brow sits more caudal than this defined position along the superior orbital rim, brow ptosis can again be diagnosed.

Great care should be placed on evaluation of the position of the hairline in relation to the brow, whether the forehead is short or long, the quality of the hairline or developing male pattern baldness, and the presence of any deep transverse forehead rhytids. These findings could have direct impact on the choice of surgical technique for brow lifting.

During physical examination, it is important to have the patient sit with their eyes closed until one notices the frontalis is completely relaxed. With firm pressure on the forehead to immobilize the frontalis, the patient can open their eyes. If the brow position is now lower than when previously looking straight forward, they are likely using frontalis hyperactivity to compensate for brow ptosis. A blepharoplasty alone could reduce the frontalis hyperactivity, as the visual field deficit is no longer driving compensation. This can lead to a more ptotic brow postoperatively. If the examiner corrects the ptotic brow position up onto the proper position on the superior orbital rim or above, thus correcting pseudoexcess of the upper lid, and there is still a redundancy of eyelid skin noted, then a concurrent blepharoplasty should be considered.

Brow Ptosis in Facial Palsy

After a thorough understanding of anatomy, aesthetic and physical evaluation, and the normal aging processes resultant in the senile ptotic brow, the pathology and subsequent treatment of the brow in the setting of facial nerve paralysis can be better appreciated. The same processes of the senile brow ptosis occur in the setting of facial palsy. The frontalis typically prevents severe caudal displacement of the medial two-thirds of the brow even in a patient with advanced signs of facial aging. However, the dense paralysis of the frontalis muscle in facial palsy creates a unique scenario where the entire forehead and brow descend. This can often crowd the superior lid in older palsy patients.

As discussed above, the procerus and depressor supercilii, and medial orbicularis fibers can all depress the medial brow when activated. These muscles can often receive contributions and innervation from the zygomatic branches of the facial nerve [14–17]. In contrast, the frontalis only receives motor innervation via the frontal branch. Thus, in an isolated frontal branch paresis, the medial brow can still be depressed without any counteracting frontalis tone, potentially exacerbating medial brow ptosis further [8]. In a complete or partial unilateral facial palsy, this lack of frontalis activity eventually leads to superior visual field deficits and compensatory contralateral frontal branch hyperactivity, leading to an exaggerated asymmetry due to the intact frontal innervation of the contralateral frontalis. This emphasizes the physical examination of the patient as described above, as the possibility for compensated brow ptosis is even more likely in senescent facial palsy given the propensity for contralateral frontalis hyperactivity (Fig. 6.2a). If the brow is in a ptotic position once the frontalis is neutralized on the healthy side, a bilateral brow lift may be considered because this would likely be the new resting position after the paralyzed

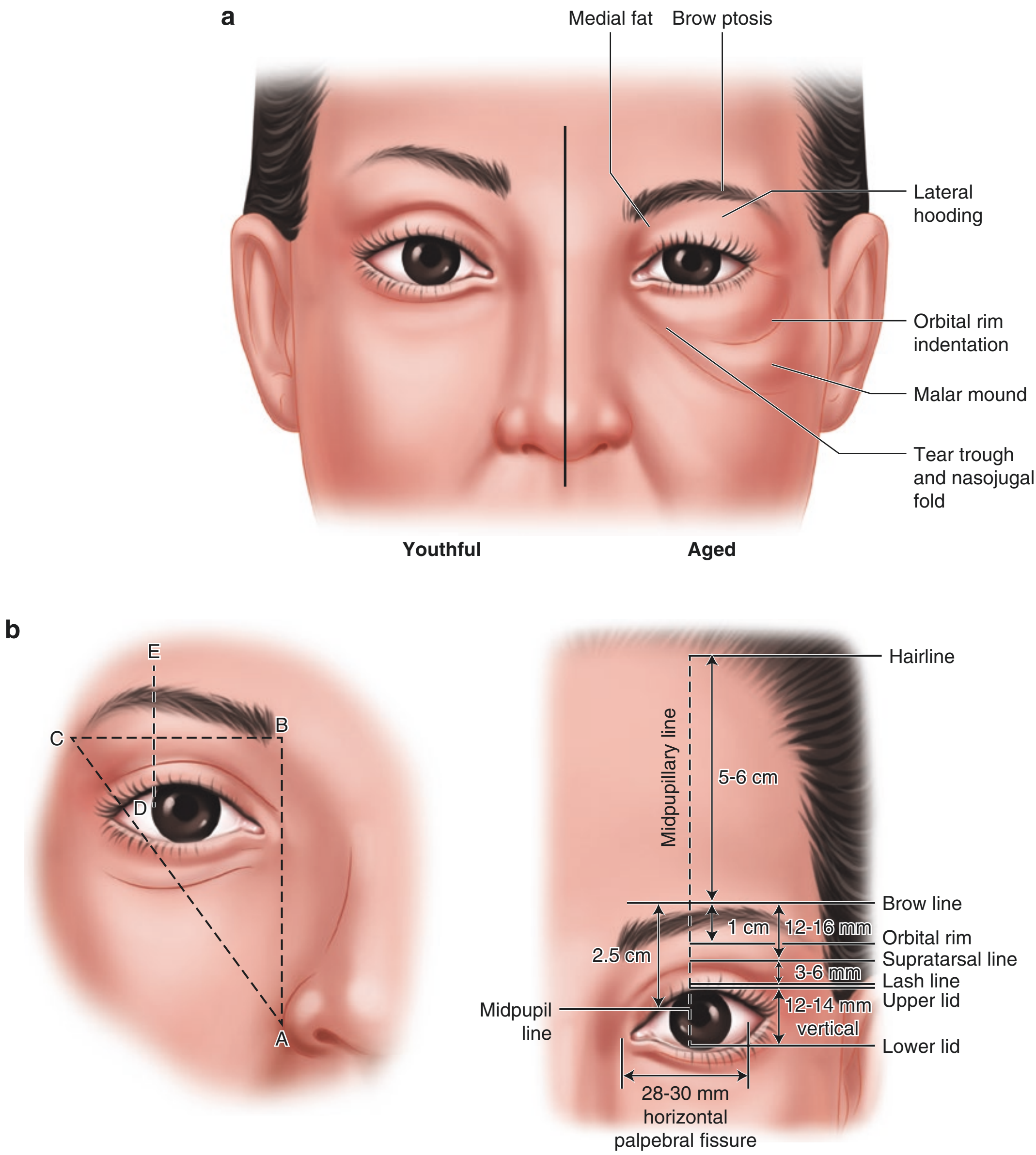

Fig. 6.1 (**a**) Youthful upper face and brow vs. Normal aging upper face and brow (**b**) Standardized measurements and ratios for the normal healthy brow and upper face

side is addressed. Doing so removes the neural drive for constant frontal branch activity.

Although this chapter is to focus on brow rehabilitation, it must be stated that the chief concern in the setting of facial palsy is ocular protection and avoidance of exposure keratitis and corneal damage. Evaluation of the brow is not complete without a thorough examination of the periorbita, globe and cornea, the presence of a blink reflex, lagophthalmos, paralytic ectropion, signs of chronic exposure, and the ability to protect the cornea with either a Bell's phenomenon or adequate lid closure. The reconstructive surgeon cannot proceed with brow elevation before first considering whether a concurrent or preoperative adjunctive procedure to assist with ocular protection is indicated. In the setting of identified concurrent brow ptosis and dermatochalasis with the examination maneuvers described above, one must not be over exuberant with skin excision *and* brow lifting. Exacerbating or creating lagophthalmos in a facial palsy patient compromises the central tenant of ocular protection.

Treatment of Brow Palsy in the Setting of Facial Palsy

Considerations in Treatment Not every patient with facial paralysis needs surgery addressing the brow. Some of the first major considerations when seeing a new facial palsy patient and considering surgery is the duration of palsy, the suspected pathology or cause, and whether recovery can reasonably be expected. A conservative watch and wait approach may be indicated in the setting of suspected Bell's palsy, a patient who had intratemporal nerve grafting at the time of tumor extirpation, or with a history of acute trauma where continuity of all facial nerve branches can reasonably be assumed.

Surgical intervention for patients with suspected discontinuity of CN7 in the acute or subacute setting includes nerve grafts and nerve transfers, and expected dynamic reanimation of the brow depends on the how and where the nerve transfer or graft is coapted. While priority for targets with cross-facial nerve grafting and even transfers typically include branches to the zygomaticus major and the orbicularis, we commonly utilize a truncal coaptation when performing a masseteric nerve transfer in the setting of acute or subacute facial paralysis [18]. In these patients, there is rarely recovery of the frontal branch and additional interventions for the brow should be discussed. However, in a patient with a direct coaptation of the frontal branch after trauma, for example, surgery for brow ptosis should wait until complete dynamic recovery has plateaued.

Patient's age is another chief consideration, where even in the setting of chronic and complete facial palsy, very young patients do not typically present with significant brow ptosis. They are more common to have contralateral frontalis hyperactivity, and thus treatment of this patient population mainly includes counseling, education of the possibility of future procedures and options, and chemodenervation of the hyperactive frontalis to improve symmetry [19]. The other most common indication for conservative treatment with chemodenervation is in the setting of synkinesis or aberrant regeneration of facial nerve causing medial brow depression, furrowing, or upper lid skin pseudoexcess when attempting a smile or other facial mimetic movements.

As the course of time and chronic denervation continue, these younger patients are more likely to be indicated for treatment with unilateral brow lifts and potentially contralateral chemodenervation. It is in the context of the aging patient with longstanding complete paralysis where bilateral brow lifts are most commonly indicated, with or without a concurrent blepharoplasty.

Static Procedures

Techniques for brow lifts can be separated into endoscopic versus open approaches. Open approaches can be further divided into coronal, pretrichial or anterior hairline, temporal, transblepharoplasty incision, or direct. Dissection planes most commonly used are subperiosteal or subgaleal. Suspension techniques for securing elevation for either open or endoscopic approaches vary and are often debated, but include skin excision, suture techniques, and device placement. Knowledge of the advantages and disadvantages of each technique will arm the reconstructive surgeon with the tools necessary to indicate the proper procedure to the specific patient, which can present with a large variability in the degree of palsy or brow ptosis (Fig. 6.2b).

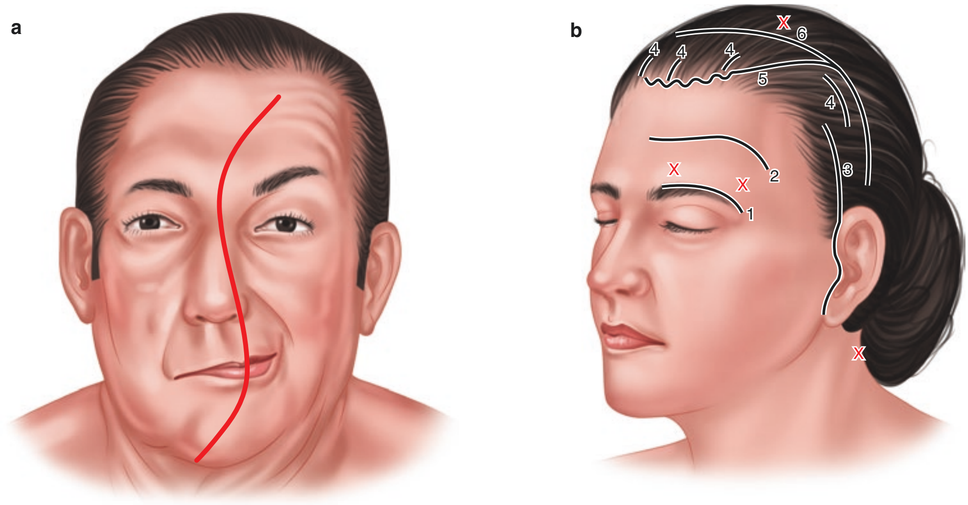

Fig. 6.2 (**a**) Typical appearance of the face with a right facial palsy. (**b**) Incisions for various static brow lift procedures: 1. Direct brow; 2. Mid-forehead approach; 3. Temporal brow lift; 4. Endoscopic approach; 5. Pretrichal approach; 6. Coronal approach

Direct Brow Lift The direct brow lift has classically been described as the approach of choice in patients with complete facial palsy due to its powerful effect and control on elevation: It is capable of correcting large, >10 mm discrepancies in brow position [20]. This is explained by the elastic band principle, which dictates that the further away the suspension point is from the brow, the less effective the lift will be [21]. A supraciliary incision placed directly above the brow hairline or just caudal to the superior border brow assuredly offers a powerful control over positioning after an ellipse of forehead skin is removed.

Originally described in 1930 by Passot [22], this technique had fallen out of favor in cosmetic brow lifting due to critiques regarding conspicuous scars and potential for sensory changes due to damage to the supraorbital nerve. This has led to the teaching that direct lifting techniques should indicated in older patients with deep rhytids or dense brow hair that can camouflage the visible scars, a thinning hairline, or male patterned baldness that would make coronal approach scars unacceptable, or in a patient with a high hairline or convex forehead slope that would make endoscopic techniques difficult to execute [19].

There is relatively sparse evidence regarding the complications after direct brow lifting, particularly in the facial palsy population. Green [23] and Booth [24] showed in their respective case series' that postoperative scarring was of little concern with careful layered closure and the right patient selection. These studies, echoed by other publications, showed low complication rates with regards to postoperative sensory changes if the dissection plane is brought more superficially in the subcutaneous layer at the medial brow over the supraorbital and supratrochlear nerve regions [25, 26].

The mid-forehead incision is a variant of the direct brow lift that utilizes a forehead crease a few centimeters above the brow to attempt to camouflage the scar even further. Indications would be the same as described for the direct supraciliary approach above, but with a deeper forehead rhytid that could potentially offer greater postoperative scar satisfaction, particularly in the setting of a receding hairline, thinning hair, or unfavorable eyebrow features. Typically, this approach involves dissection in the subcutaneous plane to just below the orbital rim, leaving the frontalis down. The orbicularis muscle is identified and sutured with the overlying skin flap to the frontal periosteum via discontinuous blunt dissection [19]. Several studies have concluded that there were minimal complications and acceptable scars when indicated correctly and advocated its use over scars immediately above the brow [27, 28]. There was no quantifiable data given, however.

Perhaps the variability in reports over the scarring in direct brow lifting is that few studies only look at patients with facial paralysis. One such study that does suggests that there is less postoperative scar hypertrophy when direct brow lifts are done in facial palsy patients because of the dense lack of tone of the underlying musculature [20]. They also concluded in favor of direct brow lifts in this population, citing brow symmetry in 65% of patients and visual field improvements in 85% of patients at 3-year follow-ups. Of note, they used nonabsorbable sutures directly fixed to the periosteum in their technique.

In summation, the direct brow lift is an approach our group and many other reconstructive surgeons use in the setting of facial palsy in pursuit of the benefits of optimal control, symmetry, durability, and power, while working to minimize the prominent scar. Periosteal sutures, bone anchors, or plate constructs are all efficacious in supporting the lifted brow [8].

Key Points

- More acceptable scar in older patients with more static rhytids, receding or thinning hairline, with a careful layered closure, and without constant muscle tone in the setting of CN7 palsy
- Powerful control and most lift per skin excised
- Transition to more superficial subcutaneous plane medially to avoid damage to sensory nerves
- Consider periosteal fixation for improved longevity

Coronal Brow Lift This open technique is a powerful correction of forehead rhytids and glabellar frown lines with simultaneous lifting of the brow, unlike direct techniques. One can utilize either the posttrichal incision for hidden scars within the hair-bearing scalp or pretrichal incisions that can potentially correct a high hairline. However, the scars are readily apparent in those with a thinning or receding hairline such as in male-pattern baldness. This may be a relative contraindication.

The approach typically involves an incision 4–6 cm posterior to the anterior hairline toward the pinna, beveling to minimize risk of incisional alopecia. This is useful for a low hairline, where typically 1.5 mm of anterior hairline displacement is necessary for every 1 mm of eyebrow elevation [29]. Elevation then can take place in the subgaleal or subperiosteal plane, and the brow is lifted with a myotomy along the forehead after wide elevation and excision of 1–2 cm of scalp anterior to the incisions [30]. Greater scalp excision, up to 3–4 cm, can be performed laterally versus medially to correct the common issue of more severe lateral brow descent. There is evidence to suggest the subperiosteal lift is advantageous for improved vertical lift and longevity of the result [31].

A variant of the coronal lift, the temporal brow lift, utilizes incisions over the temporalis muscle and the dissection plane is just above the deep temporal fascia to avoid frontal branch injury [32]. This approach spares the vertex incision of the traditional coronal brow lift.

Disadvantages to this technique are the frequent, although typically temporary, morbidities including sensory changes, cicatricial alopecia, contour irregularities, and asymmetry [33]. In the facial palsy setting, this approach could be used in the somewhat younger population with moderate brow ptosis. The increased distance of the incision from the target brow renders this approach somewhat weaker and increasingly prone for recurrence.

Key Points

- Relative contraindications include thinning hair, male-pattern baldness
- Requires more excision per brow lift than direct approaches
- Pretrichal approach can lower a highest hairline
- Common morbidities include scar complications and temporary sensory changes to the scalp

Endoscopic Brow Lift This technique, described in the early 1990s, quickly gained popularity in cosmetic brow lifting due to comparable results with coronal approaches and high satisfaction [34–37], but with a low incidence of complications seen commonly with coronal lifts, such as scarring, alopecia, and postoperative sensory changes [38]. In contrast to direct lifts that rely on an element of tissue excision, the endoscopic lift relies on suspending the galea or periosteum in an elevated position until adherence is obtained by healing. Thus, it is necessary to use some type of suspension in order to support the forehead and brow in its new position. A host of options for this have been described, including spanning sutures, k-wires, suture anchors, and percutaneous screws [39–41].

Further advantages to this procedure is that the preservation of both the supratrochlear and supraorbital is offered under direct visualization and the incisions required are undoubtedly more minimally invasive. Some studies questioned the efficacy and durability of endoscopic brow lifts in the setting of facial palsy, with some showing unsatisfactory results in older patients with large discrepancies in brow position [42]. More recent publications have advocated its use, however [43, 44].

Perhaps one key in making this technique more effective, as described by Dukic et al., is elevating both brows simultaneously as well as the complete upper third aesthetic unit [44]. This perhaps better addresses the contralateral hyperactive frontalis, thus leading to improved symmetry. This study showed continued lift and symmetry at 1-year follow-up and safety of utilizing concurrent adjunctive procedures, such a gold weight or blepharoplasty, at the time of the lift. Disadvantages to the technique are the needs for specialized equipment, a higher learning curve, and difficult in patients with a high hairline or acutely sloped foreheads. Moreover, in the setting of facial paralysis, it will less likely provide long-lasting results. If this approach is used in the setting of facial paralysis, it is likely in the younger patient, and the patient should understand they will likely need additional surgeries for brow support as they age.

Key Points

- Requires learning curve and specialized equipment
- Differs from other techniques which rely on excision
- Limited incisions avoid common morbidities of coronal approaches
- Differences in dissection, fixation, and addressing bilateral brows concomitantly can possibly improve results in complete facial palsy although this approach may be limited to young patients with mild brow ptosis

Transblepharoplasty Browpexy This technique utilizes a standard blepharoplasty incision and often is coupled with a blepharoplasty to address dermatochalasis in conjunction with the browpexy. Most approaches utilize a long-lasting absorbable or nonabsorbable suture and fix the brow from the deep undersurface to the periosteum above the superior orbital rim. The corrugators or procedure can be addressed at the same time if desired to treat glabellar rhytids [45] if the contralateral side is simultaneously addressed. Advantages are its inconspicuous scar that hides well in the upper lid. However, it offers a weak lift in comparison with other techniques. In our experience, this approach is sufficient in younger patients or in those with incomplete palsies with some residual frontalis tone. In the setting of complete frontal branch palsy, particularly in an older patient with a heavy forehead and brow, skin redundancy, and severe ptosis, the direct approach offer a more satisfactory, long-term result.

Key Points
- Emulates a direct lift in conjunction with concomitant blepharoplasty to address a true upper eyelid skin excess
- Important to perform adequate undermining and exposure to prevent overhang of soft tissues
- Important to fix lift to periosteum or deep temporal fascia
- Inadequate in our experience for complete facial palsy in patients with significant brow ptosis and heavy soft tissues

Dynamic Procedures for the Paralytic Brow – The Deep Temporal Nerve as a Donor

While static brow lifts are the current mainstay of rehabilitation of the upper third aesthetic unit in facial nerve palsies, dynamic reanimation can potentially provide a more natural and satisfactory result. The majority of research on periorbital dynamic reanimation has focused on either nerve transfers or free functional muscle transfers to the eye in efforts to restore an involuntarily blink reflex or a dynamic, voluntarily, for protective eye closure [46, 47]. While protective efforts of the globe of are of higher priority, the concept of dynamic reanimation to the brow shares many similarities and, in some cases, need not be mutually exclusive.

The deep temporal nerve, the motor branch to the temporalis, is a potential powerful source of donor axons in direct vicinity to frontal and zygomatic branches of the facial nerve. While anatomic descriptions had been established, our group demonstrated a surgical approach to the consistent anatomy and sufficient number of potential axons in the middle division of the deep temporal nerve [48]. It reliably courses 1 mm posteriorly every 1 cm cephalic from a starting point 4 cm anterior to the tragus along the zygomatic arch. This nerve, given its redundancy in innervating the temporalis, could be a rich donor nerve in acute and subacute palsies to the temporal or zygomatic branches for both periorbital and frontalis innervation. In chronic palsies, it could power free functional muscle transfers as previously described for eye closure [47, 49].

