Contemporary Oral Oncology

Oral and Maxillofacial Reconstructive Surgery

Moni Abraham Kuriakose
Editor

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To my parents for igniting the fire for gaining and sharing knowledge
To my teachers and colleagues for keeping that fire burning
To my students for keeping me on my toes
To Rohan and Mili for keeping me grounded
To my patients for enduring our quest for cure
To Maria for being a patient partner in this quest

Foreword

Writing and editing a comprehensive multivolume text and a reference source on a focused topic is a dream of a life time for scores of academicians, but only a handful are capable of and committed to realize that dream. Dr. Moni Abraham Kuriakose is to be commended to bring that dream to a reality in the field of oral cancer. He has successfully gathered an assembly of world-class leaders from all corners of the globe to contribute to this exhaustive four-volume treatise on the current state of the art and science of oral oncology. The organization and planning of such an in-depth reference source takes deep understanding of the biology of the disease, and mastery in clinical management of the patient. The editor in chief has very carefully selected scholars from the Roswell Park Memorial Institute, coupled with others from North America, Europe, and Australasia, in the specialty of oro-maxillo-facial surgery and oncology, to have a global perspective of the disease. This provides a global perspective from different geographic regions of the world, with diverse patient populations and varied socioeconomic and cultural differences.

Although, the commonly identified etiologic agents for oral cancer are prevalent throughout the world, the biological behavior and natural history of these tumors are different in various regions of the world. For example, the presentation and behavior of oral cancer seen in South Asia is quite different than that in the western world. The authors have very elegantly delved into the biology of these differences and have highlighted the frontiers in research in this area. Similarly, practical issues in the clinical management of patients in diverse socioeconomic regions are discussed to make this a valuable resource for clinicians throughout the world.

This four-volume, in-depth, and exhaustive text presents frontiers in current research in basic sciences and the biological basis of carcinogenesis, tumor progression, metastases, and recurrence. The breadth and depth of the biology of squamous carcinoma covered in the text by global experts is impressive. Equally well covered are the chapters on diagnosis, treatment, operative technical details, and outcomes: both functional and oncologic. Each chapter is well illustrated with photographs, and superb artwork, to convey to the reader the intricate details from biological processes, to surgical techniques. Each and every chapter is accompanied by an endless list of references, to make this a “go to” resource and a reference text on the

topic. This opus of oral oncology from molecular signatures to CAD-CAM technology in reconstructive surgery is a one of a kind publication on this subject published in a long time.

The four-volume set in *Contemporary Oral Oncology*, will have a solid place in the libraries of medical schools, postgraduate institutions, Cancer centers, and specialty departments in Universities. It is a wonderful state-of-the-art resource for the trainee as well as the practitioners of oral oncology, to remain current with the topic, and as a ready reference in basic and clinical research as well as day today management of patients. This exhaustive work stands alone in the presentation of biology, diagnosis, clinical care, prevention, and outcomes in oral cancer.

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Preface

Oral oncology is emerging as a distinct discipline. Comprehensive management of oral cancer requires multidisciplinary input of interconnected specialties. Every aspect of the management from diagnosis, treatment, reconstruction, and rehabilitation has biological basis. The biologic understanding of oral cancer and the treatment is changing with time. Understanding and updating developments in each of the related fields are essential to offer the patients the best possible treatment.

This book, in four volumes, is an in-depth reference guide that covers all aspects of the management of oral cancer from a multidisciplinary perspective and on the basis of a strong scientific foundation. Individual volumes are devoted to tumor biology, epidemiology, etiology, and prevention; diagnosis and treatment options; reconstructive surgical techniques; and rehabilitation and supportive care. By integrating current scientific knowledge into a manual for comprehensive care of the oral cavity cancer patient, this book is expected to fill a substantial void in the literature. Further key features are attention to the practical significance of emerging technology and the inclusion of contributions from authors in diverse geographic locations and practice settings in order to ensure that the guidance is of global relevance. The text is supported by ample illustrations and by case studies highlighting important practical issues.

There is lack of a single multidisciplinary comprehensive reference guide in oral oncology. This book is envisioned to fill this substantial void in literature. This book is intended for both trainees and practicing specialists in oral oncology. During my training, clinical practice, and research, I had the opportunity to gain knowledge and skills from different disciplines that includes dentistry, medicine, oral and maxillo--facial surgery, general surgery, otolaryngology, plastic surgery, and basic science research spanning three continents. This unique opportunity provided me an insight into the importance of cross-fertilization of ideas from different disciplines and geographic regions. This book is an attempt to impart that principle to the field of oral oncology.

The first volume is dedicated to tumor biology, epidemiology, etiology, emerging role of cancer stem cells, and the prevention of oral cancer. It opens by discussing

oral carcinogenesis in general and the role of different carcinogens and human papillomavirus in particular. Global epidemiology and changes in disease prevalence are then addressed. Up-to-date information is provided on emerging cancer biomarkers, and the biologic basis of personalized therapy is explained. Histopathological features of malignant and premalignant neoplasms and their relevance to management are described. Further chapters focus on the current status of chemoprevention, the management of oral submucous fibrosis, and the value of various diagnostic adjuncts. This volume concludes by critically evaluating the efficacy of oral screening methods.

The second volume deals with diagnosis and management of oral cancer. This volume addresses a range of management issues in oral cancer, from imaging and staging through to the roles of radiation therapy and chemotherapy. Principles of ablative surgery are explained, and neck dissection and sentinel lymph node biopsy techniques are described. Detailed consideration is also given to the management of complications, salvage surgery and re-radiation, the biologic basis of treatment failure, and emerging approaches to overcome treatment resistance. The inclusion of resource-stratified guidelines will meet the needs of practitioners in different geographic regions with varying resources.The third volume is devoted to the reconstructive surgical techniques used in patients with oral cancer. Following introductory chapters outlining the general principles of reconstructive surgery in the oral cavity and the planning of maxillofacial reconstruction, detailed descriptions of the options and techniques employed in reconstruction of each of the functional subunits are provided. Important technologic advances are also discussed, including image--guided surgery, robotic surgery, and tissue-engineered and prefabricated approaches. Finally, the current status of face transplantation for maxillofacial reconstruction is reviewed.

The last of this four-volume book deals with the most important and often neglected aspect of rehabilitation and supportive care. This volume focuses on the topic of comprehensive rehabilitation and supportive care in oral cancer. The coverage includes the role of maxillofacial prosthodontics, advances in anaplastology techniques, and management of oral mucositis during radiation and chemotherapy. Holistic and supportive care approaches are discussed, and advice is provided on post-therapy surveillance and the use of different measures to assess quality of life. Nutritional evaluation and management and issues relating to healthcare economics are also considered. This volume will be of interest both to practicing specialists and to ancillary service staff involved in the care of oral cancer patients.

This book was authored by leaders in the field from diverse medical disciples and geographic regions. I thank the authors whose expertise and hard work that has distilled a vast body of information into a clear and detailed discussion of various aspects of oral oncology. I would like to express my thanks to the Springer Nature for supporting me in developing this book, to Wilma McHugh for project management and constant support, and to Abha Krishnan and Eswaran Kayalvizhi for the editorial assistance.I have personally benefitted immensely by the tutelage of many mentors notably Sripathy Rao, Paul Salins, K. Kamalamma, Adrian Sugar, Anwar Perriman, Montague Barker, Paddy Smith, Brian Awry, John Hawksford, Keith

Postlethwaite, Leo Stassen, Ian Martin, Andrew Ryan, Collin Edge, Mark DeLacure, Wesley Hicks Jr., Thom Loree, Richard Bankert, and my colleagues at New York University: Mark DeLacure, Richard Cohen, Robert Glickman, Fang-An Chen; Roswell Park Cancer Institute: Wesley Hicks Jr., Hassan Arshad, David Cohan, Vishal Gupta, Robert Lohman, Wong Moon, Can Ozturk, Cemile Ozturk, Paul Tomljanovich; Amrita Institute of Medical Sciences, Kochi: Subramanya Iyer, Jerry Paul, Sherry Peter, Pramod Subash, Maria Kuriakose; and Mazumdar-Shaw Cancer Center, Bangalore: Vikram Kekatpure, Amritha Suresh, Naveen Hedne, Vijay Pillai, Vinay Kumar, and Praveen Birur. Many of their thoughts will be reflected in this work. I am also indebted to my clinical and research fellows at New York University, Amrita Institute of Medical Science, Mazumdar-Shaw Cancer Center, Roswell Park Cancer Institute, and research associates and doctoral students at Mazumdar-Shaw Center for Translational Research, Bangalore.

Buffalo, NY, USA

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Contents

Reconstructive Surgery in Oral Cancer

1

Subramania Iyer, Deepak Balasubramanian,
and Rinku George

Defects resulting from the treatment of oral cancers can lead to devastating psychological and functional deficits. Adding quality to the cure has been given importance in the current management of these cancers, in which reconstructive surgery has taken a lead role. The reconstructive armamentarium has expanded much during the past few decades offering the surgical oncologist a variety of methods to choose while the reconstruction is being considered. This paper will briefly look into the progress that has been made in oral cancer reconstruction, discuss the various options, and provide an algorithmic approach to help in choosing the appropriate method of reconstruction in a particular defect.

1.1 General Principles of Reconstruction as Applied to Reconstruction of Defects Resulting from Oral Cancer Resection

Reconstructive surgery has undergone vast changes in the past few decades. In the modern era, practice of reconstruction dates back to the 1930s. Carl Eggers [1] in Annals of Surgery in 1938 describing an elegant method for forming a subcutaneous tube for esophageal reconstruction exemplifies the yearning of surgeons to devise novel reconstructive methods. The importance of retaining the blood supply of the composite tissue moved in to cover the defect was getting recognized in the

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1960s. This concept was initially used in the reconstruction of head and neck defects by McGregor who described the forehead flap based on the superficial temporal vessels [2]. Similarly another flap, which has remained a workhorse and relevant even today, is the deltopectoral flap described by Bakamjian [3]. Subsequently the era of myocutaneous flaps started which heralded the concept of primary reconstruction in head and neck cancers. The initial report was that of the use of platysma myocutaneous flap in 1978 by Futrell [4]. But the pioneering effort was from Ariyan who described the pectoralis major myocutaneous flap in 1979 [5]. The pectoralis major flap remains a workhorse flap even today. This was followed by a plethora of myocutaneous flaps like trapezius [6], latissimus dorsi [7], and sternomastoid [8] flaps. Even bone-containing flaps like sternomastoid with clavicle and trapezius with scapula were described to reconstruct composite resections [9, 10].

The next revolutionary change in the concept of reconstruction of head and neck cancer defects came with the advent of free tissue transfer using microvascular techniques. Krizek [11] first reported the feasibility of microvascular reconstruction, but the first successful clinical case was reported by Daniel in 1973 [12]. Following this, every conceivable tissue from all over the body with different tissue compositions has been successfully transferred to the head and neck to reconstruct defects. This achieved the important objectives of allowing for multiaxial reconstruction of large defects and transfer of special functions like sensation and movements. Even though free flaps have not significantly affected the cumulative survival rates in head and neck cancers, they have allowed the oncologist to treat more advanced cancers with surgery and maintain the survival rate [13]. Currently, free flap reconstruction has become the preferred technique in reconstruction of the majority of head and neck cancer defects. The most significant improvement that has been achieved with their application has been in the reconstruction of bony mandibular defects and defects following extensive skull base defects.

1.2 Oral Cavity Subsites and Their Reconstructive Requirements

The subsites of the oral cavity include the buccal mucosa, floor of the mouth, retromolar trigone, tongue, and the hard palate. All these have distinctive patterns of spread of the tumors thereby dictating the surgical treatment. In addition, they also have differing reconstructive requirements based on their structure and function. Even though the lips do not qualify to be included as oral cavity subsite due to their differing oncologic behavior, they are also dealt in this discussion since reconstruction of lip and commissure defects are of paramount importance for the functional rehabilitation.

1.3 Lips

Lips are covered externally by the skin and internally by mucosa containing in between them the sphincter muscle orbicularis oris. A lip seal is essential for proper swallowing as well as articulation. Hence, maintaining adequate lip height allowing them to meet as well as a sphincter action becomes the most important factors when reconstruction of the lip defects is considered. For the sphincter action, both upper

and lower lip integrities are required. But loss of lower lip is functionally more significant since the barrier effect of the lower lip is lost. The resultant drooling can be a severe handicap. Most of the lip defects, which are seen in the reconstructive practice, are limited to the lips only. These are managed by local rearrangement of the lip tissues or utilizing the adjacent soft tissues. But occasionally the lip defects accompany extensive buccal mucosal defects where the management is difficult and may need import of tissue from distant areas.

1.3.1 Principles of Lip Reconstruction

Small lip defects should always be replaced with lip tissue itself. This gives excellent outcomes as the sphincter action is maintained giving good functional results and also good esthetic results. But larger defects may require non-lip tissue (cheek flaps or free flaps) for reconstruction, which unfortunately are suboptimal esthetically and poor functionally. Using the skin creases that surround the lips for placing incision can help hide the scars and incision lines (e.g., nasolabial fold, the mentolabial sulcus).

1.3.2 Lower Lip

1.3.2.1 Isolated Mucosal and Skin Defects

Mucosal advancement from either side is the choice after lip shave for mucosal diseases. The skin defects can be covered by grafts, but may result in esthetically unappealing result in hair-baring area in males. Here, conversion of the defect to full-thickness one and applying direct closure might be better options.

1.3.2.2 Full-Thickness Small Defects

More tissue is available in the lower lip for mobilization than in the upper lip due to the laxity of the lower lip. Hence, larger defects of the lower lip can be closed primarily when compared to the upper lip especially in the elderly. Thus defects up to one-third or more of the lower lip can be closed primarily, whereas in the upper lip, defects that can be closed likewise are smaller.

Primary closure of the defects is facilitated by a “V”-shaped excision. The base of the V should be in the lip margin which should be slightly angled to merge with the orientation of the resting tension lines in that particular part and also to blend into the mentolabial crease.

1.3.2.3 Defects More Than One-Third But Less Than One-Half of the Total Length

Recruiting tissue from adjacent area usually by a local flap should close these defects. Abbe or Estlander flaps are useful in these defects; the former for central and the latter for lateral defects. These are based on the labial vessels of the upper lip. The flap is designed in the upper lip one-half as wide as the defect in the lower lip.

For lesions that are more appropriate for rectangular resection, reconstruction with a Schuchardt procedure can be considered [14, 15]. The remaining lip is slided from one side or both sides with labiomental skin and gingivobuccal mucosal

incisions. The side, which allows greatest advancement, is chosen for the flap. This advancement can also be done using the step ladder principle.

1.3.2.4 Defects More Than One-Half But Less Than Two-Thirds of the Total Length of the Lower Lip

These defects need recruitment of tissues from the adjacent cheek. Gilles fan flap, Webster-Bernard flap, and Karapandzic flap are some of the flaps available [16, 17]. The Karapandzic flap is the most useful since it tries to restore the sphincter function. This is a rotation-advancement flap which maintains the nerve supply of the orbicularis muscle. The main drawback of the flap is the narrowing of the oral aperture.

1.3.2.5 Defects More Than Two-Thirds or Total Lower Lip Defects

Tissue from other areas needs to be imported to reconstruct these defects. Bilateral nasolabial flaps, Webster-Bernard flap, or a microvascular free flap can be used in these large defects. In the Webster-Bernard flap, the cheek tissue is medially advanced to form the neolip excising the tissue near the nasolabial fold to permit this advancement. Bilateral nasolabial flap interdigitating to form both the surfaces of the entire lip is another option (Fig. 1.1a–c). This has the inherent benefit of a

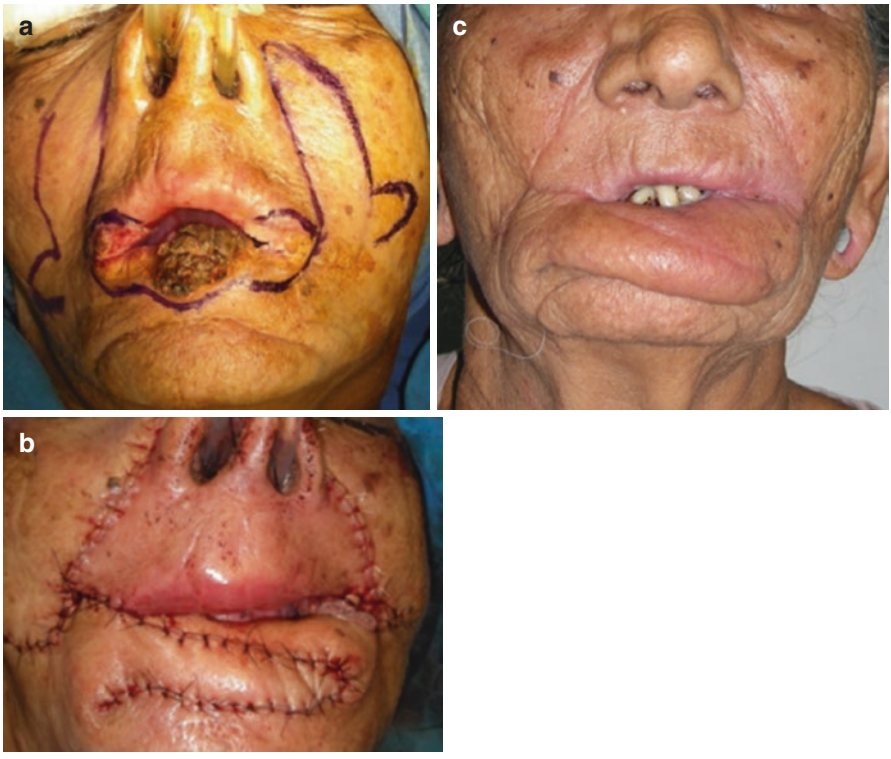


Fig. 1.1 (**a**) Lesion lower lip, bilateral nasolabial flap marked. (**b**) Nasolabial flap inset. (**c**) Late result showing good lip competence

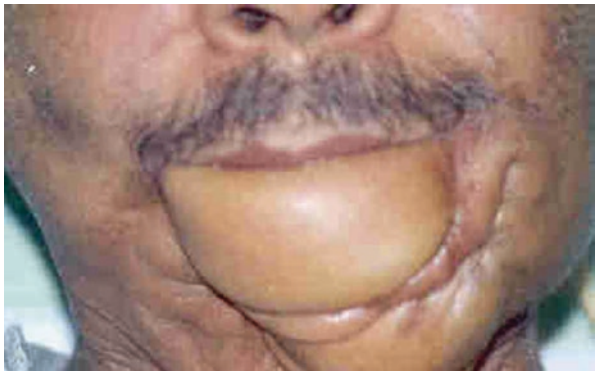


Fig. 1.2 Radial forearm free flap for total lower lip reconstruction

superior suspension to the reconstructed lip which may prevent its subsequent eversion. While considering free flaps, a thin flap like the RFFF may be the best option. The sphincter action may need to be restored using facial or palmaris longus tendon sling (Fig. 1.2).

1.3.3 Upper Lip

The closure of *defects more than one-fourth but less than one-half* depends on the location of the defect, whether it is a midline defect or a lateral defect, and the laxity of the skin. In old patients with very lax tissue, defects of up to one-half the total length of the lip can be closed primarily. In a midline defect of the upper lip, a cheek advancement flap with peri-alar crescents or an Abbe flap is an option. The lateral defects can be closed with an Estlander flap, where further correction of microstoma is done at a later stage. When Abbe flap is designed, positioning the Abbe flap in the middle of the lip gives the most acceptable donor site scar than scars in the lateral part. The width of the flap could be limited to one-half of the defect to be reconstructed [18, 19]. *Larger defects of the upper lip* may require import of distant tissue, either pedicled or free. Forehead, reverse submental, superficial temporal-based hair-bearing, and radial forearm flaps have been used in these defects.

1.4 The Tongue and Floor of the Mouth

The tongue plays a very important role in aiding speech, mastication swallowing, and taste. Functional characteristics vary greatly within the tongue; hence, the reconstructive goals also differ in tongue defects in relation to their position and the volume. The tip has the most mobility followed by the lateral surfaces. The extremely mobile tip region plays a major role in articulation. It is difficult to replicate the loss of tip by any flap due to their inherent heaviness of the flap tissue. The central part provides the bulk, as it forms the anterior wall of the oropharynx. The lateral tongue tissue is also relatively more mobile than the base and plays a role in articulation. But the major functional role it plays is in swallowing. The bolus propulsion into the

oropharynx depends on its mobility, bulk, as well as the presence of a well-formed sulcus. The central and posterior tongue has its functional role mainly in the oropharyngeal bolus transport for the swallowing. Hence, bulk is important while considering reconstruction of defects of this area.

1.4.1 Classification of Glossectomy Defects

The defects can be classified based on the volume of the tongue resected. The groups reflect the functional disability caused by the resection as well as the need for tissue replacement. For the mobile anterior tongue, this can be as follows:

(a) Less than one-third defects
(b) One-third to one-half tongue defect
(c) Subtotal and total resections

Variable amounts of the base tongue may be an additional component in the resection especially in subtotal or total resections of the mobile tongue.

The volume of the resection-based classifications has an inherent drawback that they do not always represent the functional implications. For example, the loss of tip or the sulcus mucosa and floor of the mouth will have differing functional implications when reconstruction is considered. However, they give an easier practical way of creating an approach to decide the reconstructive option.

(a) Less than one-third defects

Small tumors of the tongue require a partial glossectomy and the resultant defect if less than one-third need not be reconstructed. Reconstruction in these small defects may hinder the movement of the normal tongue and adversely affect speech especially if the tip is preserved [20] (Fig. 1.3).

(b) One-third to two-thirds

Controversy still exists whether a hemiglossectomy defect is left unreconstructed or not. Either free or regional flaps are used to reconstruct defects of this size. The choice depends on whether the defect includes the floor of the mouth also. Figure 1.4 depicts the algorithm followed by the senior author to choose the method in these subgroups. Free flaps are preferred over pedicled flaps since they do not have the constraining effects of the pedicle on the reconstructed tongue. When the floor of the mouth is available for suturing, the reconstructive options include the lateral arm (Fig. 1.5a, b)), radial forearm, and anterolateral thigh (ALT) flap. When extensive floor of mouth resection is done leaving no fringe of mucosa for suturing, formation of a sulcus may be attempted. This is done best by using a radial forearm flap or an ALT flap with radical thinning of one edge at the region of the sulcus (Fig. 1.6a, b). Among the pedicled flaps, only the submental flap equals the qualities of the free flaps. Buts its use is limited to female patients with enough submental skin laxity and with no gross involvement of the lymph nodes by the disease (Fig. 1.7).

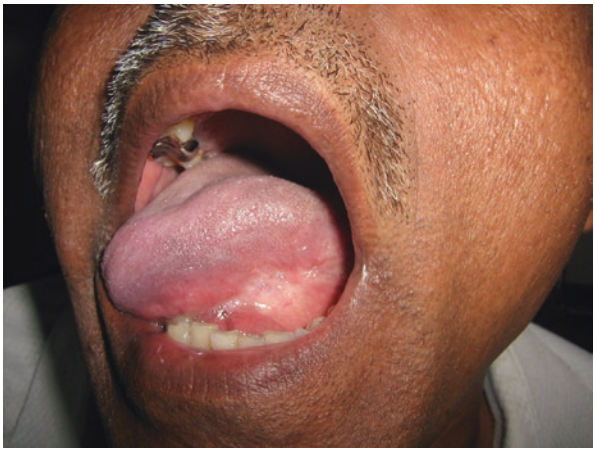


Fig. 1.3 Post-op of a laser excision with less than one-third defect of the tongue – well-healed tongue with no limitation of movement

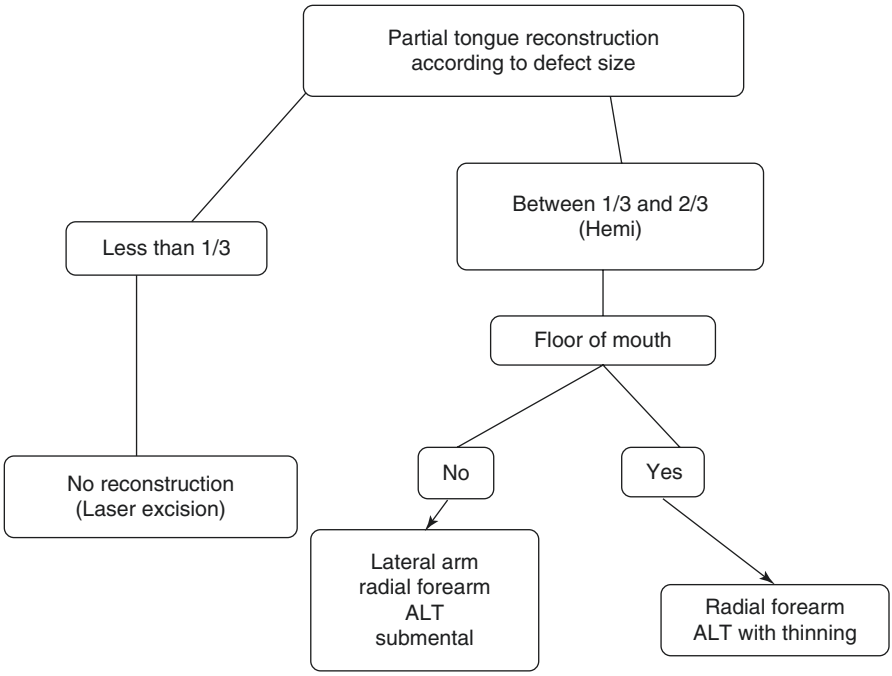


Fig. 1.4 Algorithm for tongue reconstruction

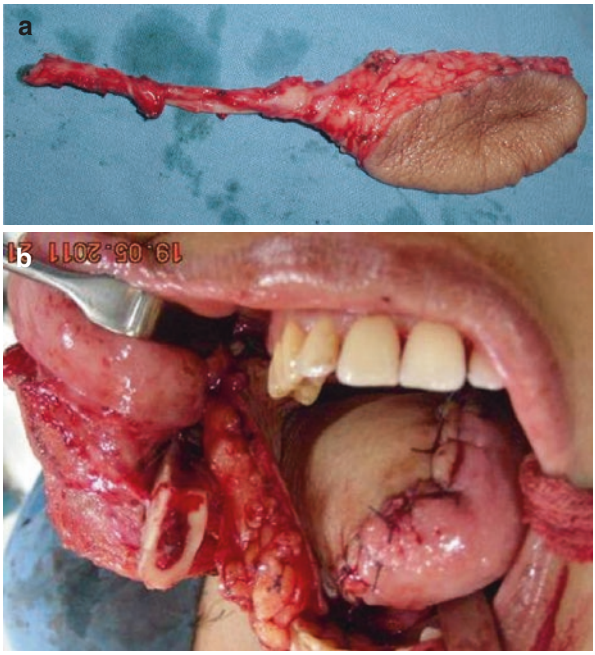


Fig. 1.5 (**a**) Lateral arm flap harvested. (**b**) Flap being inset

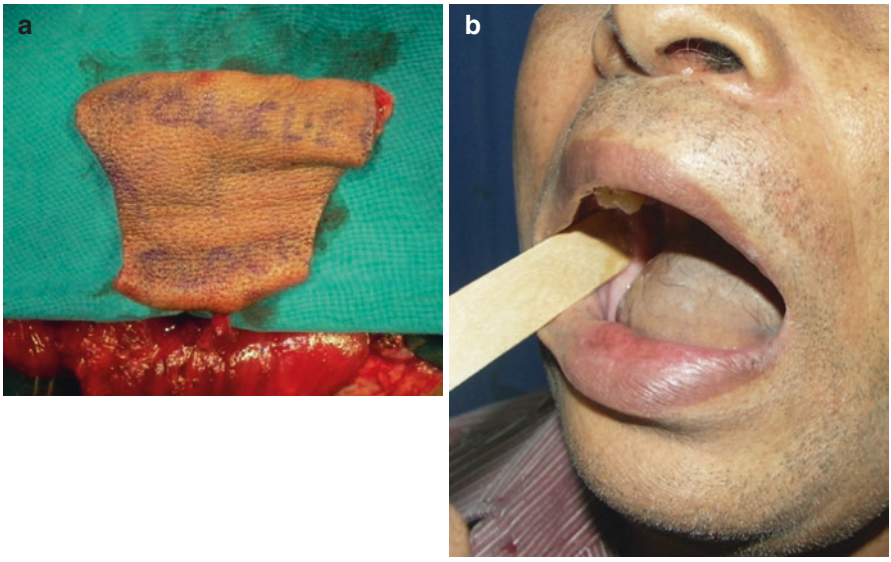


Fig. 1.6 (**a**) Differential thinning of ALT flap for tongue and floor mouth reconstruction for recreating of the sulcus. (**b**) Healed ALT flap showing a well-formed sulcus in the right floor mouth

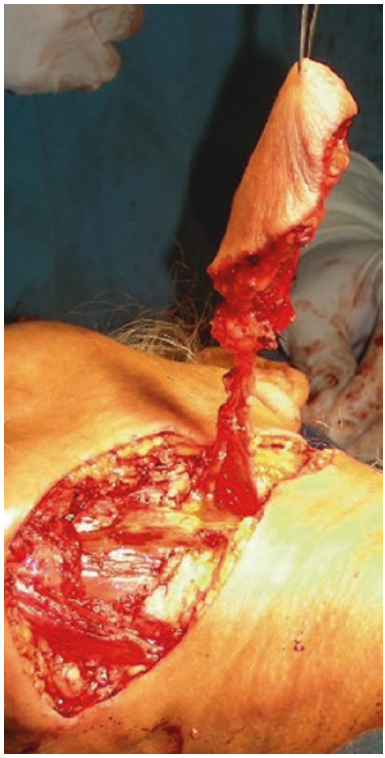


Fig. 1.7 Harvested submental flap for tongue reconstruction. Note the thin pliable skin

1.4.2 Base of the Tongue and Total Glossectomy Defects

Small base of tongue defects can be closed primarily. If transoral laser surgery has been used for the resection, the defects are left unsutured for spontaneous healing.

In larger defects, the functional problem to be addressed includes preventing dysphagia in the oropharyngeal stage due to the loss of bulk of the tongue base. Equally important is the prevention of aspiration while swallowing. Whether the larynx is preserved or not for oncologic clearance will dictate the reconstructive method. If laryngectomy is carried out in association with glossectomy, the reconstruction becomes simplified. The only requirement would be a bulky skin line flap, which forms the food conduit in the oral cavity and oropharynx. This could be either by a pedicled pectoralis major myocutaneous flap or free flaps like anterolateral thigh or rectus abdominis flaps. In younger patients and where the disease is clearly away from the vallecula, total or base tongue glossectomy sparing the larynx is possible. In these cases, flaps like rectus abdominis or ALT will be more appropriate [21].