Given the chronic contraction of the temporalis in supporting the mandible, this nerve is poised to provide superior tone to a transferred nerve target or functional muscle over the masseteric nerve that is more commonly seen in 5 to 7 transfers. Of course, more clinical data and research is necessary before this option proves superior to the current gold standard of static lifts of the brow. However, the field of facial reanimation will only be improved by the constant strive toward a more natural, functional, and aesthetic result.

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7 Surgical Rehabilitation of Facial Paralysis – Eyelids and Lower Face

Jason Cohn, Tom Shokri, Aurora G. Vincent, Marc H. Hohman, Yadranko Ducic, and Fiyin Sokoya

Introduction

Facial expression is an integral component of interpersonal communication, facilitating nonverbal cues and providing insight into an individual's intentions and emotional state [1]. In addition to nonverbal communication, facial muscles are responsible for numerous essential facial functions [1]. Facial paralysis can lead to facial asymmetry, lagophthalmos with subsequent exposure keratopathy, eyelid retraction, ectropion, nasal obstruction secondary to nasal valve collapse, impaired oral competence with drooling, articulation deficits, and synkinesis, ultimately culminating in a significantly deleterious effect on a patient's quality of life [1–4].

Facial paralysis can result from several etiologies; most common are "Bell's" palsy and iatrogenic injury from tumor extirpation [15]. Other causes include, but are not limited to, congenital malformations (such as Möbius Syndrome), trauma to the temporal bone or face, infectious diseases (such as herpes zoster, Lyme disease, or syphilis), autoimmune conditions (such as lupus or multiple sclerosis), metabolic derangements, and toxic exposures [3, 5, 15]. Regardless of the underlying cause, facial paralysis is a devastating condition with a spectrum of clinical manifestations necessitating individualized management.

A patient with facial paralysis needs to be examined systematically to determine which deficits are present. A zonal approach is often employed, examining the face from top to bottom, in repose and with a series of expressions, assessing both voluntary and involuntary movements [32]. In addition to a thorough examination, determining the time course and severity of the paralysis will inform the prognosis, the need for management, and the type of manage-

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J. Cohn
Department of Otolaryngology and Facial Plastic Surgery, Philadelphia College of Osteopathic Medicine, Philadelphia, PA, USA

T. Shokri
Division of Otolaryngology, Penn State Milton S. Hershey Medical Center, Hershey, PA, USA

A. G. Vincent
Otolaryngology, Head and Neck Surgery, Madigan Army Medical Center, Tacoma, WA, USA

M. H. Hohman
Facial Plastic and Reconstructive Surgery, Madigan Army Medical Center, Tacoma, WA, USA

Y. Ducic
Otolaryngology and Facial Plastics Associates, Fort Worth, TX, USA

F. Sokoya (✉)
Otolaryngology – Head and Neck Surgery, University of Arizona, Tucson, AZ, USA

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ment necessary. Rehabilitation of the chronically paralyzed face should be performed zonally as well, deficit by deficit, because the facial nerve's myriad functions cannot be rehabilitated with a single intervention. Surgical rehabilitation can restore facial motion and facial symmetry; numerous interventions and techniques have been developed and improved over the past two decades. This chapter provides an overview of the management of facial paralysis for the reconstructive surgeon.

Anatomy

A thorough understanding of the anatomy of the facial nerve is useful in identifying the cause of paralysis and in achieving surgical rehabilitation. The facial nerve somatomotor cortex is located within the frontal lobe's precentral gyrus. From the precentral gyrus, corticobulbar fibers project to the facial nucleus in the pons where they decussate, projecting to both ipsilateral and contralateral facial nuclei. The upper segment of the facial nucleus, which receives ipsilateral and contralateral nerve fibers, ultimately innervates the forehead. The lower segment of the facial nucleus only receives contralateral fibers, however, and innervates the midface, mouth, and neck. Thus, facial nerve lesions proximal to the facial nucleus typically only result in a contralateral, lower facial palsy. Efferent nerve fibers exit the facial nucleus at the ventral pontomedullary junction of the brainstem and travel to the porus acusticus of the internal auditory meatus. The nervus intermedius contributes sensory and parasympathetic fibers to the facial nerve in the internal auditory meatus. The facial nerve is then transmitted through the meatal, labyrinthine, tympanic, and mastoid segments of the temporal bone. The meatal foramen is the narrowest portion of the fallopian canal, and, as such, it is a common site of nerve compression and injury from nerve swelling caused by varicella zoster reactivation, Bell's palsy, or temporal bone trauma. The labyrinthine segment ends at the geniculate nucleus, where the first branch of the facial nerve, the greater superficial petrosal nerve, exits. The intratemporal facial nerve also gives rise to the nerve to the stapedius, the chorda tympani, and Arnold's nerve, which provides sensory innervation to the external auditory canal [6, 7].

The facial nerve traverses the stylomastoid foramen, where it is accompanied by the stylomastoid artery, as it exits the temporal bone. It then gives off motor branches to the posterior auricular muscles, the posterior belly of the digastric muscle, and the stylohyoid muscle, after which the main trunk divides into terminal branches generally categorized as frontal, zygomatic, buccal, marginal mandibular, and cervical, although their arborization patterns vary extensively from individual to individual [34]. The facial nerve innervates all muscles of facial expression from their deep surfaces with the exception of three: levator anguli oris, buccinator, and mentalis [5, 8].

The main trunk of the facial nerve can be identified roughly 1 cm anterior, inferior, and deep to the tragal pointer. It lies deep to the plane of the posterior digastric muscle, in line with the tympanomastoid suture line. When these landmarks do not reveal the main trunk, a retrograde dissection of a distal branch, such as the marginal mandibular nerve, can aid identification, as can mastoidectomy with distal dissection through the stylomastoid foramen. The main trunk enters the parotid gland where it branches at the pes anserinus into upper and lower divisions. From there, the frontal branch travels superiorly along the deep aspect of the temporoparietal fascia to supply the frontalis, corrugator supercilii, and procerus muscles [9–11]. The course of the frontal branches is well approximated by Pitanguy's line, which runs from a point 0.5 cm below the tragus to a point 1.5 cm above the lateral brow [10]. The zygomatic branches travel across the central third of the zygomatic arch to innervate the orbicularis oculi and contribute to innervation of the midface muscles. Buccal branches course superior and parallel to Stensen's duct superficial to the masseter muscle, often running superior and inferior to the transverse facial vessels; they supply the zygomaticus, buccinator, nasalis, and upper lip musculature [12, 13]. The marginal mandibular branch courses along the inferior border of the parotid in close proximity to the facial vein. It lies superficial to the retromandibular and posterior facial veins, within the cervical fascia deep to the platysma. It courses superiorly over the gonial notch to innervate depressor labii inferioris, depressor anguli oris, and mentalis. Finally, the cervical branch primarily innervates the platysma, although it's innervation can occasionally arise from the marginal mandibular branch or even accept a contribution from the ansa cervicalis [33]. Redundancy exists between collateral branches of the zygomatic and buccal nerves, with both contributing motor innervation to midface musculature. This redundancy results in higher rates of both functional recovery and synkinesis development following distal nerve injury [14].

Understanding the relationship between the facial nerve and the fascial planes of the face is critical for either avoiding unintentional injury to the nerve or permitting efficient identification of it for reinnervation or repair. The superficial musculoaponeurotic system (SMAS) of the face, described by Mitz and Peyronie in 1976, is contiguous with the mimetic musculature anteriorly, the platysma inferiorly, and the temporoparietal fascia superiorly, although the last relationship is not always clinically apparent due to decussation and compression of the fascial planes at the zygomatic arch [35]. Nevertheless, the relationship of the facial nerve to these fasciae remains consistent; the nerve always travels on their deep surfaces or just deep to them as it courses to its target muscles.

Management of the Upper Face and Eye

Acute Periocular Care

Injury to the facial nerve that inhibits transmission of nerve signals to the orbicularis oculi causes poor eye closure, both from reduced upper eyelid movement and lower lid laxity, and risks exposure keratopathy. In the vast majority of acute facial paralysis, the face will recover, but the cornea needs to be protected in the interim, as recovery can take weeks to months. Meticulous eye care is of paramount importance to prevent a permanent eye injury. Exposure keratopathy can be prevented with frequent application of moistening eye drops, ophthalmic ointment, eyelid stretching, and taping at night [32]. Other tools, such as a moisture chamber or a scleral contact lens can also be used to prevent corneal desiccation [1, 3, 4, 36]. Frequent application of eye drops can be tedious, however, and eyelid taping can cause abrasions of the skin. Surgical interventions to improve eyelid closure are worthwhile in patients who cannot maintain conservative care, in those with an expected prolonged recovery process, and in cases where no return of function is anticipated at all.

Upper eyelid loading through implantation of a platinum or gold weight is a simple, safe, effective, and reversible procedure that can be completed in the clinic setting (Fig. 7.1). Local anesthetic is injected into the upper lid, and a short blepharoplasty incision is made. The orbicularis is incised, and dissection proceeds superficial to the orbital septum, down to the tarsal plate and eyelid margin. The weight is positioned superficial to the tarsal plate at or within 2 mm of the eyelid margin. More superior placement of the eyelid weight will make it less visible to an onlooker, but can cause the eyelid to open when the patient lies supine, which should be avoided. The weight is sutured into position, centered above the medial limbus, as paralytic lagophthalmos is typically most pronounced medially. The orbicularis oculi is then reapproximated and the skin is closed.

Weighted implants permit passive eye closure with gravity and, therefore, protect the cornea and prevent exposure keratopathy. Although platinum weights are slightly more expensive than gold weights, they have been associated with reduced capsule formation, tissue reactions, and extrusion. Furthermore, platinum has a higher density, so appropriate upper lid loading can be achieved with a thinner implant that has a lower profile and improved cosmesis [3, 4, 15].

Fig. 7.1 Picture showing 1.2 gram gold weight placement in a plane deep to the orbicularis oculi muscle, superficial to the tarsal plate

In addition to eyelid weight placement to improve upper eyelid closure, there are many lower lid procedures to improve ectropion, epiphora, and lower lid laxity. Tarsorrhaphy and a lateral tarsal strip tightening, for example, are simple procedures that can further improve eye closure and protection by improving the lower lid position [3]. In one case series, tarsorrhaphy resulted in a 90% rate of corneal ulceration resolution [4]. Similarly, performing a lateral tarsal strip has been shown to decrease patient dependence on lubricating drops and resolution of corneal foreign-body sensation [32]. While these procedures are generally well tolerated, they are not risk-free. Common complications include granuloma formation, development of a suture abscess, dehiscence, and lateralization of the lacrimal punctum with recurrence of lid laxity and epiphora [4]. For patients to whom a tarsorrhaphy is cosmetically unacceptable, a lateral tarsoconjunctival flap may present a more acceptable option [37]. Fig. 7.2 presents a treatment algorithm for acute periocular management in patients with facial paralysis.

Chronic Periocular and Forehead Rehabilitation

After acute eye protection, chronic facial palsy with brow ptosis and facial asymmetry can be addressed with a surgical brow lift. Static suspension of a ptotic brow is often performed concurrently with upper eyelid loading and lower lid tightening because desquamation of epithelial cells from the ptotic brow onto an exposed cornea can exacerbate exposure keratopathy [32]. Asymmetric or unilateral brow lifting is also appropriate for patients without evidence of recovery 3 months after injury and in those in whom the facial nerve was sacrificed or transected, when no recovery is expected [4]. The goal of the procedure should be to split the difference between the position of the normal brow in repose and with elevation, thereby minimizing the chance a casual onlooker will notice asymmetry; typically, placing the paralyzed brow 2–3 mm superior to the normal side will accomplish this [50, 51].

Approaches to brow lift commonly employed in facial rejuvenation can also be applied after facial palsy; correction of the ptotic brow can be achieved

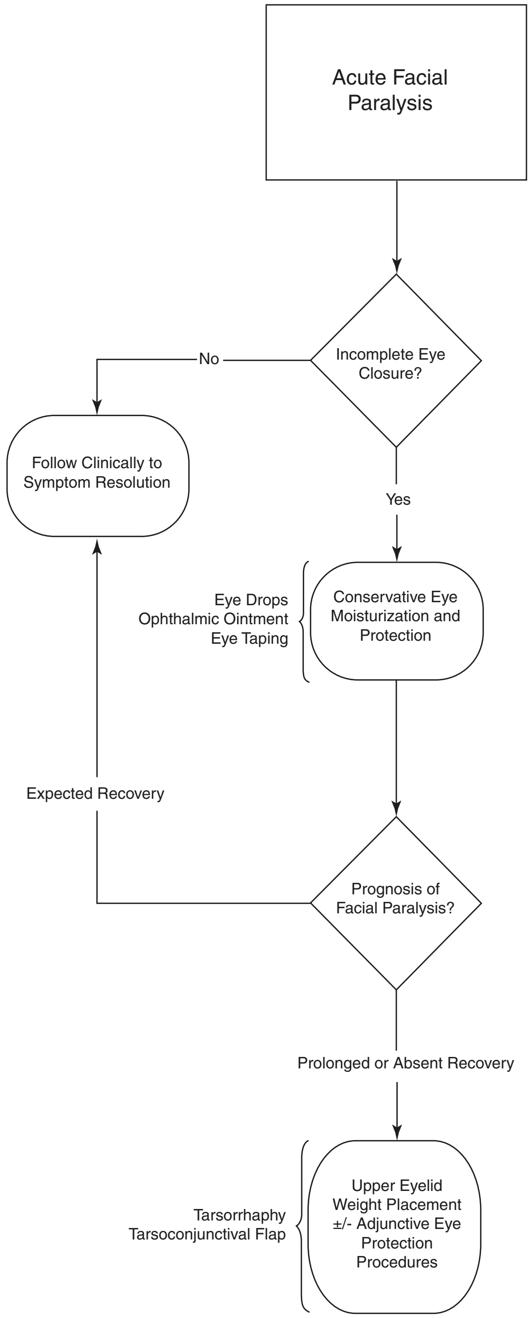

Fig. 7.2 Acute care algorithm for facial paralysis. While awaiting possible nerve recovery or planning for more extensive procedures, protection of the cornea is paramount to prevent permanent injury

through standard endoscopic, coronal, pretrichial, midforehead, direct, and trans-blepharoplasty approaches. Endoscopic brow lift is performed through multiple short incisions just posterior to the hairline, with subperiosteal dissection, release of the arcus marginalis, and elevation of the brow. It can improve brow ptosis without creating facial scars, although its ability to effect asymmetric change is limited compared to other techniques. A direct brow lift, in contrast, allows precise correction of brow asymmetry, but with the drawback of creating a visible scar. A direct brow lift is achieved with the elliptical excision of skin and subcutaneous tissue superficial to the orbicularis oculi, just superior to the brow. The dermis beneath the hair-bearing brow can be suspended to the periosteum of the frontal bone to improve the durability of the lift. A trans-blepharoplasty brow lift includes an incision in the upper eyelid, superior dissection superficial to the orbital septum to the arcus marginalis, and superior suspension of the brow either with suture or an absorbable implant. This approach allows improvement of brow asymmetry without extensive subperiosteal dissection and without creating an obvious facial scar. For patients seeking facial rejuvenation, a trans-blepharoplasty brow lift can be combined with an upper lid blepharoplasty. In the case of facial paralysis, however, an upper blepharoplasty is usually avoided or performed very conservatively so as not to worsen already-impaired eye closure. In the case of a patient with heavy soft tissues and marked brow ptosis, a suspension with nonabsorbable suture anchored to a miniplate on the frontal bone can be very effective, with longevity comparable to that of the aforementioned techniques [38].

Management of the Midface and Smile

The treatment of facial paralysis is determined by the etiology, duration, and severity of the paralysis. If recovery is not expected, long-term restoration of facial function may be required. Alternatively, if nerve recovery is expected, temporizing measures bridging the interval between injury and the expected onset of neural regeneration may be indicated. Therefore, the timing of onset and duration of paralysis often determine the treatment. Furthermore, given the complexity of facial nerve pathology, management often includes a multidisciplinary team approach [1, 5].

Rehabilitation of the midface can be accomplished through reinnervation or reanimation; the latter is often subcategorized into static and dynamic interventions. Reinnervation seeks to use native facial musculature, while reanimation restores function by replacing nonfunctional muscle. Static reanimation, which suspends facial structures to improve symmetry and function at rest, can be performed at any time in the course of treatment, though it is often delayed when some degree of nerve function is expected to return. Dynamic interventions use regional or free muscle transfer to restore movement that seeks to mimic natural facial function; they are among the most complex techniques in the facial paralysis surgeon's armamentarium.

Because native facial musculature provides more natural function than transferred muscle, particularly with respect to the vector of the smile, it should be employed for rehabilitation whenever possible, making reinnervation preferable to reanimation. Reinnervation procedures should ideally be performed within 6 to 9 months of the onset of paralysis in order to leave enough time for new axons to reach the target muscles while the muscles remain viable. Beyond 1 year after onset of paralysis, reanimation is generally more successful, and reinnervation becomes less reliable because denervated muscles develop nonfunctional motor end plates and irreversible atrophy after 18–24 months [1, 2, 5]. When the facial nerve has been sacrificed or transected and cannot be primarily repaired, reinnervation procedures should be considered early. In cases of Bell's palsy or facial nerve trauma, when the nerve is believed to be intact, reinnervation procedures should be delayed 3–6 months to allow for natural nerve recovery, which often will occur. After nerve transposition, donor axons regrow through the distal facial nerve framework until they reach the motor endplates of the target muscles. Axons regrow at a rate of 1 mm per day, thus return of movement after reinnervation will still be delayed be several months while the axons are growing. For this reason, reinnervation is typically not successful when performed for facial palsy that has persisted for more than a year; while facial muscles may be viable at the time of transfer, they may have deteriorated in the intervening months before a signal is restored. Reanimation procedures, which involve replacement of muscular and nervous components, may be considered at any time for patients who lack distal nerve branches and/or functional facial muscles, and for patients with chronic facial paralysis who are more than 12 months from onset [15].

Synkinesis, abnormally high resting tone and dyscoordinated movement, results when regenerating axons innervate incorrect muscles or a combination of correct and incorrect muscles. This phenomenon can occur after an injury to any single nerve that innervates multiple muscles; the laryngeal and extraocular muscles are other examples, though their synkinesis may be less apparent than that of the facial muscles. Neuropraxia and Sunderland type 2 injuries do not produce synkinesis because the axons remain enclosed within intact endoneurium all the way to the target muscle; in order for synkinesis to occur, the injury must at least disrupt the endoneurium [39, 40]. Patients with synkinesis will experience involuntary eye closure with voluntary smile, for example, and their complaints typically stem from overstimulation of facial muscles, rather than a lack of signal. Physical therapy can help with neural retraining, but often adjunctive procedures that limit aberrant, excessive muscle tone are required. Chemodenervation from injection of botulinum toxin is common; the platysma and periocular musculature are often targeted. The effects of the injection are limited, however, and patients must present for multiple, repetitive procedures over time, ultimately leading to antibotulinum toxin antibody development and decreased effectiveness of the injections. Surgical platysmectomy can more permanently relieve excess platysmal activation. Similarly, selective neurectomy allows improvement in aberrant eye closure and may improve the smile, though, given the robust collateral innervation of the midface, synkinetic movement may return [16–18].

Reinnervation

Primary Nerve Repair

When direct repair of facial nerve discontinuity is performed, there is greater chance of achieving improved resting tone, coordinated movement, and perhaps less post-paralytic synkinesis. Therefore, when possible, particularly in the setting of acute nerve transection, primary neurorrhaphy with a tension-free closure should be attempted after freshening the nerve ends [24, 25]. In cases of nerve defects exceeding 5 to 10 mm, mobilization of the mastoid segment may be necessary to allow tension-free neurorrhaphy [26, 27]. When proximal and distal segments of the nerve are present but a tension-free repair is not feasible, an interposition nerve graft may be used. Common donor nerves include the great auricular nerve, sural nerve, and medial antebrachial cutaneous nerve. Cadaveric and synthetic nerve grafts are available as well [41]. The surgeon must weigh the advantages and disadvantages of tension on the neurorrhaphy site, which may compromise blood flow in vasa nervorum, against addition of a second suture line with an interposition graft, as up to 50% of axons may be lost at each neurorrhaphy [43]. Traditionally, two to three epineural 9–0 or 10–0 nylon sutures are placed at each neurorrhaphy site, taking care to trim back any axonal bloom beforehand. The coaptation can then be circumferentially enclosed in a vein graft or synthetic regeneration matrix, and secured with tissue sealant to avoid axonal growth into surrounding tissues, though the efficacy of this modification is poorly studied [2, 4, 5, 15]. If there is a mild to moderate amount of tension on the repair, it may be beneficial to leave up to a 5 mm gap between the nerve ends if they are enclosed by a sheath; when there is no tension at all, a tissue glue may suffice for coaptation without the need for microsuturing [44].

Nerve Transfer

Hypoglossal Nerve Transfer

In circumstances where there is no access to the proximal facial nerve for primary repair but the mimetic muscles remain viable, reinnervation with nerve transfer may be the best option [5]. Historically, donor nerves have included the phrenic nerve, accessory nerve, ansa cervicalis, recurrent laryngeal nerve, hypoglossal nerve, masseteric nerve, and contralateral facial nerve [1–3, 5]. The hypoglossal nerve has commonly been used due to its close proximity to site of repair, consistent location, and robust axonal supply [28]. Hypoglossal nerve transfer provides restoration of facial tone with excellent improvement in facial symmetry at rest [5]. Classically, the procedure involved complete transection of the hypoglossal nerve and coaptation to the main trunk of the facial nerve, but this has fallen out of favor due to resultant difficulties with speech, swallowing, and mastication, many of which worsen over time [1–3]. Additionally, while this approach improves resting facial tone, severe synkinesis necessarily results, making meaningful facial expression exceptionally challenging for the patient. Over time, however, hypoglossal nerve transfer has evolved to minimize tongue morbidity while still restoring facial function. Modern techniques have demonstrated efficacy from longitudinally splitting the hypoglossal nerve and only transferring a partial thickness segment. Other authors describe partially incising the hypoglossal nerve distal to the descendens hypoglossi, then placing an interpositional “jump” graft from the side of the hypoglossal nerve to the receiving facial nerve branch. This modification has been shown to preserve tongue function in the majority of patients; however, a weaker facial response and longer recovery times have also been seen. When a nerve transfer is employed to reconstruct an individual facial nerve branch and rehabilitate a single facial function, synkinetic mass movement can be avoided; other techniques are then used to address remaining facial function deficits as part of the overall treatment plan [47].

Masseteric Nerve Transfer

The motor nerve to the masseter muscle also represents a potential donor in nerve transfer procedures. Close proximity of the masseteric nerve to the buccal branch of the facial nerve allows a shorter distance for axonal regrowth with expedited recovery and return of smile, often in 3–4 months following reinnervation. Sacrifice of the descending branch of the masseteric nerve is associated with minimal morbidity, as the proximal masseter branches are left undisturbed [29]. This nerve branch is also similar in caliber to the buccal branch of the facial nerve. Furthermore, in 40% of adults, natural masseter contraction occurs during normal smile; therefore, some patients have the capacity to develop an effortless smile without consciously clenching their teeth [2, 3]. In general, though, the use of the masseteric nerve to drive a smile will require a deliberate effort on the part of the patient, at least initially. Younger patients often possess sufficient neural plasticity to achieve a spontaneous smile if they are motivated and compliant with physical therapy. The primary functional difference between hypoglossal and masseteric nerve transfers is that the hypoglossal nerve can provide good resting facial tone but causes a donor muscle deficit proportional to the amount of nerve transferred; the masseteric nerve has a low basal firing rate and thus provides less resting facial tone, but causes minimal donor muscle deficit despite transfer of the entire nerve. Only rarely has masseteric nerve transfer has been associated with atrophy of the masseter muscle with resultant cosmetic deformity and facial twitching with mastication [2].

Cross-Face Nerve Graft

The cross-facial nerve graft (CFNG) relies on peripheral branches of the contralateral, intact facial nerve to innervate the paralyzed muscles; it is therefore the procedure most likely to produce a truly spontaneous and emotive smile [2]. A branch of the contralateral, intact, facial nerve that produces oral commissure excursion and smile is identified. Next, a cable graft is coapted in an end-to-end fashion to the donor buccal branch, tunneled across the upper lip, and coapted end-to-end with a comparable recipient facial nerve branch. The appropriate recipient facial nerve branch is generally not stimulable, but can nevertheless be identified with confidence because its location corresponds to that of the donor branch on the normal side. Due to the long graft length, potential for axonal loss at two neurorrhaphies, and comparatively low axonal count in the donor facial nerve branch, CFNG is not a very reliable technique in older patients, although it may be useful for either rehabilitation of an individual facial deficit or to innervate a free muscle flap. The sural nerve is an ideal graft for cross-face applications due to its length, caliber, and limited donor-site morbidity. The primary risk associated with CFNG is causing a weakness on the normal donor side, though it is unlikely to be significant and may, in fact, improve overall symmetry [2]. The procedure is contraindicated in patients at risk for developing bilateral facial paralysis in the future, mostly commonly due to neurofibromatosis type 2.

Reanimation

Free Muscle Transfer

Free muscle transfer has become the current gold standard in dynamic reanimation of longstanding, irreversible paralysis [1, 2]. The gracilis free flap was the first free-tissue transfer procedure for facial reanimation and is the most commonly used donor muscle in the United States due to its ease of harvest, minimal functional morbidity, inconspicuous donor site incision, and excellent contractility [1–3, 5, 45]. Gracilis free muscle transfer can result in improved smile excursion and quality of life scores [4, 15]. The adductor artery with its venae comitantes and the anterior branch of the obturator nerve supply the gracilis muscle; the facial artery and vein are the most commonly used recipient vessels because of their proximity and vessel size match [1].

Free muscle transfer for facial reanimation can be performed in either one or two stages. Two-stage reconstruction includes initial development of cross-face innervation, usually via a sural nerve graft. After allowing sufficient time for axons to grow through the graft, typically 6–9 months, a second surgery is performed to transfer the muscle and coapt the CFNG to the obturator nerve [1, 2, 5]. The recipient site is exposed via a sub-SMAS approach, and buccal fat may be removed to reduce the appearance of facial bulk after muscle transfer. Classically, the gracilis is sutured to the modiolus and either the zygomatic arch or the temporalis fascia with the goal of moving the oral commissure in a superolateral vector to produce a "Mona Lisa" smile, which does not generally result in significant dental show. The two-stage procedure is most successful in younger and thinner patients, likely due to improved nerve regeneration and lighter muscle load. Less than optimal smile results are multifactorial; often they are due to insufficient donor axon count, poor axon migration across multiple coaptation sites, relative muscle ischemia with scarring and atrophy, scarring with skin tethering, or age-related influences on nerve regeneration [1].

One-stage gracilis transfer using the masseteric nerve as a donor is recommended for bilateral facial paralysis in children or unilateral cases in adults, although the hypoglossal and deep temporal nerves have also been described as donors [1]. While its potential to provide a spontaneous and symmetric smile is lower than that of a CFNG-driven gracilis, success rates for masseteric nerve-driven gracilis transfer are higher, at 94% versus 84% [46]. In order to combine the benefits of both approaches, spontaneity and symmetry with reliability, some surgeons have begun to dual innervate their gracilis transfers with both the masseteric nerve and a CFNG [49]. Another modification that appears to improve functional results is the splitting of the gracilis flap into multiple paddles in order to mimic the function of native facial muscles more closely, thereby producing a more natural, dentate smile [48]. Ultimately, results from gracilis-free muscle transfer can be limited by the excess bulk the muscle brings to the face and its slow contraction rate compared to fast twitch native facial muscles [53].

In addition to the gracilis, use of free latissimus dorsi, pectoralis minor, rectus abdominis, serratus anterior, sternohyoid, extensor carpi radialis brevis, and abductor hallucis muscle flaps have been described with promising results [1, 2, 5, 53, 54]. Additional donor nerves include the contralateral buccal branch of the facial nerve or the ipsilateral mylohyoid branch of trigeminal nerve.

Several combinations of both static and dynamic procedures may be implemented as well, including use of an anterolateral thigh (ALT) free flap and a temporalis tendon transfer. The ALT flap is used to provide contour and bulk, typically after tumor extirpation requiring removal of a significant volume of tissue, while the temporalis tendon transfer provides support and a gliding plane for the transferred muscle [5]. The motor nerve to the vastus lateralis has been used along with the ALT flap for large, post-ablative soft tissue defects [3].

The degree of movement seen with free tissue transfer is typically greater than that with regional muscle transfer. However, due to the complexity of microneurovascular reconstruction, requirement for inpatient flap monitoring, significant morbidity, undesirable added bulk to the face, and an extended recovery period prior to dynamic movement, regional muscle transfer is preferable in patients who either cannot tolerate long surgical interventions or have no recipient vessels. [1, 2]

Regional Muscle Transfer

The mainstay of regional muscle transposition is the temporalis muscle transfer. The temporalis tendon or muscle can be released and transferred to the oral commissure to create volitional oral commissure excursion when the patient bites down [1, 2, 5]. The classic procedure produces significant tissue bulk over the zygomatic arch, an external scar, as well as temporal hollowing, and has the potential to cause temporomandibular joint dysfunction [2, 3, 5]. Facial contour derangement can be mitigated with an orthodromic approach, which involves removing the temporalis tendon and the coronoid process of the mandible, and reattaching them to the oral commissure through a transoral or nasolabial fold incision [3, 5, 30] (Fig. 7.3). A limitation with temporalis muscle transfer is that the spontaneous, emotional smile seen in cross-face grafting cannot be produced. However, patients are often able to smile without physically clenching their teeth [1]. There is also an improved mean oral commissure excursion following post-ablative reconstruction, though this does not necessarily correlate to facial symmetry [31].

Fig. 7.3 Picture showing transfacial orthodromic temporalis tendon harvest for facial reanimation

Masseter muscle transposition is another option due to its proximity to the oral commissure, muscular size and power, and ease of accessibility [3]. That said, it has a limited range of tissue rotation, may produce an unnatural smile vector, and can cause masticatory difficulties [2, 5]. Another option for local muscle transposition is the anterior belly of the digastric muscle for depressor anguli oris and depressor labii inferioris paralysis [2, 5]. The digastric muscle is separated from its posterior belly and rotated superiorly and medially to the commissure of the lower lip. Successful digastric muscle transfer mimics normal downward motion of the lip [1, 3]. Numerous muscle transfer options are available for rehabilitation of the perioral area, but frequently, other deficits, such as nasal valve collapse, require additional techniques to be used.

Static Rehabilitation

Static suspension procedures can restore resting symmetry of the face and improve nasal passage obstruction. They can be used as adjuncts to reinnervation or reanimation surgeries, or they can be used as a standalone rehabilitation for patients who cannot tolerate longer, more complex surgeries, or for those who are not interested in dynamic rehabilitation.

Static suspension of the alar base, melolabial fold, and oral commissure is a simple and effective means of decreasing nasal valve collapse and oral incompetence, and improving facial symmetry at rest [3, 4, 15]. Structures are suspended superolaterally to the zygomatic arch or, more commonly, to the temporalis fascia. Suspension is often accomplished via a modified Blair incision and elevation of a facial flap, though it may be performed using more limited access if appropriate. For oral commissure suspension, the modiolus is identified by following the facial artery and the zygomaticus major muscle; it is then elevated and lateralized in the vector of a natural smile. For recreation of a melolabial crease, material is sutured subcutaneously just medial to where the crease should be, and then suspended [42]. For lateralization of the nasal ala, a separate incision in the alar–facial crease can be created, and suspension material affixed to the fibrous tissue and sesamoid cartilages immediately deep to the alar crease. The material can then be tunneled to the temporalis fascia or suspended through a larger facial flap [32].

Fascia lata, harvested from the lateral thigh, is a reliable, strong material that provides a steady, durable suspension (Fig. 7.4). It can be harvested through a single, long, vertical incision in the lateral thigh or through two short, horizontal incisions, one superior and one inferior. The width of the fascia lata is sufficient to allow suspension of the oral commissure, melolabial fold, and nasal ala. Further, there is no risk of foreign body reaction when using autologous materials. Suspension of the external nasal valve, nasolabial fold, and oral commissure with three separate strips of fascia lata has been shown to significantly improve patient-reported Facial Clinimetric Evaluation (FaCE) scores and midfacial appearance [21]. Similarly, fascia lata suspension of the nasolabial fold has demonstrated significant improvement in patient-reported Nasal Obstruction Symptom Evaluation (NOSE) scores [22]. Due to its favorable outcomes, tensile strength, resistance to resorption, and biocompatibility, fascia lata has become increasingly favored for facial suspension [20].

Fig. 7.4 Picture of tensor facial lata graft in the superior lateral vector for restoration of facial symmetry and correction of a ptotic midface. Additional strips could be added for restoration of asymmetric lower face

Alloplastic materials such as Gore-Tex have also been used for facial suspension. They are associated with higher rates of infection and extrusion than autologous materials, however [19]. Suture vector and bone-anchored suture (Mitek) techniques for nasal ala suspension have also been described, but they have demonstrated failure rates approaching 25% [23]. All methods of facial suspension are subject to tissue relaxation, so deformities should be overcorrected in the operating room, expecting some degree of ptosis in the short term. Also, facial suspension is subject to the long-term effects of gravity, and a need for resuspension should be anticipated every few years.

As an alternative to facial suspension procedures, there are other static options described. The modiolar rotational cheiloplasty, for example, involves superomedial rotation of the oral commissure with lateral transposition of the alar base [52]. The procedure can be completed in a relatively short time in the operating room and restores resting symmetry of the mouth, improves or eliminates difficulty with drooling and oral incompetence, and alleviates nasal passage obstruction. It is an excellent option for patients with chronic flaccid paralysis who are not suited for or do not wish to undergo free tissue transfer.

Static techniques are sometimes considered a last resort when a free muscle transfer has failed or the patient is a poor surgical candidate, but the reality is that they are far more versatile than any other modality, providing rehabilitation of every facial structure from the brow to the oral commissure and they play a vital role in any multimodality facial rehabilitation plan.

Conclusions

Rehabilitation of facial paralysis can be accomplished with a variety of surgical and nonsurgical methods. Fig. 7.5 summarizes surgical techniques that can be used for rehabilitation of

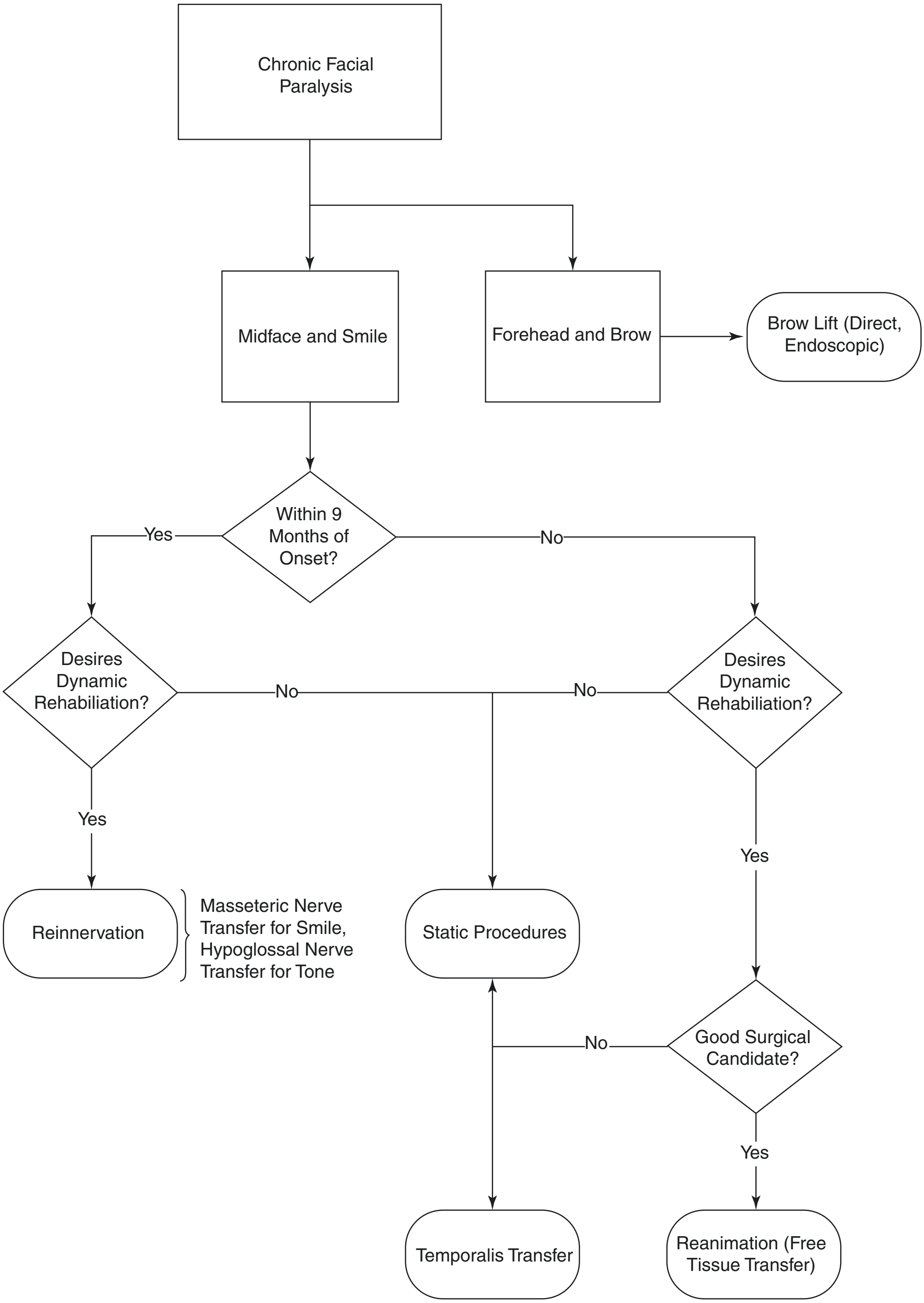

Fig. 7.5 Management of chronic facial paralysis. If there are viable facial muscles, then reinnervation should be attempted. If facial muscles are absent or have undergone fibrosis, then reanimation procures can provide dynamic rehabilitation. Static procedures can be performed at any time, as standalone therapy or in conjunction with other procedures. For patients who cannot tolerate a long surgery with free tissue transfer, dynamic rehabilitation is possible via temporalis transfer

chronic facial paralysis. Surgical options include static and dynamic procedures, each with its own unique advantages and drawbacks. A zonal, individualized assessment is critical to developing the best management plan for each patient.

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8 Parotidectomy Defect and Facial Nerve Reconstruction

Abel P. David, P. Daniel Knott, and Rahul Seth

Key Abbreviations

ADM	Acellular dermal matrix
ALT	Anterolateral thigh
RF	Radial forearm
SAI	Supraclavicular artery island
SIF	Submental island flap
SMAS	Superficial muscular aponeurotic system

Introduction

The reconstruction of the post-parotidectomy defect requires an understanding of many reconstructive techniques to meet the aesthetic and functional goals for each patient. Here we review the reconstructive approaches for superficial parotidectomy, total parotidectomy, and radical parotidectomy defects. Smaller resultant defects can be reconstructed with either free grafts or local muscle/rotational flaps, and larger ones may require pedicled musculocutaneous flaps or microvascular free flaps. In cases of parotidectomy with facial nerve sacrifice, functional restoration is important to consider at the time of ablative surgery. Early facial reanimation can mitigate the impact on the patients' quality of life and improve their functional outcomes. However, according to a 2019 study, only a fraction of patients, about 30%, receive at least one concurrent facial reanimation procedure at the time of their radical parotidectomy [1].

An overall understanding of the reconstructive goals after parotidectomy is essential for the following: (1) reestablishing facial contour and symmetry, (2) avoiding Frey's syndrome, (3) restoring facial nerve functions, (4) minimizing morbidity from adjuvant therapy, and (5) allowing for tumor surveillance.

Superficial Parotidectomy

The primary objective of superficial parotidectomy reconstruction is to restore facial symmetry and contour, and is easiest when the facial nerve is identified and protected during primary surgery. When repaired secondarily, there is a higher risk of unintended facial nerve injury. Patient appearance and symmetry after parotidectomy has been shown to be an important metric of patient wellbeing, and measures taken to correct

A. P. David
Department of Otolaryngology-Head and Neck Surgery, University of California, San Francisco, San Francisco, CA, USA

P. D. Knott · R. Seth (✉)
Division of Facial Plastic and Reconstructive Surgery, Department of Otolaryngology-Head and Neck Surgery, University of California, San Francisco, San Francisco, CA, USA
e-mail: P.Daniel.Knott@ucsf.edu; Rahul.Seth@ucsf.edu

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their facial depression have been shown to significantly improve patient reported quality of life scores [2, 3]. Additional considerations should also be made to create a barrier between the exposed facial nerve and the elevated cheek skin to prevent Frey's syndrome, also known as gustatory sweating. Frey's syndrome is a common complication in patients after superficial parotidectomy that is caused by aberrant innervation of sweat glands in the overlying skin by severed parasympathetic fibers [4, 5]. The incidence of Frey's syndrome after superficial parotidectomy ranges widely, from 38% to 86%, based on subjective or objective measures [6]. Patients with larger tumor resections are at a higher risk of developing Frey's syndrome according to a retrospective study by Lee et al. [7]. They found that the incidence of Frey's syndrome doubled in patients with tumors greater than 4 cm (33%) compared to those with tumors less than 4 cm (18%) [7]. Manola et al. similarly showed a statistically significant correlation between tumors greater than 3 cm and an increased risk of objective findings (measured by the Minor's starch test) and subjective symptoms of Frey's syndrome [8].

There are several options available for reconstructing the volume deficit and prophylactic measures to prevent Frey's syndrome, and these include only positioning of autogenous fat graft, acellular dermal matrix, or autogenous vascularized tissue grafts such as the sternocleidomastoid rotational flap, the temporoparietal fascia rotational flap, and the superficial muscular aponeurotic system (SMAS) advancement flap.

Although reconstruction is best performed at time of the resection, post-parotidectomy secondary reconstruction can be performed if needed. Facial depression can be managed with injectable dermal fillers or with surgical interventions as described above. Surgical interventions may place the facial nerve at risk, and should be employed with caution. Secondary management options for Frey's syndrome are available as well. Botulinum toxin A injection can provide relief from gustatory sweating and flushing but this effect is temporary and requires repeat injections. Secondary surgical interventions for the treatment of Frey's syndrome also may place the facial nerve at risk and can be considered in cases refractory to medical management [9].