Dynamic muscle reconstruction has been attempted using reinnervated musculocutaneous flaps like rectus abdominis, gracilis [22], and ALT flaps. Innovative

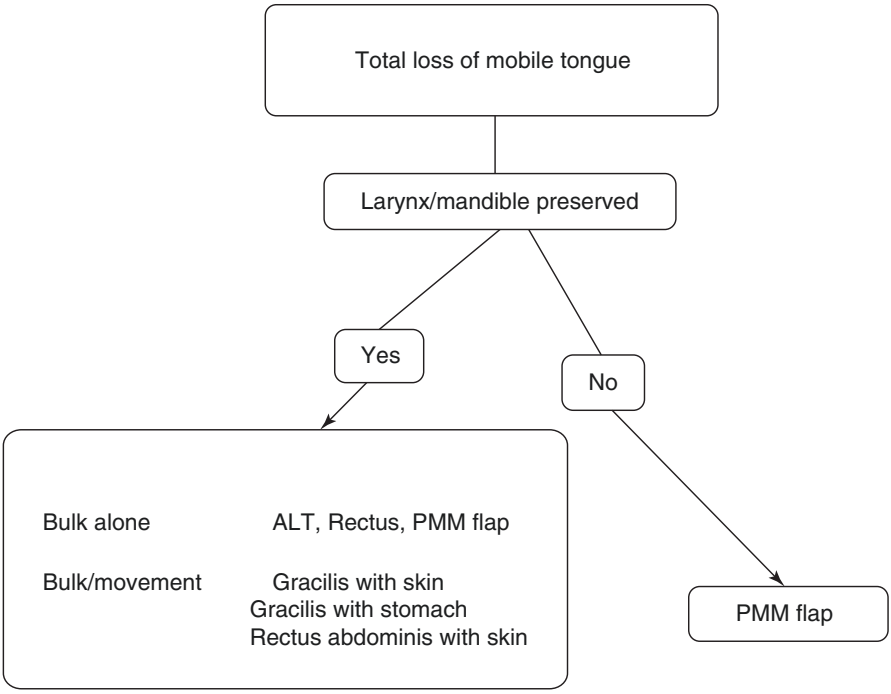


Fig. 1.8 Algorithm for total glossectomy defects

provision of dynamic bulk and secreting mucosal surface has also been reported combining gastro-omental flap and gracilis muscle [23].

The senior author for reconstruction of larger tongue defects follows the algorithm depicted in Fig. 1.8.

1.5 Floor of the Mouth

The floor of mouth defects could be either very shallow or deep depending on the depth of tumor infiltration. The defect may include a marginal mandibulectomy (Fig. 1.9). The reconstructive requirements for a floor of mouth defect includes provision of a supple and soft epithelial cover to prevent subsequent fibrosis as well as filling up the deep cavity to prevent a sump effect leading to salivary collection. The associated marginal mandibulectomy defect will require cover with a vascularized flap. The drawback of most of the flaps used in floor of mouth reconstruction is the excessive bulk. This leads to pushing up of the tongue as well as eversion of the lips. The reconstructive methods available include the use of full-thickness skin grafts, locoregional flaps like nasolabial (Fig. 1.10a, b) and infrahyoid flaps, and free flaps like radial forearm flaps. Even though sometimes ideal due to their

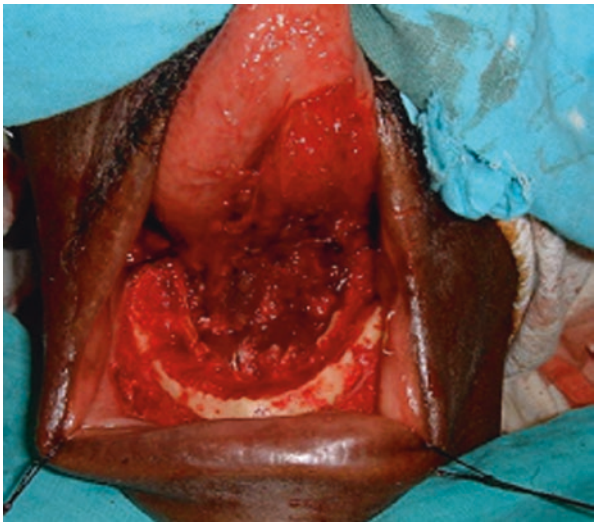


Fig. 1.9 Floor of mouth defect with associated marginal mandibulectomy

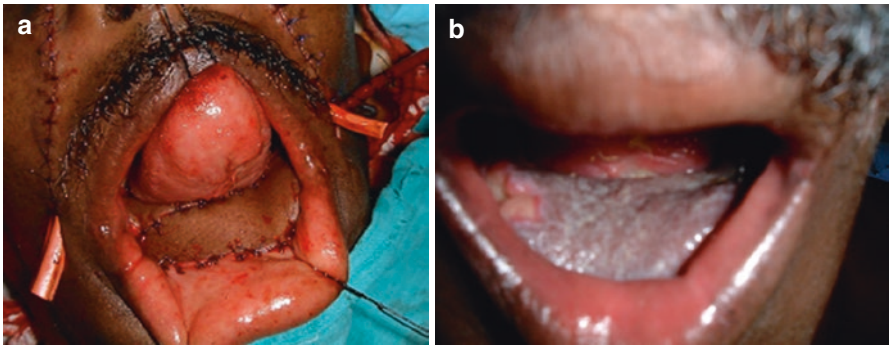


Fig. 1.10 (**a**) Nasolabial flap being inset into the floor of the mouth. (**b**) Shows 6-month post-op of the nasolabial flap

thickness, full-thickness grafts can be a problem since their take is not assured and their behavior during the subsequent radiation therapy cannot be predicted.

1.6 Cheek and Buccal Mucosa

The cheek defects can be classified for the reconstructive purposes by the extent of their depth. The defects could be shallow or deep. They could be full thickness with or without mandibular and maxillary loss. The reconstructive requirements also vary accordingly. In general, the buccal mucosal replacement needs to be with thin, hairless, and pliable tissue. The algorithmic approach for deciding the

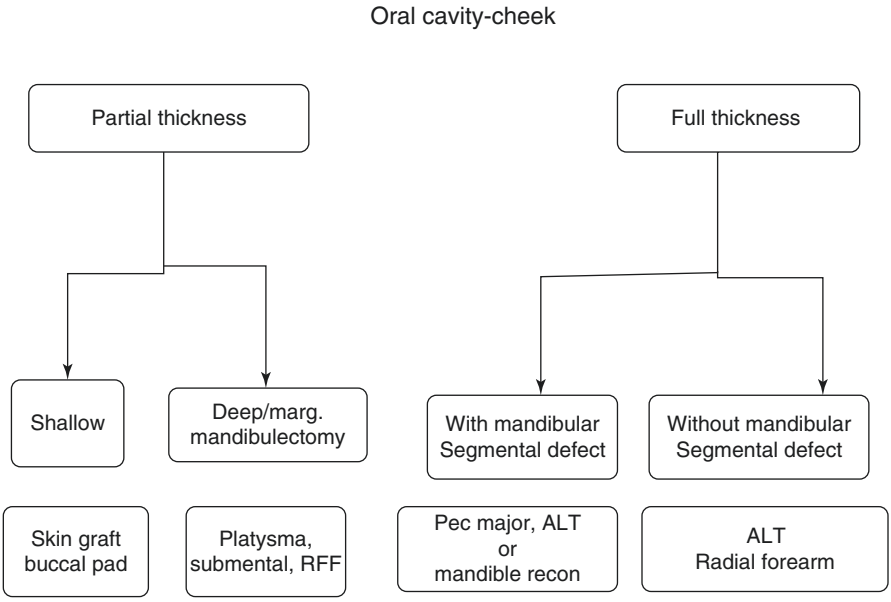


Fig. 1.11 Algorithm for cheek defects

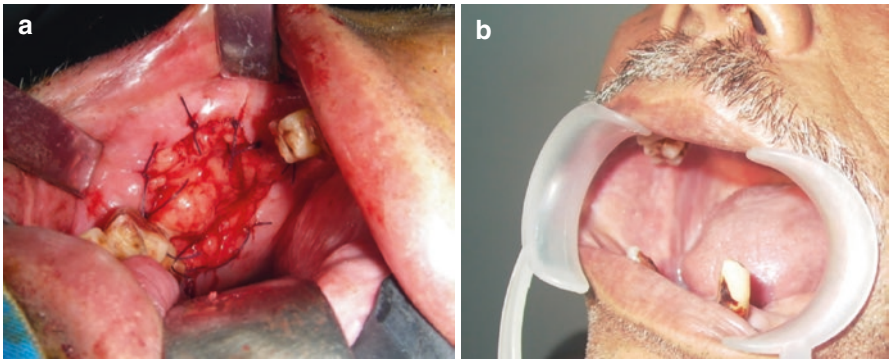


Fig. 1.12 (**a**) Cheek defect covered with buccal pad of fat. (**b**) Buccal pad epithelialized well 4-month postoperative

reconstructive methods is described in Fig. 1.11. For shallow defects, simple methods like full-thickness grafts or buccal pad of fat could be used. The buccal pad of fat could be teased out to cover a large area and left to mucosalize by itself (Fig. 1.12a, b). The deep mucosal defects with or without exposed bone (marginal mandibulectomy) will need flaps. Regional flaps that could be used include submental flap (Fig. 1.13) in a female patient or less commonly infrahyoid or platysma flaps. But a free radial forearm flap is the common and appropriate choice in majority of the defects (Fig. 1.14).

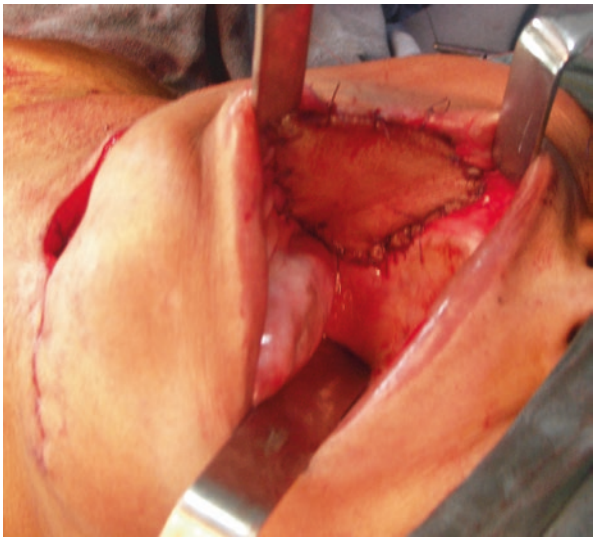


Fig. 1.13 Submental flap for cheek defect in a female patient

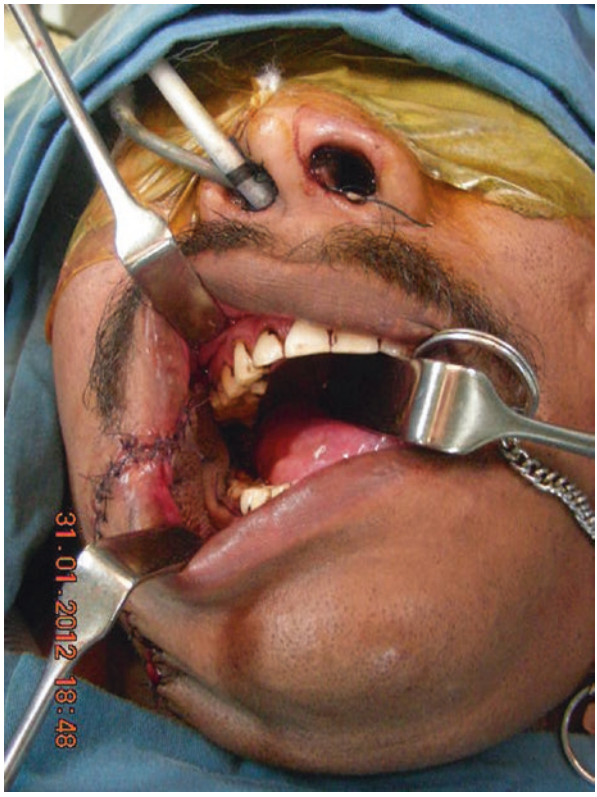


Fig. 1.14 Radial forearm flap for a buccal mucosa defect

1.7 Mandible

Reconstruction of mandible in itself is a subject of detailed discussion which is beyond the scope of this chapter. However, the principles of reconstruction as well as an algorithmic approach to make the choice will be dealt with.

Continuity of the mandible is essential for preserving the form of the face and functions of speech and swallowing. Hence, its reconstruction becomes an important factor which determines the quality of life of many surgically treated oral cancer patients. Reconstruction is mandatory in central mandibular defects to prevent debilitating Andy Gump deformity. Even though not mandatory, reconstruction of the lateral mandibular defects is important in younger and dentate patients in order to retain or rehabilitate occlusion. The principles of mandibular reconstruction are depicted in Fig. 1.15a, b.

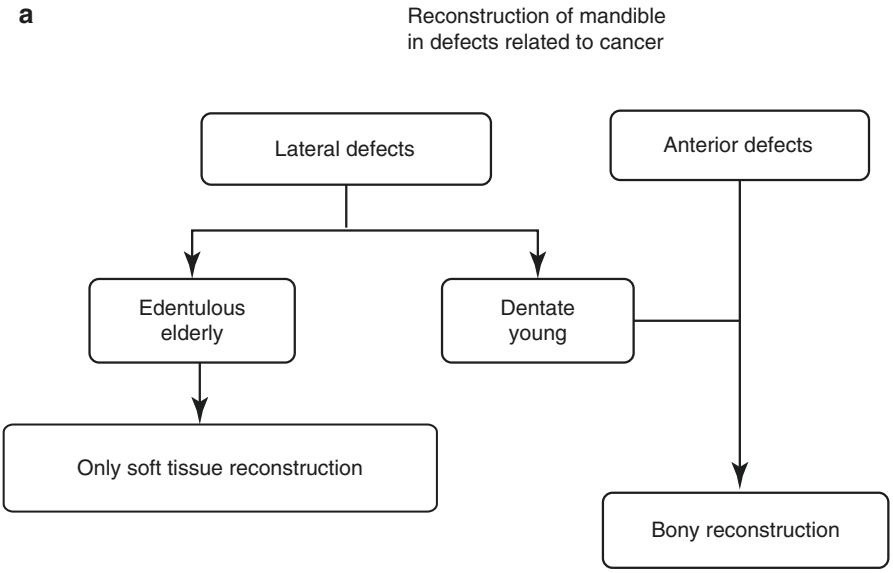
When mandibular reconstruction is contemplated, free vascularized bone is the choice in post-oncology treatment-related defects. This is necessitated by to the presence of radiation therapy, either in the past or as an adjuvant in the management of these patients. Non-vascularized bone or alloplastic materials will not withstand the detrimental effects of present or past radiation therapy. Free fibula flap is the choice for vascularized bone replacement in most of the centers (Fig. 1.16a–d). Scapula, iliac crest, or radius also could be used as the bone for reconstruction. The choice of flap depends on the site and extent of bony and soft tissue defect as well as institutional practices. In general, free fibula with or without another soft tissue flap will be sufficient in all the situations. If pedicled flaps incorporating bone is to be chosen as the method, pectoralis major muscle incorporating the sternum might be the best choice. They may be considered in the cases where medical fitness doesn't allow free tissue transfer, when free flaps have failed after repeated attempts, or when expertise cannot be sought. However, if possible, a vascularized bone free flap will be more ideal.

1.8 Hard Palate

The palate forms the separation between the oral and nasal cavities. Hence, the primary aim of reconstruction of these defects is achieving oronasal separation. The defects can be lateral, central or extensive, and bilateral (Fig. 1.17a, b). Involvement of the soft palate in the resection makes the reconstruction complex, where the objectives will include, in addition, achieving velopharyngeal competence.

Using obturator is an excellent choice in cases where fabrication and retention of it is possible. This will need good dentition and mouth opening. However, the obturator may need to be very large even for a small defect. Achieving velopharyngeal competence using an obturator is practically difficult. Hence, in these situations as well as in patients where obturator fashioning and retention is difficult due to lack of teeth and presence of trismus, reconstruction becomes a better choice.

a



b

Reconstructive need for soft tissue	Defect position		
	Anterior	Lateral	Combined
Minimal to moderate	Fibula DCIA Scapula	Fibula DCIA Scapula	Fibula
Large	Fibula	Fibula (Pec Major/ALT)	Fibula And another soft tissue flap

Fig. 1.15 (**a**) Algorithm for need of bone flap. (**b**) Algorithm for the choice of bone flap

Reconstruction of the palatal defects can utilize locoregional tissue or free flaps. Facial artery myomucosal flaps can close smaller lateral defects (Fig. 1.18). Palatal transposition flaps are also useful in reconstructing smaller defects. Temporalis myofascial flaps can close larger unilateral defects (Fig. 1.19), but have an inherent possibility of causing trismus occasionally. Larger defects generally need free tissue transfer and radial forearm flap suits them best (Fig. 1.20). The dorsal surface which is open to the nasal or sinus cavity can be reinforced by a layer of fascia which has

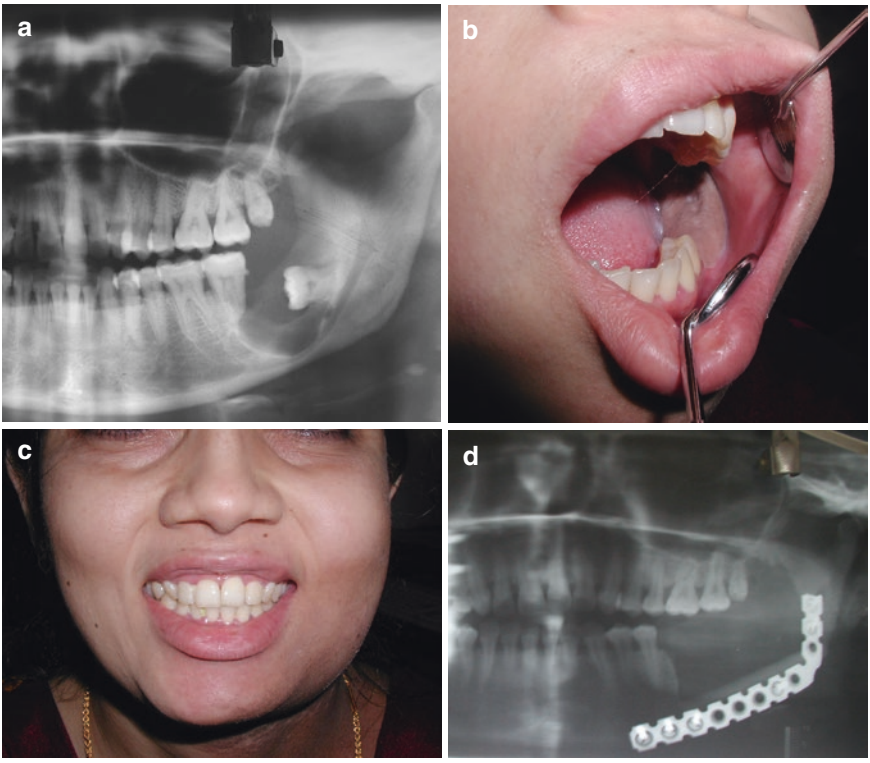


Fig. 1.16 (**a**) OPG of an alveolar tumor on the left lower alveolus. (**b**) Post-op of the patient with a reconstruction done by a fibula free flap. (**c**) Post-op showing good cosmesis and occlusion. (**d**) Post-op OPG showing a well-healed vascular bone

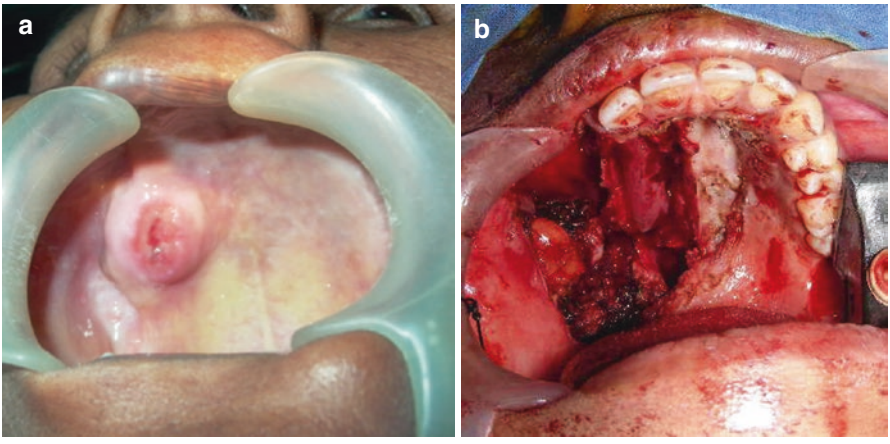


Fig. 1.17 (**a**) Lesion in the hard palate. (**b**) Hard palate defect after excision

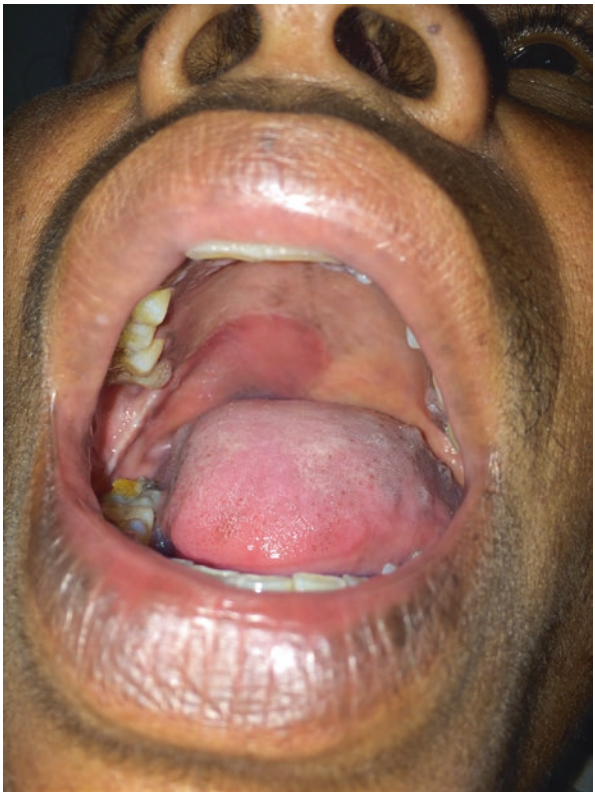


Fig. 1.18 Well-healed FAMM flap in the hard palate

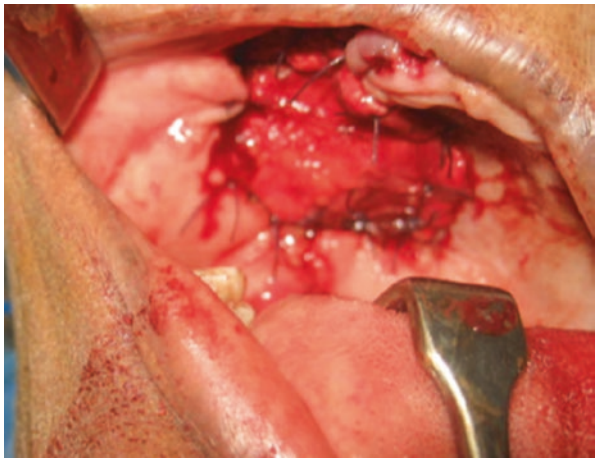


Fig. 1.19 Temporalis flap for palatal defect

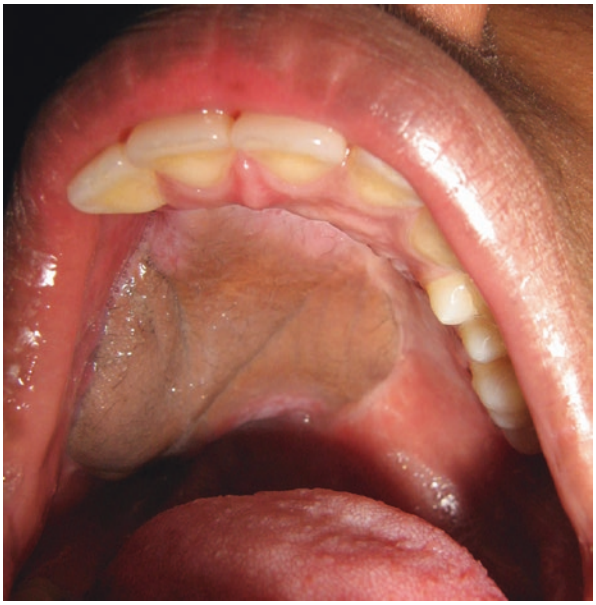


Fig. 1.20 Two-year postoperative result showing partial mucosalization of a radial forearm flap for the palate

been turned over to give added protection to the exposed pedicle. When soft palate excision is necessitated, suturing a superior-based posterior pharyngeal flap onto the dorsal surface of the radial forearm flap can prevent velopharyngeal incompetence.

1.8.1 Facial Skin Defect

Local flaps because of the color and texture match are ideally suited for facial skin reconstructions. Please see chapter of local and regional flaps by Dr. Fernandes. Various flaps are designed to align the incision lines along the line of tension (Fig. 1.20a–c). In addition, whenever possible, replacing the entire facial esthetic subunit rather than partial replacement leads to better esthetic result (Fig. 1.21).

Conclusion

Ablative surgery in the oral cavity results in esthetic and functional deficits. Reconstruction of such defects needs a careful understanding of the function and proper application of a suitable flap for reconstruction. Microvascular reconstruction permits adequate reconstruction especially in bony and skull base defects.

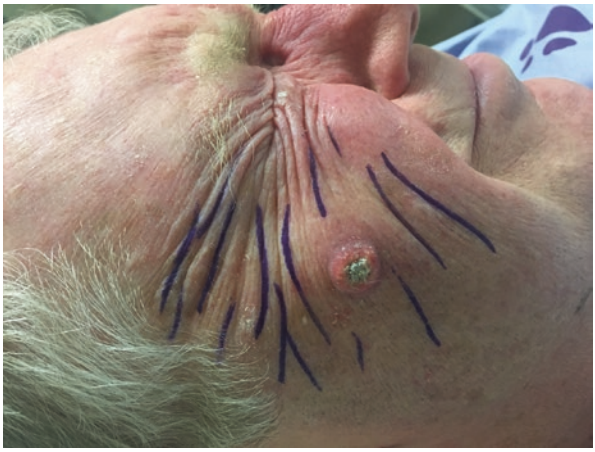


Fig. 1.21 Facial line of tension

References

1. Eggers C. Reconstruction of esophagus. Ann Surg. 1938;107:50–4.
2. McGregor IA, Reid WH. The use of the temporal flap in the primary repair of full thickness defects of the cheek. Plast Reconstr Surg. 1966;38:1–9.
3. Bakamjian VY, Long M, Rigg B. Experience with the medially based deltopectoral flap in reconstructive surgery of the head and neck. Br J Plast Surg. 1971;24:174–83.
4. Futrell JW, et al. Platysma myocutaneous flap for intra-oral reconstruction. Am J Surg. 1978;136:504.
5. Ariyan S. The pectoralis major myocutaneous flap. A versatile flap for reconstruction in the head and neck. Plast Reconstr Surg. 1979;63(1):73–81.
6. Demergasso F, Piazza M. Trapezius myocutaneous flap in reconstructive surgery of head and neck cancer: an original technique. Am J Surg. 1979;138:533.
7. Quillen CG. Latissimus dorsi myocutaneous flaps in head and neck reconstruction. Plast Reconstr Surg. 1979;63:664.
8. Ariyan S. One stage reconstruction for defects of the mouth using a sternomastoid myocutaneous flap. Plast Reconstr Surg. 1979;63:618.
9. Siemssen SO, Kirkby B, O'Connor TPF. Immediate reconstruction of a resected segment of the lower jaw using a compound flap of clavicle and sternomastoid muscle. Plast Reconstr Surg. 1978;61:724.
10. Dufresne C, et al. Reconstruction of mandibular and floor of mouth defects using the trapezius osteomyocutaneous flap. Plast Reconstr Surg. 1987;79:687.
11. Krizek TJ, Tani T, Desprez JD, Kiehn CL. Experimental transplantation of composite grafts by microsurgical vascular anastomoses. Plast Reconstr Surg. 1965;36(5):538–46.
12. Daniel RK, Taylor GI. Distant transfer of an island flap by microvascular anastomoses. A clinical technique. Plast Reconstr Surg. 1973;52(2):111–7.
13. Hanasono MM, Friel MT, Klem C, Hsu PW, Robb GL, Weber RS, Roberts DB, Chang DW. Impact of reconstructive microsurgery in patients with advanced oral cavity cancers. Head Neck. 2009;31(10):1289–96.
14. Rehrmann A. Soft tissue substitution in combined defects of the chin, vestibule and lip by means of "crossed double round flaps" according to Schuchardt. Dtsch Zahn Mund Kieferheilkd Zentralbl Gesamte. 1966;47(9):315–21.

15. Ergün SS. Reconstruction of the labiomental region with local flaps. Dermatol Surg. 2002;28(9):863–5.
16. Luce EA. Reconstruction of the lower lip. Clin Plast Surg. 1995;22(1):109–21.
17. Langstein HN, Robb GL. Lip and perioral reconstruction. Clin Plast Surg. 2005;32(3): 431–45.
18. Culliford 4th A, Zide B. Technical tips in reconstruction of the upper lip with the Abbé flap. Plast Reconstr Surg. 2008;122(1):240–3.
19. Yih WY, Howerton DW. A regional approach to reconstruction of the upper lip. J Oral Maxillofac Surg. 1997;55(4):383–9.
20. Sun J, Weng Y, Li J, Wang G, Zhang Z. Analysis of determinants on speech function after glossectomy. J Oral Maxillofac Surg. 2007;65(10):1944–50.
21. Rigby MH, Hayden RE. Total glossectomy without laryngectomy – a review of functional outcomes and reconstructive principles. Curr Opin Otolaryngol Head Neck Surg. 2014; 22(5):414–8.
22. Haddock NT, DeLacure MD, Saadeh PB. Functional reconstruction of glossectomy defects: the vertical rectus abdominus myocutaneous neotongue. J Reconstr Microsurg. 2008; 24(5):343–50.
23. Sharma M, Iyer S, Kuriakose MA, Vijayaraghavan S, Arun P, Sudhir VR, Chatni SS, Sharan R. Functional reconstruction of near total glossectomy defects using composite gastro omental-dynamic gracilis flaps. J Plast Reconstr Aesthet Surg. 2009;62(10):1277–80.

Planning of Maxillofacial Reconstruction

2

Discuss the Role of Image and 3D Model-Based Planning of Maxillofacial Reconstruction

Felix P. Koch, Vinay V. Kumar, and Peter Schulz

2.1 Introduction

The primary aim of treatment of patients with oral cancer is to remove the disease in entirety, thereby saving the patient's life. Hence, traditionally, treatment outcomes and research on patients with oral cancer have centered on factors such as tumor response to treatment, locoregional control of disease, disease-free survival, and overall survival at defined points of time [17]. However, therapeutic interventions for the treatment of oral cancer produce significant amount of disfigurement and altered function [44, 46]. During the last couple of decades, providing patients with improved functional outcomes has become the goal in treatment of patients with head and neck cancers [2, 25, 29]. The therapy decision is as well influenced by aspects of life quality after treatment [16, 20, 24, 34]. It has also been suggested that, at the time of diagnosis, patients seek prolonged survival, whereas following curative treatment patients' concerns shift from survival toward improvement and maintenance of their quality of life [33, 40].

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Due to these aspects, additional goals for the treatment of oral cancer have been developed. Providing good functional and aesthetic outcomes to achieve satisfactory quality of life has gained importance, in addition to the main goal of curative treatment. The goal of modern maxillofacial reconstructive surgery is the restoration of form as well as rehabilitation of function. When the jawbones have to be resected for the treatment of these pathologies, reconstruction is centered on providing optimal functional outcomes (in terms of masticatory rehabilitation) as well as aesthetics.