Abdominal Fat Grafting

Autologous free grafting is a commonly used technique for correcting facial depression after superficial and total parotidectomy that requires little additional operative time, is relatively simple to perform, and has minimal donor site morbidity [10, 11]. The most common complications include hematoma or seroma formation at the donor site and persistent overcorrection may require fat graft debulking [12]. A low abdominal incision is used to harvest slightly larger volume fat graft than the defect to compensate for atrophy over time and is placed into the defect en bloc (Fig. 8.1). Fat grafting is associated with high patient satisfaction, provides improved aesthetic outcomes, and leads to lower rates of Frey's syndrome [10, 11, 13].

The volume deficit of the parotidectomy site can likewise be reconstructed with a composite graft of deepithelialized dermis and fat, also known as a dermofat graft. The addition of the dermis is believed to help prevent fat necrosis and minimize graft atrophy [14, 15]. Dermofat grafts are harvested from the lower abdomen and the incisions are typically larger than for autologous fat grafts. Once the composite graft is har-

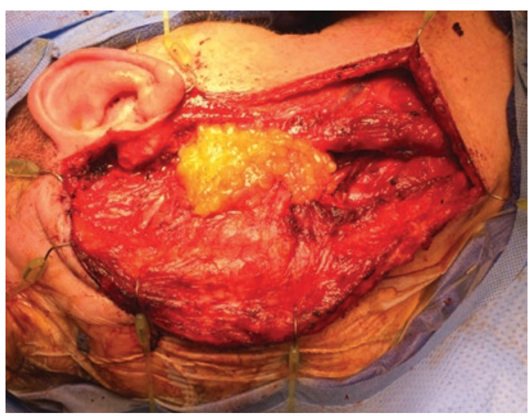

Fig. 8.1 En bloc abdominal fat graft positioned for volume restoration

vested, it requires de-epithelization and is placed in the defect en bloc. There is also low donor site morbidity and additional operative time associated with dermofat grafting. Nosan et al. used dermofat grafts to restore volume after superficial parotidectomies, with a 10–15% overcorrection in volume, and found that only 11% of patients had facial concavity at 4.5 years [16]. Combined dermofat grafting and SMAS plication with a 10–20% overcorrection have been described by Curry et al. to have a statistically significant decrease in facial asymmetry and symptomatic Frey's syndrome when compared to non-reconstructed controls [17]. However, in patients undergoing parotidectomy for malignancy it may not always be feasible to elevate the SMAS. Many authors recommend an initial volume overcorrection of 10–20% for the best results, and in patients who receive preoperative and postoperative radiation the fat resorption rate can be increased.

It was once recommended that autologous fat grafting should only be performed after parotidectomy for benign tumors, so that it does not hinder tumor surveillance in cases of malignancy [17]. However, Conger et al. did not find abdominal fat grafting to interfere with clinical or radiologic surveillance [10]. Radiographic tumor surveillance has many advantages over the clinical exam because it allows for the observation of lateral and deep spread of recurrent tumors, and in patients who undergo fat grafting, there is a distinct appearance of fat on MRI that allows it be easily distinguished from other tissue.

Acellular Dermal Matrix Placement

Acellular dermal matrix (ADM) is derived from human cadaveric dermis and can be used to correct the volume deficit that results from superficial parotidectomies. ADM are cut to the shape of the parotidectomy defect and folded to achieve the desired thickness and are then carefully secured within the defect (Fig. 8.2). The advantages of ADM use include the lack of donor site morbidity and little additional operative time. ADM grafts have been shown to drastically decrease the rates of Frey's syndrome when compared to controls, and in a meta-analysis of five randomized control studies there was a 85% relative risk reduction [6, 18, 19]. The rates of complications, particularly seroma formation and site infection, were comparable to controls and there were no cases of graft extrusion [18, 19]. One study found that ADMs were associated with a 25% rate of seroma formation when compared to 9% for controls [6]. In a randomized trial of 36 patients who underwent superficial or total parotidectomy, there were comparable rates of Frey syndrome, donor site morbidity, complications, facial nerve function and operative time in groups that underwent reconstruction with either fat grafting or ADM. However, patients who received fat grafting had higher subjective aesthetic scores and lower operative costs compared to those patients that received ADM [20].

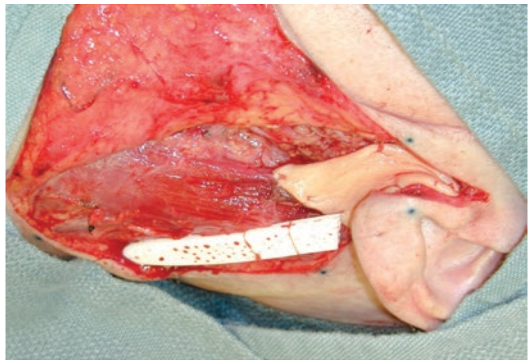

Fig. 8.2 Acellular dermal matrix folded and secured into position of a superficial parotidectomy defect

Local Muscle or Facial Rotational Flaps

Sternocleidomastoid Rotational Flap

The sternocleidomastoid muscle (SCM) rotational flap is one of the most commonly used methods of restoring post-parotidectomy contour deformities and preventing Frey's syndrome. It was originally described by Jost et al. in 1968 [21]. The blood supply to the SCM consists of the occipital artery in the superior third, the superior thyroid artery in the middle third, and the thyrocervical trunk in the inferior third [22]. The flap can be inferiorly or superiorly based, or the middle portion of the SCM can advanced anteriorly; however, the most common variation is the superiorly based method [23].

In a superiorly based flap, the SCM is divided in half at the septum and a horizontal incision is used to free the flap from the anteromedial insertion at the sternum. Isolating and protecting the spinal accessory nerve are important objectives during this dissection. The muscle flap and cervical fascia is rotated superiorly into the defect and sutured to the parotidomasseteric fascia. For an inferiorly based flap, the SCM is released from its superior attachment near the mastoid and rotated anteriorly into the defect and secured to the zygomatic arch and masseter muscle [21, 23, 24].

Some of the early studies regarding the usefulness of the SCM flap for reconstructing parotidectomy defects were promising. Casler and Conley found a significant reduction in the incidence of Frey's syndrome and improved aesthetic results with the use of the SCM flap [25]. However the body of evidence regarding the use of the SCM flap after parotidectomy remains mixed, specifically the effect on the incidence of Frey's syndrome. In a meta-analysis by Sanabria et al. [26], they evaluated 12 studies regarding the prevention of Frey's syndrome and cosmetic outcomes in SCM flap recipients after parotidectomy. They found one meta-analysis, two randomized control trials, and the remainder were nonrandomized trials. Seven of the 12 studies were in favor of the use of the SCM flap for the prevention of Frey's syndrome. In these studies, Frey's syndrome was either measured subjectively by onset of patient-reported symptoms or objectively by the Minor's starch test. In the end, Sanabria and colleagues were unable to conclusively determine whether SCM flap reconstruction lowers the incidence of Frey's syndrome due to the paucity of high-quality randomized control trials. They did find that effect on cosmetic results did favor the use of the SCM flap [26].

Over time, the SCM flap can begin to atrophy, so a slight overcorrection at the time of surgery may be desirable [23]. Also, patients may notice a contour defect of the neck as a result of rotating a portion of the SCM [14]. The remaining defect after SCM flap rotation can be corrected by anterior advancement of the posterior belly of the SCM muscle [27]. In complex facial reconstructions, a portion of adipofascial anterolateral thigh free flap can be used to fill in the SCM defect. This is done by suturing the distal, thinner portion of the ALT to the remaining SCM or sternal clavicular head [28].

The SCM flap is a commonly considered reconstructive method for the post-parotidectomy defect because of its proximity to the surgical field and its ability to provide a significant amount of soft-tissue volume. However, it can be associated with potential injury to the facial nerve, spinal accessory nerve, and the great auricular nerve [25, 29, 30]. Coupled with the secondary contour deformity created in the neck, it should be used appropriately.

SMAS Advancement Flap

The SMAS is comprised of the fibrous layer of the superficial cervical fascia (Fig. 8.3) and transmits, distributes, and amplifies the activity of muscles of facial expression. It extends from the platysma inferiorly, to the galea aponeurotica superiorly, and to the nasolabial groove medially. The SMAS is in continuity with the temporoparietal fascia, where the superficial temporal artery and frontal branch of the facial nerve are found. In the parotid region, the SMAS is just superficial to the parotid fascia. After parotidectomy, the

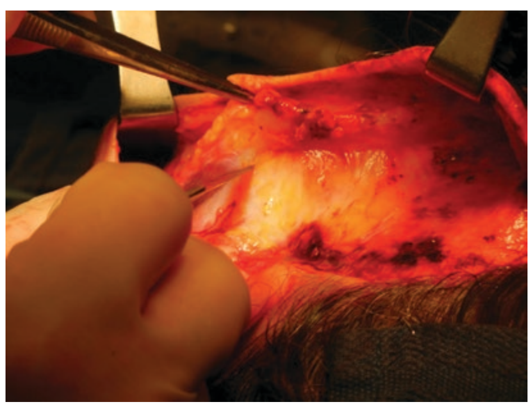

Fig. 8.3 SMAS flap elevation superficial to the parotidomasseteric fascia. Plication of this layer may be used to fill a posteriorly based parotid defect

SMAS layer is elevated, sutured to the zygomatic periosteum and parotidomasseteric fascia to cover the parotid bed [31, 32].

The SMAS advancement flap has been studied in its ability to reduce Frey's syndrome and improve the aesthetic outcomes after parotidectomy. In their original study, Allison and Rappaport found only 2 cases of Frey's syndrome in 112 patients reconstructed with SMAS flaps [31]. In a more recent meta-analysis including 11 studies, 9 studies found a decrease in the incidence of Frey's syndrome after SMAS flaps and two studies found an increase incidence. Despite the conflicting results in individual studies, the meta-analysis supported a statistically significant protective effect of SMAS flaps for the prevention of Frey's syndrome, with an odds ratio (OR) of 0.25 and 0.42 in random-effect and fixed-effect models. It was hypothesized that sometimes small defects are created during SMAS elevation, allowing for a pathway for aberrant reinnervation, and could contribute to some incidences of Frey's syndrome after SMAS advancement flaps [33]. Manola et al. [8] showed that in patients who underwent parotidectomy for tumors greater than 3 cm or those who received SCM flaps or SMAS flaps both had a lower risk for objective symptoms of Frey's syndrome – measured by the Minor starch test – when compared to controls (no SCM or SMAS flap). However, only those patients who received an SCM flap had a lower risk of reporting subjective symptoms. Also, patient reported satisfaction of their cosmetic results were higher in both the SCM and SMAS flap reconstructed groups compared to controls, with a slight advantage to the SCM group [8].

Overall, the SMAS advancement flap is an appropriate option for reconstructing small, posteriorly based defects and for the prevention of Frey's syndrome. It requires little additional operative time, uses the same surgical scar as a parotidectomy, and can reconstruct these defects without an overly bulky appearance.

Temporoparietal Fascia Rotational Flap

The temporoparietal fascia (TPF) flap is a thin, pliable, well-vascularized fascial flap based on the superficial temporal artery. The temporoparietal flap is bordered by the frontalis muscle anteriorly, the occipital muscle posteriorly, the galea aponeurotica superiorly, and the auricular muscles and SMAS inferiorly [34]. It is used to reconstruct the post-parotidectomy defect by providing a barrier for the prevention of Frey's syndrome and correcting the volume deficit. The TPF flap can be harvested as a double-layered fascial flap by including both the temporoparietal fascia and the temporalis fascia, this provides additional strength and bulk [35]. The flap is carefully raised in a sub-follicular plane to avoid causing alopecia and the fascia with its vascular supply are carefully exposed. The flap is raised off the temporalis muscle in order to include the temporalis fascia. The temporoparietal fascia is raised up to the inferior border of the zygomatic arch and the flap is turned over and secured to the edges of the parotidectomy defect (Fig. 8.4) [34, 35].

Fig. 8.4 Elevation of a TPF flap and inferior reflection for coverage of superficial parotidectomy defect

Ahmed and Kolhe [35] found a significant decrease in the severity and incidence of Frey's syndrome, and their study demonstrated an incidence reduction from 43% in non-reconstructed controls to 8% in those reconstructed with the TPF flap. They also noted less noticeable contour defects in the TPF group when compared to controls [35]. The complications associated with this reconstructive technique include alopecia, frontal branch paralysis, and hematoma formation. Poor aesthetic outcomes with this technique are largely associated with the elongated scar that is created in the temporal region [34]. It has also been shown to increase operative time by about 45 minutes on average [35].

Total Parotidectomy with or without Need for Skin Coverage

Total parotidectomies result in a larger facial concavity and may include the removal of overlying skin depending on the pathology and extent of the tumor. For this reason, these defects often require more extensive reconstructive techniques, like regional pedicled flaps or microvascular free flaps. Reconstructive surgeons must consider the tumor characteristics, patient comorbidities, and plans for additional adjuvant therapy prior to undergoing prolonged and more complex reconstructive surgery. Certain total parotidectomy defects can be reconstructed conservatively by less complex means, like those mentioned above, especially in patients with more severe comorbidities. In this section we discuss the use of supraclavicular artery island flaps, submental flaps, and free tissue transfer using anterolateral thigh and radial arm free flaps.

Regional Pedicled Flaps

Supraclavicular Artery Island Flap

The supraclavicular artery island flap (SCAIF) was first described in 1949 by Drs. Kazanjian and Converse and was developed for the release of postburn head and neck contractures [36, 37]. It is based on the supraclavicular artery, a branch of the transverse cervical artery [37]. Emerick et al. [38] described its utility and reliability for the reconstruction of parotidectomy and lateral skull base defects. The advantages of the SCAIF are better color match compared to free flaps from distant donor sites, ease of harvesting, and the ability to cover moderate to large defects (7 cm by 10 cm on average) [38]. The most common complication associated with supraclavicular artery island flap is donor site wound dehiscence [39].

Submental Flap

The submental artery island flap was first described by Martin et al. in 1992 as a cutaneous, musculofascial, or osteocutaneous flap based on the submental artery, a branch of the facial artery [40]. Its advantages include a long arc of rotation, proximity to the surgical field, good color match for head and neck defects, and has acceptable donor and flap complication rates [41, 42]. It has been successfully used for the reconstruction of parotidectomy and lateral skull base defects [41–44]. Patel et al. noted that the submental island flap (SIF) had a lower operative time compared to free flaps, however the flap sizes were considerably smaller [44]. The flap, although limited in size, can be modified through additional harvesting of mylohyoid and anterior belly of the digastric muscles to fit the size and shape of the defect [43]. The disadvantages of the SIF include is its relatively small tissue component, making it suitable only for small- to medium-sized defects, and it cannot be used in patients who have known level I nodal disease [42–44].

Free Tissue Transfer

Microvascular free flap reconstruction has become an important method for restoring large, sustained tissue volumes when locoregional methods are insufficient. The applications for free flap reconstruction have greatly expanded, including use for reconstruction for lateral facial defects [45, 46]. Compared to the locoregional and free grafting techniques mentioned earlier in this chapter, free flap reconstructive methods are more resistant to postoperative radiation and may help reduce their untoward effects. Additionally, increased blood supply in the area of the defect can promote improved wound healing, and provide a more durable tissue volume over time [47].

When a total parotidectomy is done for malignant tumor resections, it is often the case a lymph node neck dissection is also performed. With this surgical exposure, donor blood vessels are readily available for microvascular anastomosis. When a neck dissection is not performed, donor vessels may still be accessible through the existing parotidectomy defect or the vascular pedicle can be tunneled under the skin to an access incision where suitable vessels exist [48].

Here we discuss two free flap reconstruction methods, the ALT free flap for larger defects and the radial forearm free flap for smaller parotidectomy defects [49]. These two methods have low associated morbidity and there are advantages and disadvantages to using either [50]. These methods can provide skin coverage in addition to tissue volume. The ALT free flap harvest provides access to tissues that may be used in concurrent facial reanimation procedures, detailed later in the chapter.

Anterolateral Thigh Free Flap

The ALT free flap is an essential reconstructive modality for lateral facial defects. It is typically harvested as an adipofasciocutaneous flap based on the lateral circumflex femoral artery system. The harvested skin usually has poor color match – as the skin on the thigh is paler than the chronically, sun-exposed skin of the face – however, this mismatch can be reduced with additional procedures [51]. The donor site can be closed primarily, resulting in a long linear scar or with a split-thickness skin graft – usually only needed in cases where a wide flap is raised [52]. There is minimal donor site morbidity associated with the ALT free flap and most patients are able to ambulate shortly after surgery [50, 53].

The ALT free flap can be tailored to the size, shape, and depth of the resultant defect. Thin ALT flaps can be folded on itself or thick flaps can be primarily thinned to accurately fill in the parotid bed defect [54, 55]. For primary volume reconstruction, it can be deepithelialized and provide bulk beneath a cervicofacial advancement flap (Fig. 8.5). In cases of an SCM muscle resection, it can be used to restore the volume deficit of the lateral neck [28]. It also lends itself to the harvesting of additional tissue grafts, like vastus lateralis muscle, tensor fascia lata grafts, and motor nerve to vastus lateralis (MNVL) grafts (Fig. 8.6) that may be used for static and dynamic facial reanimation procedures [56]. Concomitant ALT volume reconstruction and facial reanimation procedures will be discussed in a later section of this chapter.

Radial Forearm Free Flap

The radial forearm (RF) free flap is a fasciocutaneous flap based on the radial artery and associated venae comitans or cephalic vein. The flap is thin and pliable, allowing it to easily contour the

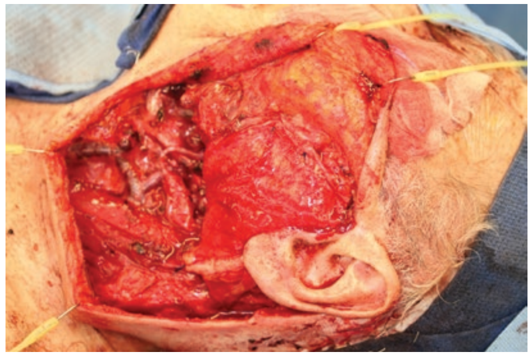

Fig. 8.5 Buried ALT free flap deepithelialized for recreation of lateral facial volume and contour

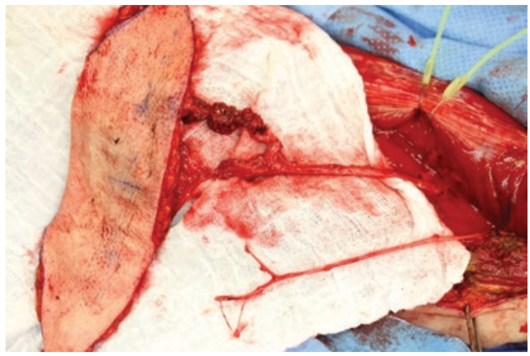

Fig. 8.6 Harvest of the ALT free flap with simultaneous harvest of the nerve to the vastus lateralis

Fig. 8.7 RF flap for reconstruction of upper cheek and parotidectomy defect. Color match and contour are closely approximated by the RF flap

cheek without excess bulk (Fig. 8.7) and has a long vascular pedicle [57]. It has low associated donor site morbidity [50], often does not require debulking procedures when compared to the ALT free flap, and may have lower rates of donor site seromas [58] and wound dehiscence compared to

ALT free flaps [59]. Also, since the forearm receives more chronic sun exposure than the lateral thigh, the RF free flap can provide better skin color match than the ALT free flap [60]. In general, due to its small size, the radial forearm free flap is suitable for shallow, small volume reconstruction [49]. When necessary, the RF free flap can be deepithelialized and folded on itself for use in deeper defects [58]. When the reconstructive surgeon selects the appropriate free tissue transfer technique, they must consider the size of the defect to match the composite defect tissue types [61].

Radical Parotidectomy

In about 20% of malignant parotid tumor resections, facial nerve sacrifice is required, and the extent depends on the degree of tumor invasion and spread along the nerve. Sacrificing the facial nerve in radical parotidectomies leaves the patient without critical functions of the facial nerve: blinking, corneal protection, nasal airflow, and oral competence. The reconstruction of these defects is challenging because in addition to restoring the volume deficit and providing skin coverage, the reconstructive surgeon must consider procedures to restore the facial nerve functions that have been lost [62]. This requires a customized plan for each patient that takes into account the patient's reconstructive needs, medical comorbidities, and ability to undergo prolonged surgery.

Facial reanimation procedures should be performed at the time of primary resection when possible, as the nerve branches are more easily identified. Also, this importantly reduces the duration of facial paralysis and development of myofibrosis [1, 63]. In the past, reconstruction may have been delayed until the completion of oncologic treatment, which may explain the low rates of concurrent facial reanimation procedures at the time of radical parotidectomy [1]. It has been shown that postoperative radiation and positive nerve margins do not appear to affect nerve reconstruction outcomes [64–66]. This section will highlight options for facial nerve reconstruction, which include primary coaptation, cable grafting, and nerve substitution. This enables the best ability for long-term restoration of facial tone and function. Dynamic or static reanimation procedures can be performed in conjunction with reinnervation procedures to provide more immediate rehabilitation of the paralyzed face.

Primary Coaptation

Primary nerve coaptation when performed without tension has a high degree of axonal regeneration since there are fewer sutured nerve junctions. Minimizing tension, which can impair the nerve's vascular supply, rupture endoneurial connective tissue, and increase scarring, is the most important consideration in primary nerve repair [67, 68]. If a tension-free anastomosis cannot be achieved, a cable graft is preferred. Spector and colleagues demonstrated that nerve mobilization to bridge the gap between nerve ends in a tension-free manner to allow for primary coaptation yielded superior results to cable grafts [69]. Nerve mobilization by a number of means, including mastoidectomy and nerve rerouting, can bridge gaps up to 15–23 mm [70, 71]. Intraoperatively, the distal nerve section must be identified and can be done so with an electrical nerve stimulator up to 72 hours after transection [67]. Even though perineurial or fascicular repair would yield more precise alignment of the nerves, the increased tissue handling and disruption of the nerve substance makes it less advantageous to epineural repair. A few sutures in the epineurium are capable of reapproximating the nerve segments and are easier and faster to perform while minimizing internal nerve trauma. Alignment of the surface landmarks on the nerve, such as the vasa nervorum, and an epineural sleeve technique can help guide nerve fibers to their target organs and improve axonal regeneration [67, 68].

Cable Grafting

Cable grafting has been used for the rehabilitation of facial nerve function after parotidectomy since 1955 [72]. When a segment of facial nerve is resected in a radical parotidectomy, proximal and distal nerve stumps may not be easily anastomosed in a tension-free manner. In these situations, a cable graft (nerve graft) can provide a conduit for reinnervation without tension to provide improved clinical outcomes [73]. Radical parotidectomy patients may also undergo adjuvant radiation therapy due to their more invasive tumors. In patients who received nerve grafts after facial nerve sacrifice, postoperative radiation did not appear to affect facial outcome scores [65, 74].

Both sensory nerves and motor nerve grafts have been used for facial nerve grafting. Some of the commonly used sensory nerve grafts include the cervical sensory nerve, sural nerve, great auricular nerve, lateral antebrachial cutaneous nerve (LACN), and the anterior division of the medial antebrachial cutaneous nerve (MACN) [65, 68, 74]. While sensory nerves were some of the earliest and more widely used nerve grafts, recent rat nerve regeneration model studies suggest improved motor nerve regeneration with motor nerve grafts when compared to sensory nerve grafts. These results may be attributed to neurotrophin specificity of motor Schwann cells [75] or by more closely matched Schwann cell basal lamina tubes. Motor nerves have larger basal lamina tubes than sensory nerves and are believed to increase the number of nerve fibers that cross the nerve graft coaptation [76].

The motor nerve to vastus lateralis (MNVL) is a common motor nerve graft, and is accessible during an ALT free flap harvest. The MNVL is easily identified and has low associated morbidity due to redundant innervation of the vastus lateralis. Additionally, the MNVL has multiple branches (Fig. 8.8), which can be anastomosed to several distal branches of the facial nerve with similar length to the sural nerve [77].

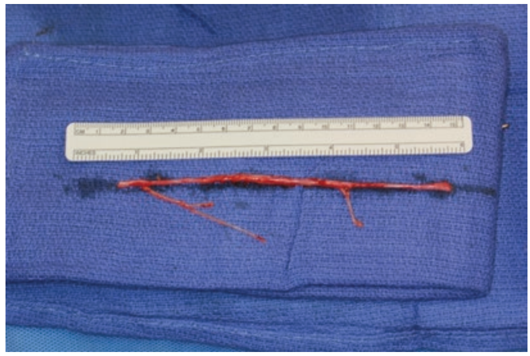

Fig. 8.8 Nerve to vastus lateralis

Nerve Substitution

Hypoglossal Nerve

The original hypoglossal nerve suture technique, described by Stennert in 1979, was used to reanimate the lower face with a complete ipsilateral hypoglossal nerve and the upper face with facial nerve interpositional grafts [78]. The advantage of having dual nerve input is the prevention of upper and lower face synkinesis – the activation one muscle group resulting in movement of multiple muscle groups. However, these patients developed dysphagia from ipsilateral tongue atrophy. The technique was refined by Manni et al. through the use of a hypoglossal jump nerve suture – the hypoglossal nerve is incised and is coapted side-to-end to an interpositional graft, which is then coaptated end-to-end to distal facial nerve branches [79]. Volk et al. describes a successful series of facial reinnervation within 12–16 months in four patients, avoiding upper and lower face synkinesis and tongue hemiatrophy [80].

Nerve to Masseter

The use of the nerve to masseter for facial reanimation was first described by Spira in 1978 [81]. This technique is used when the proximal stump of the facial nerve cannot be grafted and there are intact distal facial nerve branches [82]. The masseteric nerve is the largest motor branch of the trigeminal nerve with an average diameter of 2-mm and has axon counts that match favorably with the facial nerve [83]. The masseteric nerve is reliably and quickly identified within the subzygomatic triangle (Fig. 8.9), for which boundaries include the zygomatic arch superiorly, the temporomandibular joint posteriorly, and the frontal branch of the facial nerve anteroinferiorly [84].

Fig. 8.9 Nerve to masseter is found within the masseter within the subzygomatic triangle

The masseteric nerve transfer has the ability to provide an unconscious smile, and less synkinesis when compared to the hypoglossal nerve substitution [85, 86]. Patients who undergo a hypoglossal nerve transfer must press their tongue against their palate or teeth to produce a smile. There is lower donor site morbidity because the proximal nerve to masseter remains intact, and the descending distal portion is sutured to the facial nerve [82]. Masseteric nerve transfer has a low rate of complications, which include instances of masseter atrophy and ocular discomfort with chewing [86].

In a meta-analysis by Murphey et al. [86], the overall time to nerve recovery with MNVL was about 5 months on average, ranging from 2 to 7 months. This varied with age and whether the coaptation was to the main facial nerve trunk or to the zygomatic/buccal branch. Patients older than age 40 and main facial nerve trunk anastomoses had longer recovery times. Oral commissure excursion showed about an average 9 mm improvement in four studies [86], with as much as 12.5 mm of improvement seen in one study [87].

Temporalis Tendon Transfer

The temporalis muscle tendon unit transfer for facial suspension was first described by McLaughlin in 1953 [88]. As a result of mobilizing and transposing the temporalis tendon, the reconstructive surgeon can restore voluntary, symmetric smile and commissure excursion [89]. The indications for muscle tendon unit transfer, first used for the rehabilitation of peripheral nerve injury in the extremities, parallel the indications for the paralyzed face. The muscle tendon unit transfer can reduce the time of function loss as the nerve function recovers, provide additional power to reinnervated muscles, and can substitute as a primary procedure when the likelihood of nerve recovery is poor [90]. It has been successfully combined with nerve grafting and free tissue transfer techniques for the rehabilitation of facial paralysis [91, 92].

The temporalis muscle is a muscle of mastication innervated by the mandibular branch of the trigeminal nerve. The temporalis muscle originates from the temporal fossa, crosses beneath the zygomatic arch, and attaches to the coronoid process of the mandible [93]. The temporalis tendon transfer begins with an access incision made intraorally or extraorally. The buccal space is dissected, mobilizing the temporalis tendon, and exposing the coronoid process. The coronoid is then transected and transposed toward the modiolus. It is then attached near the corner of the lip, near the insertion of the zygomaticus muscles. This mimics the action of the zygomaticus muscle and recreates a melolabial fold [94]. The degree of traction on the temporalis tendon is determined by intraoperative stimulation of the temporalis muscle to generate a tension–excursion relationship [95]. After this procedure, patients should perform muscle-retraining exercises and physiotherapy to optimize a symmetric and spontaneous smile [96, 97].

Static Facial Slings

Dynamic procedures may not be suitable for all patients, particularly those with significant medical comorbidities who may not tolerate lengthy, complex surgical procedures. These patients may benefit from static suspension, which can be performed with shorter surgical times and provide immediate results [98]. The static sling is often used to address nasolabial fold asymmetry and improve oral competency and can complement dynamic reanimation procedures.

The goal of the static sling is to suspend the nasolabial fold and the oral commissure to the zygomatic arch and the temporalis fascia [99]. The sling can be made of various materials including autologous tissue [100], allografts [98], synthetic grafts [101], or permanent suture-based slings [102]. During the early stages after surgery, the cosmetic outcome may be poor due to overcorrection, but should improve as the sling stretches over time [99].

Free Tissue Transfer for Facial Nerve Reanimation

Free functional microvascular transfer of muscles, such as the gracilis, latissimus, pectoralis minor, and sternohyoid flaps, have been successfully used for the rehabilitation of facial paralysis [103, 104]. However, these free muscle transfer techniques are not usually considered during primary reconstruction after radical parotidectomy. They are adjunctive procedures after oncologic treatment is complete and stable or when prior reanimation procedures were inadequate.

Comprehensive Reanimation Approach

A tailored reconstructive approach to the specific nerve defect is required. As described previously, nerve reconstruction is performed depending on the nerve defect, whether that may require a primary coaptation or a cable graft. Commonly seen in radical parotidectomy, resection of the facial nerve includes much of the intraparotid nerve. A cable graft with multiple branches is used to reconstruct the nerve from the main trunk to the distal facial nerve branches after frozen section clearance of tumor at the cut nerve edges. In order to provide strong motor input to the dominant smile producing facial nerve buccal branch, the nerve to masseter is coapted to that branch (Fig. 8.10). Use of a temporalis tendon transfer or static sling can be used to provide immediate improved facial positioning, especially in the patient who is prone to facial droop due to age-related changes. Periorbital procedures such as upper eyelid weight placement for correction of lagophthalmos and lateral tarsal strip for ectropion repair may be performed concurrently or staged.

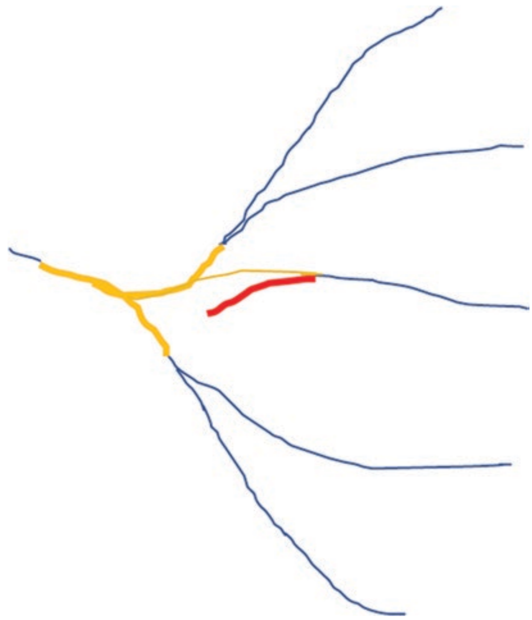

Fig. 8.10 Intraparotid facial nerve resection is replaced with a cable graft. The nerve to masseter is coapted to the dominant smile producing branch

Conclusion

There are many considerations that must go into choosing and designing a reconstructive strategy for parotidectomy defects. When addressing the parotidectomy defect, one must consider the volume of the defect, whether skin or the facial nerve is involved, and how to minimize additional morbidity with these procedures. With the reconstructive goals for parotidectomy reconstruction in mind, the reconstructive plan can be tailored to provide optimal outcomes for the patient.

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Part III

Special Considerations

9 Role of Prosthetics and Osseointegration in Lateral Craniofacial Reconstruction

Michael Kinzinger and Arnaud F. Bewley

Introduction

Lateral craniofacial ablative procedures can involve resection of the auricle. This leaves patients with a cosmetically devastating defect which is difficult to reconstruct with autogenous tissues. Auricular reconstructive surgeries expose patients to multiple surgical procedures, donor site morbidity from autologous cartilage harvests, the potential for implant rejection, and the considerable risk of unsatisfactory cosmetic outcomes. Facial prosthetics offer an alternative rehabilitation option. Adhesives, eyeglasses, and soft tissue pockets or bridges have all been attempted for prosthetic retention. However, these options are fraught with problems relating to hygiene, skin breakdown and inflammation, prosthetic discoloration, poor retention, and poor acceptance of the prosthetic. Furthermore, adhesives may lose their hold in humid environments, or when the patient perspires [1]. Osseointegrated implants offer a fixation option that can reliably and precisely bear a prosthesis, carries little morbidity, requires minimal long-term care, has excellent ease of use, and is associated with excellent cosmetic outcomes [1, 2].

M. Kinzinger · A. F. Bewley (✉)
University of California, Davis Department of Otolaryngology Head and Neck Surgery, Oakland, CA, USA
e-mail: abewley@ucdavis.edu

Historical Perspective

Osseointegrated implants were made possible due to experimental and clinical research groundwork laid by Brånemark in the middle of the last century [3]. His work in animal models provided the histologic proof of concept for osseointegration of biocompatible pure titanium. These studies identified bone and osteoblastic cells in close association with the implant without intervening soft tissue. These early studies also demonstrated the ability of these implants to reliably bear a masticatory load, both in animals and then in humans. From these studies, osseointegration is defined as "a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant." [4] Brånemark and colleagues then went on to describe the appropriate delicate surgical technique and healing period to facilitate osseointegration of titanium implants and demonstrated the viability of the technique in dental rehabilitation [5]. Although the technique was first described for use in dental rehabilitation, it was quickly adapted for use in orbital, nasal, and auricular prostheses [4]. Although all of these sites can be effectively treated by osseointegrated implant borne prosthetics, the auricular site is the most reliable, with success rates near 99% in most studies [4, 6, 7].

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Patient Selection

As always, proper patient selection is critical to make good surgical outcomes possible. Any patient with a total or partial defect of lateral craniofacial tissue is a potential candidate for an implant-borne prosthesis, provided there is usable bone for osseointegrated implant placement. A deficiency of bone can potentially be remedied by a bone graft while issues with soft tissue coverage can be addressed by a split-thickness skin graft [4].

The quality of available bone for implantation must be considered. Radiation has known effects on the success rates of osseointegration. Parel and Tjellstrom analyzed a series of 240 patients in the United States and in Sweden with craniofacial osseointegrated implants. In the American cohort, patients who had received radiation had a 65% implant success rate, while nonradiated patients enjoyed a 94% success rate, with similar results in the Swedish group [8]. Accordingly, patients who have received temporal bone radiation must be counseled about the significantly poorer success rate of osseointegration. However, implant success in the temporal bone appears to be less affected by radiation than other craniofacial sites [9].

Although radiation is known to hinder osseointegration, hyperbaric oxygen therapy has shown promise in improving outcomes after bone implantation. Granström and coworkers demonstrated this in a prospective study of 78 patients who underwent ablative craniofacial surgery for malignancy, and later underwent osseointegrated implantation for placement of implant borne prostheses. Temporal, nasal, maxillary, and mandibular defects were included in the analysis. Groups of patient who were irradiated before implantation, nonirradiated, and irradiated then treated with hyperbaric oxygen (HBO) therapy were compared. The irradiated group lost 53% of implants, while no implants were lost in the nonirradiated or irradiated plus HBO groups over at least a 3-year follow-up [10]. Limited data suggest that the risk of implant failure increases with increasing time since radiation, and with increasing radiation dose. Notably, 50–65 Gy is considered of low risk for implant failure [9].

Importantly, the patient and any caretakers should be assessed for their ability to care for the implant. Patients who are unable to maintain appropriate hygiene are at higher risk of localized infection around the abutment or implant failure. Such patients may benefit from the use of magnetic retention attachments rather than clip bars since this makes daily hygiene easier [1]. Patients should be counseled not only on required hygiene but also on the risk of implant damage with physical activity, and on realistic expectations for cosmesis [11].

Absolute contraindications for implantation are the presence of osteitis at the implant site, terminal illness, or mental illness precluding tolerance of an implant [12]. The age of the patient should also be considered. Children as young as 9 have been successfully rehabilitated with auricular prosthetics [11, 13].

Preoperative Preparation

In most reports, the patient is referred to the maxillofacial prosthodontist before ablative surgery. This allows for a mold of the diseased ear to be made, and for preoperative photographs to be taken. If the ear is not present for reference in modeling the prosthesis, a new one can be fabricated by using the contralateral normal ear for reference. A CT of the normal contralateral ear is obtained, and then mirrored. From this mirror image, a prosthesis can be created using 3D printing techniques [14]. The preoperative preparation should include creation of a template to guide implant placement during surgery.

In general, implantation can be performed under local anesthesia which makes the technique viable for even those patients with significant medical comorbidities. This can obviate the need for extensive preoperative medical workup in select patients. Implantation is most commonly accomplished in a staged fashion after cancer resection or recovery from trauma.

The use of preoperative CT scanning is controversial, with some authors recommending mandatory scanning to evaluate the thickness of the temporal bone cortex, and others downplaying them as unnecessary, especially in the pediatric population [11]. Instead, sequential drilling is recommended, with an initial depth of 3 mm, extended to 4 mm if possible [15]. In children under a year of age, bone grafting can be employed to obtain the necessary 3 mm thickness of temporal bone to be implanted [13].

Surgical Technique

The principles of osseointegrated implantation include careful site preparation, delicate placement of the implant, complete embedment of the implant in recipient site bone, and the prevention of inflammation around the implant [3]. For auricular prostheses, implant sites are selected on the bone of the mastoid process. At least two implants are necessary to firmly attach a prosthesis, though other authors recommend up to four implants [2, 12, 15]. In general, these are placed posterior and superior to the site of the external auditory canal, at a distance of about 20 mm [2, 12]. The position of the implants may be affected by the surgical defect at hand, making the input of a maxillofacial prosthetist useful. The prosthodontist may also provide an implantation template to be used intraoperatively to ensure good implant placement.

Implantation may be completed in one or two stages. The one-stage procedure, in which the skin-penetrating abutment is placed in the same setting as the placement of the osseointegrated implant, can be used for most adult patients with good quality bone and soft tissue [12]. The two-stage implantation procedure is best chosen for situations in which the implant is at higher risk of failure, such as implants into previously irradiated bone, or for prosthetic rehabilitation of the midfacial skeleton [9, 12]. Since the skin is closed over the implant for the osseointegration period, the implant benefits from an osseointegration period in which it is sealed beneath skin and periosteum. Most authors recommend a 3-month period between the stages if this approach is chosen. In irradiated patients, a 4-month osseointegration period is recommended [9].

Once the position of the implant is selected, the bone is marked with methylene blue within a small gauge needle using the surgical template as a guide. Then a curved incision is made 30 mm posterior to the external auditory canal and dissection is taken down to just superficial to the periosteum. The skin and subcutaneous tissue overlying the implant site is generously thinned, including shaving off any hair follicles, until the skin is about as thick as a full-thickness skin graft. This ensures a thin, immobile, hairless implant site, which is important to diminish postoperative cutaneous inflammation [1]. Next, the guide drill is used to create holes in the bone at the marked implant site. Spacers are used to drill first to 3 mm, and then 4 mm if there is adequate bone thickness [15]. Generous irrigation is used at all times to minimize thermal injury to the bone. Next, a small countersink is created using the system's specialized burr, again using copious irrigation. Then the implant itself is screwed into the drilled hole, using a torque wrench to ensure the appropriate tightness is achieved. In the one-stage procedure, a biopsy punch is used to make a hole in the skin over the implant, and a percutaneous abutment is placed onto the implant through this hole. The incision is then closed and a protective dressing is placed over the abutments. In the two-stage procedure, the skin is closed over the implant and after osseointegration is complete at 3 months, a second procedure is performed to place the percutaneous abutments.

Postoperative Care

The implants must not be subjected to a load for 3 months after implantation. Therefore, patients who have undergone the one-stage procedure must be informed of this and should be provided with a protective otologic dressing for use while in bed. Although good hygiene is necessary for the life of the prosthetic to avoid peri-implant inflammatory reactions, hygiene is especially critical for the first month of the postoperative period in one-stage patients. Although the preferred hygiene regimen varies by author, these regimens generally include a combination of protective dressing, local wound care, and a short course of a topical antimicrobial.

Table 9.1 Hoger's Classification for percutaneous implants

Grade 0	No skin inflammation
Grade 1	Mild redness
Grade 2	Red and moist tissue, without granulation
Grade 3	Red and moist tissue, with granulation
Grade 4	Inflammation requiring implant revision

Fig. 9.1 Osseointegrated implant placement in a patient with anotia. Note the bone-anchored hearing aid (BAHA) implant at the top right of the image. No support bar was used, and the prostheses was secured to the implants using a combination of magnetic and clip abutments

The most common postoperative complication is the development of a localized inflammatory reaction of the skin at the implant site. This may be described by the scale described by Holgers [16] (Table 9.1).

Fixation of the clip or magnets may be performed after the completion of osseointegration at 3 months [2, 7]. Patients who undergo the two-stage procedure have this performed at 4 weeks after the second stage to allow healing of the skin around the abutment.

Results

In terms of implant survival, several studies have demonstrated the importance of the site of implantation, with the lateral craniofacial skeleton enjoying the best and most reliable results in several studies, with implant survival rates approaching 100% in nonradiated patients, and patients treated with hyperbaric oxygen [7, 10, 12].

The literature generally describes patient satisfaction outcomes as good to excellent [2, 12]. Figures 9.1 and 9.2 are postoperative results in a

Fig. 9.2 The same patient with his custom-made auricular prosthesis in place

patient with anotia who was rehabilitated with an osseointegrated prosthesis.

Conclusion

Lateral craniofacial surgery carries a risk of significant cosmetic defects relating to resection of the auricle when it is involved with malignancy. These defects are difficult to surgically reconstruct in a satisfying manner. Furthermore, the reconstruction also frequently involves multiple trips to the operating room. Osseointegrated titanium implants offer a firm foundation for the application of prosthetics. In the vast majority of cases this can be accomplished in a single procedure under local anesthesia. In the lateral temporal bone, osseointegration is reliable, with significant rates of implant failure seen only in radiated patients. The implants and prosthetics themselves are easy to care for, well tolerated by patients and provide a lifelike replacement for the lost auricle. Osseointegrated implant-borne prosthetics should be considered for rehabilitation of the patient undergoing lateral craniofacial surgery.