Over the past decades, the fields of medical imaging and imaging-based applications have grown. These have greatly influenced maxillofacial reconstructive surgery. Computed tomographic scans have been the method of choice to conduct preoperative planning [11, 39]. Cone beam tomography (CBT) has been an alternative technique for imaging of the recipient site, especially during functional planning [39]. Moreover, surface scanning techniques have also been utilized for imaging the soft tissue and dentition (intraoral scan).

2.2 Rationale for Planning of Maxillofacial Reconstruction

2.2.1 Complexity of the Facial Bones

Ablative treatment for oral cancer often involves the removal of parts of the maxilla or mandible and associated structures. Ablative treatment of maxillofacial bony structures is also performed in cases of large benign tumors involving the jaws, infective conditions such as osteomyelitis as well as large traumatic defects. The jawbones are bones with anatomic as well as functional complexities. There are no other bones in the human body, which have a similar function and anatomic shape of that of the jawbones. Hence, replacement of jawbones are technically challenging wherein planning forms an important step in treatment.

The shape of the mandible may be described as a three-dimensionally complex, horseshoe-shaped long bone. The condyle and ascending ramus of the mandible are oriented in a vertical plane. They are joined to the body of the mandible, which lies in a horizontal plane. Further medially, the body of the mandible curves in the sagittal/transverse plane to form the symphysis, which meets the counterpart symphysis of the other half. In addition to the complex overall structure of the mandible, the body and symphysis portion of the mandible need further special attention in reconstructive surgery as they house the functional units of dentition. The alveolar process of the mandible, which functions to bear the teeth, is in a different sagittal/transverse plane when compared to the corresponding inferiorly placed basal bone which is responsible for the external form and aesthetics. This is often referred to as the “two arch” concept. The “alveolar arch” is medially placed when compared to the “basal bone arch.” In order to replicate the anatomy of the mandible, especially the height of the mandible in the tooth-bearing segment, it is often necessary to perform a reconstruction taking into effect the two arches. In case where a straight

bone like the fibula is chosen as the flap, a double-barrel reconstruction has to be performed, where the fibula bone is osteotomized and placed over each other to increase the height of the reconstruction. The two barrels of the fibula will not be exactly over each other as the alveolar strut of the bone must be medial as compared to the basal strut of bone.

The shape of the maxilla is even more complicated and difficult to anatomically reproduce. Therefore, the goal in bony reconstruction of the maxilla is to provide a stable bony base that can form a secure alveolar ridge for the support of implants, thereby leading to a possibility of dental rehabilitation. Additionally, if areas of aesthetic importance of the maxilla and associated bones are removed (such as the zygomatic prominence), they have to be reconstructed to restore symmetry and aesthetics. It is obviously technically challenging to shape a straight bone like the fibula to functionally reconstruct the maxilla. Hence planning in reconstructive surgery is extremely important to shape the donor flap to conform to the recipient defect.

2.2.2 Improving Functional Outcomes

In cases where jawbones have been resected due to oral cancer or other pathologies, various reviews have shown that only about 15–25 % of patients that have been reconstructed end up with functional dental rehabilitation, the remainder of patients staying functionally crippled [9, 36]. These functionally crippled patients are often of low self-esteem, avoid social gatherings, and are frequently dependent on others for basic needs such as dietary preparation. Many factors are responsible for the low rates of functional rehabilitation in reconstructed patients. Unavoidable reasons could be poor medical status of the patients that do not favor the placement of implants for dental rehabilitation, poor disease control, and patient wishes, where they do not want to undergo additional procedures for complete oral rehabilitation. Financial reasons could also be an important factor for patients in many countries where there is no insurance that covers for rehabilitation following oral cancer. However, one of the most important reasons for such a low rate of rehabilitation, which could be avoidable, occurs when there was poor planning. In these cases, the reconstructed bone is in a poor anatomic relation to favor oral rehabilitation with implants. Proper planning and accurate execution are the most important factors to enable successful functional rehabilitation.

2.2.3 Improving Communication Between Treatment Team Members

To provide successful functional rehabilitative treatment outcomes, many team members are involved in the treatment of the patient. From a purely maxillofacial reconstructive point of view, these teams consist of the ablative surgeon responsible for the resection of the tumor and curative treatment, the reconstructive surgeon responsible for reconstruction of the defect. Additionally a maxillofacial surgeon

cares for dental implants and an adequate gingival soft tissue condition, so that the prothodontist could finish the functional rehabilitation. The clinical delivery of the interim and definitive prosthesis is the responsibility of the maxillofacial prosthodontist, who in turn relies on the maxillofacial laboratory technician to fabricate the prosthesis.

Poor communication between the vastly different teams would result in poor functional outcomes. Strong communication generally exists between the ablative and reconstructive teams. However, the communication with the prosthetic and rehabilitation team prior to ablative surgery is often not optimal. Often, the maxillofacial surgeon and the prosthodontist are involved a few months after the patient has been reconstructed, when the patient is sent for an opinion regarding rehabilitation possibilities. The bony reconstruction would have been already completed and might not be in a functionally ideal position. To obtain functionally favorable outcomes, the patient would then have to undergo further bony as well as soft tissue surgical procedures such as additional bone grafting, re-osteotomy to reorient the bone segments, vertical distraction osteogenesis, vestibuloplasty, soft tissue grafting, etc. These additional surgical procedures subject the patient to further difficulties, financially as well as otherwise, that may lead to demotivation and apathy of the patient and incompliance.

Modern planning methods that envision the end functional result prior to ablative surgery can eliminate most of these problems. A robust planning tool will greatly improve the communication in between the various team members and will provide a blueprint for the team members to execute their respective roles. The planning tool can also be used to communicate to the patient on the probability of their treatment outcomes, thereby providing positive motivation and incentive to undergo functional rehabilitation.

Since 3D imaging has been introduced in ablative cancer surgery, surgeons have the chance to visualize the extent and infiltration of the tumor into the surrounding tissues and can plan the resection margins very precisely [15]. This close communication is important, as any intraoperative spontaneous change of the resection borders makes the surgical planning useless.

2.2.4 Decreasing Treatment Time

As described before, reconstruction of the complex jawbones is technically challenging. Without the help of surgical templates, the osteotomy of the donor site flap to shape and inset into the three-dimensional recipient defect is frequently time consuming. Conventional eyeball osteotomy, shaping, and insetting procedures are typically done after the flap has been detached from the donor site and introduced to the recipient site by trial and error method. This leads to increased ischemia time and a sense of haste while performing the procedure. Additionally, bending and shaping of the osteosynthesis plates, without preoperative planning, can lead to further time consumption. However, with the development of technology and meticulous planning tools, the shaping of the donor site can be made according to

predefined osteotomy patterns that can be performed at the donor site, with the vascular pedicle still intact. Provision is also made to incorporate placement of dental implants and loading of interim dentures that can decrease not only the operative time, but also overall treatment time. With meticulous planning, prior bending of osteosynthesis reconstruction plates, or even manufacturing of customized osteosynthesis plates are possible, thereby decreasing the difficulty and time consumption during surgery. A decrease in surgical time ultimately leads to decrease in treatment costs as well as the possibility of more patients to be treated faster.

2.2.5 Decreasing the Learning Curve

Traditionally, mastering of reconstructive maxillofacial surgery has been dependent on a long learning curve, often with inconsistent results during the skill acquisition phase [37]. Although flap harvesting and microvascular anastomses are relatively straightforward procedures, one of the main areas of skill acquisition is the process of shaping and insetting the flap into the recipient site that would result in a functionally and aesthetically favorable outcome. Until recently, the overall success in maxillofacial reconstruction has relied mainly on the use of two-dimensional imaging modalities as well as trial and error. With the use of planning methods, virtual surgical planning and CAD CAM-based modeling, it has been easier to predictively perform reconstructive surgery thereby permitting many more surgeons to perform the procedure.

2.3 Imaging Considerations in Planning for Maxillofacial Reconstructions

Since 3D imaging has been introduced in ablative cancer surgery, surgeons have the possibility to visualize the extent and infiltration of the tumor into the surrounding tissues and can plan the resection margins to great accuracy [15].

Multiple modalities have been used to diagnose and image tumor margins in patients with oral cancer. MRI, CT (with and without contrast), and PET/CT imaging have been evaluated for diagnosis of soft tissue involvement without significant differences between the imaging modalities [6, 32]. For bone resection planning, however, the CT scan has the best contrast and highest resolution. CT scan can be used to acquire data from both the tumor site and the donor site. Cone beam computed tomography can also be used to acquire data of the hard tissues; however, they are limited to the oral region and not from the donor site. The advantage of cone beam computed tomography is that it is less expensive as well as it subjects the patients to lesser dosage of radiation. Additionally, surface-scanning procedures such as photogrammetry or laser surface scanning procedures may be used for accurate visualization of the patient's facial surface topography or for 3D image capturing of dental models. The data from all imaging modalities mentioned above are in DICOM format, which stands for Digital Imaging and Communication in Medicine

[4], except surface scanning procedures, which are stored in .stl (Standard Triangulation Language) format.

For the planning of microvascular flaps, the preoperative imaging by computed tomographic angiography (CT angio), MRI catheter angiography, or Doppler ultrasound scanning has become standard examination modalities to evaluate the perforator status or to investigate the blood perfusion of the donor site (e.g., the lower limb before the microvascular fibula transplantation). Not only the presence of vessels but also their diameter and length are important information to plan suitable donor and receipting vessels ([35]).

Computerized tomography is carried out with a fan beam that rotates around the region to be examined. This rotation has to be at least 180°, which allows the measurment of specific absorption of each rotation degree. Their subsequent conversion, dependent on the specific absorption, permits the generation of a three-dimensional space, called as "voxel" [49]. Computerized tomography takes the absorption coefficient of a particular structure as the basis of data generation, and hence it is possible to image not only bony structures but also soft tissue structures with this modality. In contrast, the cone beam tomography (CBT) procedure is characterized by a cone or pyramid-shaped beam projecting onto the region of interest. From these individual projection images, the desired voxels are calculated. One should keep in mind that the calculated voxels based on CT as well as CBT resolution are burdened with errors. Theoretically, an improved resolution may be achieved by CBT as compared to CT. According to the literature, however, a realistically accounting, spatial resolution relates to 0.2–0.3 mm utilizing the DVT technique [53].

Virtual planning involves data acquisition, processing, visualization, analysis, and eventually computer-assisted design and manufacturing (CAD/CAM) output procedures. The workflow for digital planning starts with acquisition of data from sufficient imaging. This includes the pathology, the donor flap region as well as its perfusing vessel anatomy if the anamnesis suggests arteriosclerosis. Most commonly, this is done by CT scans of donor as well as pathology sites, and CT angiography when required to determine vascular supply. CT scans are generally carried out in 1 mm sections or lower, with 512 × 512-pixel resolution [11]. These data, in the DICOM format, are transferred to the computer workstation for further data processing. Axial, coronal, and sagittal images can be readily seen, and the necessary diagnosis can be made with these two-dimensional data. Additional to these data, the patient's personal data, the date of recording, and technical information of the recording procedure are also available.

However, for digital planning, three-dimensional rendering of the data is required. Hence, after acquisition of the data, it has to be processed. To utilize the data from CT scans for digital planning purposes, specific computer softwares are required that could process DICOM format. Although many softwares are available for the same, Osirix® (Pixmeo SARL, Geneva, Switzerland) is described here as a representative of free software that is currently available. Osirix® is used both for analysis and for handling of DICOM data [1].

2.3.1 Surface Rendering for Further Digital Three-Dimensional Imaging Planning

There are basically two rendering mechanisms to employ DICOM data for the generation of three-dimensional objects: surface rendering and volume rendering. For bony structures, the surface rendering technique is the method of choice (Fig. 2.1). It provides the key to edit clear demarcations of the three-dimensional object to be created. However, for soft tissue structures, volume rendering has been recommended. Both techniques are similar, but differ in the underlying algorithms. The surface rendering method requires utilization of the "marching cubes algorithm" [51]. 3D visualization of CT image data requires a segmentation step that associates specific gray values to each tissue. Hence, the specific threshold of the tissue to be chosen must be selected. Although it is possible to have a 3D visualization of the data in the DICOM format, however for modifying the data such as deleting and superimposing structures (typically done for virtual surgery), a change in the file format is necessary.

2.3.2 Stereolithography File Format as the Basis for Further 3D Processing

The stereolithography file format (STL) can now be considered as the gold standard in 3D imaging. Conversion of the DICOM data format made by surface rendering into STL format makes it easier to perform virtual surgical steps. Additionally, the

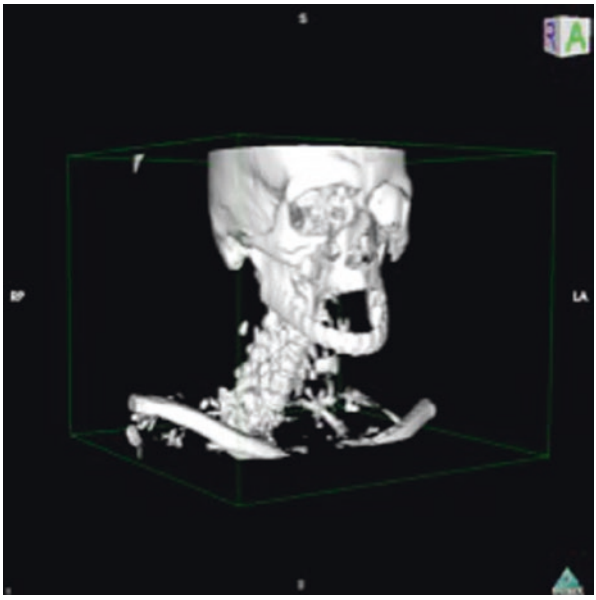

Fig. 2.1 3D surface rendering of a DICOM data set. In this patient example, a resection defect of the mandible was bridged using a reconstruction plate. 3D surface rendering was done by the software OSIRIX® (Pixmeo, Geneva)

STL format serves as a common exchange file format to transfer data between different CAD CAM systems.

Basically, a STL file is composed of many small triangles with defined 3D-coordinates [48]. For example, to obtain an approximation of a circular three-dimensional surface, it is composed of many small triangles. This results in increased accuracy and also the size of the file. In principle, every 3D printer and every CAD CAM design software are in a position to process STL files, even in cases where a transformation of the STL file into another file may be locked (Fig. 2.2).

2.3.3 Intraoral Scans Serving as Additional Imaging

Intraoral scans are being increasingly used in dentistry, prosthetics, and implantology. The concept of digital "backward planning" that has been commonly utilized for the implantation of artificial teeth can also be included in the three-dimensional reconstruction of bones. For example, to include a fixed prosthetics in the upper jaw for the adequate reconstruction of the mandible it appears helpful to conduct an intraoral scan of the dental prosthesis [52]. Again, a conversion of the recovered data into STL files is possible, and these data can be adapted to data generated by CT or CBT. Many times, visualization of dental occlusion in CT data is often erratic as it cannot be accurately visualized due to limited resolution of the cuspal and occlusal anatomy of the teeth. In addition to metallic dental restorations, orthodontic appliances create scatter and streak artifacts on CT scanning. Hence, surface scanning of the plaster cast model or intraoral scanning can provide better accuracy of the dental arch. The data from surface scanners can be incorporated to the respective area of CT Scans.

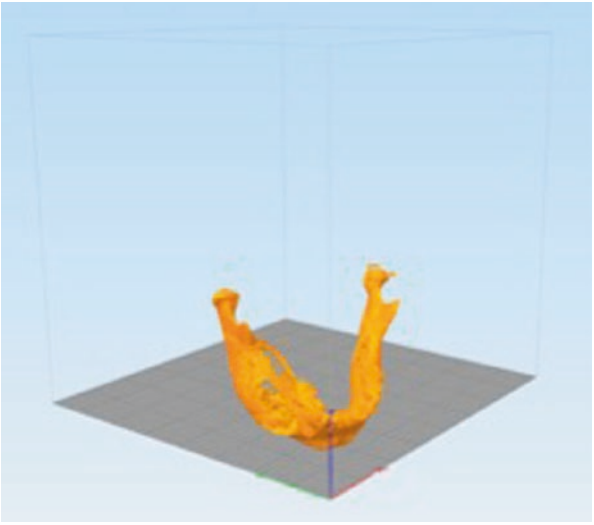

Fig. 2.2 An STL file for further editing after conversion from a surface-rendered DICOM format. This patient example shows an ameloblastoma of the right mandible

2.3.4 Virtual Ablative, Reconstructive, and Rehabilitative Planning

Several software systems (e.g., IndividualPlan GmbH, Wiesbaden, Germany; Mimics®, Materialise; Voxim®, IVS Solutions; Straumann Guide) are commercially available for dental implant planning and fabrication of surgical guides. Some of these virtual software solutions allow for the import and exchange of the most common medical image data formats used for surgical planning. The latter include different 2D and 3D visualization procedures, quantitative assessment (e.g., length, angle and volume measurements), mirror imaging and surface matching procedures, planning of virtual bone osteotomies or of dental implant position, and cephalometric analysis. These programs usually incorporate an output for rapid prototyping model manufacturing. However, more complex image processing, analysis and visualization, measurements, and incorporation of customized implants require more sophisticated software and tools. In order to do this, different software packages must often be combined and data must be transferred.

2.4 Factors to Be Considered Planning of Maxillofacial Reconstruction

The planning for maxillofacial reconstruction consists of three major steps: (1) basic considerations; (2) reconstruction plan; (3) transfer into the surgical site (Table 2.1).

Table 2.1 Planning algorithm for maxillofacial reconstruction

1. Basic considerations
Diagnosis (mouth opening, function, general health)
Prothesis (radiopaque pins or radiopaque teeth)
Imaging (including prothesis, double scan with nonradiopaque prothesis)
Definition of defect size:
(a) Primary reconstruction: resection plan
(b) Secondary reconstruction: repositioning of the condyle, resection of osteomyelitis
2. Reconstruction plan
Soft and bone tissue needed
Prothodontic rehabilitation plan
Length of pedicle needed
Flap selection, selection of donor site
Positioning and molding of the flap, dental implant plan
3. Transfer into surgical site
Dental-based inverse treatment
Model-based planning
Virtual planning

2.4.1 Basic Considerations

Planning for reconstructive surgery is closely dependent on the ablative surgical plan, the reconstructive surgery being performed, and the method of functional rehabilitation ultimately to be provided to the patient. As these factors vary completely from one patient to the other, maxillofacial planning is customized to each patient being treated.

There are various factors that must be considered while taking into account planning for maxillofacial reconstruction. Broadly, they must take into consideration the patient's wishes, what kind of functional outcomes they wish to have, and consider this input with the background of their medical condition, prognosis of treatment, and financial status (if applicable). The planning is dependent on the information obtained from various imaging and diagnostic sources. Once this information is obtained, the timing for reconstruction surgery (in terms of primary and secondary reconstruction) is planned. It is then decided on which reconstructive option is suited for the patient in terms of the type of flap to be used. Ultimately, the method of prothodontic rehabilitation needs to be considered as well (whether an obturator is favorable, or removable prostheses supported on dental implants or fixed dental rehabilitation supported on dental implants, or if no dental rehabilitation is required). Incorporation of all of these factors is required to ideally plan for maxillofacial reconstruction.

2.4.1.1 Multidirectional Planning

There are various methods to plan for maxillofacial reconstruction depending on the availability of materials and equipment. Planning for maxillofacial reconstructive surgery is ideally multidirectional. Successful planning envisions the desired functional-aesthetic outcome as a starting point. With this goal in mind, which is emphatically patient specific, the entire reconstruction is planned step by step, backward. Backward planning starts with fixing the ideal position of functional occlusion. Once the teeth are envisioned in the correct position, the donor site bone is planned to be placed according to the functional position. This position of the donor site bone placement decided the amount of bone required and the necessary osteotomy steps to be carried out to shape the donor bone.

Simultaneously, planning also incorporates forward planning directions. Forward planning first takes into account the extent of the tumor, the extent of involvement of bony and soft tissue structures, the resection plan, the extent of the resultant surgical defect, the general medical condition of the patient, and the appropriate the reconstructive options available. Hence a multidirectional approach, incorporating both methods of planning: backward and forward, is essential. Planning for maxillofacial reconstruction hence includes resection, reconstruction, and rehabilitation plans, which need to be coordinated to achieve the best result possible.

It is obvious, that, in order to achieve optimal outcomes with a multidirectional approach, a comprehensive multidisciplinary team approach is needed. There should be excellent coordination between the ablative surgeon, reconstructive surgeon and/or maxillofacial surgeon, the prosthodontist, and the laboratory

maxillofacial technician. A truly beneficial treatment outcome can only result from the active involvement of these individual team members in the planning process.

2.4.1.2 Medical Anamnesis

The starting point for planning starts with the data acquisition of the specific patient. The first point to note is the kind of maxillofacial reconstruction and the rehabilitative options the patient desires. Most patients when provided with an option would choose to be completely rehabilitated. However, the feasibility and probability of the type of functional rehabilitation needs to be carefully considered.

The presenting complaints and the anamnesis status of the patient are important factors that would decide the treatment plan. The patient's general health conditions including age decide on the extent of surgery. In patients with a poor general health status concerning neurologic or cardiovascular status, it might be wiser to perform a shorter and simpler reconstruction by a reconstruction plate and local flaps. In this situation, it is important to convey to the patients, the limited possibility of functional rehabilitation. The remaining units of dentition can still preserve masticatory function, if they are not to be resected. The goal of reconstruction is to provide aesthetic as well as improving wound-healing outcomes following ablation. If the septum of the nose, the orbital floor, and more than one third of the soft palate are affected, however, a surgical solution is favored (Shaw et Brown, *Lancet Oncol* 2010).

When reconstruction by local tissue is planned, surgeons need to coordinate the surgical approach for resection and reconstruction: the nutrition patterns of the local flaps, the arc of rotation, and the robustness of the pedicle supply have to be considered. Good communications between the various teams are required especially when the ablative surgical team is different from the reconstructive surgical team.

2.4.1.3 Timing of Reconstruction Surgery

In general a primary reconstruction, immediately after resection, and a secondary reconstruction, several month after resection, can be distinguished.

If primary reconstruction is planned for the patient, the anticipated postresection defect is taken into consideration for planning. In primary reconstruction for cases of slow growing tumors such as ameloblastoma, the original bone could have been deformed (Case 2.4 Fig. 2.31a) In these cases, sagittal mirroring must be performed to transfer the normal anatomy of the nonaffected side. In most cases of midface reconstructions, sagittal mirroring would need to be performed to estimate the asymmetry and plan the osteotomies for correction (Case 2.4 Fig. 2.31b). The osteotomy plan could be communicated to surgery by a CAD cutting splint and CAD osteosynthesis plates. These plates are gained by bending them on the basis of a reconstructed, mirrored 3D print. Since laser-sintering techniques are available, the osteosynthesis material can be CAM manufactured directly from the 3D data.

Primary reconstruction is technically much easier to perform, than a secondary, because the tissue and vessels are not affected by scars or radiation therapy. The tissues are in a natural position, favoring functional and aesthetic rehabilitation. However, a drawback in primary reconstruction cases when using digital planning

is that the resection and reconstruction plan are orchestrated by digital planning, both being mutually interdependent on the accuracy of each other. Virtual CAD/CAM planning and production of resection splints, however, need a few days to be delivered by express order or even a few weeks, depending on the supplier and location and connectivity of the hospital. If the resection plan changes intraoperatively, either because the tumor size has changed during the waiting period, or due to any other reason, it leaves the virtual planning nonfunctional.

In cases when secondary reconstructions are planned, reconstruction plates are inserted after cancer resection as a temporary measure to bridge the gap of resection defects and maintain continuity of the mandible. On an average, however, the plates breakdown or perforate the external skin after 6–18 months, especially if they are applied in the chin region. For long-term survival, reconstruction plates are just recommended for defects of less than 6 cm and in the body region of the mandible [27, 43]. Also the application of alloplastic condylar joint plates articulated in the glenoid fossa could cause severe complications such as fractures, infections, or perforation of the skull base. Therefore primary, alloplastic reconstructions usually require a secondary reconstruction of the bone.

Secondary reconstructions make it more difficult to achieve functional and aesthetic outcomes, require an additional surgical procedure of long duration, and increase the treatment time and costs. The condyles are often not in ideal position and there is often shortening of the remnant parts of the original bone.

In primary reconstructions, the oral mucosa or external skin resection necessitates the transplantation of a skin paddle if adjuvant radiation therapy could be necessary. In cases of secondary reconstructions, the submental and cervical skin is often shrunken and very tight due to radiation therapy. In many cases where a reconstruction plate was placed primarily, the plate perforates the skin and would have already been removed prior to the reconstruction appointment [27, 43]. In cases of plate removal, the remaining discontinuous fragments of the mandible are pulled upward by the temporal and masseter muscles. The condyles are often dislocated out of the glenoid fossa, rendering patients to breathing problems. The condylar joint position needs to be planned to be readapted to a physiologic position before the planning for bony reconstruction starts. The condylar position could be fixed with the help of a CT scan of the jaw before resection. If not available, then during surgery, the condyles are placed in a centric position in the fossa in such a way that the coronoid processes do not go beyond the zygomatic arch. To release the soft tissue tensions during secondary reconstruction, additional soft tissue is often required which is typically planned as another skin flap at the submental region. For treatment of the submucous fibrosis, a microvascular radial forearm flap sometimes is necessary.

The condylar joints could be dislocated out of the condylar fossa, even in cases of near total resection defects of the mandible. In these situations, the anterior dislocation of the condyle could provide more pharyngeal space and better breathing. These cases are very difficult to reposition. The strong muscular forces and the tight soft tissue due to scaring tend to keep the mandible and joints in a closed position. These forces could even be of such large magnitude to break the osteosyntheses

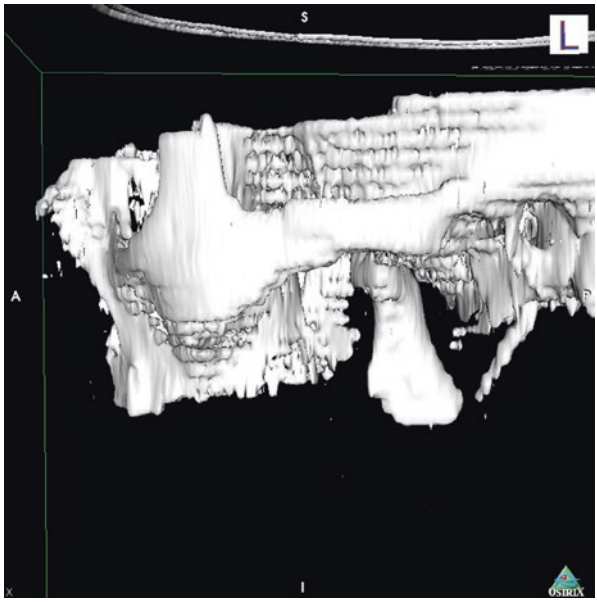

Fig. 2.3 CT scan of a patient who underwent a near total resection of mandible with postoperative infection leading to loss of reconstruction plate. The patient had to protrude the mandible to prevent collapse of the airway. This produced luxation of bilateral mandibular condyles. The condyles have to be repositioned during computerized planning for reconstruction with a free fibula flap

plates or cause fracture of the screws. If not released, these forces could lead to the malposition of the microvascular flap, or cause kinking of the pedicle that could lead to flap necrosis (Fig. 2.3).

Post radiotherapy, many patients would end up with reduced mouth opening due to radiation fibrosis. There is no general solution to correct this shrinking and scarring. Fracture of the coronoid process along with release of scars, use of another soft tissue flap such as the radial forearm flap, autologous fat transplantation, and injection of botulinum toxin into the elevator muscles of the mandible could be attempts for improvement of this condition.

Provision of dental rehabilitation is also dependent on jaw mobility. Post reconstructive surgery and in the prosthetic phase of treatment, adequate access for impressioning procedures, seating of the dentures, and auxiliary dental preparation require adequate mouth opening. These additional factors must be taken into account prior to planning for reconstructive surgery.

2.4.2 Reconstruction Plan

2.4.2.1 Choice of Reconstruction Method

Once the basic considerations in planning of reconstruction surgery are decided, the next step of planning considers the type of reconstruction (the particular flap to be used). The choice of the type of flap depends on many factors such as the amount of bone to be reconstructed, the amount of soft tissue to be reconstructed, the location of the defect, donor site problems, and patient and surgeon preferences. The position and length of the pedicle and the extent of the skin paddle required decide on

the type of flap. If dental implants are planned, the rotation of the bone transplant and the side of harvesting are discussed to decide which bone surface is taken for dental implant placements. As complete functional rehabilitation is the goal for modern reconstructive surgery, patients often wish to have their masticatory function rehabilitated.

Hence, in these situations, vascularized bone-containing free flaps are the reconstructive option of choice. If well planned, these flaps have sufficient bone and soft tissues that can aesthetically and functionally reconstruct postablative defects. They also serve as a bony base for the insertion of osseointegrated dental implants to fulfill masticatory rehabilitation. It has been shown by various studies that implant-supported dental rehabilitation improves oral health and general health-related quality of life in patients with reconstructed jaws [5]. Although not universally agreed, it has been suggested that in patients with lateral defects of the mandible, if occlusal rehabilitation by means of dental implants are not considered, there is no significant advantage in subjecting the patients to complex, time-consuming, microvascular bony reconstructions of the jaws. Instead, a simplified procedure of using a reconstruction plate with adequate soft tissue cover provides comparable quality of life outcomes [45].

Although many donor sites are available for harvesting vascularized bone-containing free flaps (such as the fibula, iliac bone, and scapula), the free fibula flap has been the most commonly used flap in jaw reconstructions [3, 22, 31]. The advantages of the free fibula flap in comparison to other vascularized bone-containing free flaps is that it can provide a large length of robust bone (around 22–26 cm in the adult) which can be osteotomized and shaped to reconstruct defects of most dimensions involving the jaws. The flap is supplied by the peroneal vessels, which are mechanically robust, anatomically reliable, and of sufficient length (about 15 cm of pedicle length) and diameter (2–3 mm in diameter). The fibula flap can be harvested as an osteomyocutaneous flap, in which, the skin paddle is reliable, thin, pliant, and of satisfactory size that enable it to be tailored to most intraoral and extraoral defects. The soleus muscle cuff can also be harvested along with the flap for added soft tissue bulk if required. The sural nerve, which is in close proximity to the flap, can be additionally harvested to provide a sensate flap. The donor site morbidity is acceptable and the location of the donor site permits simultaneous two-team approach, the ablative team, and the reconstructive team to work simultaneously.

An important advantage of the flap is that the fibula bone is highly favorable for the insertion of osseointegrated dental implants [21]. The fibula bone is about 10–15 mm in cross section, with its thick cortical borders accounting for about 3–7 mm. This permits implants to be placed with bicortical support (Fig. 2.4). Additionally, the cortical bone is of high density (ranging from 1200 to 1600 Hounsfield units). Implants placed into such dense bone will have high primary implant stability with implant stability quotient (ISQ) values of higher than 65. It has been shown in multiple studies that the survival rates of implants placed in the fibula equal that of implants placed in jawbones [9, 13].