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10 Technical Issues in the High-Risk Patient

Margaret S. Roubaud and Matthew M. Hanasono

Introduction

Lateral craniofacial reconstruction requires thoughtful planning and careful execution to restore a patient's aesthetic and functional goals. Many patients undergoing lateral craniofacial reconstruction can be considered "high-risk" candidates for a multitude of reasons, including medical comorbidities, previous surgery, chemotherapy and/or radiation, and chronic corticosteroid use. Early recognition of a patient's complicated presentation and thoughtful planning may help to avoid later technical issues. When technical issues do arise, judicious use of appropriate surgical maneuvers may salvage an otherwise seemingly impossible challenge.

Evaluation of the High-Risk Patient

All patients should be assessed for the ability to tolerate prolonged surgery, whether local, pedicled, or microvascular reconstruction is required. Age alone has not been shown to be a contraindication to complex and potentially extensive surgeries [1]. However, comorbidities that are found in older patients, such as peripheral vascular, cerebrovascular, or cardiovascular diseases, should be viewed with caution. Risk factors for wound-healing complications and infection should be considered, such as poor nutritional status, diabetes mellitus, tobacco use, certain types of chemotherapy, prior radiation and surgery, and corticosteroid use. Specific to free flap surgery, patients should be questioned regarding a history of previous free flap loss, thromboembolic events, repetitive miscarriages, and a personal or family history of known hypercoagulable conditions such as disorders involving factor V Leiden, anticardiolipin antibody, antithrombin III deficiency, protein S deficiency, protein C deficiency, or lupus anticoagulant. Any suspicion for a hypercoagulable disorder warrants referral to a hematologist for evaluation prior to undertaking a free flap [2].

Whenever possible, steps are taken to optimize the high-risk patient prior to surgery. For example, nutritional repletion, optimization of blood sugar control, tobacco cessation, and necessary vascular interventions should be prioritized. However, if such interventions are untenable due to imminent disease progression or exposure of sensitive anatomic structures, then surgery must proceed despite these issues. In these instances, quantification of the severity of the comorbidity may be prudent. An example includes preoperative CT angiogram of the lower extremities to assess the extent of peripheral

M. S. Roubaud · M. M. Hanasono (✉)
Department of Plastic Surgery, The University of Texas MD Anderson Cancer Center, Houston, TX, USA
e-mail: msroubaud@mdanderson.org; mhanasono@mdanderson.org

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vascular disease and determine if suitable donor flaps are available. While it is debatable whether a free flap should be attempted in the setting of a hypercoagulable condition, microsurgeons have reported successful free flap reconstruction when the patient is treated with appropriate anticoagulants during the perioperative period, albeit with lower success rates than the general population [3]. Our interpretation is that the potential risks of flap loss must be outweighed by the benefits (i.e., no satisfactory local tissue or pedicled flap solution exists, or that free flap loss can be compensated for by a non-free flap solution as a "back-up" without significant harm to the patient).

As functional and aesthetic concerns are part of the ultimate reconstructive outcome, these should be evaluated and documented prior to surgery. Many high-risk patients will have undergone previous treatment, including surgery or chemoradiation. Preoperative function should be noted since prior dysfunction may worsen the prognosis for functional restoration. In particular, for maxillary surgery, previous resection, malocclusion, deficient midface projection, or soft tissue retraction should be noted. Additionally, lip deficiency, eyelid malposition, or visual problems should be documented. For patients with parotid or temporal bone tumors, facial nerve function should be assessed. Nerve repair, nerve transfer, and static slings are usually performed immediately in these patients, while periocular and dynamic reanimation procedures are frequently depending on adjuvant treatment as well as surgeon preference. Specifically for orbital and skull base patients, brow position, lid laxity, eye closure, and frontalis muscle function should be documented. Hearing and balance should also be evaluated preoperatively if these functions may potentially be affected by surgery.

Flap Selection in the High-Risk Patient

Several key structures are involved in lateral craniofacial reconstruction, as mentioned in previous chapters. In particular, the temporal bone, maxilla, orbital bones, and skull base give shape and dimension. In general, like should replace like for the most optimal and long-lasting results, although there are instances when soft tissue alone is more expedient and can be sufficient to achieve a reasonably good contour. The fibula and scapula are excellent sources of bone stock for the maxilla. Numerous soft tissue flaps are available for both bulk and cutaneous coverage as mentioned in previous chapters.

A common pitfall in the reconstruction of high-risk lateral craniofacial defects is the inaccurate assessment of the defect. The lateral face and skeleton are convex and the soft tissue deficit is often greater than predicted. When previously radiated or operated sites are reopened, scar tissue often "springs back," creating a defect larger than the resection alone. Many times, while cutaneous tissue may not be resected, defects become unclosable on the surface due to loss of domain. Furthermore, previously radiated tissue may become ischemic or nonviable and the patient would benefit from a wider resection than needed just to achieve negative oncologic margins.

In the head and neck cancer patient who will require adjuvant radiation, it is paramount to plan for volumetric decrease in the flap with treatment. While one flap may be the most straightforward reconstruction, the surgeon must not be closed-minded to the idea of a second or even sometimes a third simultaneous flap. A nasomaxillary reconstruction is doomed to collapse and fistulize if adequate nasal lining is not achieved. Insufficient soft tissue coverage over bone or hardware is likely to result in exposure. In extensive defects, particularly those that involve multiple tissue types, such as cheek–mandible–buccal mucosa, more than one free flap or a chimeric flap (a single flap with multiple components such as the subscapular artery-based latissimus/parascapular bone/parascapular skin) may be needed to achieve the most optimal results [4].

In the high-risk patient, it is safest to choose workhorse flaps with adequate volume for the defect. It is prudent to avoid donor sites in risky wound areas, such as the abdomen in the morbidly obese. Preferential use of free flap with long pedicles can help to avoid the need for vein grafts, which take additional operative time and may add to the complexity of the case [5]. In the case of double or triple flaps, it is preferred to select flaps with multiple side branches on the pedicle, such as the anterolateral thigh flap, as secondary flaps may be "piggy-backed" on to the main pedicle if vessel availability is sparse (see following section).

Vessel Selection and Anastomosis in the High-Risk Patient

In patients with significant vascular disease, recipient and donor vessels may be in poor shape with significant stenosis and/or calcific plaques. In patients who have had prior irradiation, neck dissection, or free flap surgery, commonly used recipient blood vessels, such as the branches of the external carotid artery and the internal or external jugular vein, may not be available. In these instances, the operating surgeon is facing a "vessel-depleted" neck, whether quantitatively or qualitatively. Preoperative imaging, such a CT of the head and neck with IV contrast, may give insight into the presence and patency of potential recipient vessels.

If vasculature is sparse or heavily diseased, the surgeon should anticipate the use of alternate blood supply, such as the transverse cervical artery and vein, or vein grafting from otherwise unreachable sources [6]. Frequently, vein grafts to the contralateral neck or ipsilateral transverse cervical vessels can circumvent hours of struggle with suboptimal inflow or outflow. When done in an expeditious and planned manner, vein grafting may be ultimately more efficient than trying to force a small caliber vessel to function. Most recent studies show no differences in flap success rates between those utilizing vein grafts and those that do not [7, 8]. Furthermore, it may avoid potentially catastrophic misadventures with highly diseased or scarred carotid and jugular vessels.

When the transverse cervical blood vessels are not available, then recipient vessels outside the head and neck should be explored [9, 10]. The operating surgeon must plan accordingly, and patients should be counseled regarding the potential for additional incisions, including distant recipient blood vessel sites and vein graft donor sites. Other sources of regional recipient blood vessels include the internal mammary artery and vein, the thoracoacromial artery and vein, and the cephalic vein [11–13].

In multiple flap surgeries, the authors have found "piggy-backing" one flap onto another to be a reliable way of performing two or more free flaps with only a single set of recipient blood vessels. Either an end-to-side anastomosis is performed or a side branch arising from the main vascular pedicle is used as the recipient blood vessels for the additional free flap (Fig. 10.1) [9]. Others have described using the distal pedicle as

Fig. 10.1 Multiple free flap reconstruction in a vessel depleted neck. The left mid-skull base, maxilla, and mandible have been reconstruction with combined fibula and anterolateral thigh (ALT) free flaps. The ALT free flap was anastomosed via a vein graft to the internal mammary artery for inflow and the external jugular vein for outflow. The fibula free flap pedicle artery and vein were anastomosed to side branches of the ALT free flap pedicle artery and vein, respectively

recipient blood vessels, creating a so-called “flow-through” free flap. Anecdotally, this has been suggested to be a less reliable technique [14]. Of course, the risk of piggy backing and flow through free flaps are that if the anastomosis to the main recipient blood vessels develops a thrombosis, all flaps will potentially be lost, so there should be a high degree of confidence in the reliability of the recipient blood vessel flow and technical quality of the microvascular anastomosis.

Flap Inset

Flap inset is acritical aspect of the reconstruction and not to be ignored. In the high-risk patient, a careful inset may be the difference between a short hospital stay and successful reconstruction and one marked by leak, fistula, or delayed healing. In the radiated or scarred patient, tissue quality is almost universally poor. The tissues are inelastic, poorly vascularized, and friable. Bone structures may have poor stock and fracture easily.

When working with mucosal tissues, it is essential to properly align epithelialized flap with healthy mucosal edges. While the authors prefer single, interrupted tissue sutures to minimize tissue ischemia, mattress sutures may be required to achieve improved tissue eversion. Sutures are generally spaced 5–8 mm apart to provide an airtight/watertight seal while minimizing suture burden.

When insetting a muscle or myocutaneous flap into a deep cavity, it is essential to obliterate all areas that may collect fluid and create infections. When obliterating a sinus, the surgeon must ensure all mucosa has been removed to prevent mucocele. If a nasal passageway or sinus is to remain open, stenting the tissue may be required with nasal trumpets or cartilage grafts. High-risk patients, especially those with diabetes or immunocompromised states, will have poor ability to fight infection. Closed suction drains are used routinely to avoid fluid collections and encourage apposition of flap tissues to the skull base.

If a flap is to be placed over bone or rigid surface, the tissue must be sufficiently lax to prevent compression on the pedicle when maximum edema occurs. Additionally, the surgeon should have little hesitation to perform external soft tissue resurfacing if there is a question of a tight closure, as redundant tissue may be easily excised in a secondary procedure while undue pressure can certainly compromise the vascularity of an entire flap (Fig. 10.2). If a flap is bulky or heavy, it is often prudent to inset it to the periosteum of the facial skeleton with permanent suture to prevent descent and traction on the pedicle or critical facial structures such as the eyelids. Nonviable or protruding bone should be removed with a cutting bur, or else bony exposure or infection due to osteoradionecrosis is likely to occur in the future.

In recent years, the addition of computer-aided design and computer-aided modeling (CAD–CAM) technology has also facilitated the planning and inset of difficult facial reconstructions [15, 16]. Particularly in patients when bone stock is poor or limited from previous treatment, careful preoperative CAD–CAM planning may allow the surgeon to model his or her desired bony plates and drill holes off preoperative imaging. It may reduce osseous manipulation and drilling errors [17]. In most cases, CAD–CAM-assisted bone reconstruction pertains to maxillary and mandibular reconstruction in those temporal bone and parotid lesions that extend anteriorly and deeply to involve these structures [18].

Computer technology can also be used to create patient-specific implants, such as custom titanium, porous polyethylene, or polyetheretherketone (PEEK) cranioplasty implants, which may be needed in lateral skull base reconstruction when the resection involves temporoparietal calvarium [19]. The advantage of such implants is that they save time because they are prefabricated prior to surgery and, perhaps, more importantly restore calvarial shape perfectly based on CT images of the defect (Fig. 10.3). The disadvantage is that they are most useful in delayed cases when the defect is known and is of limited use in immediate reconstruction. PEEK and porous polyethylene implants can be used for reconstruction immediately following calvarial resection if the extent of resection can be accurately estimated. If in doubt, the implant can be manufactured slightly larger than needed and reduced with a cutting bur.

Fig. 10.2 A patient underwent a right lateral temporal bone resection (**a**). She was reconstructed with an ALT free flap, using the skin paddle to close both the external auditory canal and the neck incision, to minimize compression of the flap and microvascular anastomosis (**b**). Several months later, the neck skin paddle is almost unnoticeable following debulking and partial excision (**c**)

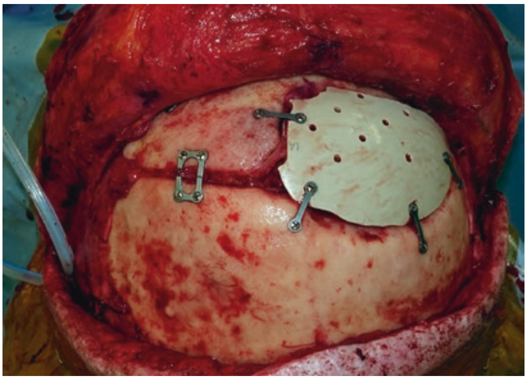

Fig. 10.3 Polyetheretherketone (PEEK) custom-made or "patient-specific" cranioplasty for a parietal calvarial defect in a patient who has undergone multiple craniotomy and skull base resections for cancer. The patient had an infected cranial bone segment that was removed and covered with a latissimus dorsi free flap. After adequate antibiotic treatment, the free flap was elevated off of the dura and a delayed cranioplasty was performed

By comparison, traditional titanium mesh cranioplasty may result in imperfect shape aesthetically and leave protruding edges that may later become exposed.

Anticipating/Managing Complications in the High-Risk Patient

Arguably, one of the most important preoperative conversations the surgeon should have with the high-risk patient is a discussion of likely complications. Open and early discussion of likely setbacks allows the patient to have realistic expectations from the outset. In particular, discussion of the importance of postoperative protocols and monitoring emphasizes the role the patient plays in his or her own result.

Functional goals as well as possible complications should be discussed. In particular, orbital exenteration patients and those receiving prosthetics, such as a maxillary obturator, should be aware of the timing between resection and donning of such devices. At our institution, patients will frequently have a temporary prosthetic or obturator upon conclusion of the case. However, it may take 6–8 weeks for swelling to resolve and the construct to be finalized. This may be longer in cases of radiation. The patient must understand that premature donning of devices or dental rehabilitation will lead to ill-fitting constructs, poorly retained dental wear, or wound breakdown. Furthermore, fluent speech and nasal air escape may take therapy or continued adjustments.

In resections involving the nasal lining or maxillary sinus, patients should understand the length of time they may have to retain a nasal trumpet or have issues with airflow. In general, the authors keep nasal trumpets 2–3 weeks after surgery and nasal stents for multiple months to prevent collapse, especially in the multiply resected or radiated patient. Many patients are not prepared for possible recurrent sinus infections or obstructed outflow tracts after midface reconstruction and this should be discussed early and often. In the operated and radiated patient, nasal crusting and sinusitis may be chronic and meticulous postoperative nasal hygiene is requisite. Even with frequent irrigation, antibiotic treatment and periodic endoscopic debridement may be necessary.

Aesthetic goals should be understood and tempered. While the ultimate reconstructive success is the symmetric and harmonious face, multiple operations may be required to achieve this. Furthermore, some surgical scars may never fade, color match may be difficult, and facial projection may change with time. If patients have facial nerve involvement, they must understand the protracted time it may take for neurologic recovery. During this period, they will likely experience drooling, corneal irritation, and facial disharmony. All patients should be counseled to the chance of permanent paralysis.

Most studies have shown that the greatest risk for flap compromise occurs in the first 48–72 hours following surgery [20, 21]. In our experience at the MD Anderson Cancer Center, the incidence of flap vascular compromise after head and neck reconstruction is 6.6% and total flap loss is 2.6% [22]. In the senior author's opinion, the most common cause of arterial thrombosis is intimal injury, particularly when working with friable radiated vessels. Therefore, the high-risk patient population requires special attention to nontraumatic technique and the avoidance of unnecessary manipulation of recipient vessels. The most common cause of venous failure is physical obstruction of the vein by tension, kinking, or compression. The surgeon must remember that radiated or scarred tissues have poor elasticity and are prone to exuberant and prolonged swelling from lymphedema. Sufficient flap laxity and volume must be given on inset. Other causes for flap failure include infection, hematoma, or hypercoagulability [22]. Meticulous technique and postoperative monitoring as well as selective use of antibiotics and anticoagulation therapy in high-risk patients can help prevent these issues.

Flap salvage is paramount on early diagnosis and intervention. As further evidence to the importance of diligent monitoring in the first few days after surgery, in our experience, the flap salvage rate is 61% when compromise occurred within 72 hours and 13% after 72 hours from surgery [20]. Most likely, attempts at flap salvage are less successful after 72 hours due to a delay in diagnosis once flap monitoring is less stringent or to a smoldering subclinical issue such as infection. Although many patients will manifest infection with a fever, white count, or erythema, it is the authors' experience that these can be very subtle and misleading in patients such as the elderly, diabetic, previously radiated, or immunocompromised. A high index of suspicion must be carried for these patients and early operative washout followed by culture-directed antibiotics is recommended.

A cerebrospinal fluid (CSF) leak can happen as a result of lateral craniofacial reconstruction, especially in surgeries involving skull base resections. As these resections involve removing tumors from the floor of the anterior, middle, or posterior cranial fossae, with or without the dura, they can result in early or late CSF leak. The defects must be reconstructed with sufficient vascularized soft tissue to isolate the intracranial contents from the sinonasal cavities or the outside world, especially in patients with a history of radiation or planned adjuvant radiation. The use of careful dural closure and pedicled pericranial flaps is highly advocated in the neurosurgery literature [23, 24]. Similarly, the use of highly vascularized myocutaneous or fasciocutaneous flaps is advocated for their ability to obliterate dead space and provide a seal against sinonasal contamination [25–27]. Closed suction drains are generally recommended, but placed away from dural repair suture lines to decrease the risk for a leak; however, they still encourage apposition of the flap tissues to the skull base. When a CSF leak is diagnosed, the patient is usually first treated with a lumbar drain and bed rest. If this fails to resolve the issue, operative reexploration may be indicated.

Conclusion

Lateral craniofacial reconstruction can be successfully achieved in the high-risk patient. Many technical issues can be avoided by careful preoperative and intraoperative plans that reduce comorbidities and anatomical surprises. Postoperative protocols should be tightly followed, and patients should be prepared for possible hurdles. With adequate preparation, many high-risk patients can be converted to routine cases with successful outcomes.

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11 Lateral Craniofacial Reconstructive Challenges in the Developing World

Johannes J. Fagan, Wayne Manana, and Ottie (JE) Van Zyl

Introduction

Because 90% of people in low-income countries lack access to basic radiotherapy [1], surgery often is the only treatment for craniofacial tumors. Achieving soft tissue cover of exposed brain, dura, and bone, and to restore skin and soft tissue defects and cosmesis, are key to our ability to undertake many lateral craniofacial resections. Not to be able to provide soft tissue cover may deem some oncologically "resectable" tumors to be "unresectable." Yet less than 5% of patients in low-income countries have ready access to safe, affordable, and timely surgery [2].

Lateral craniofacial resection and reconstruction in limited resource settings are further complicated by delayed presentation with advanced tumors resulting in large surgical defects; and lack of good anesthetic, nursing, and perioperative care [3]. Reconstruction of craniofacial surgical defects presents challenges in many developing countries due to a lack of reconstructive services [4] and has been identified as an obstacle to establishing head and neck services in Africa [5]. Lateral cranial base resections requiring complex reconstructive surgery are also demanding in terms of financial and human resources, as well as operating time and ICU care; this may raise ethical questions about whether such major, expensive, and time-consuming surgery can be justified in resource-constrained settings, especially in cases where survival benefits are marginal.

Free tissue transfer flaps have revolutionized head, neck, and skull base surgery as many tumors that were previously considered unresectable because of poor reconstructive options can now be resected with acceptable functional and cosmetic results. Good results can be achieved in tertiary hospitals even in developing world settings, for example, our own institution in Cape Town reported a 94% success rate for free tissue transfer flaps for head and neck reconstructions using only loupe magnification in a setting where prompt reexploration of a compromised flap is generally not possible due to restricted access to emergency operating rooms [6]. However, access to free tissue transfer services in many developing countries is generally very poor [5].

Because of poor availability of free tissue transfer flap reconstruction, reliance is often placed on local and regional flaps, many of which are now less commonly used in developed

J. J. Fagan (✉)
Division of Otorhinolaryngology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa
e-mail: johannes.fagan@uct.ac.za

W. Manana
Specialist Oral & Maxillofacial Surgeon, Harare, Zimbabwe

O. (JE) Van Zyl
Groote Schuur Hospital, Cape Town, South Africa
e-mail: ottie@mweb.co.za

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countries. This chapter presents some of these reconstructive options that may be considered for lateral craniofacial surgical defects in resource-constrained settings when free tissue transfer options are not always available or are unsuitable for medical or other reasons. Such flaps may also be valuable to reconstructive surgeons in developed countries, especially when a free flap fails or donor vessels are not available in the neck.