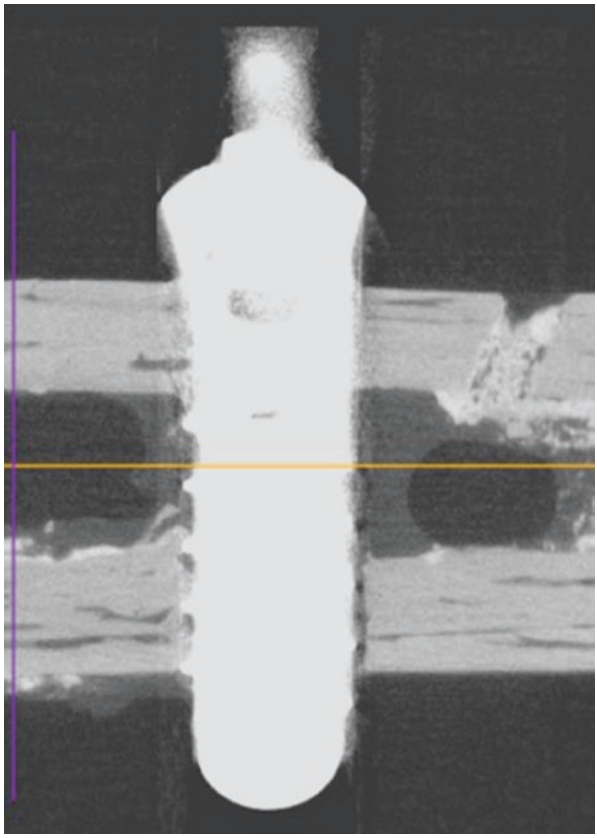

Fig. 2.4 (Hermann Goetz, Forschungsplattform Biomaterialien, University Medical Center of Johannes Gutenberg University, Mainz, Germany & Vinay V. Kumar). A human explant specimen of implant in fibula showing bicortical support

Converting a relatively straight bone like the fibula to shape the mandible requires meticulous planning, not only in morphologic alteration but also considering the osteotomy as well as pedicle orientation.

A consideration during planning of the pedicle is that it should never be situated to a bony edge or be kinked, as it would hinder the venous blood flow. For the fibula planning, the pedicle should be positioned to the oral lingual side to avoid the possible compression by the scared external skin. Another important aspect is the position of the pedicle in the anterior two third of the body of the mandible. If the pedicle exits to the mandibular angle region and anastomosed with cervical vessels, there is a possibility of the vein or artery to be easily kinked and strangulated. In order not to turn the pedicle after transplantation, the course of the vessel should be considered. The aspects of the skin paddle position and the side of anastomosis finally decide the side of leg that should be harvested (Table 2.2).

2.4.2.2 Soft Tissue Factors in Reconstruction Surgery

Soft tissue resection and reconstruction mainly rely on anatomical landmarks and the surgeon´s hands. In contrast to planning for bony reconstruction, where one can

Table 2.2 Algorithm to choose the fibula donor site in dependence on jaw, pedicle, and skin flap orientation

		Pedicle anastomosis		
		Right neck	Left neck	
Skin paddle position	Lingual	Left leg	Right leg	Mandible
	External	Right leg	Left leg	
Skin paddle position	Palatinal	Right leg	Left leg	Maxilla
	External	Left leg	Right leg	

rely on defined and stable landmarks, planning for soft tissue reconstruction is more difficult. Many navigation systems are available, but are still expensive to be considered on a routine basis. Navigation systems rely on 3D imaging (CT or MRI), which has been taken before surgery. However, soft tissue landmarks are often not stable and changes occur by mouth opening or by muscle relaxation. These changes are not considered by these systems. The installation of intraoperative CT or MRI in combination with a navigation system could help to implement the resection plan for soft tissue. The intraoperative MRI, however, is extraordinarily expensive and very few centers have access to this technique in the operation theater. At the moment, no evidence-based data are available to suggest the superiority of such technology.

Planning for soft tissue reconstruction must not only consider the reconstruction of extraoral cutaneous component, but also of the intraoral soft tissue structures such as the alveolar mucosa and lingual and vestibular spaces. For functional oral rehabilitation and long-term success of implants, it is important to provide fixed mucosal tissue around implants as well as vestibular and lingual sulci for maintenance of oral hygiene.

For mandibular reconstruction, the free fibula flap may be used as an osseous flap or as an osseocutaneous flap [19]. Osseous flaps are used when there is minimal soft tissue or mucosal resection done [18]. In these circumstances, the floor of the mouth is sutured onto the labial or buccal mucosa to achieve primary closure. When these patients present for implant-supported dental rehabilitation, there is often insufficient vestibular depth, along with a lack of attached mucosa and lack of keratinized mucosa [26].

In cases of mandibulectomy with extensive mucosal/intraoral soft tissue defects, osseocutaneous free flaps are utilized, where the skin flap is used as a replacement of the intraoral mucosal defect. In view of oral rehabilitation of these patients, this skin flap is a poor substitute for the attached oral mucosa as they are excessively bulky, mobile, and of poor texture (often with the presence of hair appendages) [8, 21]. Moreover, in between the fibula bone and the outer surface of the skin flap, there are layers of fat and muscle, which forms a compressible bed (much like a multilayered mattress) when used as a support for prosthetic rehabilitation (Fig. 2.5).

Additionally, in cases where a single-barrel fibula is used for mandibular reconstruction, and the barrel is placed corresponding to the lower border of the mandible (a technique that is followed to achieve symmetry of the mandible following reconstruction), there is excessive soft tissue thickness as well as inadequate vestibular

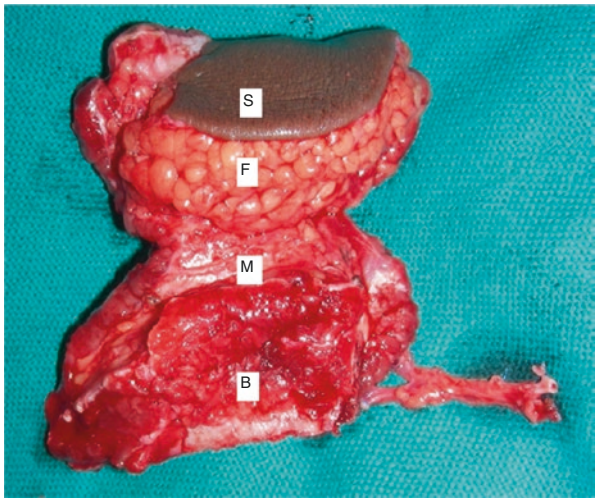

Fig. 2.5 Cross section of deep circumflex iliac artery–based composite free flap. The figure describes multiple layers of the flap that consist of *S* skin, *M* muscle, *F* fat, *B* bone. This can be compared to a compressible mattress

space [41]. Therefore, some prefer a positioning in between the crestal and lower border of the mandible. Then, however, the bony edges of the remnant segments of the mandible could compromise the pedicle and need to be resected and rounded.

In all of these situations, if soft tissue problems are not addressed, implant-supported dental rehabilitation can lead to complications such as poor hygiene around implants, hyperplastic peri-implant tissue, soft tissue infections, and abscesses may eventually lead to loss of implants and the dental rehabilitation [10].

Hence, it is important that planning for intraoral soft tissue modifications be considered during treatment planning. To provide fixed mucosa around dental implants, a number of techniques have been described that include: various grafting procedures using either split thickness skin grafts [14] or palatal connective tissue grafts [7]; thinning of the cutaneous paddle either during flap inset or during implant insertion/abutment connection [28]; thinning of the cutaneous paddle using liposuction [23]; laser resurfacing of the soft tissue; topical silver nitrate application [9]; and vestibuloplasty [12]. As these procedures involve harvest of an additional donor site, it must be well explained to the patient prior to start of treatment.

Denture-guided epithelial regeneration has been another method for predictable soft tissue outcomes [30] (Fig. 2.6). Using this technique, the reconstructed bone is left open intraorally and covered with a provisional prosthesis, fixed to the immediately placed implants (immediate loading). If no radiation is applied, the noncovered bone will be overgrown by the oral mucosa within 4–5 months. Another commonly followed method for the development of fixed mucosa around the implant is the prefabrication technique, first described by Vinzenz [47], and developed by Rohner. This is a two-staged technique, where, in the first stage, a split thickness skin graft is harvested and fixed onto the fibula bone in a predetermined position and covered for the uptake. Six to eight weeks later, when reconstruction is carried out, the fibula bone would already have a layer of fixed mucosa around the implants [38].

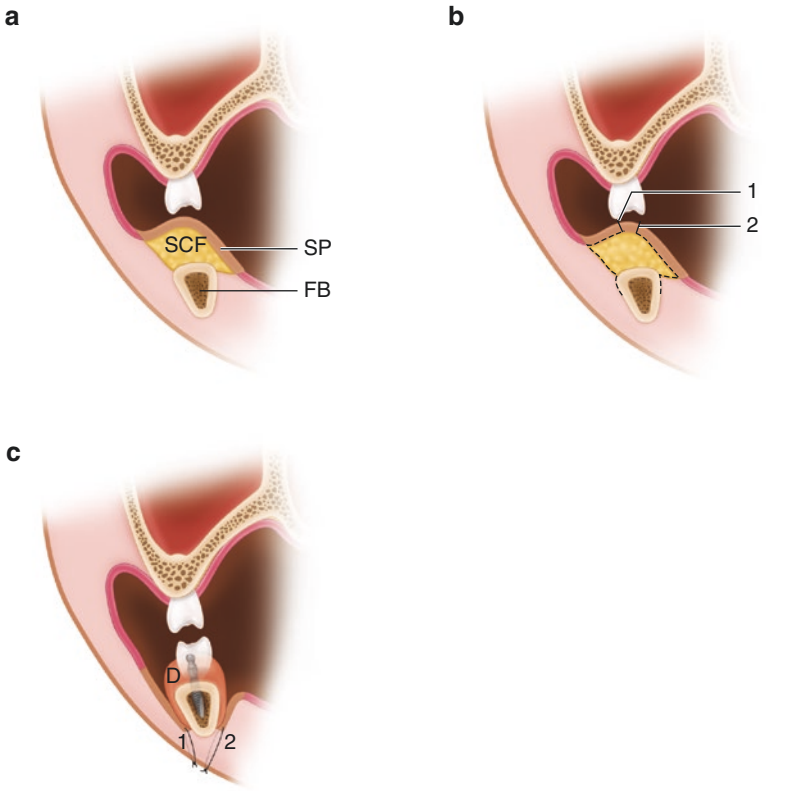

Fig. 2.6 A schematic diagram of the surgical technique. (**a**) Shows the preoperative coronal cross-sectional picture of the fibula bone (FB) with subcutaneous fat (SCF) and the skin paddle (SP). (**b**) Describes the incision at points 1 and 2, the dissection and removal of subcutaneous fat as well as a subperiosteal dissection. (**c**) Shows the completed surgery with the skin flaps elevated, subperiosteal dissection completed and points 1 and 2 forming the depth of the buccal and lingual sulcus. Implant-supported removable denture is seen maintaining the space of the vestibule as well as providing guidance for epithelial regeneration

2.4.2.3 Dental Rehabilitation

Imaging of occlusion may be problematic in certain cases where prosthodontic metal crowns and metallic dental restoration can create artifacts on traditional radiographic or CT imaging. To gain suitable images from the CT scan, an occlusal splint prevents movements during the scan and keeps the bite slightly open. Precise imaging of the dental surfaces is important for CAM production of an intermaxillary positioning splint or a provisional, printed denture. The planning of prosthodontics at the start of surgical rehabilitation is crucial, because the functional rehabilitation as well as a stable condylar joint position demands optimal prosthodontic rehabilitation.

The dental implants inserted at planning stage orientate the fibula in terms of rotation as well as position. The next steps include planning the teeth position, the

dental implant position and angulation, and finally, the position of the bone transplant is constructed. To plan the dental implant position, a CT scan of the situation before resection including the teeth is very helpful. Otherwise, the opposing dental arch helps with the planning. If the patient is endentulous, prosthesis of the upper and lower jaw will help in indicating the implant positions. The CT scan needs to be taken with the prosthesis in situ. A splint should fix the occlusion. In case the prosthesis cannot be inserted due to the defect, a CT scan is performed of only the prosthesis and later superimposed on the patients' scan. As a prosthesis of poly methyl metha acrylate is not visible on the CT scan, there are two options: the prosthesis can be manufactured by radiopaque material, or the denture is marked by several radiopaque pins, e.g., from gutta-percha. The marked prostheses are scanned outside the patient's mouth in perfect occlusion to adjust for the density of the prosthesis. Then (virtually) using the computer software, the visible marks in the patient's CT scan and the externally scanned prosthesis are matched. The occlusional plane of the prothesis is usually parallel to the Camper's plane and that should be clinically compared to the patient's situation.

As teeth, condyle positions, the side of anastomosis, and the need of a skin flap are defined, the number of dental implants and their position are planned, depending on the prosthodontic concept. The fixation of the teeth is easily, rapidly, and inexpensively performed by metal ball attachments. More expensive and elaborate methods include fixing the teeth by a telescope-based or screw-retained denture, or with bar-supported overdentures. Although not universally agreed, it has been opined that removable prosthesis is a better option in patients with reconstructed jaws as they are easier to maintain, the need for lesser number of implants and relatively lesser cost. However, in patients with reduced manual dexterity, insertion and removal of a removable prosthesis may be problematic. In these patients, a fixed option would be beneficial provided they present for routine oral prophylaxis. In general, the prosthetic value of dental implants distally of the first molar is of limited value, because the buccal soft tissue often gets irritated in this region and maintenance of oral hygiene is difficult.

In reconstructed patients, conventional tissue-supported prosthesis is rarely possible, because of the difficult anatomical situation and a lack of saliva. Furthermore, a prosthesis based on dental implants avoids the injury of the mucosa and prevents osteoradionecrosis. However, dental implants can cause in 2–6 % osteoradionecrosis. For defects of the upper jaw, dental implants help to fix an obturator prosthesis.

After planning for the prosthesis and the number and position of implants, the fibula transplant is positioned optimally as a bony support to the dental implant. Simplifying the transverse sections of the fibula as a triangle (Fig. 2.7a, b), the implants can be placed at the bone surface between the anterior and posterior intermuscular septum or at the edge of the anterior intermuscular septum. Here sometimes a flattening of the bony edge is necessary to avoid thread exposures of the implant. Another way to avoid bone covered dental implant threads when inserted in oblique bone eminence profile is the use of implants, which have machinized implant shoulders. This provides an implant platform equal to the bone border at one side without uncovered implant threads at the other side.

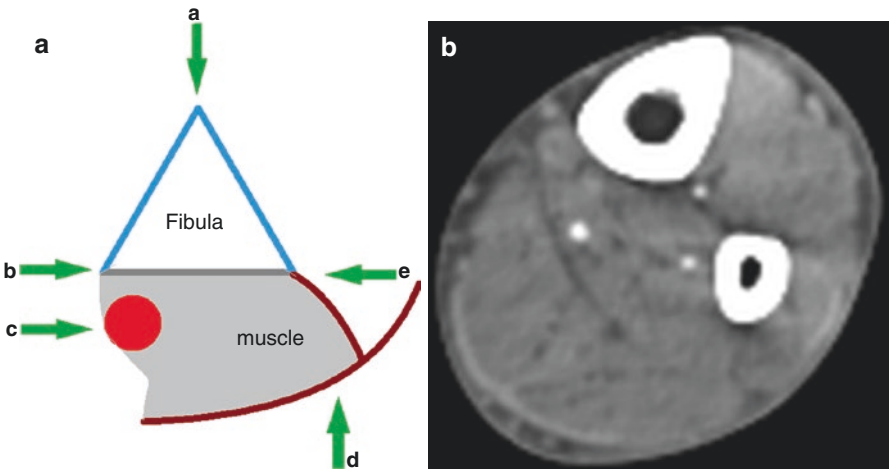

Fig. 2.7 (**a**) This scheme presents the topographic relationship of the pedicle, the skin paddle, and the septa (**a**: anterior intermuscular septum; **b**: interosseous membrane; **c**: peroneal vessels; **d**: skin paddle; **e**: posterior intermuscular membrane). Implants could be placed permeably at the blue bone sites, mainly in between the anterior and posterior intermuscular septum. (**b**) Contrast CT scan of the vessel in the leg

2.4.2.4 Planning of Individual Subunits

There are different ideas about the number of fibula fragments possible ([42]). One limiting factor is the length of each fragment, which should not be shorter than 1.5 cm. For the mandible, the condylar part including the condylar joint needs one fibula segment; the corpus needs two segments, to achieve a physiologic mandibular bending. The chin region can be reconstructed by one fragment supporting the region in between the canines. Although this geometry supports the mandibular anterior teeth in a favorable way, it could create a prognathic chin relation. Therefore, some surgeons prefer a triangular reconstruction.

For fibula transplantation, the double-barrel techniques or vertical augmentation techniques are sometimes applied to achieve a higher mandible, especially in the chin region. To form a double-barrel fibula, one must differentiate between fibula transplantation with and without a skin paddle. Understanding the fibula as a triangle in transversal sections (Fig. 2.7a, b), it is ideal to use the bone surface in between the intermuscular septa and the bone surface toward the extensor muscles for folding and attaching to each other. The way of folding influences the length of the pedicle and fibula bone segment that is needed to be removed to prevent tension or kinking of the pedicle. If the skin paddle is not planned to be harvested, parts of the surface near the flexor space can also occasionally be used for bone adaptation (Fig. 2.8a, b).

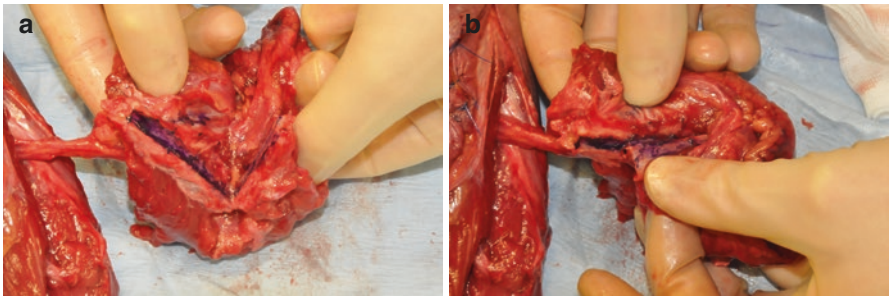

Fig. 2.8 In this human cadaver model, the close relationship of pedicle and skin paddle of the posterior intermuscular septum is shown. The double barrel can be performed by adapting (**a**) the areas in between the intermuscular septa to each other, or (**b**) adapt the area in between the intermuscular septa to the area in between the anterior intermuscular septum and the interosseous membrane

2.4.3 Transfer into the Surgical Site: Workflow for Execution of Planning in Maxillofacial Reconstruction

CAD planning could be performed virtually or manually by using 3D models of the patient's skull. These skulls are manufactured through stereolithography or recently through 3D prototyping. In all methods, the basic principles are the same. The surgeon resects the infiltrated bone segments of the printed skull and reconstructs the defect by modifying, sawing, and finally adding the printed transplants. In certain situations, when access to steriolithography or CAD CAM solutions are not available, either due to infrastructure or time constraints, a crude method of planning can be carried out using dentures and dental casts. The execution of the planning methods for reconstructive surgery can be classified according to increased accuracy and reproducibility as the following three methods:

1. Denture and cast-based inverse planning (referred to as Jugaad technique)
2. Usage of RPT/STL models that serve as preoperative planning models
3. Complete virtual planning and CAD CAM solutions

2.4.3.1 Denture-Based Inverse Treatment Planning (The Jugaad Technique)

The Jugaad technique is a useful method to plan for maxillofacial reconstructions in resource-limited settings. It is not highly accurate but is a "good enough" solution for planning. The advantage is that it is a low-cost method, which relies on the use of commonly available dental materials without the need for specialized equipment. In principle, the technique relies on fabrication of interim dentures made on altered dental casts that have undergone mock surgery. Detailed descriptions of the steps are as below.

For the preoperative planning, impressions of the maxillary and mandibular arches are made with an appropriate impression material. Two sets of casts are then fabricated, one which serves as the study model and the other as a working model.

Jaw relations are recorded and transferred onto an adjustable articulator. With the working casts mounted in the correct position, mock surgical resection of the cast is carried out. This mock surgery is done in communication with the ablative surgeon and should correspond as much as possible to the defined surgical plan. The accuracy of the resection should at least correspond to the removal of the dental units planned.

A preformed triangular bar with width of approximately 1.2 cm and length corresponding to the requirement is made from acrylic or any suitable material. This performs as an analog to the fibula. This fibula analog is then placed in relation to the resected cast in such a way as to provide an ideal base for the support of dental rehabilitation. Once the position of the fibula analog is decided, it is attached onto the altered cast using multiple layers of sticky wax or putty impression material. With this position of the fibula analog as the base, a wax-up of the denture base is created and teeth arrangement done according to the occlusion of the opposing arch.

To accommodate for the soft tissue thickness between the fibula and the denture base, attention is paid to provide a relief of about 3 mm. If a skin paddle is planned that would replace the intraoral lining, a larger relief is provided. Using multiple layers of modeling wax can predictably provide this relief. As it is difficult to predict the soft tissue outcomes that would present immediately post reconstruction, especially in terms of vestibular space, the soft tissue flange extensions of the wax-up of the interim denture is kept minimal.

Once the wax-up denture seems to be arranged in a functionally ideal position, it is then acrylized by the lost wax technique. The acrylized denture is then reintroduced onto the mounted altered cast with the fibula analog, and the positions of the implants are planned. Once again, the position of the fibula analog is checked and reconfirmed to be in a functionally ideal position. Drill holes corresponding to the positions of the implants are introduced into the denture to pass through the fibula analog. Additionally, it is convenient to provide some means by which the surgical stent can be attached onto the remaining dentition (or the opposing dentition), either with wire holes or clasps or denture hooks. This denture will now serve as the surgical stent that will guide the position of the fibula in the oral cavity. This interim denture is kept ready for surgery.

During the surgery, the resection is carried out adhering onto the previously decided surgical plan. The denture stent is then wired onto the remaining part of the jaw (or attached to the opposing jaw teeth in cases where it is not possible to attach the stent onto the remaining jaw). The fibula bone is harvested and the required osteotomies carried out. The fibula is then introduced into the recipient site. The denture stent now determines the position of the fibula bone. The fibula bone is manipulated till it assembles in the preoperatively determined position that is ideal for functional rehabilitation. Once it is in this place, it is plated with osteosynthesis plates and screws.

Through the implant drill guides incorporated in the interim denture stent, implant drill osteotomies are made into the underlying fibula. The denture stent is then removed and the implant is inserted as per manufacturers' protocol. It may be useful to use an implant that is provided with an implant carrier, as the position of the implant (and the interim denture) can be confirmed by placing the interim denture back on through the implant carrier. This now confirms that the position of the fibula is ideal to result in a functional rehabilitation.

Although not exact, this technique provides reasonably predictable functional outcomes. This technique can be considered as the most basic form of planning for maxillofacial reconstructions. This technique is useful in settings where there is limited access to high-end software and equipment. The cost incurred for planning is also minimal and hence will be of use in countries where health insurance does not cover the costs of planning for reconstruction and rehabilitation, and the patients cannot afford to pay individually for the treatment.

The disadvantages of this method are that it does not provide a resection splint or a cutting splint for the donor and recipient sites. A lot is still left to the imagination and coordination between the resection, reconstruction, and rehabilitative teams. This method only provides a reconstruction that can favor a functional outcome.

A representation of a case study using this method is shown in Case Study 2.1.

2.4.3.2 Model-Based Planning

The execution technique as described above is usually substituted by CAD/CAM techniques. The introduction of rapid prototyping and stereolithography models give haptic planning tool into the surgeons' hands.

This model-based planning uses 3D printouts of the skull and the transplants. First, the prostheses are placed in the right position. And a gingival mask is manually adapted to the alveolar parts of the jaw. The bone models are resected according to the tumor infiltration and the planned resection lines. The bone model of the donor bone is cut to fit into the defect and positioned to support the implants. Care has to be taken that the fragments are not too close (distance of 2–5 mm) to avoid the stretching of the pedicle. Silicone or wax is useful to connect the fragments. For manufacturing the cutting guide, the transplant fragments are put back into a negative form of silicone that has been produced before modification of the transplant bone. Repositioned into the original, straight form, the cutting planes from plastic or metal sheets help to get a handmade cutting splint from resin or metal (Rohner, Techiker).

All these planning efforts could provide a cutting and implant drilling guide to mold the donor bone transplant for maxillofacial reconstruction. Furthermore, the correct positions of the transplant as well as the original bone parts are necessary, especially if the condyle is malpositioned. CAD planned osteosynthesis plates help to coordinate the position of the transplant and the original bone. The correct positions of the plates are indicated by an osteosynthesis screw-drilling guide, which is combined with the resection splints. Additionally to the CAD plate and cutting splint, a CAD dental prosthesis could be fixed on the implants, which are inset in the transplant, to indicate the form of the transplant as well as its position in relation to the antagonistic jaw.

The dental implantation could be done immediately, as already described, or secondarily after the healing period. In contrast to the conventional implant placement, secondary dental implant planning after reconstruction by a fibula flap needs auxiliary implants to fix an implant drilling guide, because the alveolar crest is not high enough to give hold for fixation. The workflow starts with the marking of the prosthesis by radiopaque pins or radiopaque material. The prosthesis is fixed on the auxiliary implants in habitual occlusion and a CT scan is taken. If marked by radiopaque pins, a second scan of upper and lower prosthesis in occlusion is mandatory, because PMMA prostheses are not visible by a CT scan of the bone, while they are

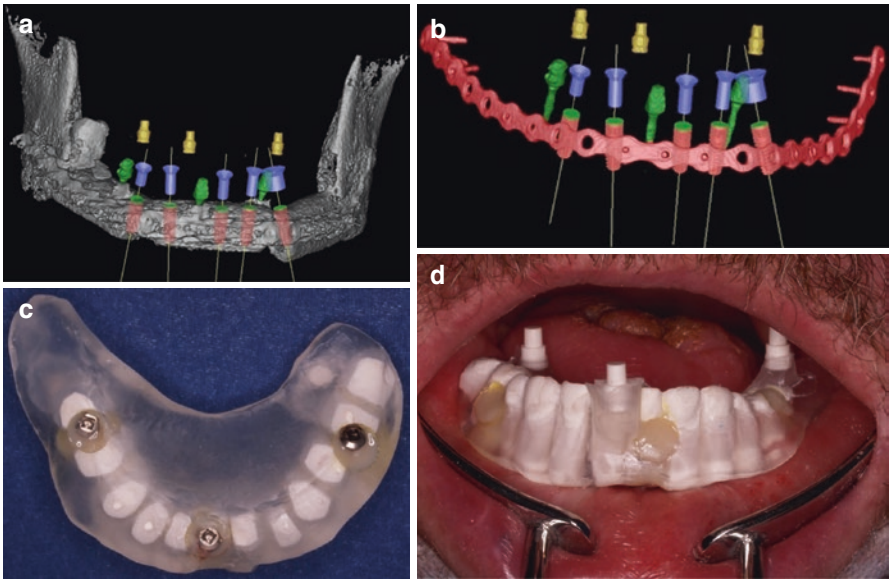

Fig. 2.9 (**a**, **b**) This CT scan of a fibula reconstruction, including auxiliary implants, demonstrates the close relationship of the hardware of implants, screws, and osteosynthesis plates. (**c**, **d**) The implants are positions by an implant drilling guide, which is fixed on the auxiliary implants (F. P. Koch & S.Wentaschek, Univ. Frankfurt a.M. & Mainz, Germany)

worn by the patient. The data of the externally and internally scanned prostheses are virtually matched to plan the implant positions (Fig. 2.9a, b). The implant drilling guide, which can then be converted from the former prosthesis, is fixed on the implants. After implant placement, the auxiliary implants could be kept to fix an interim prosthesis, till the definitive prosthesis is connected to the osseointegrated dental implants after 3–6 months. At that time, intraoral soft tissue management is carried out. The dental prosthesis helps in the procedure of soft tissue correction.

Case Study 2.2 shows a representation of a case done with this method.

2.4.3.3 Virtual-Based Planning of Reconstruction

The virtual reconstruction plan includes the same steps as described for the model-based planning, but done virtually on a computer instead of physical models.

The first step defines the basis that needs to be reconstructed, including bone fragment and condyle positioning. Case study 2.3 is taken as an example to show this technique. Case 2.3, a case of ameloblastoma of the upper jaw, the correction of the zygoma was necessary, as it has been deformed by a slow growing ameloblastoma. The surgical plan guided the osteotomy of the lateral orbital rim and the zygoma rotation. To do so, the healthy side was mirrored first. The cutting plane is transformed into a cutting splint. Accordingly, step 2 and step 3 of the reconstruction of the defect were analyzed in relation to which areas could be reconstructed by alloplastic material and which areas need a microvascular bone and soft tissue reconstruction.

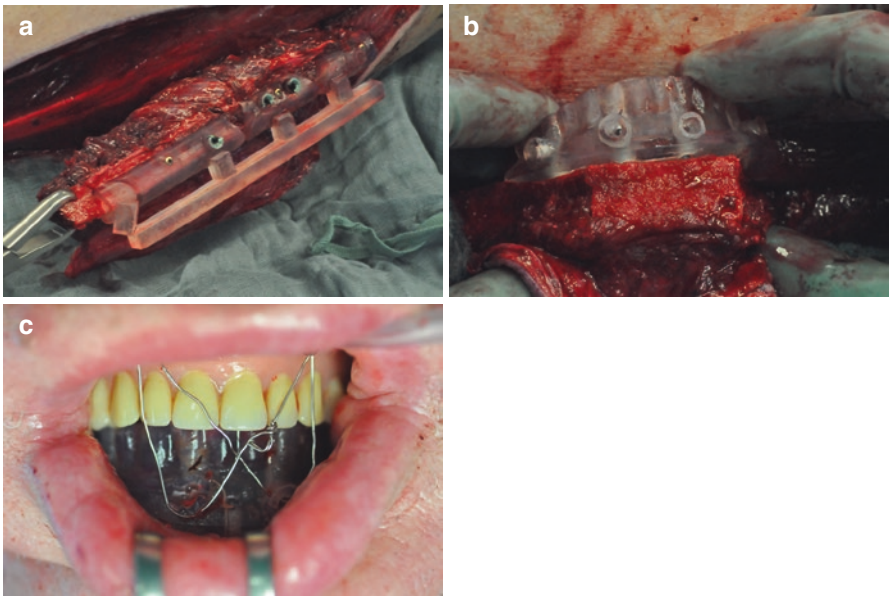

Fig. 2.10 (**a**) The CAD/CAM cutting and dental implant drilling guide is fixed on the fibula, which stays perfused during sawing and implant placement. (**b**) The CAD/CAM is preplanned, and CAD/CAM-printed prosthesis fits exactly on the new fibula situations and helps to mold the cited fibula. The prosthesis includes the implants and is virtually adapted on the surface of the fibula. Now the fibula is transferred to the facial site and (**c**) inserted in a correct intermaxillary position by mandibulomaxillary fixation (planning and production by IndividualPlan GmbH, Wiesbaden, Germany)

Then the type of flap was chosen (in this case, a free fibula flap), the orientation of skin paddle and pedicle were planned, avoiding the compression by bony edges (Table 2.2).

Then the prosthesis or dentition before resection indicates the teeth and dental implant position. In edentulous patients, prostheses of radiopaque material or prosthesis, which had been marked by radiopaque pins to match a second scan of the prostheses, gave an idea of dental implant positioning and positioning and rotation of the bone transplant.

The molding of the fibula was supported by CAD preformed reconstruction and osteosynthesis plates, which were positioned by positioning splints and drill holes. The positioning of the transplant to have a correct occlusion is indicated by a 3D-printed prosthesis, which fits exactly on the virtually planned CAD fibula (Fig. 2.10b, c). The cutting planes and implant positions are virtually transferred to the straight fibula, and the cutting and implant-drilling splint could be designed and finally printed directly (Fig. 2.10a).

The complete virtual CAD/CAM planning solution provides a cutting/implant drilling splint, resection/positioning splint for reconstruction plates, and a CAD/CAM prosthesis, indicating the form of the fibula and position of transplant. In combination with implants and preformed osteosynthesis plates, there are several

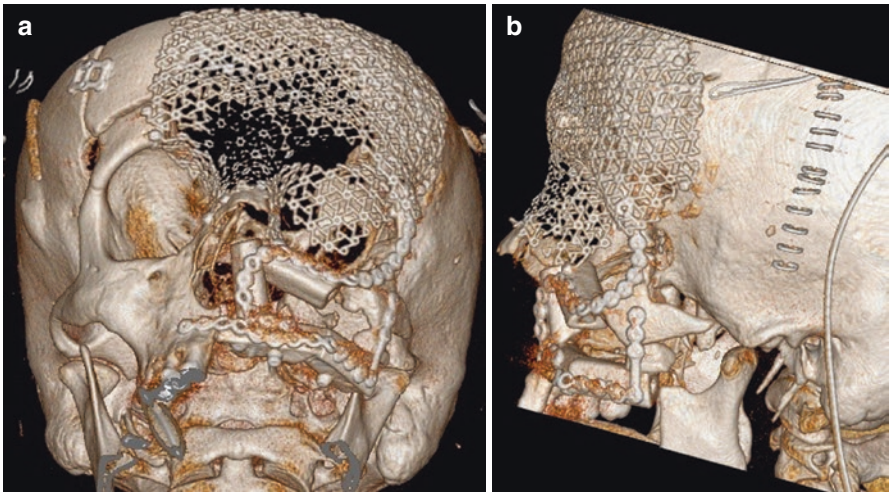

Fig. 2.11 (**a**, **b**) The complexity of an virtual planned osteotomy and repositioning of zygoma, combined with three CAD/CAM titanium implants for the orbits and frontal skull as well as a 3D molded fibula fixed with CAD preformed osteosynthesis plates is presented by case 2.4. The fibula was cut and the dental implants simultaneously inserted by a CAD/CAM cutting and implant guiding splint

tools to transfer the planning into the surgery site. The complexity of a virtual planned osteotomy and repositioning of a zygoma, combined with three CAD/CAM titanium implants for the orbits and frontal skull as well as a 3D molded fibula fixed with CAD preformed osteosynthesis plates is presented in Case Study 2.4. The fibula was cut and the dental implants simultaneously inserted by a CAD/CAM cutting and implant guiding splint (Fig. 2.11a, b).

Case 2.1 This case illustrates the workflow when planning a case with denture-based inverse treatment planning (Jugaad technique). A boy of 14 years presented with a case of failed reconstruction done at another center. The intraoral picture is shown in Fig. 2.12a and the panoramic radiograph findings shown in Fig. 2.12b. As the patient was not able to afford CAD CAM-based reconstruction, it was decided to treat him using the Jugaad technique.

Preliminary and working casts were made from the impressions of the patient. Jaw relations were recorded and transferred onto an adjustable articulator. Mock surgery of the cast was done on the articulator and a fibula analog made of acrylic was oriented in such a way as to provide the best functional reconstruction. A wax model of the reconstructed dentition was fabricated on the fibula analog as shown in Fig. 2.13. This was then acrylized and served as the intraoperative guide. Holes were drilled into the acrylized stent corresponding to the ideal positions of the implants. These will serve as the intraoperative guide for implant positioning.

The surgery was performed as per plan. After harvesting the fibula, it was inserted into the defect as per the orientation defined by the acrylic splint. Drill guides in the splint defined the position of the implants as shown in Fig. 2.14. The postoperative panoramic radiograph shows the resultant reconstruction achieved (Fig. 2.15).

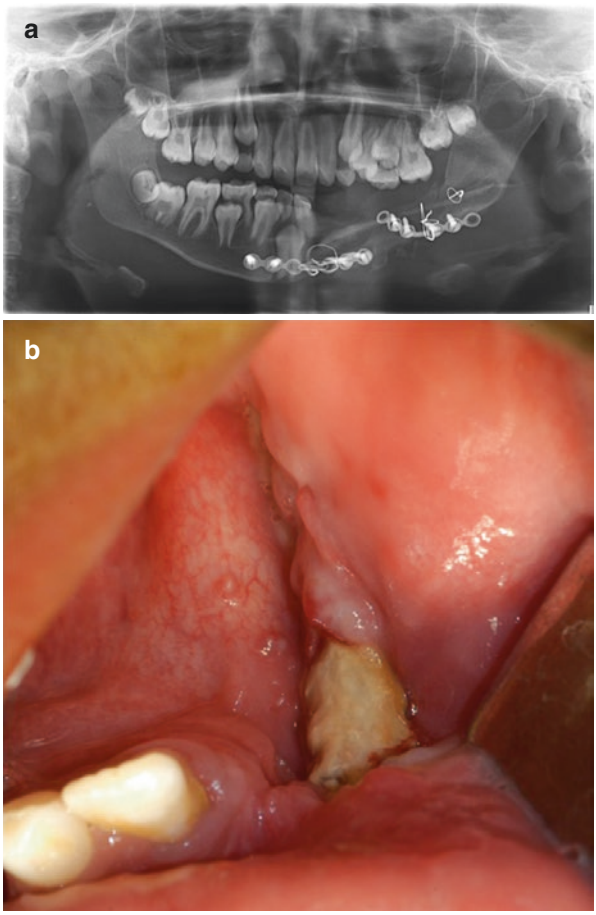

Fig. 2.12 (**a**, **b**) Preoperative panoramic radiograph and oral aspect

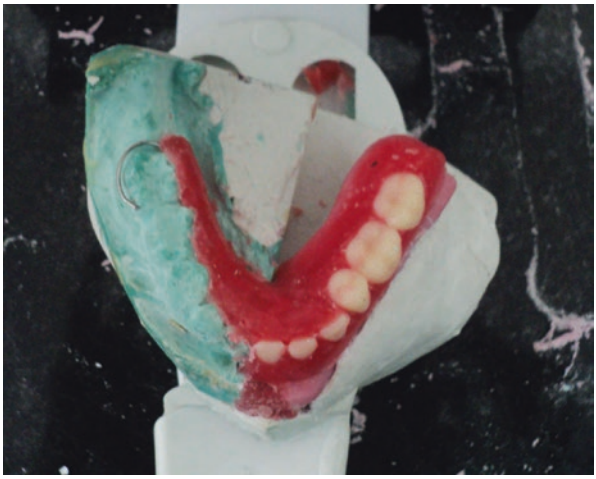

Fig. 2.13 Mock surgery of the cask in the articulator, a wax model was fabricated on the fibula

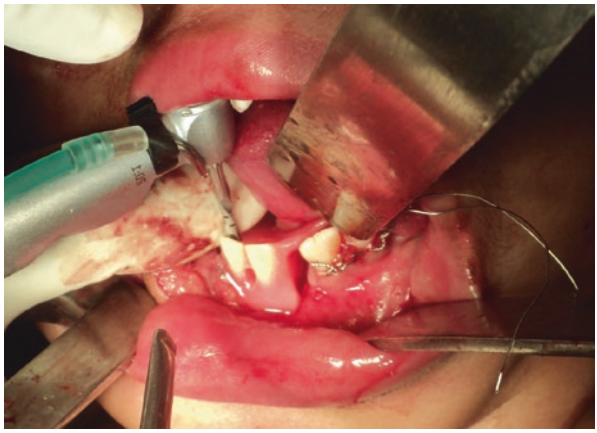

Fig. 2.14 Implant drill guide for implant placement after the fibula was transferred

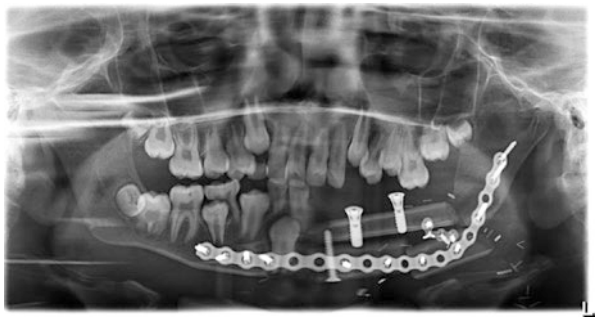

Fig. 2.15 Postoperative panoramic radiograph

Case 2.2 In this 44-year-old patient, a T4aN1M0 squamous cell carcinoma was resected 1 year ago and primarily reconstructed by a reconstruction plate by titanium. Additionally he has received an irradiation of 70 Gy. After 1 year, the reconstruction plate was perforating the skin.

Before reconstruction by a microvascular fibula transplantation, a CT scan of the face and the fibula was performed. From these data, a model was prototyped to perform a model-based CAD planning.

1. As the condyles have been in place and the mouth opening was possible, the condylar positions did not need to be corrected. A prosthesis was manufactured and adapted to the upper dentition (Case 2.2 Fig. 2.16).
2. Now the orientation of the fibula was decided. As the pedicle should be anastomosed at the right neck side and the skin paddle was orientated to the buccal side, the right fibula was chosen.
3. The prosthesis was inserted into the printed skull by maximal intercuspal occlusion. Then the condyles were fixed by silicone, before removal of the reconstruction plate (Case 2.2 Fig. 2.17). The fibula model was now inserted into the skull, shortened and trimmed to get a maximum bone segment contact (Case 2.2 Fig. 2.18). The teeth positions of the prosthesis were taken to indicate the

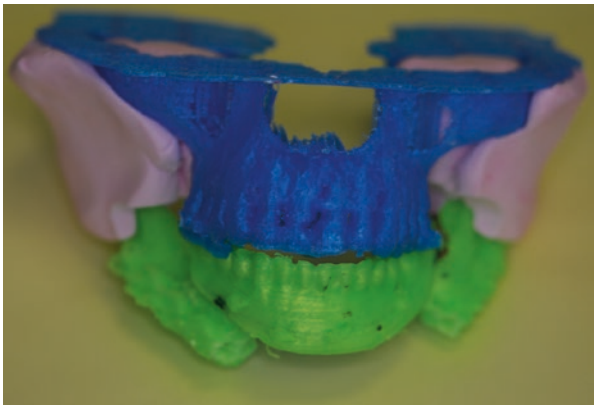

Fig. 2.16 Insertion of the dental prostheses into the printed skull

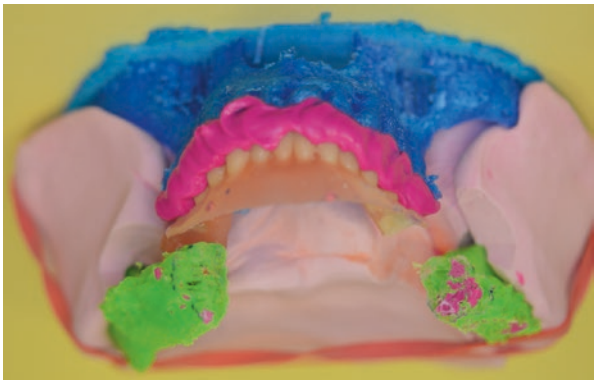

Fig. 2.17 Fixation of the condyles in correct position through dental prosthesis

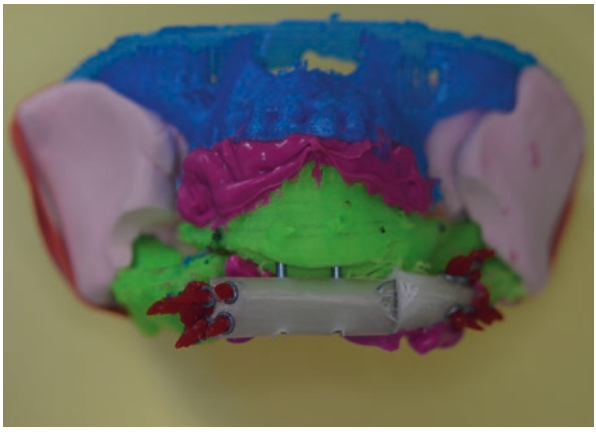

Fig. 2.18 Inset of the cutted fibula by silicone and wax

dental implant positions (Case 2.2 Fig. 2.19). The region dorsally of the anterior intermuscular septum was planned for implant drilling. The fibula segments were taken out and cutting planes were attached and linked to each other. These cutting planes were fixed to another straight fibula to produce manually a cutting guide from resin (Case 2.2 Fig. 2.20).

In this case, the fibula was preformed 6 weeks before transplantation by split skin graft transplantation (Case 2.2 Fig. 2.21), dental implants have been placed, and dental impressions were taken to mill a dolder bar for immediate loading and external fixation, at the time the fibula was transplanted (Case 2.2 Fig. 2.22a, b). The dolder bar helped to mold the fibula (Case 2.2 Fig. 2.23) and the fixed prosthesis helped to orientate it before osteosynthesis (Case 2.2 Fig. 2.24a, b).

Case 2.3 A 54-year-old patient presented with a total loss of the mandible including the floor of the mouth. Five years ago, a squamous cell carcinoma has been diagnosed and primarily treated by a radiation of 72 Gy combined with a cisplatin/5-FU chemotherapy. Three years ago an osteoradionecrosis occurred, followed by a partial resection of the mandible and finally a near total resection. The defect was reconstructed by a titanium plate, which has been covered by a pectoralis major flap. Due to flap necrosis and wound dehiscence, the patient could not keep the saliva, because he lost not only the mandible but also the floor of his mouth (Fig. 2.25a, b).

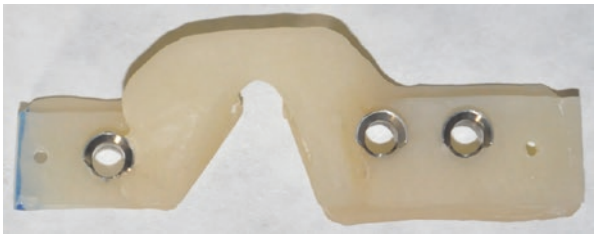

Fig. 2.19 The dental positions were planned and fixed to the fibula segment, and the cutting planes were defined

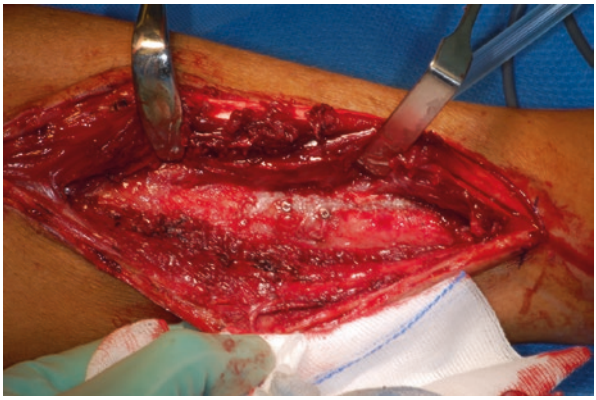

Fig. 2.20 Based on the implant position and the fibula cutting planes, a cutting/implant drilling splint was manufactured by resin

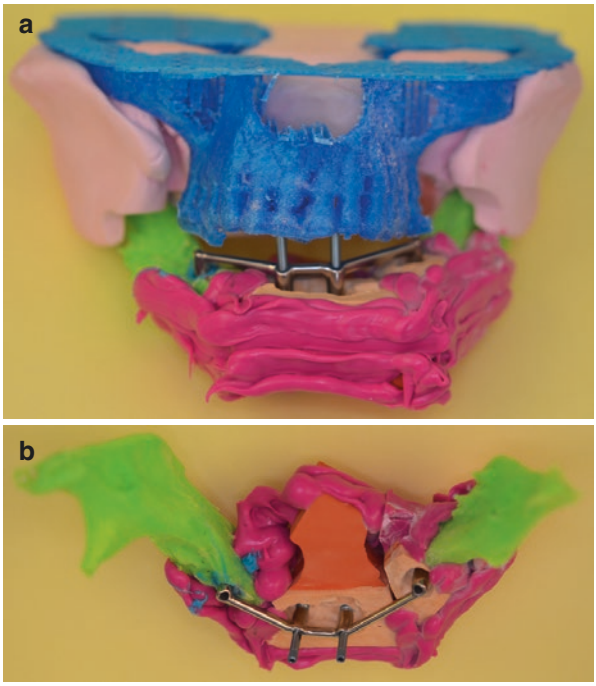

Fig. 2.21 Prefomed fibula surface after split skin was adapted to the periosteum 6 weeks before

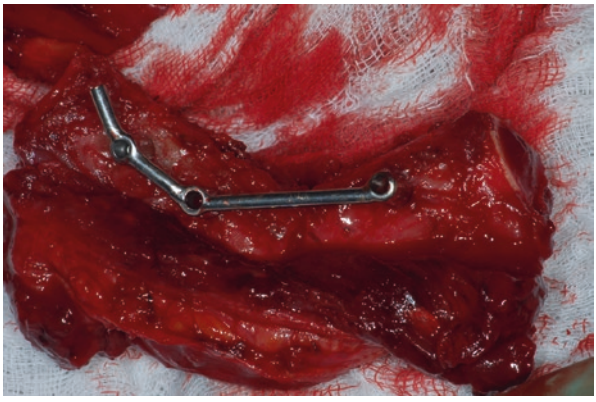

Fig. 2.22 Titanium dolder bar, which had been preoperatively milled. The implant positions have been defined by implant impressions taken during the gingival prefabrication surgery

The planning started with the virtual resection of the remnant mandibula, to achieve a defined bone edge and avoid residual osteomyelitic bone areas. Then the condyles have been matched with a CT reconstruction before resection. The upper and lower jaw teeth had been inserted virtually and dental implants were placed according to prosthetic function (Fig. 2.26a, b).

As the skin paddle is needed to reconstruct the submental region and the pedicle was orientated to the right side, the fibula was taken from the right leg (Table 2.1).

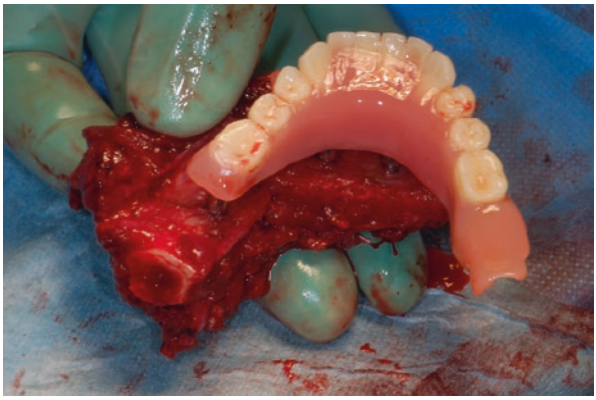

Fig. 2.23 A prosthesis has been manufactured

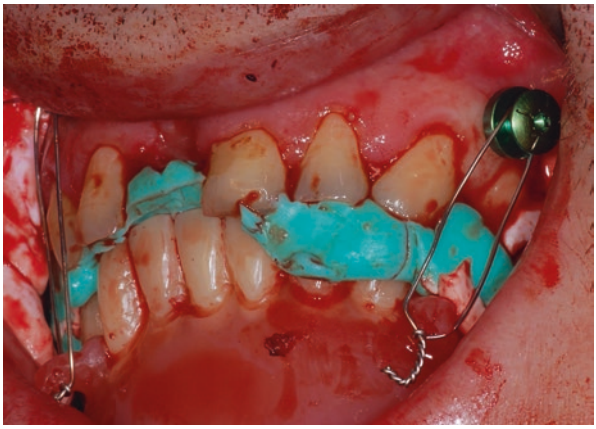

Fig. 2.24 The fixed prosthesis helped to orientate it before transplantation and saved ischemia time

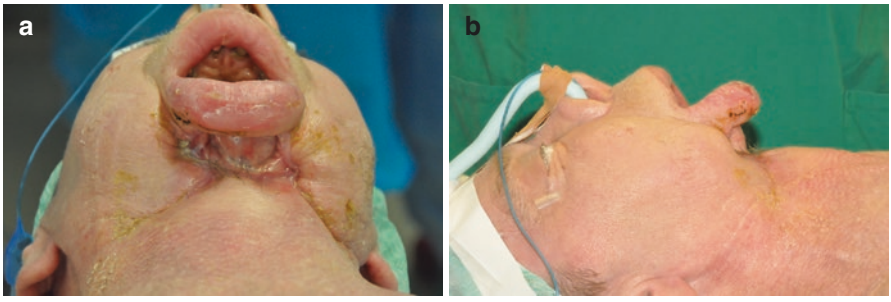

Fig. 2.25 (**a**) Submental and (**b**) lateral view

The resection splints and the fibula cutting/implant drilling splint were CAD/CAM produced (Fig. 2.27a, b). To avoid additional osteosynthesis hardware and to facilitate the fibula molding a fixateuere externe was printed and fixed by 2 mm screw additionally to the dental implant fixation by resin and temporary abutments (Fig. 2.28a, b).

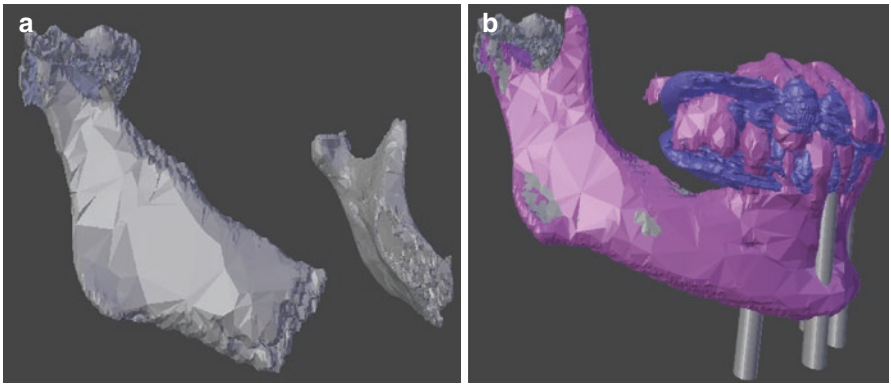

Fig. 2.26 (**a**) Remnant mandible; (**b**) repositioning of the mandible by superimposing the former mandible before resection, superimposing the prosthesis and inserting implants virtually

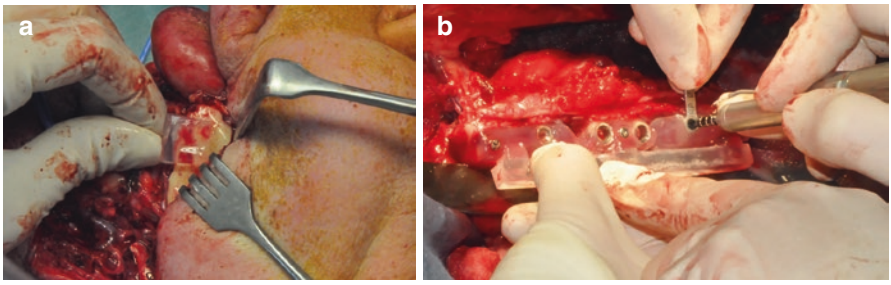

Fig. 2.27 (**a**) The resection splint defines the remnant mandible size; (**b**) the cutting and implant drilling guide (IndividualPlan GmbH, Wiesbaden, Germany)

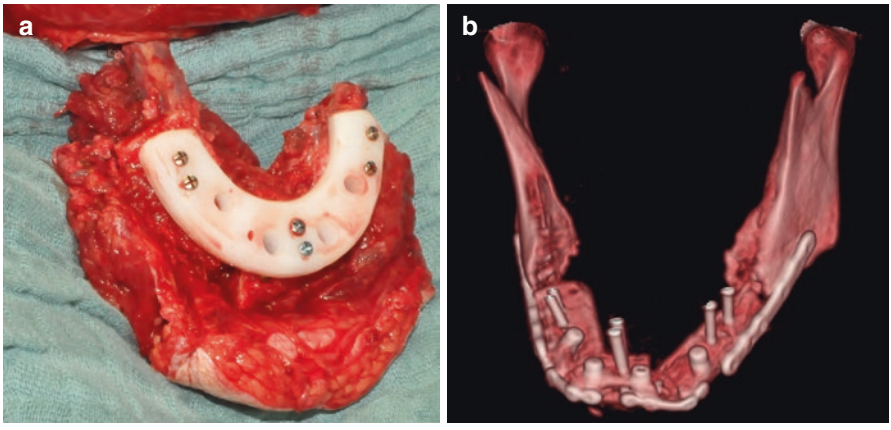

Fig. 2.28 (**a**) A CAD/CAM external fixator to position the implant and mold fibula. (**b**) CT reconstruction of the surgery result

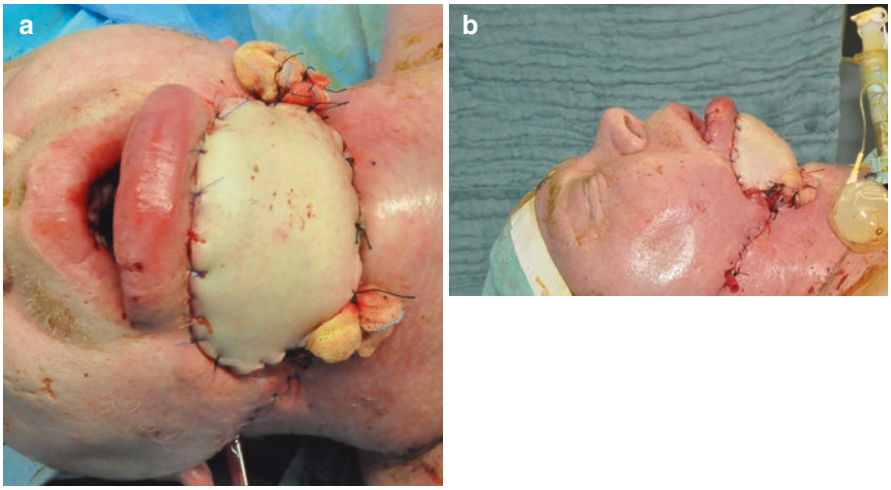

Fig. 2.29 (**a**) Submental and (**b**) lateral view after surgery

Finally the floor of the mouth as well as the mandible including dental implants was reconstructed within one surgery (Fig. 2.29a, b).

Case 2.4 A 57-year-old patient presented with a tumor mass involving the right palate, the right maxilla, the nasal cavity, the complete left orbit, and parts of the right orbit, as well as the skull base and the frontal sinus and parts of the anterior cranial fossa (Fig. 2.30).

An ameloblastoma had been removed 11 and 4 years ago. A tissue sample was collected and analyzed by histopathology. The pathology evaluation confirmed the diagnosis of an ameloblastoma recidive. The treatment options of radiation and surgery have been discussed with the patient and his family. They favored the curative, surgical approach of resection and reconstruction. As the tumor involved the anterior cranial fossa and the skull base and touched the internal carotid artery, the department of neurosurgery was involved in the case. The complex reconstruction was supported by IndividualPlan GmbH, a specialized German company.

1. The first planning step included the resection. The frontal sinus, parts of the orbits, the left eye, and the nasal bone were included. The tumor had dilated the left orbit (Fig. 2.31a). So the right facial side was mirrored to achieve a symmetric appearance again (Fig. 2.31b) and an osteotomy of the zygomatic bone was planned to readjust the orbits (Fig. 2.31c).
2. Having defined the resection defect and facial bones after inward rotation of the left zygoma, the reconstruction was planned. The aim was to achieve a symmetric appearance, the closure of the open palate, and the functional rehabilitation by dental implants. A combination of CAD titanium implants and autologous vascularized as well as nonvasularized fibula transplants need to be applied. The frontal parts of the skull, nasal and orbital bones had been reconstructed by CAD titanium implants (Fig. 2.32; IndividualPlan GmbH, Wiesbaden, Germany). The

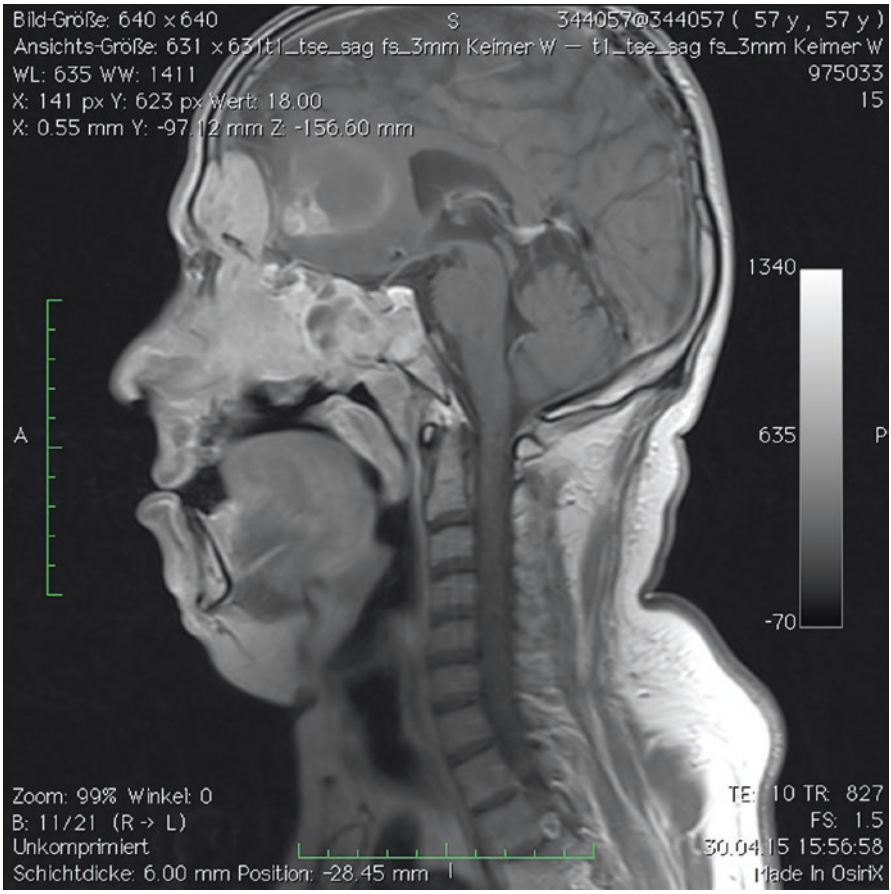

Fig. 2.30 Sagittal MRI scan, showing the extent of the ameloblastoma, affecting the maxilla, the cavum nasi, the orbits, skull base, and the anterior fossa

left maxilla, palate, and eye were reconstructed by microvascular fibula transplantation. Dental implant for later functional rehabilitation has been included in the planning. A nonvascularized bone transplant replaced the infraorbital rim (Fig. 2.33). To cover the palate, the skull base, and the left orbit after enucleation of the left eye, the fibula skin paddle was taken. The pedicle was planned to the left side to be anastomosed to the facial vessels, after the temporal vessels had been damaged by previous operations. As the skin paddle was needed to the palatinal part, the left fibula was taken.