Local Flap Options for Lateral Craniofacial Defects

Lateral craniofacial defects require not only soft tissue cover, but also variable amounts of tissue bulk to restore facial contour and to cover dural repairs. While local random flaps may provide skin cover, they are thin and generally do not provide much bulk (Figs. 11.1 and 11.2). Additional bulk can however can be achieved by placing a free fat graft or a muscle flap, for example, temporalis or pectoralis major, deep to the skin flap. Other local options include split- and full-thickness skin grafts. A muscle flap can covered with a split skin graft, or a graft bed can be prepared with negative pressure wound therapy to achieve granulation tissue over

Fig. 11.1 Example of local skin flap utilizing the auricular skin

Fig. 11.2 Retroauricular transposition skin flap

exposed bone followed by skin grafting. Another method to achieve granulation tissue cover over exposed bone is to employ matrix wound dressings, followed by skin grafting, though these dressing are unfortunately expensive.

Regional Flaps

Regional flaps have distinct advantages over free tissue transfer flaps for selected soft tissue defects in the head and neck such as reduced operating time, donor site morbidity, level of surgical expertise required, and cost. Regional flaps that may be considered for lateral craniofacial defects include temporoparietal fascia or fasciocutaneous flaps, as well as temporalis muscle, pectoralis major, deltopectoral, latissimus dorsi, cervicofacial or cervicothoracic rotation, submental artery island, and supraclavicular flaps. Considerations when selecting a flap include the size, depth, and position of the defect; presence of cervical metastases; whether the vascular pedicle has been preserved during the resection; and the reach of the flap. The temporoparietal fasciocutaneous flap is based on the superficial temporal vessels; therefore, the external carotid and superficial temporal arteries need to be intact. The temporalis muscle flap, on the other hand, is based on the anterior and posterior deep temporal arteries that are branches of the internal maxillary artery, and hence the external carotid artery system. Pectoralis major flaps can reach as high as the zygoma, but the skin paddle may need to be extended distal to the pectoralis major muscle and below the costal margin where it becomes a random flap and the vascularity is less reliable (Fig. 11.3). Even though deltopectoral flaps have been used for lateral craniofacial defects, they may have limited reach due to a limited arc of rotation unless the length of the deltopectoral flap is increased with a surgical delay for 2–3 weeks prior to flap elevation (Fig. 11.4).

The latissimus dorsi musculocutaneous flap is a reliable flap and is transposed through the axilla, underneath and then through the upper part of the pectoralis major muscle, to reach the neck. It can be used for large defects of the neck up to the zygomatic arch (Fig. 11.5). The lateral-

Fig. 11.3 Pectoralis major flap used to cover for lateral temporal bone defect. (Permission: Prof Evelyne Diom)

Fig. 11.4 Extended reach of deltopectoral flap following surgical delay

Fig. 11.5 Latissimus dorsi musculocutaneous flap reaching the postauricular region

based forehead flap, although leaving an unsightly donor site, is a simple and reliable option for cheek reconstruction (Fig. 11.6). Various large scalp rotation–transposition flaps are available to reconstruct lateral cranial defects with skin grafting of the donor site (Fig. 11.7).

Fig. 11.6 Lateral-based forehead flap. (Permission: Prof Evelyne Diom)

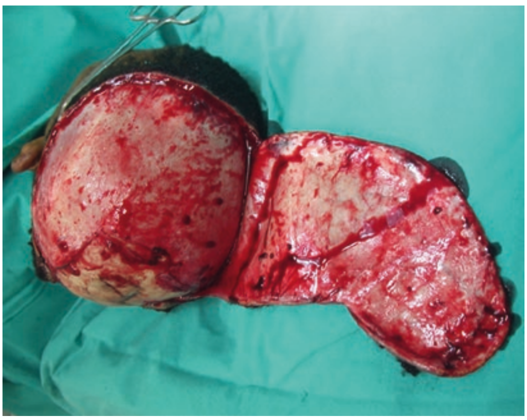

Fig. 11.7 Scalp rotation–transposition flap

The remaining discussion will focus on three useful flaps: the cervicofacial/cervicothoracic rotation, submental artery island, and supraclavicular flaps.

Cervicofacial and Cervicothoracic Rotation Flaps

The cervicofacial flap in its modern form was first described by Juri and Juri [7]. Conceptually it is a random flap comprising of skin, subcutaneous fat, superficial neck veins, and platysma muscle. It includes the very delicate, thin, superficial cervical fascia, just deep to the skin that envelopes the platysma and the muscles of facial expression and extends from the epicranium above to the axilla and upper chest below; over the face it is represented by the superficial musculoaponeurotic system (SMAS). It has a wide pedicle and can be employed to cover large anterolateral craniofacial defects (Figs. 11.8 and 11.9). Superiorly it can reach the supraorbital margin, laterally the postauricular area, and medially up to the midline (Figs. 11.8 and 11.9). It provides an excellent match in terms of skin color, thickness, and texture; can be performed under local anesthesia; provides concomitant exposure for neck dissection and parotidectomy; has very acceptable donor site scars, which are camouflaged in the cheek borders; requires minimal surgical time; and has minimal postoperative morbidity. As it is a thin flap, additional bulk may need to be achieved with a pectoralis major muscle flap placed deep to the cervicofacial flap. It may also be a good option in patients not suitable for free tissue transfer flaps, for example, higher risk or elderly patients who cannot tolerate prolonged microvascular reconstruction operations.

After completing the tumor resection, the skin incision is commenced at the posterior edge of the soft tissue defect, carried posteriorly beyond the tip of the mastoid, and then turning vertically is continued inferiorly along the anterior border of the trapezius muscle. Preserving the external jugular vein inferiorly reduces venous engorgement. A cervicofacial flap is then raised in a plane superficial to the SMAS, the parotidomasseteric fascia, but deep to the superficial cervical fascia surrounding the platysma to preserve the capillary network within the fascia, while intermittently checking whether enough skin has been elevated to close the defect without undue tension. A cervicothoracic flap may need to be elevated by extending the incision across the lateral third of the clavicle onto the anterior chest wall over the pectoralis major muscle to sufficiently mobilize skin and to improve the arc of rotation. Even though epidermolysis and distal necrosis of the distal flap has been reported in up to 31%, wounds generally heal by secondary intention [8] (Fig. 11.10). The cervicofacial/cervicothoracic rotation flap is therefore a good option for small-to-large relatively superficial lateral craniofacial defects, particularly in patients medically unsuitable for free flap reconstruction.

Fig. 11.8 Cervicofacial rotation flap used to cover a lateral craniofacial defect

Fig. 11.9 Cervicothoracic rotation flap used to cover an anterolateral craniofacial defect

Submental Artery Island Flap

The submental artery island flap is an axial fasciocutaneous flap that includes skin, subcutaneous tissue, submental fat, lymph nodes, and platysma and is pedicled on the submental artery and vein (Fig. 11.11). It is bulkier than the cervicofacial rotation flap, and additional bulk can be achieved by including the anterior belly of digastric and mylohyoid muscles in the flap (Fig. 11.11). The lower margin of the mandible can also be included for bony reconstruction of, for example, the inferior orbital rim [9]. The submental artery supplies a large skin paddle of as much as 10 × 16 cm, extending from one angle of the mandible to the other. The maximum anteroposterior dimension of

Fig. 11.10 Distal necrosis of cervicothoracic rotation flap healing by secondary intention

Fig. 11.11 Submental artery island flap and vascular pedicle based on facia artery and vein. Note that the anterior belly of digastric has been included in this flap

the skin island is limited by the ability to achieve primary closure; this in turn depends on skin laxity and age. The entire flap can be pedicled on one submental artery because of crossover perfusion between the left and right submental arteries. The submental artery and vein branch from the facial artery and vein close to the inferior edge of the mandible. Because the vascular pedicle has a length of up to 8 cm and has a wide arc of rotation, it may be used for defects of the lower two-thirds of the face, oral cavity, oro-, and hypopharynx (Fig. 11.12). By further dissecting toward its origin from the facial artery, the pedicle can be lengthened by an additional 1–2 cm to reach the lateral canthus of the eye and the zygomatic arch (Fig. 11.12). The facial artery and vein must be preserved during the lateral craniofacial resection. A relative contraindication is when there are cervical metastases to Level 1a of the neck as fat and lymph nodes of the submental triangle are included in the flap.

Supraclavicular Flap

The supraclavicular flap is a pedicled axial fasciocutaneous flap based on the supraclavicular artery, which generally branches from the transverse cervical artery in the supraclavicular fossa [10]. It is centered over the shoulder joint and extends from the supraclavicular region up to the lateral surface of the upper arm, over the deltoid muscle (Fig. 11.13). Because of its long pedicle and broad arc of rotation, it can be used for a variety of head and neck defects including the lateral skull base, face, and parotid regions (Fig. 11.13). Like cervicofacial rotation flaps, the texture and color match that of the skin of the face, and it is generally hairless. It is also however a thin flap, and deeper defects may require an additional muscle flap for bulk. It is however simple and quick to raise, is highly reliable, and may be beneficial for high-risk patients who cannot sustain long surgeries.

Regional Flaps in Developed Countries

Even though free flaps have generally supplanted regional flaps in developed countries, it should be

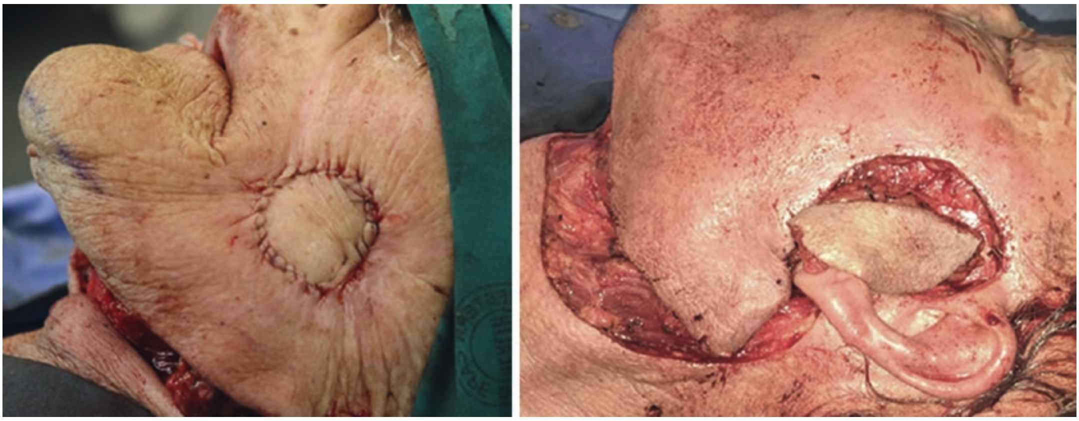

Fig. 11.12 Examples of submental artery flap used for cheek and preauricular defects

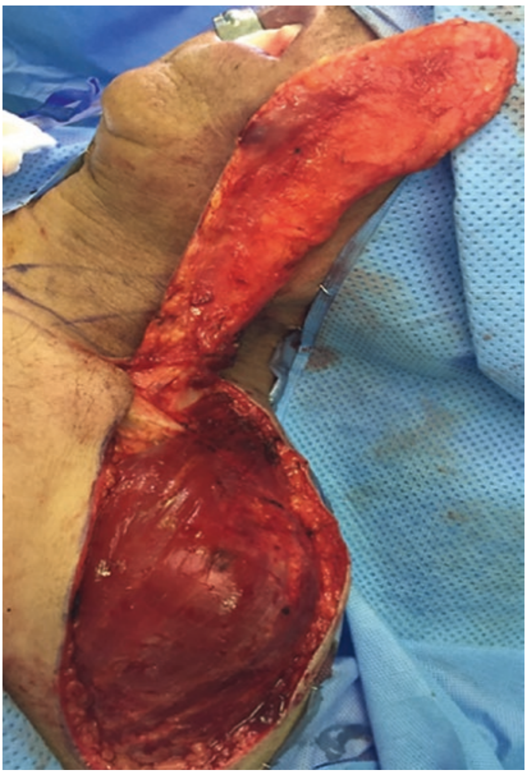

Fig. 11.13 The reach of the supraclavicular flap is clearly illustrated. (Permission: Dr. Mohammad Al Falasi) [10]

apparent from this chapter that regional flaps may sometimes be preferable to free flaps in terms of skin color and texture, donor site morbidity, length of surgery, surgical complexity, and cost. They may also have an important role when surgical salvage is required for failed free flaps or when suitable donor vessels are not available in the neck.

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12 Emerging Technologies in Lateral Craniofacial Reconstruction

Axel Sahovaler, Marco Ferrari, and Jonathan Irish

Introduction

Defects present in the lateral craniofacial region are particularly challenging to reconstruct. This is due to the tissue variety (bone, cartilage, muscle, skin) and different anatomical structures (mandible, maxilla, orbit, auricle) located in close proximity [1]. Currently, rather than simply covering the defects, more personalized reconstructions are pursued to restore function and aesthetics.

Computer-assisted surgery (CAS) refers to the use of computer technology in the medical field to optimize a surgical procedure. Three-dimensional (3D) printing, computer-aided design (CAD)/computer-aided manufacturing (CAM), and intraoperative navigation represent different components of CAS and are being increasingly applied in the reconstruction of complex craniomaxillofacial defects. All share the same principle which is capturing patient-specific parameters from computer tomography (CT) and magnetic resonance imaging (MRI) and by employing digital planning software increase surgical precision, reduce variability in outcomes, and enhance accuracy in the results. Furthermore, latest technologies have been able to incorporate 3D printed biocompatible materials, which can be seeded with stem cells to stimulate new tissue formation [2].

Despite the fact that many centers worldwide have adopted CAS in the reconstructive algorithm for over a decade, new developments in the field still take place. This chapter will provide some general concepts about these technologies and also describe the latest innovations, in an effort to provide a summary of present and future applications of such emerging advancements.

A. Sahovaler
Department of Otolaryngology – Head and Neck Surgery/Surgical Oncology, University Health Network, Toronto, ON, Canada

Guided Therapeutics (GTx) Program, Techna Institute, University Health Network, Toronto, ON, Canada
e-mail: axel.sahovaler@uhn.ca

M. Ferrari
Department of Otolaryngology – Head and Neck Surgery/Surgical Oncology, University Health Network, Toronto, ON, Canada

Unit of Otorhinolaryngology – Head and Neck Surgery, University of Brescia, Brescia, Italy

Techna Institute, University Health Network, Toronto, ON, Canada

J. Irish (✉)
Department of Otolaryngology – Head and Neck Surgery/Surgical Oncology, University Health Network, Toronto, ON, Canada

Techna Institute, University Health Network, Toronto, ON, Canada
e-mail: jonathan.irish@uhn.ca

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Three-Dimensional Printing, CAS, and Intraoperative Navigation

Since its invention in the 1980s, 3D printing has been extensively used in medical applications. According to a recent review [3], craniomaxillofacial surgery was the surgical domain with the second highest percentage of publications using this technology. Also known as additive manufacturing, it is a process that begins with the conversion of CT and MRI images from data imaging and communications in medicine (DICOM) format into standard tessellation language (STL) format by different software options. Once in a printable format, the file can be imported to the 3D printer for creation of a specific model [4]. Three-dimension printing and modelling in lateral craniofacial reconstruction can be employed to build custom-made facial prostheses, assist during the surgical procedures, and promote tissue regeneration.

Prosthetic Rehabilitation

In cases where complex reconstructions are not an option due to poor oncologic prognosis, multiple comorbidities, or patient refusal, prosthetic rehabilitation represents an invaluable option, especially in the orbit and auricle. The conventional prosthetic manufacturing process initiates by sculpting a wax pattern of the missing ear or orbit and then creating a life-like prosthesis replacement [5]. This represents an extremely time-consuming process and operators have to rely on skilled artistic approaches [6]. The use of technology has changed the conventional workflow by 3D printing a negative multiple piece mold to cast the final prosthesis. The complex convoluted contours of the auricle can be captured by advanced 3D imaging techniques such as surface laser scanning. Furthermore, spectrophotometry can be utilized to optimize color matching. This accelerates the process to a great extent, with the possibility of delivering the prosthesis at the second appointment [5]. In orbital prosthetic rehabilitation, 3D printing has allowed a smoother transition between the prosthesis and the surrounding tissues, by digitally establishing areas of contact, and thus facilitating an improved prosthesis to tissue adaptation, which is critical in this anatomical area [7]. Ongoing work is exploring the 3D printing of facial expression models, which can simulate the shape of facial movements and achieve better fitting of the prosthesis [8]. Databases containing morphological details of diverse anatomical structures have also been applied to try to simplify the digital process of the prostheses fabrication [9].

Computer-Assisted Surgery

The possibility of virtually manipulating patients' imaging has enabled surgeons to preoperatively and even intraoperatively (Fig. 12.1) plan the surgical procedures. Both the ablation and reconstruction can be designed in advance; cutting margins are predefined and osseous components of the chosen flap are accommodated to a virtually created defect, evaluating which is the best reconstructive option. As a result, different approaches and possible final outcomes can be analyzed and compared. Using 3D printing, all this information can be used to print cutting guides for both the resection and reconstruction, create intermediate models of the reconstruction (Fig. 12.2), and enable custom-made titanium plates (also known as patient-specific plates "PSP") for the planned operation, in a process known as computer-assisted design/computer-assisted manufacturing (CAD/CAM). This brings a higher degree of precision during the ablation and reconstruction, largely facilitating the inset of the bony free flaps. Dental implants positioning within the free flaps can also be predetermined [10].

This technology has proven to be feasible and has been implemented by many surgical groups in maxillomandibular reconstructions. Thus, more recent research work is concentrated on comparing CAD/CAM approaches with traditional techniques. Reduction in the operative and ischemia times were found with virtually planned mandibular reconstructions, as there was almost no need for revision osteotomies or adjusting the bone during the flap inset. In addition, better bony union rates were obtained in postoperative CT scans with CAS. Noteworthy, there have been no major differences in postoperative complications between the approaches [11–13]. When pre- and postoperative CT scans were used to

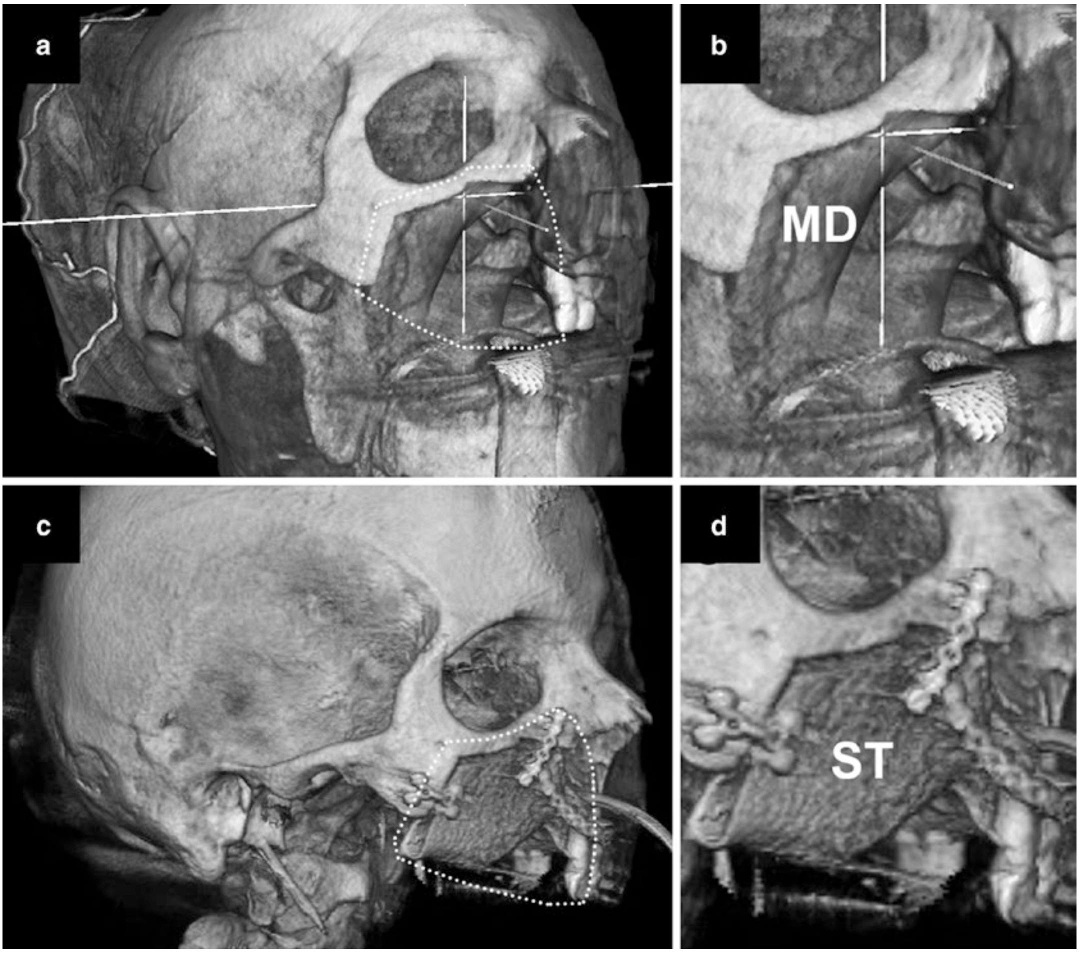

Fig. 12.1 Example of 3D surface rendering from a cone-beam-computed tomography acquired intraoperatively (Guided therapeutics – GTx – operating room, University Health Network, Toronto, Ontario, Canada) (**a**, **b**) An infrastructure maxillectomy defect (MD) was carried out and the defect is evaluated and measured to optimize the reconstruction. (**c**, **d**): A scapular tip free flap (ST) was utilized for the reconstruction, and an adequate inset ensuring appropriate midfacial projection was confirmed intraoperatively. (Courtesy of Michael J. Daly (MSc, PhD), and Harley H.L. Chan (PhD) (Guided Therapeutics (GTx) Program, TECHNA Institute, University of Toronto, Princess Margaret Cancer Centre, Toronto, Ontario, Canada. Department of Otolaryngology – Head & Neck Surgery/Surgical Oncology, University of Toronto, Princess Margaret Cancer Centre, Toronto, Ontario, Canada)

measure the accuracy of the reconstruction, virtually planned procedures were superior in reestablishing the mandibular angle, bigonial diameter, and chin protrusion [14] (Fig. 12.3). Functionally, there were no clear benefits in virtually planned procedures as mouth opening, protrusion, or laterotrusion were similar between both groups [15]. Still, these findings are based on retrospective small series often with heterogeneous populations, and measurements are done by unblinded examiners.