3. All the planning was performed completely virtual. The resection splints, drilling guides for the osteosynthesis screws, and the CAD preformed osteosynthesis plates, as well as the CAD titanium meshes for the frontal bone reconstructions, were CAD produced. The CAD/CAM fibula cutting splint included an implant drilling guide to mold the fibula and insert prothodontically functional dental implant for the frontal teeth as well as the first left premolar.

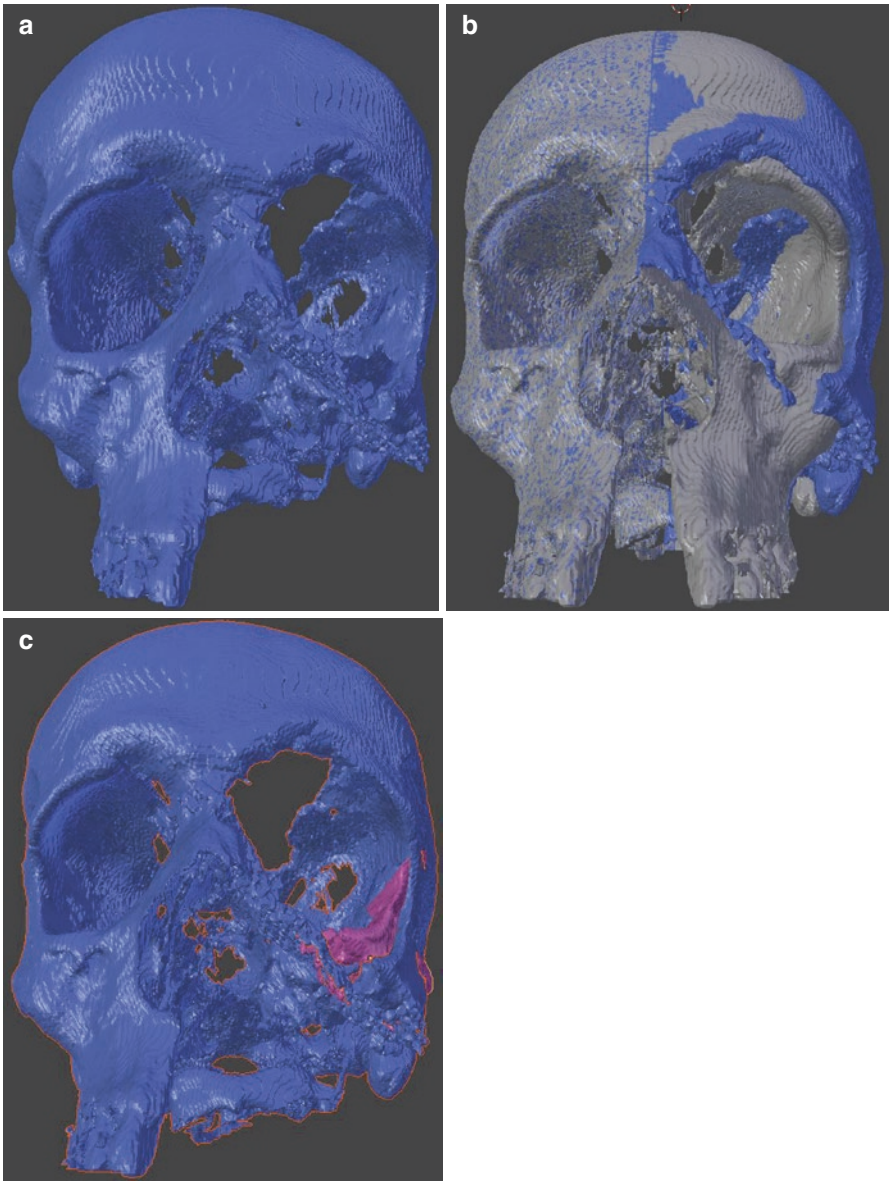

Fig. 2.31 (**a**) The slowly growing tumor dilatated the left orbit and displaced the lateral orbital rim; (**b**) therefore the right facial side was mirrored and shows clearly the discrepancy. (**c**) By an osteotomy of the left lateral orbital rim, the orbits were assimilated (IndividualPlan GmbH, Wiesbaden, Germany)

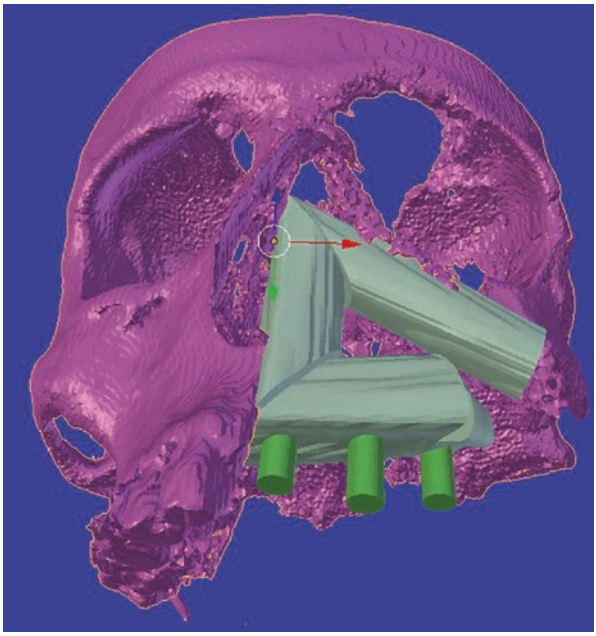

Fig. 2.32 The maxilla was reconstructed by a microvascular fibula flap, with dental implants and a skin paddle to cover the palate, the skull base, and the left orbit

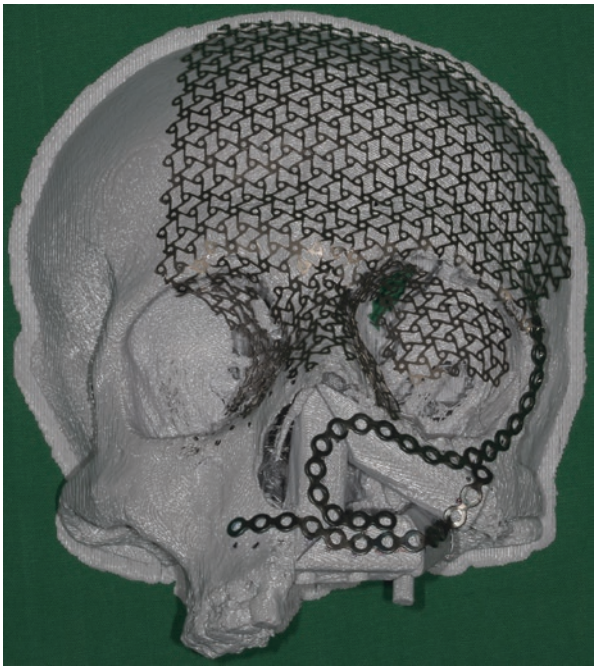

Fig. 2.33 Rapid prototyping of the defect reconstruction including dental implants and CAD titanium implants

The resection was done in two steps: first the resection of the tumor parts of the anterior cranial fossa and two weeks later the resection and reconstruction of the facial and skull base parts were performed. Due to a close relationship to the internal carotid arteries, the resection demanded an intraoperative stereotactic navigation (Department of Neurosurgery, Goethe University Frankfurt). The facial en bloc resection demanded a Dieffenbach-Weber approach as well as coronal incision (Fig. 2.34a–d). For symmetry of the orbits, the zygoma was osteotomized by a CAD/CAM cutting splint and repositioned. The fibula was molded at the leg part by the sawing splints in order to keep ischemia time less than 60 min. Also the dental implants were inserted and the

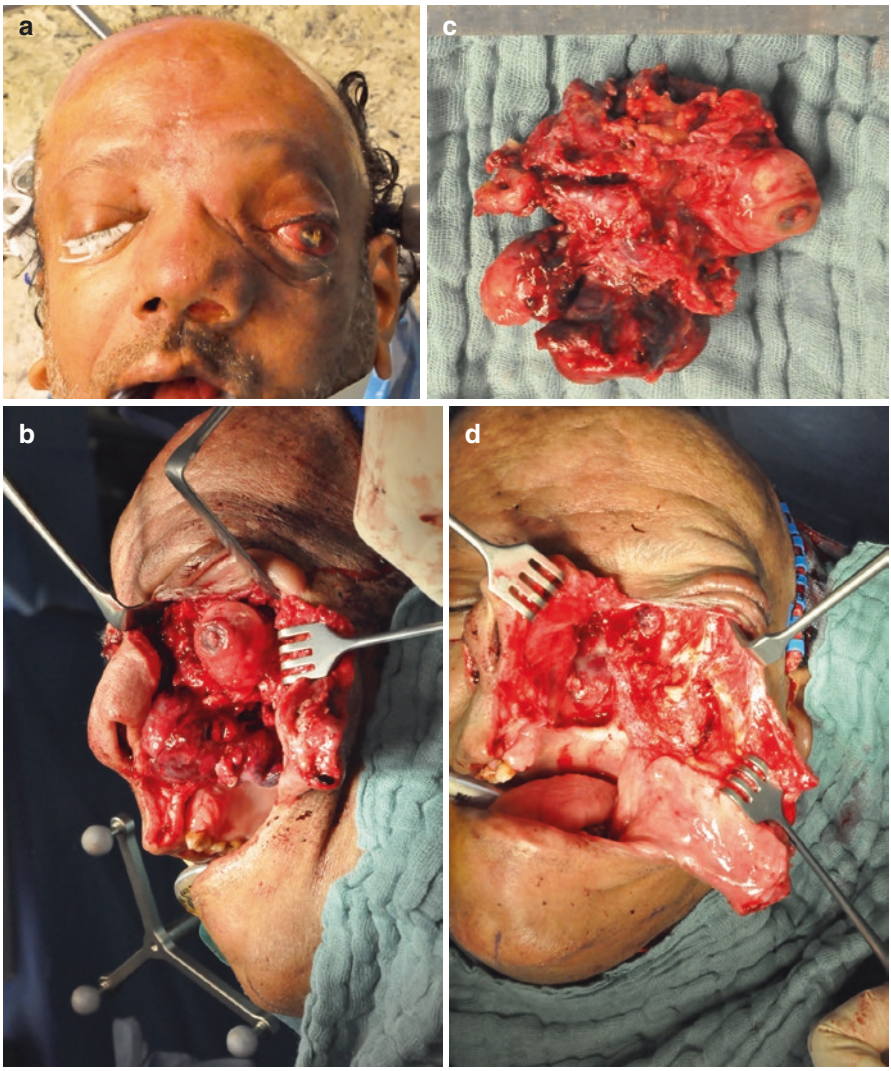

Fig. 2.34 (**a**) The ameloblastoma of the cavum nasi, the right/left orbits including the left eye and the anterior fossa were resected through a Dieffenbach-Weber and a bicoronal access and resected en bloc (**b**, **c**). The huge defect was covered by a CAD/CAM molded transplant (**d**)

preformed osteosynthesis plates were fixed while the fibula kept being perfused (Fig. 2.35a, b). To keep a sufficient pedicle length, the infraorbital rim has not been included in the microvascular fibula part and the proximal fibula part was transferred as an avascular bone graft to the infraorbital rim, covered by the skin paddle and muscles. The frontal part of the skull and nose were reconstructed by CAD titanium mesh implants. Two more CAD implants reconstructed the medial wall of the right orbit and the cranial and lateral wall of the left orbit (Fig. 2.36).

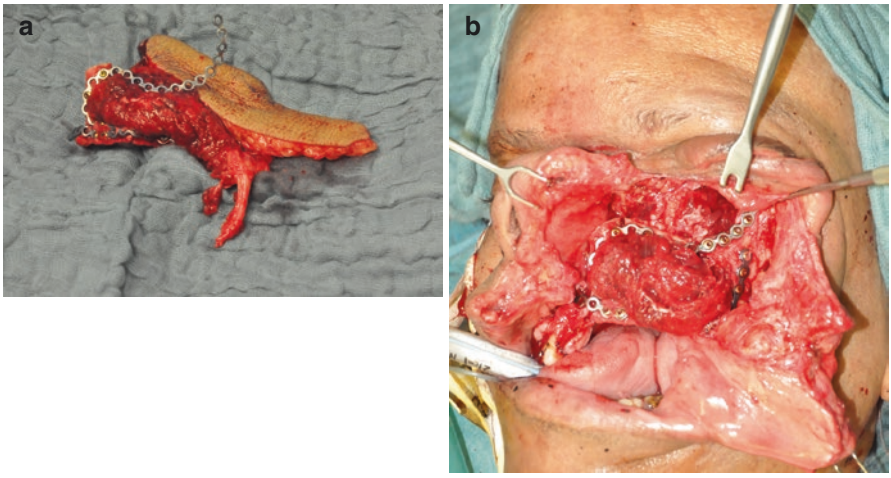

Fig. 2.35 By a CAD/CAM splint, the implant insertion and cutting of the fibula was performed (**a**). The CAD preformed osteosynthesis plates helped to orientate the fibula and kept the ischemia time low, because the molding took place during the fibula was still perfused in the leg; (**b**) The fibula was transplanted to reconstruct the upper jaw, the skin paddle was taken to reconstruct the palate, the epipharynx and the orbital floor

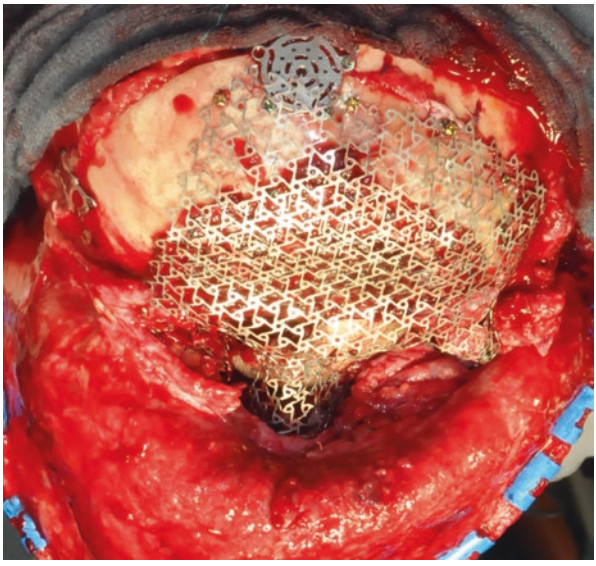

Fig. 2.36 CAD titanium implants reconstructed the frontal bone and the frontal sinus

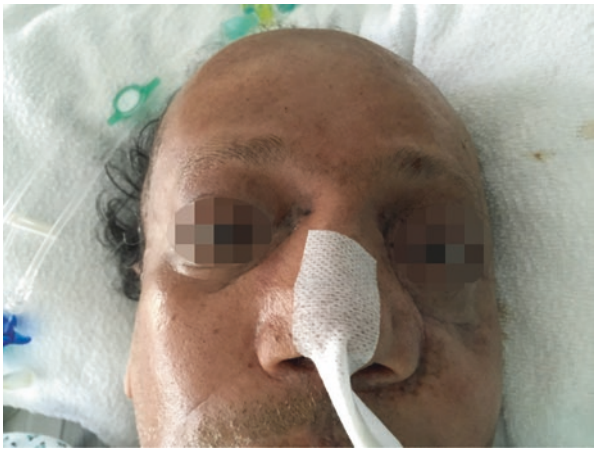

Fig. 2.37 Clinical aspect 4 weeks after surgery, including the artificial eye, individually adapted to the resection defect

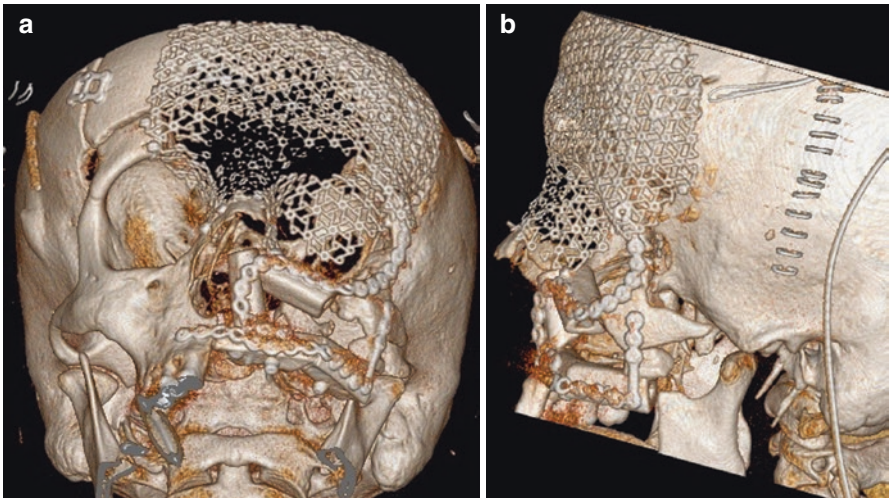

Fig. 2.38 3D reconstruction after surgery

After a reconvalescence of 4 weeks after surgery, an artificial eye was inserted and a blepharoplasty of the left lower eyelid was performed (Fig. 2.37). Figure 2.38 presents the surgery result by a CT reconstruction after surgery. Prosthodontic rehabilitation will take place 6 months of healing time after reconstructive surgery.

References

1. Albert S, Cristofari JP, Cox A, Bensimon JL, Guedon C, Barry B. Mandibular reconstruction with fibula free flap. Experience of virtual reconstruction using Osirix®, a free and open source software for medical imagery. Ann Chir Plast Esthet. 2011 Dec;56(6):494–503. doi: 10.1016/j.anplas.2009.12.008. Epub 2010 Jun 19. French.
2. Albornoz CR, Pusic AL, Reavey P, Scott AM, Klassen AF, Cano SJ, Cordeiro PG, Matros E. Measuring health-related quality of life outcomes in head and neck reconstruction. Clin Plast Surg. 2013;40(2):341–9. doi:10.1016/j.cps.2012.10.008.PMID: 23506775.
3. Baliarsing AS, Kumar VV, Malik NA, B DK. Reconstruction of maxillectomy defects using deep circumflex iliac artery-based composite free flap. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;109(3):e8–13.
4. Bidgood WD Jr, Horii SC, Prior FW, Van Syckle DE. Understanding and using DICOM, the data interchange standard for biomedical imaging. J Am Med Inform Assoc. 1997;4(3):199–212. Review.
5. Bodard AG, Salino S, Desoutter A, Deneuve S. Assessment of functional improvement with implant-supported prosthetic rehabilitation after mandibular reconstruction with a microvascular free fibula flap: a study of 25 patients. J Prosthet Dent. 2015;113(2):140–5.
6. Bolzoni A, Cappiello J, Piazza C, Peretti G, Maroldi R, Farina D, Nicolai P. Diagnostic accuracy of magnetic resonance imaging in the assessment of mandibular involvement in oral-oropharyngeal squamous cell carcinoma: a prospective study. Arch Otolaryngol Head Neck Surg. 2004;130(7):837–43.
7. Chang YM, Chan CP, Shen YF, Wei FC. Soft tissue management using palatal mucosa around endosteal implants in vascularized composite grafts in the mandible. Int J Oral Maxillofac Surg. 1999;28(5):341–3.
8. Cheung LK, Leung AC. Dental implants in reconstructed jaws: implant longevity and peri-implant tissue outcomes. J Oral Maxillofac Surg. 2003;61(11):1263–74.
9. Chiapasco M, Biglioli F, Autelitano L, Romeo E, Brusati R. Clinical outcome of dental implants placed in fibula-free flaps used for the reconstruction of maxillo-mandibular defects following ablation for tumors or osteoradionecrosis. Clin Oral Implants Res. 2006;17(2):220–8.
10. Ciocca L, Corinaldesi G, Marchetti C, Scotti R. Gingival hyperplasia around implants in the maxilla and jaw reconstructed by fibula free flap. Int J Oral Maxillofac Surg. 2008;37(5):478–80.
11. Ciocca L, Mazzoni S, Fantini M, Persiani F, Marchetti C, Scotti R. CAD/CAM guided secondary mandibular reconstruction of a discontinuity defect after ablative cancer surgery. J Craniomaxillofac Surg. 2012;40(8):e511–5. doi:10.1016/j.jcms.2012.03.015.
12. Dhima M, Rieck KL, Arce K, Salinas TJ. Development of stable peri-implant soft tissue and mentolabial sulcus depth with an implant-retained soft tissue conformer after osteocutaneous flap reconstruction. Int J Prosthodont. 2013;26(3):265–7.
13. Esser E, Wagner W. Dental implants following radical oral cancer surgery and adjuvant radiotherapy. Int J Oral Maxillofac Implants. 1997;12(4):552–7.
14. Fang W, Ma W, Ma WG, Li DH, Liu BL. A new submerged split-thickness skin graft technique to rebuild peri-implant keratinized soft tissue in composite flap reconstructed mandible or maxilla. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012;113(3):e4–9.
15. Ferrari S, Raffaini M, Bianchi B, Sesenna E. Secondary oro-mandibular reconstruction using revascularized bone flaps. Minerva Stomatol. 1998;47(3):75–85.
16. Fingeret MC, Vidrine DJ, Reece GP, Gillenwater AM, Gritz ER. Multidimensional analysis of body image concerns among newly diagnosed patients with oral cavity cancer. Head Neck. 2010;32(3):301–9.
17. Funk GF, Karnell LH, Robinson RA, Zhen WK, Trask DK, Hoffman HT. Presentation, treatment, and outcome of oral cavity cancer: a National Cancer Data Base report. Head Neck. 2002;24(2):165–80.

18. Gennaro P, Della Monaca M, Aboh IV, Priore P, Facchini A, Valentini V. “Naked microvascular bone flap” in oral reconstruction. Ann Plast Surg. 2014;73(2):164–9.
19. Goh BT, Lee S, Tideman H, Stoelinga PJ. Mandibular reconstruction in adults: a review. Int J Oral Maxillofac Surg. 2008;37(7):597–605.
20. Gotay CC, Moore TD. Assessing quality of life in head and neck cancer. Qual Life Res. 1992;1(1):5–17.
21. Hakim SG, Kimmerle H, Trenkle T, Sieg P, Jacobsen HC. Masticatory rehabilitation following upper and lower jaw reconstruction using vascularised free fibula flap and enossal implants-19 years of experience with a comprehensive concept. Clin Oral Investig. 2015;19(2):525–34.
22. Hidalgo DA, Pusic AL. Free-flap mandibular reconstruction: a 10-year follow-up study. Plastic Reconstruct Surg. 2002;110(2):438–49; discussion 450–1.
23. Holmes JD, Aponte-Wesson R. Dental implants after reconstruction with free tissue transfer. Oral Maxillofac Surg Clin North Am. 2010;22(3):407–18. vii.
24. Holzle F, Kesting MR, Holzle G, Watola A, Loeffelbein DJ, Ervens J, Wolff KD. Clinical outcome and patient satisfaction after mandibular reconstruction with free fibula flaps. Int J Oral Maxillofac Surg. 2007;36(9):802–6.
25. Hutcheson KA, Lewin JS. Functional assessment and rehabilitation: how to maximize outcomes. Otolaryngol Clin North Am. 2013;46(4):657–70.
26. Iizuka T, Hafliger J, Seto I, Rahal A, Mericske-Stern R, Smolka K. Oral rehabilitation after mandibular reconstruction using an osteocutaneous fibula free flap with endosseous implants. Factors affecting the functional outcome in patients with oral cancer. Clin Oral Implants Res. 2005;16(1):69–79.
27. Kim MR, Donoff RB. Critical analysis of mandibular reconstruction using AO reconstruction plates. J Oral Maxillofac Surg. 1992;50(11):1152–7.
28. Kim DD, Ghali GE. Dental implants in oral cancer reconstruction. Oral Maxillofac Surg Clin North Am. 2011;23(2):337–45, vii.
29. Kreeft AM, van der Molen L, Hilgers FJ, Balm AJ. Speech and swallowing after surgical treatment of advanced oral and oropharyngeal carcinoma: a systematic review of the literature. Eur Arch Otorhinolaryngol. 2009;266(11):1687–98.
30. Kumar VV, Jacob PC, Kekatpure V, Hedne N, Koch FP, Kuriakose MA. The Jugaad Technique for Jaw Reconstruction: Denture Based Inverse Planning. J Maxillofac Oral Surg. 2016;15(3):346–348. Epub 2015 Sep 29.
31. Kumar VV, Malik NA, Kumar DB. Treatment of large recurrent aneurysmal bone cysts of mandible: transosseous intralesional embolization as an adjunct to resection. Int J Oral Maxillofac Surg. 2009;38(6):671–6.
32. Leslie A, Fyfe E, Guest P, Goddard P, Kabala JE. Staging of squamous cell carcinoma of the oral cavity and oropharynx: a comparison of MRI and CT in T- and N-staging. J Comput Assist Tomogr. 1999;23(1):43–9.
33. Pace-Balzan A, Shaw RJ, Butterworth C. Oral rehabilitation following treatment for oral cancer. Periodontol 2000. 2011;57(1):102–17.
34. Perry AR, Shaw MA, Cotton S. An evaluation of functional outcomes (speech, swallowing) in patients attending speech pathology after head and neck cancer treatment(s): results and analysis at 12 months post-intervention. J Laryngol Otol. 2003;117(5):368–81.
35. Pratt GF, Rozen WM, Chubb D, Ashton MW, Alonso-Burgos A, Whitaker IS. Preoperative imaging for perforator flaps in reconstructive surgery: a systematic review of the evidence for current techniques. Ann Plast Surg. 2012;69(1):3–9. doi:10.1097/SPA.0b013e318222b7b7. Review. PMID: 22627495.
36. Raoul G, Ruhin B, Briki S, Lauwers L, Haurou Patou G, Capet JP, Maes JM, Ferri J. Microsurgical reconstruction of the jaw with fibular grafts and implants. J Craniofac Surg. 2009;20(6):2105–17.
37. Rodby KA, Turin S, Jacobs RJ, Cruz JF, Hassid VJ, Kolokythas A, Antony AK. Advances in oncologic head and neck reconstruction: systematic review and future considerations of

virtual surgical planning and computer aided design/computer aided modeling. J Plast Reconstr Aesthet Surg. 2014;67(9):1171–85.
38. Rohner D, Jaquiery C, Kunz C, Bucher P, Maas H, Hammer B. Maxillofacial reconstruction with prefabricated osseous free flaps: a 3-year experience with 24 patients. Plast Reconstr Surg. 2003;112(3):748–57.
39. Schepers RH, Raghoebar GM, Vissink A, Stenekes MW, Kraeima J, Roodenburg JL, Reintsema H, Witjes MJ. Accuracy of fibula reconstruction using patient-specific CAD/CAM reconstruction plates and dental implants: a new modality for functional reconstruction of mandibular defects. J Craniomaxillofac Surg. 2015;43(5):649–57. doi:10.1016/j.jcms.2015.03.015.
40. Sharp HM, List M, MacCracken E, Stenson K, Stocking C, Siegler M. Patients' priorities among treatment effects in head and neck cancer: evaluation of a new assessment tool. Head Neck. 1999;21(6):538–46.
41. Smolka K, Kraehenbuehl M, Eggensperger N, Hallermann W, Thoren H, Iizuka T, Smolka W. Fibula free flap reconstruction of the mandible in cancer patients: evaluation of a combined surgical and prosthodontic treatment concept. Oral Oncol. 2008;44(6):571–81.
42. Strackee SD, Kroon FH, Jaspers JE, Bos KE. Modeling a fibula transplant in mandibular reconstructions: evaluation of the effects of a minimal number of osteotomies on the contour of the jaw. Plast Reconstr Surg. 2001;108(7):1915–21. discussion 1922-3.
43. Ueyama Y, Naitoh R, Yamagata A, Matsumura T. Analysis of reconstruction of mandibular defects using single stainless steel A-O reconstruction plates. J Oral Maxillofac Surg. 1996 Jul;54(7):858–62; discussion 862-3. PMID: 8676231.
44. Urken ML, Buchbinder D, Weinberg H, Vickery C, Sheiner A, Parker R, Schaefer J, Som P, Shapiro A, Lawson W, et al. Functional evaluation following microvascular oromandibular reconstruction of the oral cancer patient: a comparative study of reconstructed and nonreconstructed patients. Laryngoscope. 1991;101(9):935–50.
45. van Gemert J, Holtslag I, van der Bilt A, Merkx M, Koole R, Van Cann E. Health-related quality of life after segmental resection of the lateral mandible: Free fibula flap versus plate reconstruction. J Craniomaxillofac Surg. 2015;43(5):658–62.
46. Vaughan ED, Bainton R, Martin IC. Improvements in morbidity of mouth cancer using microvascular free flap reconstructions. J Craniomaxillofac Surg. 1992;20(3):132–4.
47. Vinzenz KG, Holle J, Wuringer E, Kulenkampff KJ, Plenk Jr H. Revascularized composite grafts with inserted implants for reconstructing the maxilla–improved flap design and flap prefabrication. Br J Oral Maxillofac Surg. 1998;36(5):346–52.

Literature

48. Burns M. The StL Format: standard data format for Fabbers. 1989. http://www.ennex.com/~fabbers/StL.asp.
49. Buzug TM. Einführung in die Computertomographie: Mathematisch-physikalische Grundlagen der Bildrekonstruktion. Berlin/Heidelberg/New York: Springer; 2002. ISBN 3-540-20808-9.
50. Ciocca L, Mazzoni S, Fantini M, Persiani F, Marchetti C, Scotti R. CAD/CAM guided secondary mandibular reconstruction of a discontinuity defect after ablative cancer surgery. J Craniomaxillofacial Surg. 2012. doi:10.1016/j.jcms.2012.03.015.
51. Lorensen WE, Cline HE. Marching cubes: a high resolution 3D surface construction algorithm. ACM Siggraph Comput Graph. 1987;21:163–9.
52. Nedelcu RG, Persson AS. Scanning accuracy and precision in 4 intraoral scanners: an in vitro comparison based on 3-dimensional analysis. J Prosthet Dent. 2014;112(6):1461–71.
53. Schulze R. DVT-Diagnostik in der Implantologie: Grundlagen – Fallstricke, ZMK. 2012.

Mandibular Reconstruction

3

Al Haitham Al Shetawi and Daniel Buchbinder

3.1 Introduction

The cartoon character Andy Gump demonstrates very accurately the physical deformity that results from loss of the anterior mandible (Fig. 3.1). The Andy Gump character was inspired by a real patient, Andy Wheat, who was born in 1890. He lost the anterior part of his mandible secondary to osteomyelitis [1]. The original surgery was performed at the Johns Hopkins Hospital, on August 28, 1915 [2].

Patients with the "Andy Gump" deformity could not eat or speak properly, drooled constantly, and rapidly became abhorrent to themselves and their families [2]. Prior to reconstructive techniques made available, this deformity was not uncommonly seen by head and neck surgeons after ablative techniques for anterior oromandibular tumors. Now, due to the advances in mandibular reconstructive techniques, this deformity is rarely seen. This chapter will discuss a step-by-step approach to contemporary mandibular reconstruction.

3.2 Historic Perspective

The loss of mandibular tissue has always challenged patients and their surgeons. Over the last century, novel procedures to reconstruct mandibular defects to achieve the best form and function continued to evolve.

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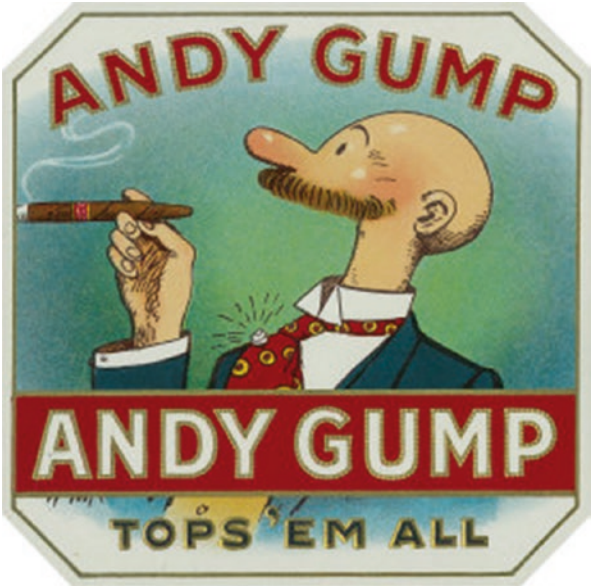

Fig. 3.1 Cartoon of Andy Gump showing the physical deformity resulting from loss of the anterior mandible

In 1833, Sir William Whymper described a case of a 22-year-old gunner in the French artillery, Monsieur Alphonse Louis, who received shrapnel injuries from an exploding shell at the Siege of Antwerp [3]. M. Louis' maxillofacial injuries included loss of the entire mandible. As a consequence, the patient had a grotesque appearance and was unable to eat or talk properly. At that time the surgeons had no knowledge or expertise on how to reconstruct the massive lower jaw defect. Where specialist knowledge or facilities were absent, improvisation was called for. A silversmith was duly approached and asked to construct a mask to act as a replacement for the deficient lower face (Fig. 3.2) [3, 4].

Almost a century later, pioneering works by Sir Harold Gillies and his team of dental surgeons and anesthetists are considered to be the first attempts at anatomical mandibular reconstruction. His patients were soldiers injured in the battles during World War I. In nearly all of the cases described by Gillies, the first of the plastic and reconstructive surgical procedures was undertaken up to 3 or more months after the initial injuries were sustained. While this period of time clearly allowed the surrounding tissue to fully heal, the facial features of these individuals were often seriously, and in many cases hideously disfigured (Fig. 3.3) [4, 6]. This led to the surgical principles such as delayed reconstruction until sepsis was absent and the use of prolonged external fixation. Tibial bone grafts and pedicled mandibular bone grafts were the standard of care at that time [7].

The experience with the wounded soldiers from World War I led to marked improvements in the anesthetic agents and techniques and the establishment of intensive care units. These advances allowed long operative procedures to be performed with relative safety. This was in sharp contrast to the multiple and short procedures with prolonged hospital stay which was previously the norm [4].

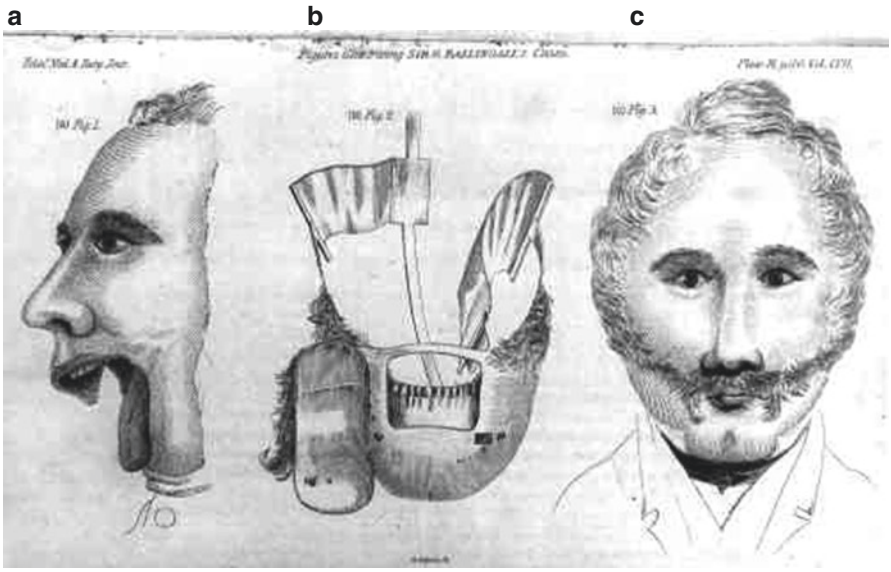

Fig. 3.2 (**a**) Drawing of the disfigured face of M. Louis. (**b**) Drawing of the mask made to cover his deformity. (**c**) Drawing of M. Louis wearing his silver mask [4, 5]

Another major advances in the surgical care for the injured patients were seen during World War II with the use of antibiotics and internal fixation of bone grafts [8]. Since World War II, a wide range of techniques for reconstruction were developed. Principles learned from post-traumatic injuries were applied to oncologic reconstructions. Nonvascularized autogenous bone grafts, pedicled osteomyocutaneous flaps, and metallic plates were used to reconstruct the mandible [9–11].

Free autogenous bone grafts were the gold standard of reconstructing traumatic and oncologic defects of the mandible in the 1950s and 1960s. These techniques relied on the use of bone harvested from the iliac crest, ribs, and tibia [12, 13]. However, problems with free bone grafts were seen in composite radical resections of malignant disease and postoperative radiation therapy. The high failure rate was due to graft resorption and infection [14–17].

Pedicled grafts, such as pectoralis major muscle with an associated rib, sternocleidomastoid muscle with a clavicle, trapezius muscle with a portion of the scapula, and temporalis muscle with a parietal bone (outer table), were used for mandibular reconstruction to avoid the problems seen with nonvascularized bone grafts. These "flaps" had less resorption compared to the nonvascularized bone grafts; however, their functional results were generally poor due to the less than optimal quality of the transferred bone, the insufficient amount of bone, and the difficulty in insetting the flap [17, 18].

In 1976, Spiessl et al. first reported the use of a three-dimensional (3-D) bendable plate for mandibular reconstruction after tumor resection. Since then, many surgeons have used similar techniques to bridge mandibular defects [19–22]. However, the use of plate, with or without bone graft, had a high rate of complications such as fracture,

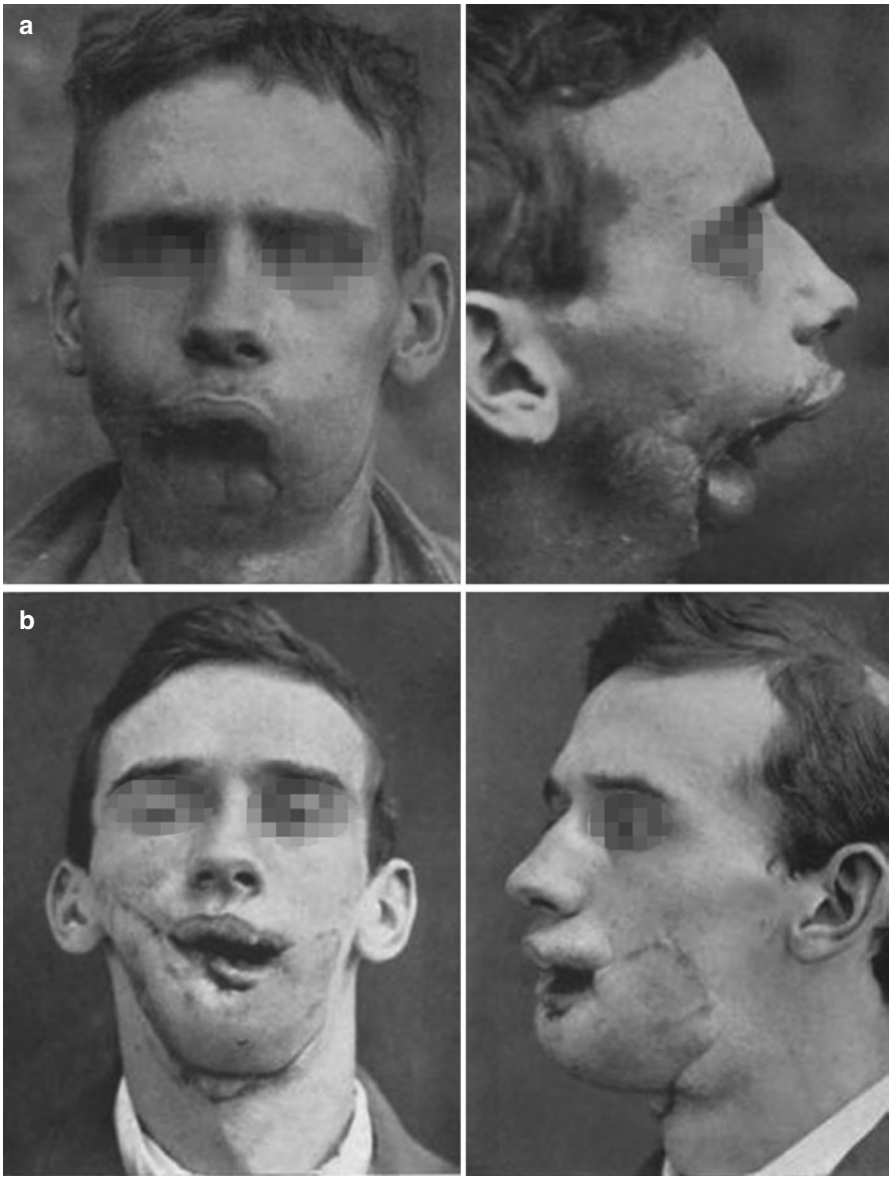

Fig. 3.3 A patient with extensive maxillofacial injuries from the series published by Sir Harold Gillies in 1920. (**a**) Frontal and lateral views of the face showing the extent of injuries before reconstruction. (**b**) Frontal and lateral views of the patient after large double-pedicle scalp flaps and with prosthetic chin in position [6]

exposure, and infection. The incidence of plate failure was even higher for defects located anteriorly and in patients receiving radiation therapy (Fig. 3.4) [17, 23–26].

Surgeons recognized the detrimental effects of salivary contamination and radiation therapy on the survival of the grafted mandible, and the general approach was

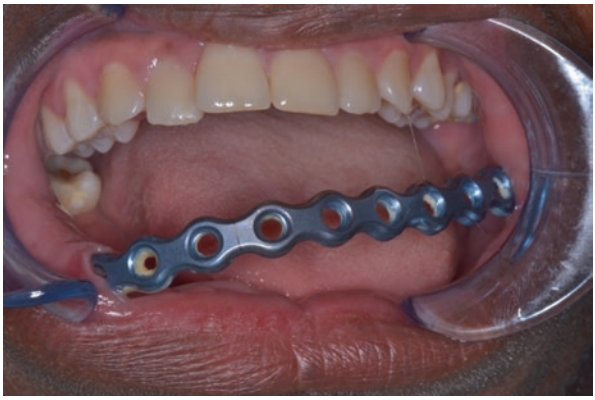

Fig. 3.4 Plate exposure in a patient who was previously reconstructed with plate only for an anterior mandibular defect

to perform delayed reconstruction after intraoral soft tissue healing was achieved and radiation therapy was completed. Unfortunately, that led to patients being subjected to multiple operations. After soft tissue healing was achieved, the efforts to secondarily reconstruct the mandible using nonvascularized or pedicled bone grafts were complicated with poor wound healing, bone resorption, fibrosis, trismus, malunion, and the inability to perform dental rehabilitation [27–29].

In the early 1980s, mandibular reconstruction was revolutionized by the introduction of free tissue transfer. In 1975, Taylor et al. introduced the fibula flap for limb reconstruction [30]. In 1979 Taylor et al. and Sanders and Mayou described the first iliac crest bone transfer based on the deep circumflex iliac artery and vein as the vascular pedicle [31, 32] Finally, in 1986, Swartz et al. introduced the scapular osteocutaneous free flap for use in head and neck reconstruction [33]. These three bone containing flaps will later become the main sites for free tissue transfer for mandibular reconstruction. In 1989, Hidalgo popularized the use of the fibula osteocutaneous flap for mandibular reconstruction in his report of a 12-case series [34]. Since then, multiple modifications and applications of the fibula flap have been proposed [35].

The high success rate and significantly improved functional outcome seen with free tissue transfer led to a paradigm shift in mandibular reconstruction [36–38]. Today, composite bone containing free tissue transfer with titanium plate fixation is the gold standard for mandibular reconstruction [35, 37, 38] (Fig. 3.5).

3.3 Anatomy and Physiology of the Mandible

The mandible forms the esthetic and functional foundation of the lower third of the face. It defines the shape of the lower face and forms the border between the neck and face. It has two major components: a horizontal U-shaped arch (body and symphysis) that supports the dentition, provides attachment of the musculature of the tongue and floor of the mouth, and indirectly suspend the larynx via the suprahyoid muscular attachments, and two vertical segments (angle, ramus, coronoid, and

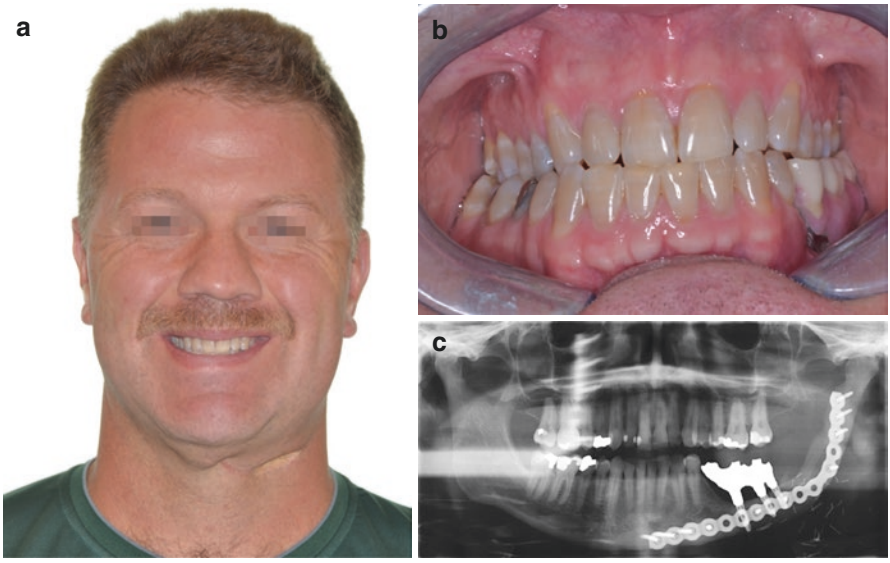

Fig. 3.5 (**a**) Frontal photo showing good mandibular contour and symmetry after mandibular reconstruction with fibula free flap. (**b**) Intraoral photo after prosthetic rehabilitation. (**c**) Postoperative panorex showing bony continuity and successful implant restoration

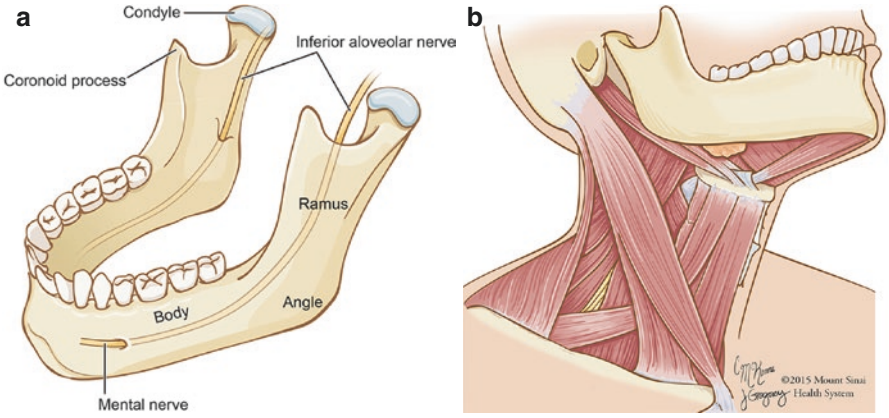

Fig. 3.6 (**a**) Bony anatomy of the mandible. (**b**) The mandible provides the functional and esthetic foundation of the lower face

condyle) that articulate with the base of the skull. The muscles attached to the mandible carry important functions such as mastication, speech, and deglutition (Fig. 3.6).

The bony anatomy of the mandible is unique. It is composed of two types of bone: basal and alveolar. The alveolar bone houses the roots of the teeth. The anterior alveolar bone and the teeth provide lower lip support and assist oral

competence. The basal bone supports the alveolar bone and houses the inferior alveolar neurovascular bundle that provides blood flow to the mandible and sensation of the lower lip, dentition, and mucosa.

The blood supply to the mandible is rich. It is partially provided by the inferior alveolar artery (centripital) and partially by the periosteal envelope (centrifugal) which is supplied by the surrounding muscles and mucosa.

The temporomandibular joint (TMJ) is a "ginglymoarthrodial" joint that has rotational and translational movements. It serves as the articulation between the mandible and the skull base and allows mandibular motion that contributes to the masticatory function.

3.4 Pathology of the Mandible

Because of the mandibular unique anatomy, it is exposed to wide range of pathologic conditions. The mandible is surrounded by mucosa which is exposed to many insults and toxins and can acquire malignant transformation. The mandible also houses odontogenic tissues which can cause a variety of odontogenic tumors, cysts, and infections. The mandibular projection puts it at risk for traumatic injuries.

These unique anatomic features expose the mandible to different congenital, infectious, traumatic, iatrogenic (e.g., osteoradionecrosis, medication-related osteonecrosis), and neoplastic conditions.

The techniques and goals of ablative surgery have not changed significantly over the past 50 years, with a goal to achieve complete extirpation of the tumor [39, 40]. On the other hand, the reconstructive techniques have changed and advanced significantly to restore the form and function of the missing tissue.

3.5 Goal of Treatment

Patients with mandibular defects often suffer from significant functional problems (e.g., salivary drooling, difficulty swallowing, and difficulty in chewing) and disfigurement that has significant emotional and psychological effects. Reestablishing form and function is the main goal of reconstructive mandibular surgery (Table 3.1).

There is no "best reconstructive method." The best method is the one that meets the objectives for a given patient. Ideally, every patient should be restored to predisease form and function. The bony and soft tissue defect size, the patient's well-being and associated comorbidities, the patient's prognosis, the need for adjuvant therapy, the donor site availability and morbidity, and the need to restore swallowing, speech, or mastication are all important considerations when planning the reconstruction.

Regardless of the prospects for a cure, optimizing the quality of life is a worthwhile and attainable goal in all head and neck reconstruction patients [41].

Table 3.1 Goals of mandibular reconstruction

Goals of treatment
Restoration of facial contour, projection, and symmetry
Restoration of the soft tissue defect to allow functional recovery of the tongue mobility and bulk, restore speech and swallowing, and restore lip competency
Allow complete and immediate wound closure to minimize risk of wound contracture, salivary leak, infections, and fistula formation
Withstand the effects of adjuvant therapy and protect the surrounding tissues
Allow dental rehabilitation and restoration of the dental occlusion
Restore the range of motion and minimize the risk of trismus when the TMJ is involved

3.6 Defect Evaluation and Classification

When the resection of the mandibular segment is partial thickness and maintains its continuity, it is referred to as a marginal resection. When the resection is full thickness and causes loss of the bony continuity, it is referred to as a segmental resection (Fig. 3.7). Segmental resection can be (1) simple (bone), (2) compound (bone and oral lining or skin), (3) composite (bone, oral lining, and skin), and (4) en bloc (bone, oral lining, skin, and soft tissue) [42].

Topography of the bony defect is paramount to the ultimate reconstructive outcome. Similar-sized mandibular defects in different segments of the arch have different cosmetic or functional outcomes [43]. For example, an anterior arch defect that results in the well-known "Andy Gump" deformity leads to devastating esthetic and functional outcome [2]. In contrast, a lateral defect in a dentate or edentulous mandible is more tolerated [17]. In general, the loss of mandibular continuity has significant effects on the mechanics of mastication especially in the dentate mandible. In addition, the disturbance in facial appearance can have a significant impact on the patient's feeling of self-confidence and desire to return to pre-disease employment and social interactions [35, 44]. Posterior defects involving the ramus and TMJ are usually camouflaged well by overlying soft tissue. Similar to the lateral defects, problems with occlusion and mastication plus deviation of the mandible will still result if these defects are left unreconstructed [17].

When dealing with a marginal mandibulectomy, the reconstructive efforts are geared toward achieving soft tissue coverage using local, regional, or free tissue transfer. A minimal of 1 cm of basal bone should remain to avoid iatrogenic fractures [45]. When dealing with a segmental resection, the reconstructive techniques become more challenging, and more analysis of the defect is required to achieve the best result [38]. As discussed earlier, nonvascularized bone grafts and pedicled bone flaps are associated with a high failure rate and have limited indications [14–17]. Free tissue transfer has become the preferred method to reconstruct segmental defects. Multiple classifications have been introduced to facilitate the planning of the reconstruction [42, 43, 46, 47]. Simple bony segmental resections can be restored with a bony flap. Compound, composite, or en bloc resections require a more

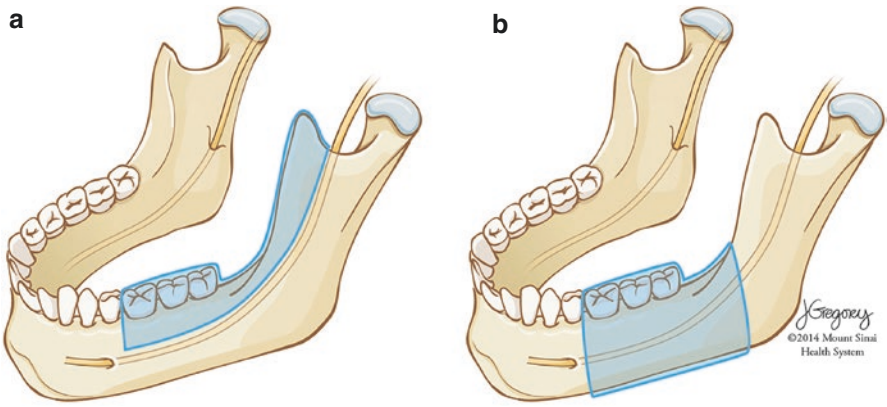

Fig. 3.7 (**a**) Marginal resection. (**b**) Segmental resection

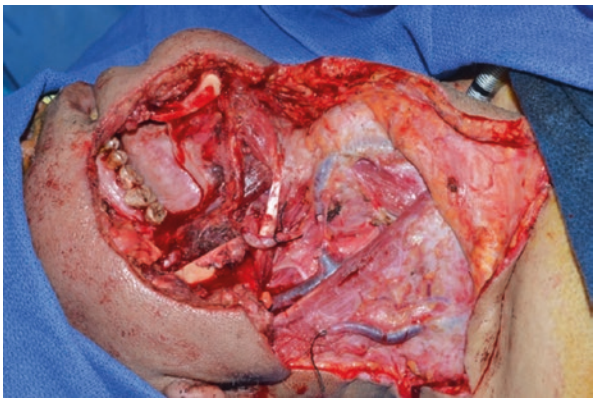

Fig. 3.8 Large en bloc resection of the mandible. The soft tissue defect component will determine the flap selection

complex reconstruction. The soft tissue defect component is the most important factor on the functional result of the mandibular reconstruction and will determine the flap choice (Fig. 3.8) [17, 47, 48].

The ideal flap should provide anatomic, functional, and esthetic restoration. Anatomically, the soft tissue coverage should restore cutaneous and mucosal lining; minimize infections, salivary leak, and fistula formation; augment the wound bed; protect vital structures (e.g., carotid vessels); and tolerate adjuvant therapy. The bony reconstruction should restore the bony height, length, and inter-arch relationship, allow the placement of dental implants and prosthesis, and, when indicated, reconstruct the TMJ articulation. Functionally, the

reconstruction should restore oral competency, speech, mastication, swallowing, and occlusion. Esthetically, it should restore facial symmetry, profile, and facial width and height.

Anterior mandibular defects should be reconstructed with vascularized bone when possible. Lateral defects are also best reconstructed with vascularized bone. However, if the patient's general medical condition or prognosis makes him/her a poor candidate for a free tissue transfer, plate reconstruction with or without pedicled soft tissue flap might be the best option [23, 49, 50].

3.7 Flap Selection

Microvascular free tissue transfer has afforded the surgeon an opportunity to more critically address the esthetic and functional outcome of mandibular reconstruction due to the wide array of tissue that can be used. Primary mandibular reconstruction has been refined to the point that it can be offered to virtually all patients who are faced with the devastating prospect of ablative surgery [47]. We will briefly review the most common bony flaps used for mandibular reconstruction (iliac crest, scapula, and fibula), followed by detailed discussion on using the fibula (Fig. 3.9). The radial osteocutaneous flap does not provide sufficient amount of bone stock and therefore has a limited role in mandibular reconstruction [35].

3.7.1 Iliac Crest Osteocutaneous Flap

The iliac crest osteocutaneous free flap, described separately by Taylor et al. [31] and Sanders and Mayou [32] in 1979 and popularized by Urken for mandibular reconstruction, is based on the deep circumflex iliac artery (DCIA) and deep circumflex iliac vein (DCIV) [51–53]. These vessels arise from the external iliac vessels (Fig. 3.10). It can be harvested with skin and muscle making it ideal for large composite defects. It provides a large cancellous bone stock that has ideal height and width for the placement of dental implants.

When the iliac crest osteocutaneous free flap is used to reconstruct lateral mandibular defects, the ipsilateral ilium is harvested using the anterior superior iliac crest as the mandibular angle. For anterior mandibular defects, opening osteotomies are necessary to contour the bone. The thin pliable internal oblique muscle can be harvested with the flap to reconstruct the lining of the oral cavity and recreate the buccal and lingual sulci. The ascending branches of the DCIA should be preserved to harvest the internal oblique muscle (Fig. 3.10) [35].

Although the iliac crest osteocutaneous free flap provides ideal bone stock for mandibular reconstruction (Fig. 3.11), the donor site morbidity is of primary

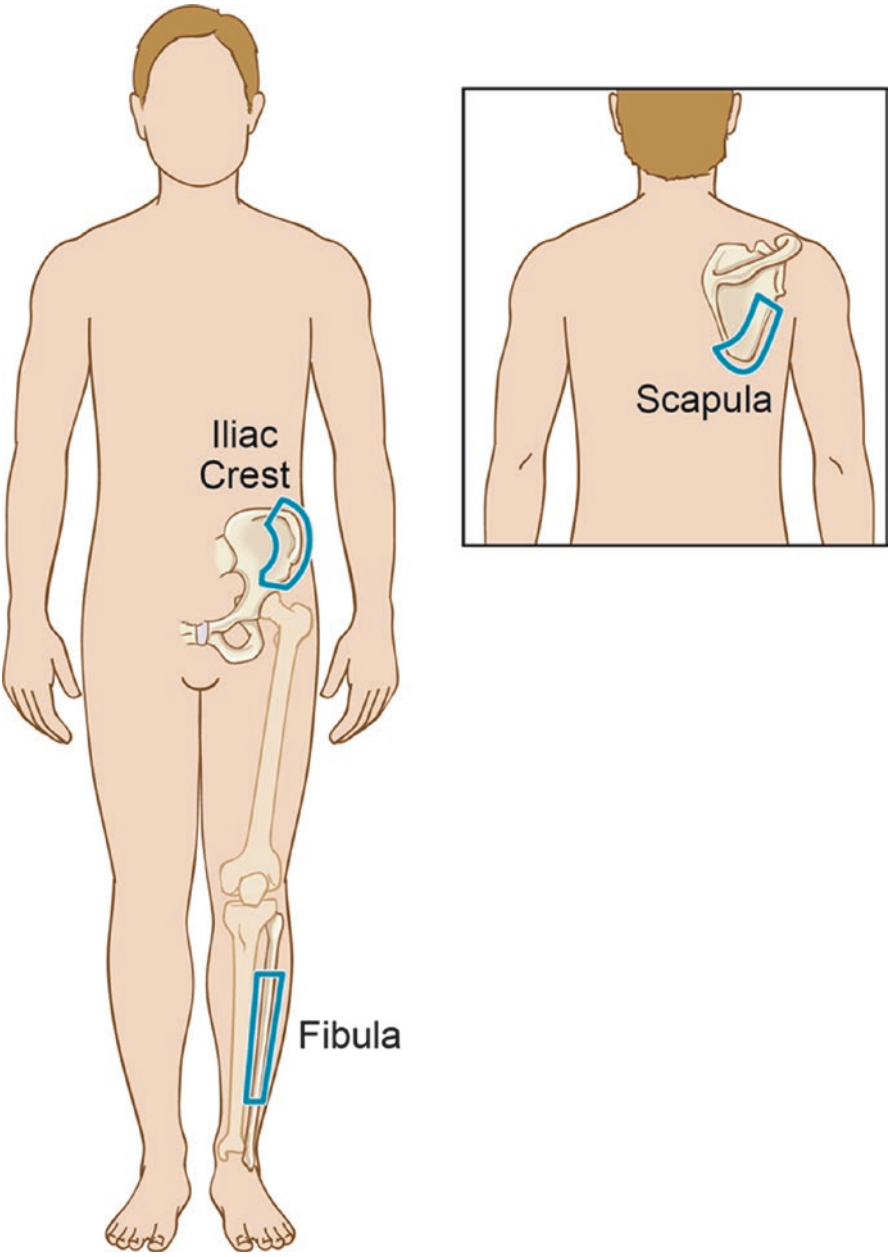

Fig. 3.9 Common donor sites for flaps used to reconstruct oromandibular defects (*JKG* ©2015 Mount Sinai Health System)

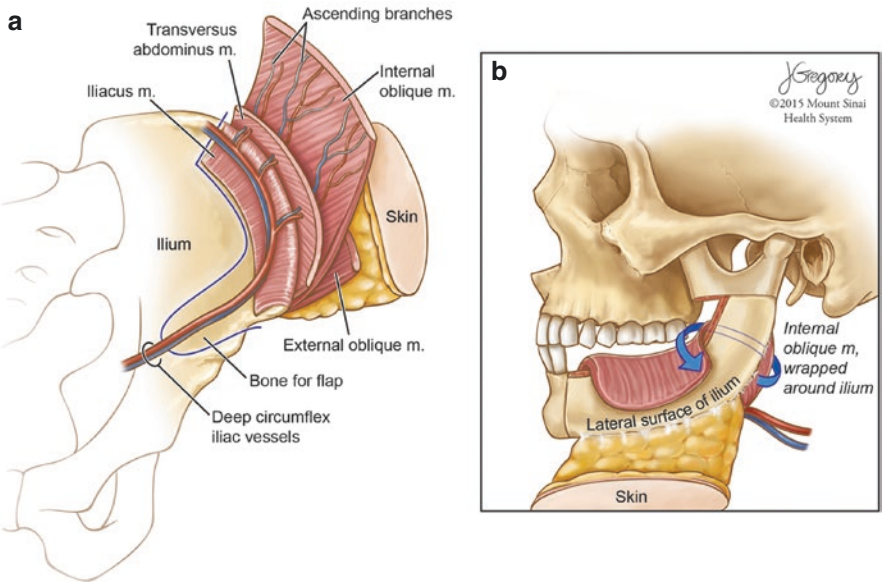

Fig. 3.10 (**a**) Anatomy of the iliac crest osteocutaneous free flap. (**b**) Inset of the iliac crest osteocutaneous free flap

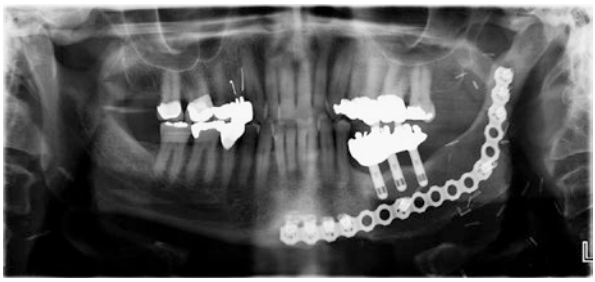

Fig. 3.11 Postoperative panorex showing the large bony stock of the iliac crest osteocutaneous free flap

concern making the fibula free flap a preferable donor site. Ventral hernia and gait disturbance are the feared complications. Reinforced closure can prevent hernia formation. Gait disturbance can be a problem in the immediate postoperative period [35]. The short vascular pedicle and the bulky skin paddle can also make the reconstruction challenging.