Cost is a critical aspect in evaluating any new technology. CAD/CAM approaches and PSP represent a major cost for many healthcare systems. Besides cutting guides and custom-made implants which have been historically supplied by the industry, the process may involve technical support and prolonged presurgical preparation time. Reports have also addressed this issue, and advocators for the CAS techniques found that difference in cost is nonsignificant [16], and even in favor of the virtually planned procedures

Fig. 12.2 3D printed models of a mandibulectomy reconstruction which will allow a preoperative bending of the reconstruction plate. Courtesy of Harley H.L. Chan (PhD) and Michael J. Daly (PhD) (Guided Therapeutics (GTx) Program, TECHNA Institute, University of Toronto, Princess Margaret Cancer Centre, Toronto, Ontario, Canada. Department of Otolaryngology-Head & Neck Surgery/Surgical Oncology, University of Toronto, Princess Margaret Cancer Centre, Toronto, Ontario, Canada)

[17] at the expense of shorter operative times. The financial considerations have led many larger volume centers to develop "in-house modelling" [18–20]. Using open access software and commercially available 3D printers, surgeons can perform their own virtually planned procedure with a considerably decreased budget [20]. In-house models emerged as an appealing option especially in economically constrained health systems, although reports so far have not included PSP nor considered the learning curve of the surgeon.

By importing the virtual data into a navigation system, it has become possible to intraoperatively guide the operation, both during the resection and reconstruction (Fig. 12.4). Intraoperative navigation surgery (INS) has been initially used in neurosurgery and endoscopic skull base procedures where critical anatomical structures could be located preserving them during tumor resections. Replicating the same concept of global positioning systems (GPS), INS comprises three basic components; a *localizer* (analog to a satellite in space), a *surgical probe* which emits tracking signals, and a *CT scan/MRI dataset* which represents the road map [21]. The localizer identifies the position of the surgical probe in a sagittal, coronal, axial, and 3D reconstruction planes in images displayed by a screen on the navigation system, providing the surgeon with real-time "on-the-table" tracking.

Two types of INS are currently available: the optical and electromagnetic navigation [22–24], which rely on an infrared camera system and an electromagnetic field, respectively. The former technology is based on the simultaneous tracking of navigated instruments and a reference frame that is mounted on the patient, providing an exceptional degree of spatial accuracy. This system requires a "line-of-sight" between the tracker and surgical probe which needs to be unblocked throughout the navigation. Moreover, lights of the operating theater might interfere with the tracking process when directed toward the infrared camera. Such technicalities limit considerably the application of this technology in surgical procedures requiring multiple surgeons, bulky equipment, and several operating room lights. Conversely, the electromagnetic navigation works even when objects are present between the tracker and navigated instruments. However, the accuracy achievable with such methodology is usually lower when compared with optical navigation

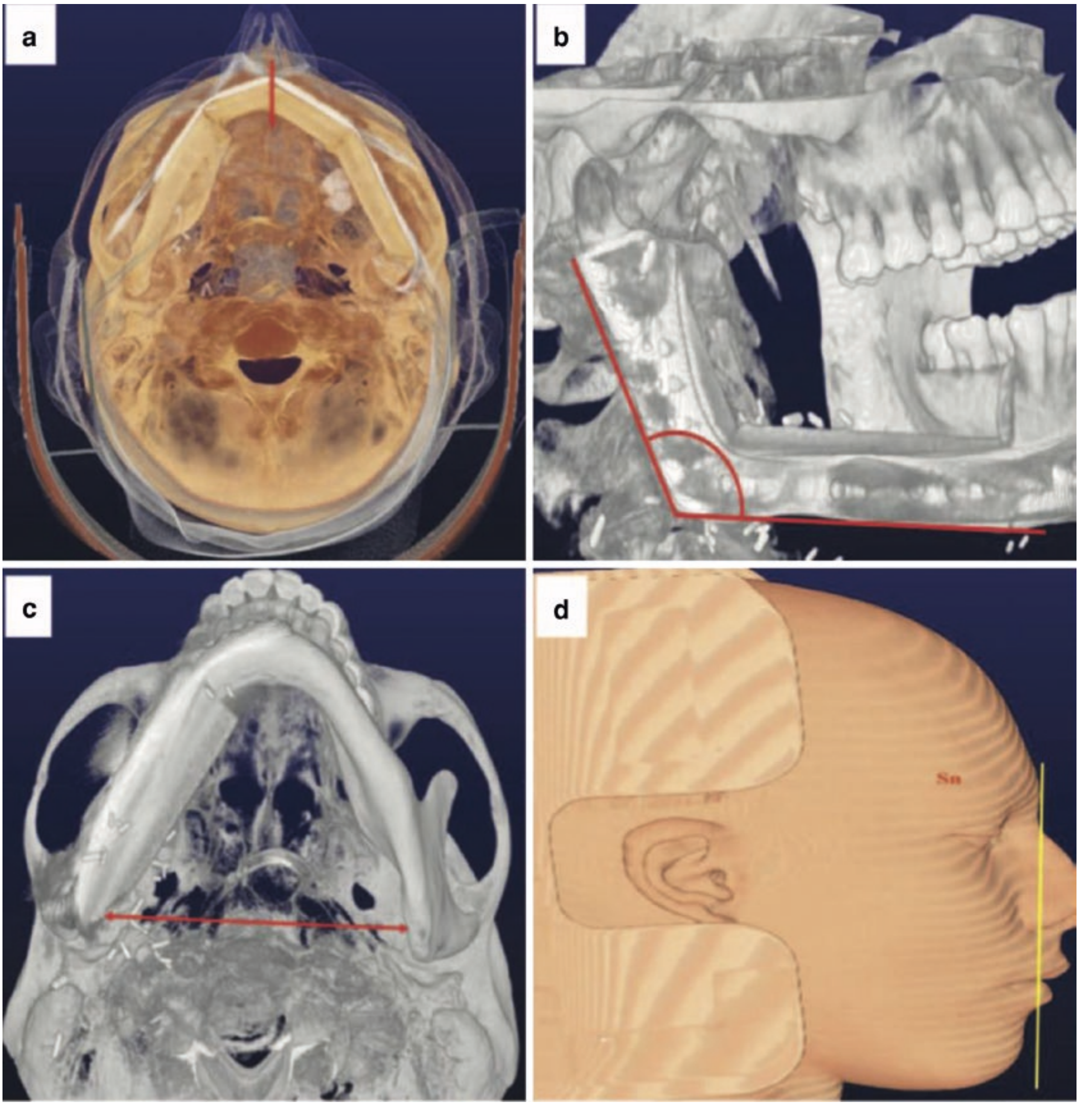

Fig. 12.3 Example of postoperative measurements after mandibular reconstructions employing free tissue transfers. (**a**) Mid-line deviation, (**b**) mandibular angle, (**c**) bigonial diameter, (**d**) chin protrusion. (Adapted from Sahovaler and Fung [59]. With permission)

and changes in the electromagnetic field within the operating theater can substantially affect navigation.

Studies using INS for maxillomandibular reconstruction [25–27] highlight the utility of this technology for the accurate and safe placement of hardware, bone grafts, movement of bone segments in vascularized tissue transfer and designing the osteotomies during the harvest [25–27]. Reports comparing patients undergoing mandibular reconstructions with free flaps treated with INS versus other techniques found that intraoperative assessment was particularly helpful when there was more than one floating osseous segment in the reconstruction and in ascending ramus and condylar reconstruction. It also assists in synchronizing the alignment of the segments by intraoperative registration and motion tracking, as the position of the neo-mandible can be shifted or rotated, resulting in substantial deviations of the free-floating mandible remnants and osseous

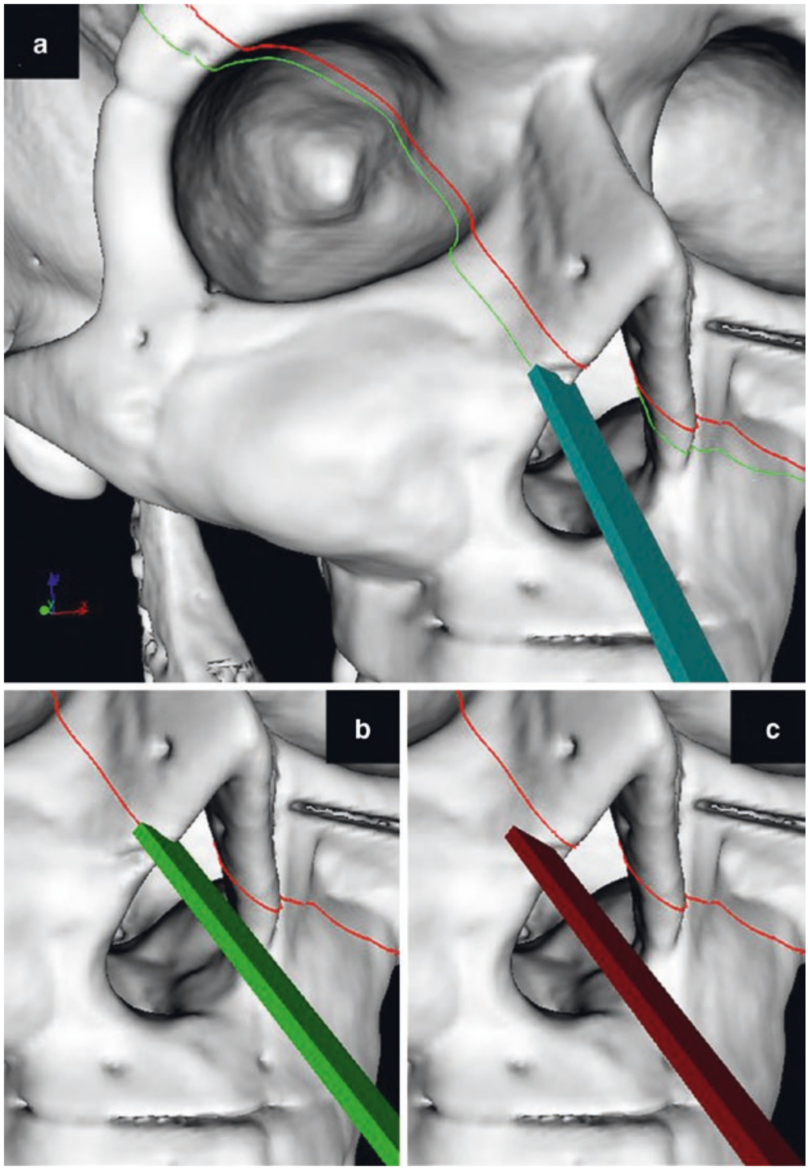

Fig. 12.4 Intraoperative navigation technology marking the direction of the osteotomies in the maxillofacial skeleton. (**a**). The planned osteotomy (red line) can be used as a reference while delineating the trajectory of cut of the osteotome/saw (green line). (**b**, **c**). The color of the virtual osteotome intuitively provides the surgeon with a real-time feedback of the adequacy of the osteotome trajectory. (Courtesy of Michael J. Daly (PhD) and Harley H.L. Chan (PhD) (Guided Therapeutics (GTx) Program, TECHNA Institute, University of Toronto, Princess Margaret Cancer Centre, Toronto, Ontario, Canada. Department of Otolaryngology-Head & Neck Surgery/Surgical Oncology, University of Toronto, Princess Margaret Cancer Centre, Toronto, Ontario, Canada))

free-flap segments. Furthermore, it has also been helpful in confirming adequate condylar positioning [21, 28].

Tissue Regeneration

Scaffolding, or tissue bioengineering, refers to the process of obtaining new tissue formation by implanting certain structures into the human body. To accomplish this, an appropriately shaped construct (or scaffold) can be manufactured and populated with tissue-forming cells that receive biological signals to regenerate tissue (Fig. 12.5). The scaffold provides a temporary framework while cells proliferate and differentiate to form new tissues/organs under the stimuli of growth factors. Scaffolding is one of the main research areas in medical bioengineering and can theoretically solve several unmet needs of the current medical practice [29].

Immediate availability after the ablation, no donor site morbidity, and a wide spectrum of potential customizations in terms of shape, size,

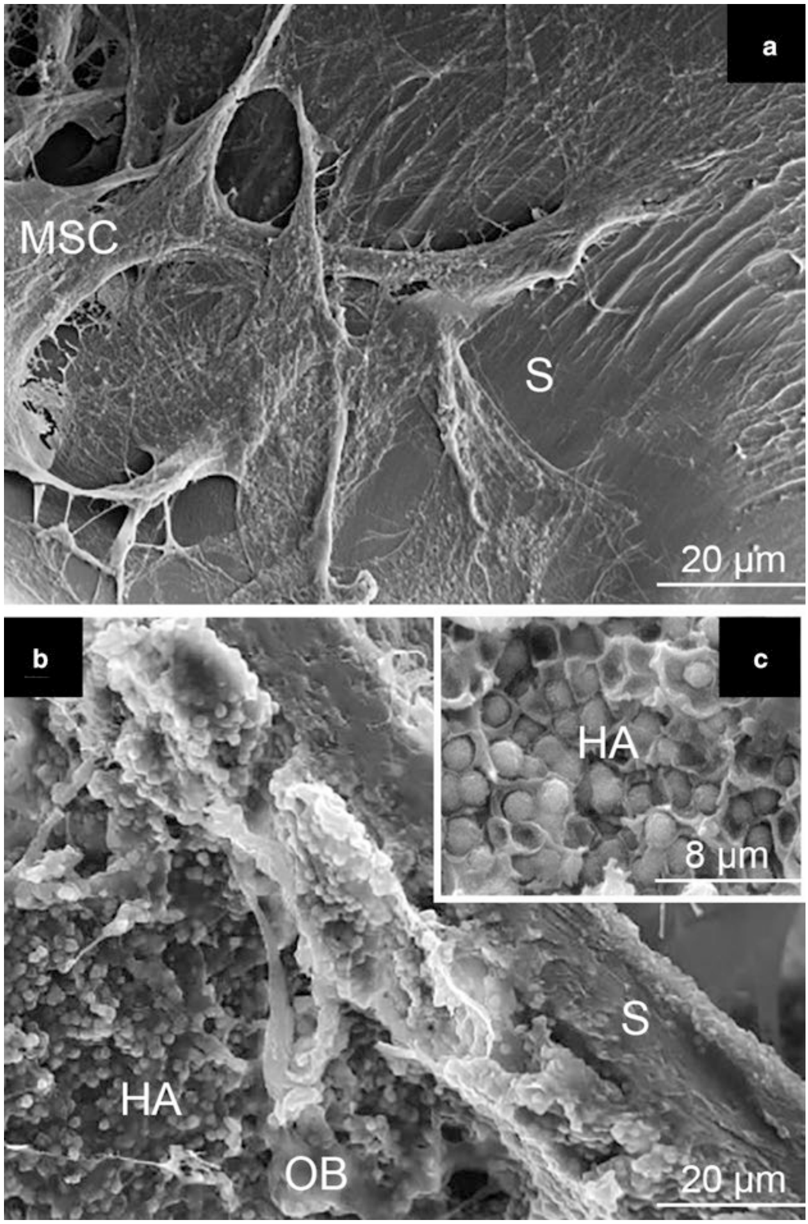

Fig. 12.5 Electron microscopy images illustrating in vitro osteogenic differentiation of mesenchymal stem cells (MSC) seeded into a scaffold (S). (**a**). A mesenchymal stem cell adheres to the scaffold surface. (**b**). An osteoblast (OB) differentiated from a mesenchymal stem cell is surrounded by hydroxyapatite deposits located throughout the scaffold surface. (**c**). High magnification of hydroxyapatite deposits. (Courtesy of Dr. Federica Re*, Prof. Domenico Russo*, and Prof. Luciana Sartore° (*Department of Clinical and Experimental Sciences, University of Brescia, Bone Marrow Transplant Unit, ASST Spedali Civili, Brescia, Italy; CREA [Centro di Ricerca Emato-Oncologica AIL], ASST Spedali Civili Brescia, Brescia, Italy. °Department of Mechanical and Industrial Engineering, Materials Science and Technology Laboratory, University of Brescia, Brescia, Italy))

and tissue composition are among the benefits of scaffolding, as many of the biomaterials employed are suitable for 3D printing. Therefore, the high degree of precision obtained with 3D printing and even INS can be combined with the regenerative potential of tissue engineering. This can be specially appealing in complex head and neck reconstruction.

New bone formation is of particular interest in lateral craniofacial reconstruction. It relies in a triad composed by the scaffold, stem cells, and growth/differentiation stimulation factors [30]. In vivo studies showed that the most relevant component of the triad is the scaffold, as stem cells and growth factors spontaneously reach the scaffold from the defect boundaries. However, reports concur that the addition of stem cells and growth factors improve the performance of new bone formation in terms of timing and bone quality [30–32]. It is imperative that biomaterials fulfill several requirements to be considered adequate for bone formation: *biocompatibility* must be present to avoid triggering an inflammatory reaction when implanted, and scaffolds have to be *osteoinductive* to stimulate primary and secondary bony tissue formation. In addition, they need to be *resorbed/degraded* as the new tissue forms and also provide *structural support* to substitute the missing bone [33, 34]. *Neovascularization* from surrounding areas must also occur [35, 36]. Ongoing research is taking place in order to find a material with these properties, and at the moment investigators are combining titanium meshes with highly vascularized tissues or scaffolding only small defects [37, 38]. Current materials for new bone formation are hydroxyapatite, tricalcium phosphate, polylactic acid, polycaprolactone, and their variants [39–41]. These materials have been used to repair calvarial, midfacial, and mandibular defects of different sizes, with high rate of success [42–44]. They can be 3D printed and populated with mesenchymal stem cells isolated from bone marrow, adipose tissue, and peripheral blood. Another strategy is to 3D print cultures of mesenchymal stem cells in combination with endothelial progenitor cells and bone morphogenic protein to enhance neovascularization of the new bone [45, 46].

Nonarticular cartilage bioengineering in the head and neck has been studied in several animal studies [47], but few clinical applications have been reported so far [48–50]. Resorption and contraction of the scaffold seem to be the most relevant challenges in auricular reconstruction and some have hypothesized that is attributable to the scaffold immunogenic activity [51]. Hydrogels (polylactic acid, polyglycolic acid, and polycaprolactone) are enriched with mesenchymal stem cells and molecules present in normal cartilage (i.e., chondroitin sulfate, chitosan, hyaluronic acid) or obtained from other natural sources (i.e., alginate, agarose), which favors chondrogenic differentiation and subsequent production of extracellular matrix [52]. Another reported strategy to obtain adequate extracellular matrix production is coculture of mesenchymal stem cells with chondrocytes [53]. In vivo animal studies in which a polycaprolactone scaffolds and a biopolymer was implanted in porcine model demonstrated maintenance of foundational support and appearance [54].

Controversies and Future Implications

Due to the intrinsic complexity in lateral craniofacial reconstruction, emerging technologies have been developed to overcome many of the challenges. Three-dimensional printing has truly optimized the manufacturing process in prosthetic reconstruction. The use of CAD/CAM and INS is promising, but lacks standardized measurements, and is based in retrospective experiences, heterogeneous and small samples, which preclude strong evidence-based conclusions. Future research will probably address these issues and better evidence will be gathered.

Probably the most novel approach is tissue regeneration. Significant research efforts are being dedicated to translate into practice the infinite theoretical benefits. Many of the lateral craniofacial scenarios that would require scaffolding techniques are related to defects following oncologic ablations [29]. Little is known on the interaction of potential residual tumor with the scaffold and stem cells. Moreover, adjuvant (chemo)radiation therapy is thought to be detrimental with respect to neo-vascularization, proliferation, and differentiation of cells within the scaffold. Nevertheless, most of these concerns are not scientifically based [55], and it has been elicited that scaffolds could also serve as long-lasting local delivery system of anticancer drugs [56].

A combination of the scaffolding and stem cells with free-flap reconstruction is a promising and interesting concept. The possibility to induce heterotopic, scaffold-based tissues and implant them in donor sites can result in bioengineered free tissue transfers that can be harvested after new tissue is formed. This hybrid approach would combine free-flap vascularization with the versatility of scaffolding, something of invaluable utility in soft tissues, bony–cartilaginous, and composite reconstructions [57, 58].

The integration of bioengineering science into the surgical treatment and reconstruction of patients with cancer is irreversible. While the majority of the ongoing research has been in vitro, there have been successful experiences in animal models. The introduction into medical practice will dramatically change several paradigms of head and neck surgery, ranging from locoregional anticancer treatment to reconstruction and rehabilitation. Only the future will reveal if the potential can be extrapolated from current preclinical studies into a "game changing" clinical practice.

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Index

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