3.7.2 Scapula Free Flap

The scapula free flap was popularized by Swartz for mandibular reconstruction in 1986 [33]. It is based on the subscapular artery and vein, which most commonly arise from the third part of the axillary artery and vein. The two major branches of the subscapular artery are the circumflex scapular artery and the thoracodorsal artery. The circumflex scapular artery runs through the muscular triangular space and branches into both transverse and descending cutaneous branches, which form the basis of the scapular and parascapular fasciocutaneous flaps, respectively. When the thoracodorsal vessel arises from the subscapular system, a latissimus dorsi flap can be harvested with the scapular flap (Fig. 3.12) [54].

This versatile flap has many advantages. In addition to the scapular bone, this flap can provide a large, separate and flexible skin paddle, allowing the reconstruction of large composite and through-and-through defects. The latissimus dorsi muscle can also be incorporated which has an important utility to cover vital neck structures especially in the irradiated patient. The ability to use the thoracodorsal artery in a reverse flow design adds significant length to the pedicle and facilitates reconstruction in the vessel depleted patient [35, 54].

The donor site morbidity is well tolerated and does not affect ambulation. This makes the flap ideal in older patients whom immobility can add significant morbidity or in patients with peripheral vascular disease [35, 54].

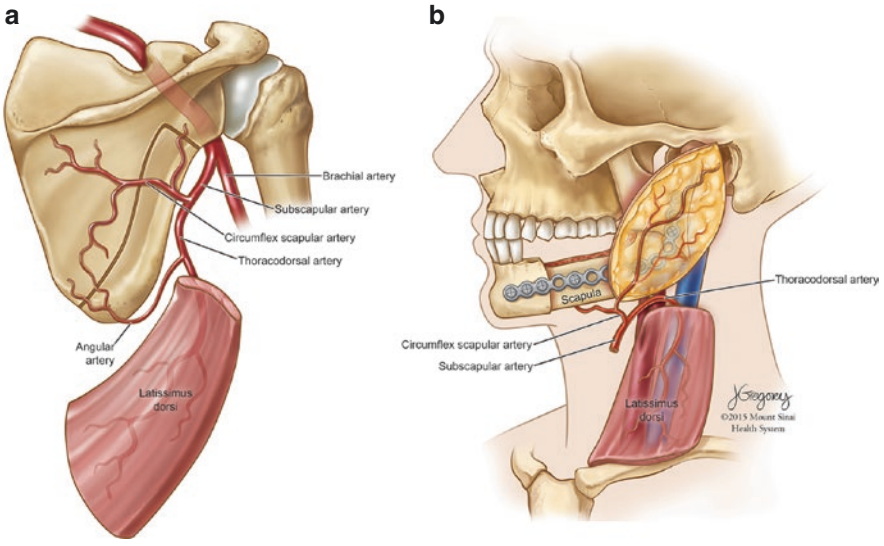

Fig. 3.12 (**a**) Anatomy of the scapula and the latissimus dorsi free flap. (**b**) Inset of the scapula free flap and the latissimus dorsi free flap

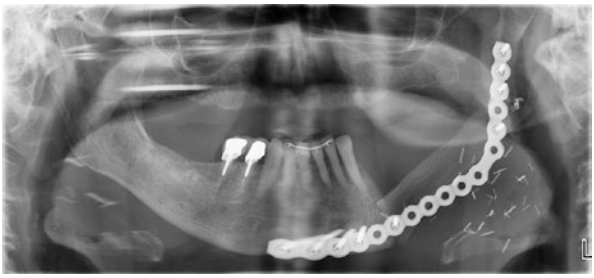

Fig. 3.13 Postoperative panorex after scapula bone flap

The decreased shoulder range of motion, the need to turn the patient during the procedure, and the difficult two-team approach are some of the disadvantages of this flap. The harvested bone provides a large bony stock; however, it can be too thin to place dental implants particularly in the female patient (Fig. 3.13) [35, 54].

3.7.3 Fibula Free Flap

Taylor et al. first introduced the fibula flap in 1975 for extremity reconstruction [30]. It was not until 12 years later when Hidalgo popularized its use for mandibular reconstruction [34]. Since then, multiple modifications and applications of the fibula flap have been proposed [55–59]. In 1994, Wei et al. popularized the incorporation of a skin paddle to the fibula and proofed its reliability [56]. The fibula free flap has since become the workhorse donor site for mandibular reconstruction [35].

The vascular supply to the fibula is through the peroneal artery and two venae comitantes. The peroneal artery originates from the posterior tibial artery. Throughout its course lateral and posterior to fibula, it maintains a uniform caliber (2–3 mm) that matches many vessels in the head and neck for anastomosis [60]. It provides both endosteal and periosteal circulation to the fibula bone making multiple osteotomies possible [56]. The peroneal artery sends multiple septocutaneous and/or musculocutaneous perforators to the skin of the lateral leg. One or two perforators can be found in the posterior crural septum at the junction of the middle and lower third of the fibula which can provide adequate circulation to a skin paddle approximately 22–25 cm in length and 10–14 cm in width [61]. When the quality or caliber of the skin perforators are doubtful, incorporation of a cuff of the underlying soleus and flexor hallucis longus muscle can be advantageous [62]. The lateral sural cutaneous nerve innervates the lateral skin of the leg, and this nerve can be preserved and reinnervated to restore sensation to the skin paddle [57].

The fibula bone is triangular in cross section with high-density cortical bone, which allows reliable osseointegration of dental implants due to primary stability,

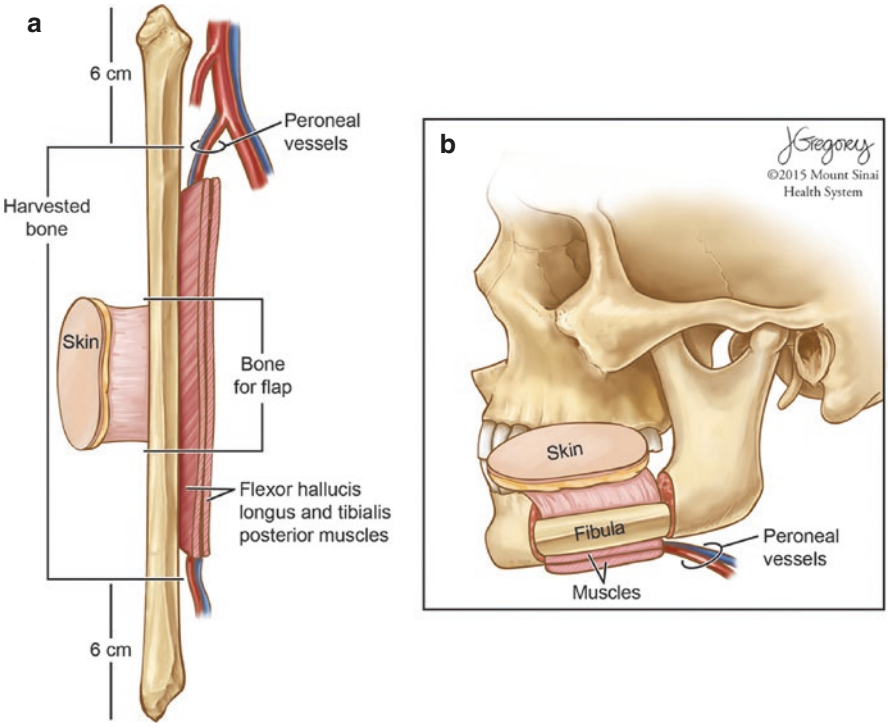

Fig. 3.14 (**a**) Anatomy of the fibula free flap. (**b**) Inset of fibula free flap

withstanding the forces of mastication [63]. 20–26 cm of bone can be harvested that allows reconstruction of large osseous defects and near total mandibulectomy defects [64]. When harvesting a skin paddle with the bone, the posterior crural septum that contains the perforators allows easy manipulation of the skin during the flap inset. The skin is pliable and thin which is ideal to restore intraoral lining. Preserving 6 cm of the fibula bone proximally and distally will maintain ankle and knee stability and will avoid injury to the common peroneal nerve which wraps around the fibular neck (Fig. 3.14).

The height of the fibula (12–15 mm) is insufficient to reconstruct both the basal and alveolar bone [65, 66]. Implant placement becomes more challenging, and prosthetics replacement of the alveolar bone will be required to provide lower lip support. Several techniques have been developed to restore alveolar bone height. The fibula can be inset 1 cm above the inferior border of the mandible to facilitate implant restoration, while a soft tissue cuff is used to fill the inferior border irregularities [67]. Double barrel design can also be used in some cases especially in symphyseal reconstruction to replace both basal and alveolar bones (Fig. 3.15) [68]. Lastly, vertical distraction has been used to increase the height of the fibula [69, 70].

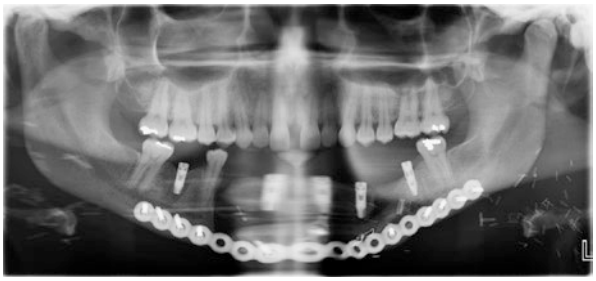

Fig. 3.15 Postoperative panorex of a double barrel fibula free flap and implant reconstruction

Table 3.2

Advantages
Long bone
Thick cortex
Long vascular pedicle with good caliper
Dual blood supply to the bone
Allows two-team approach
Can be harvested with fascia, muscle, and/or skin

Table 3.3

Disadvantages
Insufficient bone height
Long scar
Need to graft large soft tissue defect
Weakness in toe dorsiflexion
Ankle discomfort and gait disturbance

The flap is not without donor site morbidities. However, they are minimal and tolerable in most patients. The long visible scar can be problematic to young patients who prefer to wear short clothing. If the skin defect is wider than 4 cm, skin graft is required which can result in a poor cosmetic result. The function of the lower extremity can also be affected. Extensive dissection of the flexor hallucis longus muscle and/or its motor nerve can cause weakness in toe dorsiflexion. Excessive distal osteotomy can cause ankle discomfort and decreased range of motion [17, 71, 72].

Careful planning and good technique can minimize these complications. Suturing the flexor hallucis longus to the tibialis posterior muscle and the intermuscular septum can minimize its contraction. Preserving the flexor hallucis longus muscle motor nerve and minimal dissection to maintain its vascular supply can minimize muscle weakness [71, 73].

A summary of fibula free flap advantages and disadvantages is presented in Tables 3.2 and 3.3.

3.8 Fibula Orientation

The fibula is triangular in cross section and has three surfaces: a plating surface, a surface that has the vascular pedicle, and a surface that carries the skin perforates (Fig. 3.16).

When planning the reconstruction for a segmental defect, the surgeon should be aware of the orientation of the fibula bone. The plating surface should be buccal and the surface that carries the peroneal vessel should be lingual. The vascular pedicle exit point should be posterior. However, in TMJ reconstruction or in a previously operated neck with vessel paucity resulting in the need to go to the contralateral neck for a recipient vessel, the vascular pedicle should exit the fibula anteriorly to avoid acute turns at the level of the joint and having to double back down to the neck resulting in a shortened pedicle (Fig. 3.17).

By following these principles, the posterior crural septum carrying the perforators can either be superior or inferior depending on whether the ipsilateral or contralateral fibula is used. If the posterior crural septum is positioned inferiorly, the skin paddle can easily cover external skin defects or a mucosal ridge defect if the mesentery is stretched over the plating surface. If the posterior crural septum is facing superiorly, intraoral mucosal defects can be easily closed with minimal stretch of the perforators (Fig. 3.18).

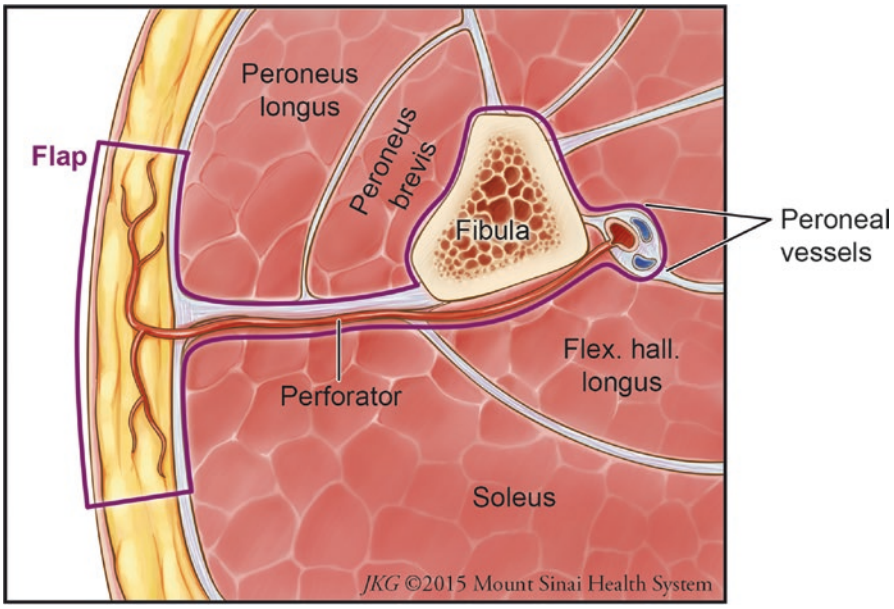

Fig. 3.16 Cross section of fibula free flap showing the perforator to the skin paddle

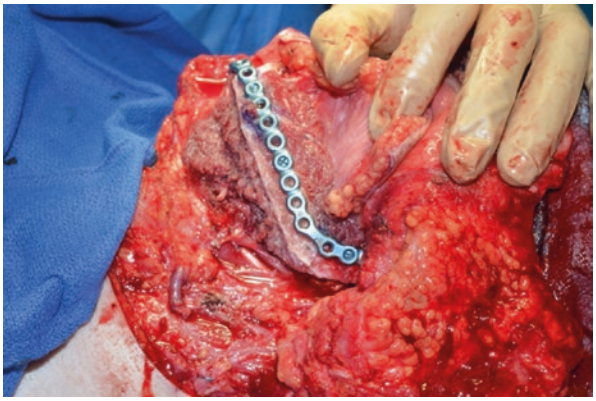

Fig. 3.17 Inset of the fibula free flap with a vascular pedicle exit anteriorly (*yellow arrow*)

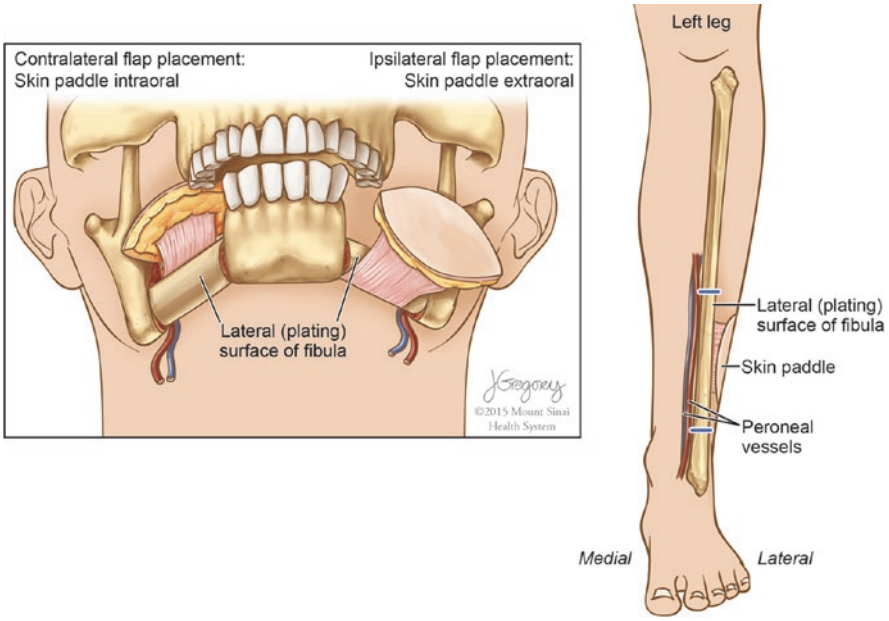

Fig. 3.18 Donor site selection: fibula free flap inset and orientation. If the ipsilateral fibula is used to reconstruct the mandibular defect and the vascular pedicle exits posteriorly (at the angle), the skin paddle will be extraoral. If the contralateral fibula is used and the vascular pedicle exits at the angle, the skin paddle will be intraoral

With preoperative lower extremity imaging, the surgeon can evaluate the vascular supply to the fibula and plan the reconstruction. In some circumstances (trauma to lower extremity or atherosclerosis), the surgeon has one available extremity for harvest. Therefore, understanding of the fibula flap orientation and geometry will allow proper planning and inset.

3.9 Plating and Fixation

The choice of fixation (rigid vs nonrigid) in mandibular reconstruction does not seem to influence the healing of the graft and the need for intervention for complications [74, 75]. However, the use of rigid fixation, using reconstruction plates, has many distinct advantages. In the case where the mandible is not distorted, the plate is contoured to the native mandible and fixed to the bone using bicortical screws proximal and distal to the area of the proposed resection. The plate is then removed and the screws are tagged. Following the mandibulectomy, the plate is replaced and secured to the remaining segment using the previously labeled screws, ensuring the exact anatomical alignment of the segments (Fig. 3.19). This is not possible when using nonrigid techniques. Furthermore, it is easier to shape the bone flap and fix it into a specific gap rather than to have to estimate its position and shape when the fragments are free floating [74]. Other advantages of rigid fixation are early resumption of oral function, avoidance of intermaxillary fixation, maintenance of the condylar position, and restoration of lower facial form [38, 76].

In cases when the tumor distorts the buccal cortex of the mandible or if the tumor margin might be violated in attempts to expose the outer cortex, the plate cannot be precontoured to the native mandible. In this situation, different techniques can be used: (1) use of temporary long miniplate, spanning the defect while resection occurs; (2) fixation of proximal mandibular segments to maxillary tuberosities with temporary supramucosal miniplates while resection occurs; (3) use of intermaxillary fixation in dentate patients with anterior segment resection; (4) use of external fixation systems [75, 77]; and (5) use of virtual surgical planning. In virtual surgical planning, a mirror image of the unaffected side can be created and superimposed on the affected side and a stereolithographic model can be generated. This "hybrid" model can be used to precontour the plate intraoperatively (Fig. 3.20) or have a

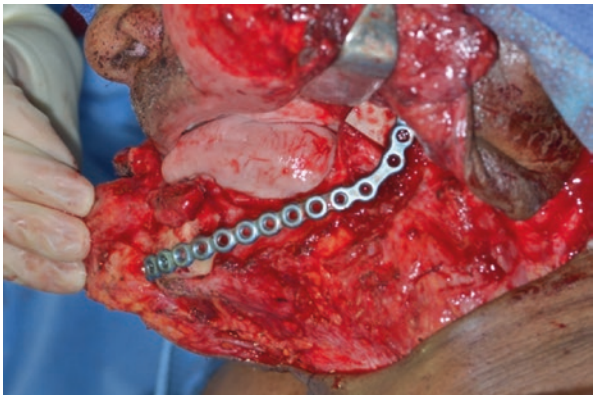

Fig. 3.19 Plate was contoured on the native mandible prior to the resection and now fixed to predrilled holes prior to flap inset

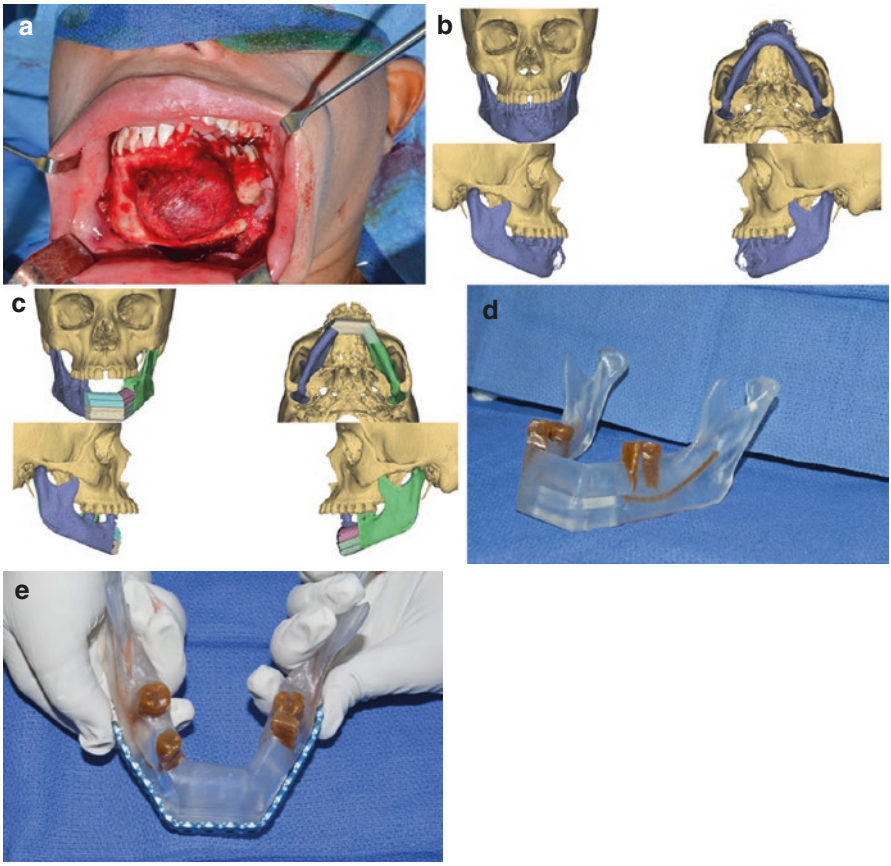

Fig. 3.20 (**a**) Tumor distorting the outer cortex of the mandible. The plate could not be contoured on the native mandible. (**b**) 3-D CT reconstruction showing the extent of the tumor with expansion of the outer cortex. (**c**) Virtual planning of a double barrel free fibula design. (**d**) Stereolithographic hybrid model was made from the virtual computer planning. (**e**) The hybrid model was used to prebend the plate

custom patient-specific plate designed and milled by the plating company [78] (Fig. 3.21).

The plate is fixed to the mandible on either side of the defect using at least 3–4 bicortical screws. With the use of the locking screws, less accurate adaptation of the plate can be accepted. However, to minimize plate extrusion, the plate should abut the underling bone and minimize the dead space. Reconstruction plates are stress shielding and will insure stability of the reconstruction during the healing period and allow early function. However, this stress-shielding effect may cause demineralization and decrease in bone strength [79].

The fibula segments should be fixed to the plate using monocortical screws to avoid injury to the vascular pedicle on the medial side. Only few screws are needed to fix the

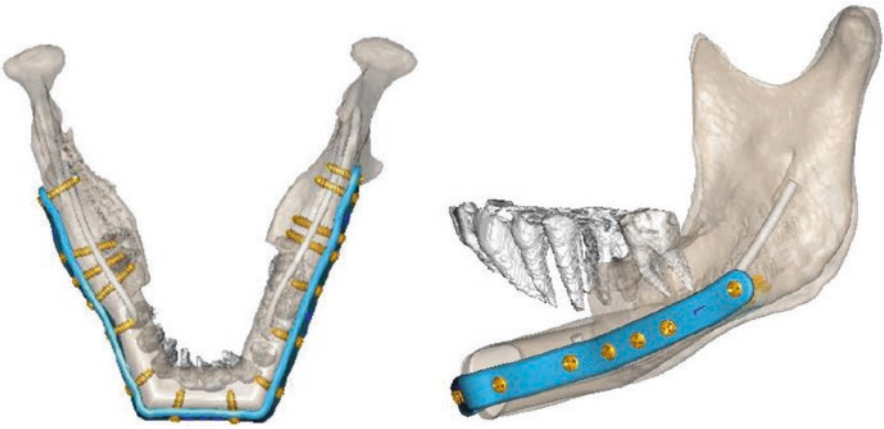

Fig. 3.21 Patient specific plate milled from a block of titanium

flap to the plate. Adherence to good technique during screw placement, including the use of a drill guide and copious chilled saline irrigation is essential to avoid thermal injury to the bone and subsequent screw loosening and hardware failure.

3.10 Flap Tailoring and Osteotomies

Depending on the size and location of the defect, a single segment, two segments, or multiple segments are used to shape the fibula to the mandibular contour (Fig. 3.22). Because of the fibula's dual blood supply, osteotomies can be done, leaving only periosteal blood supply to the osteotomized segments. The healing of the osteotomized fibula is not different between endosteal circulation only, periosteal circulation only, and circulation from both systems [56, 61]. In order to preserve an adequate blood supply, the osteotomized fibula segments should not be smaller than 3 cm [17].

Closing wedge osteotomies are used to create the 3-D contour of the mandible. The osteotomies can be done "freehand" or using computer-aided design and computer-aided manufacturing (CAD-CAM) cutting guides (Fig. 3.23). This can be done on the back table or while the fibula pedicle is still uninterrupted. The wedge design should allow adequate contouring and maximize the bone-to-bone contact between the osteotomized segments. This requires a clear appreciation of angles in more than one plane, which is easier with the flap mobile in hand rather than attached by its intact pedicle [67]. Subperiosteal dissection circumferential to the planned osteotomy should be made. A thin malleable should be placed subperiosteally on the medial surface to protect the pedicle during the osteotomy. Each osteotomized fibula segment should intimately abut the adjacent segments or native mandible without interfering soft tissue impingement to ensure bone-to-bone contact and to promote bony union. Once the contouring is done, miniplates or wires can be used to hold the segments prior to rigid fixation.

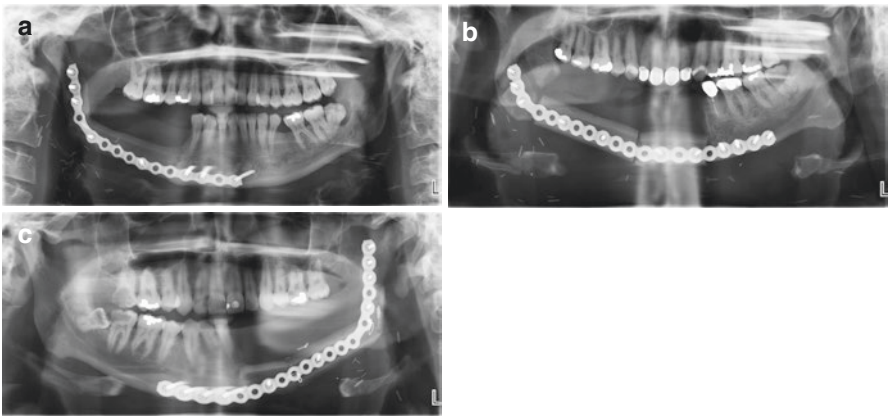

Fig. 3.22 Contouring of the fibula segments to the shape of the mandible. (**a**) One segment. (**b**) Two segments. (**c**) Multiple segments

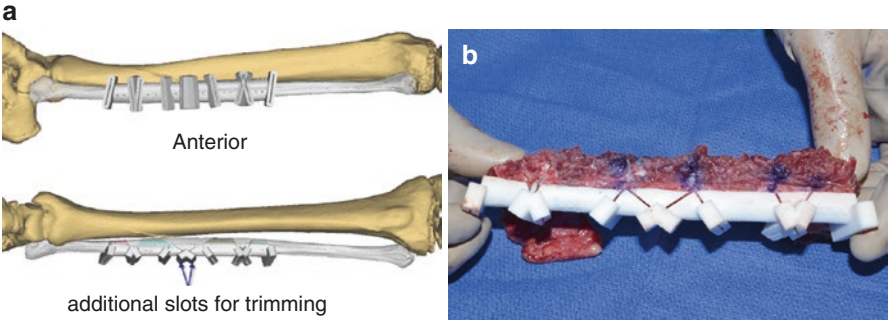

Fig. 3.23 (**a**) Virtual design of the osteotomy guide. (**b**) CAD-CAM generated osteotomy guides is used to guide the wedge osteotomies in a complex double barrel fibula free flap design

3.11 Donor Vessel Selection

There is plethora of vessels in the head and neck region that can be used for the microvascular anastomosis. However, patients with history of prior neck dissection, radiation therapy, regional metastasis or atherosclerosis may have limited options.

Recipient vessel exploration should be done prior to the flap harvest. This will allow the surgeon to plan the type of free flap, the orientation of the flap during inset, and the need for interpositional vein grafts. Ischemia time is also reduced when the vessels are ready for the microvascular anastomosis.

At least one artery and one vein should be explored, isolated, and prepared for the anastomosis prior to the flap harvest. When selecting the donor vessels, the length, location in relation to the planned flap pedicle, and caliber should be considered.

Branches of the external carotid artery and the thyrocervical trunk are most commonly used for the arterial anastomosis. The external jugular, common facial, transverse cervical, and internal jugular veins are most commonly used for the venous anastomosis.

The transverse cervical artery, a branch of the thyrocervical truck, is very useful in patients with neck vessel paucity after previous radiation and/or neck dissection. It is usually not affected by the external beam radiation therapy or neck dissection. In the more complex cases, the contralateral neck vessels should be reached to complete the anastomosis. However, this usually requires a vein graft. The internal mammary artery and vein are also available to harvest in the neck-depleted neck [80].

After the donor vessels are selected and prepared, the vessels are irrigated with a vasodilator, such as papaverine or lidocaine, and covered to prevent desiccation.

3.12 Flap Contouring and Insetting

The bony defect size is first measured. Then the pedicle length required for the donor vessel to reach the recipient vessel should be measured. Once this determination is made, the fibula flap can be tailored, and more proximal pedicle length can be gained by performing subperiosteal dissection, leaving the periosteum and muscle cuff and discarding the excess proximal bone. After ensuring adequate reach and size match of the pedicle to the donor vessels, the bony component of the flap is osteotomized and inset to the defect underneath the plate. The contoured graft is then fixed to the reconstruction plate with consideration of the geometry of the soft tissue component and the vascular pedicle. Monocortical screw fixation to the plate is recommended over bicortical screws to minimize risk of bone devascularization [67]. The bony graft should be oriented to place the vascular pedicle on the lingual side and the exit point at the angle when possible to maximize pedicle length [34].

The next step is insetting the soft tissue component of the flap. The soft tissue component of the flap is inset with care not to create torsion or tension on the small septo- or musculocutaneous perforators. Horizontal mattress sutures are used to insure watertight closure to minimize the risk of salivary leak and fistula formation. When the soft tissue paddle is used to close inaccessible defects, the skin can be partially inset prior to the bony inset.

Finishing the majority of the flap inset prior to the anastomosis has many advantages: (1) the insetting of the flap into defects of the pharynx and oral cavity must be accomplished with maximum exposure, which may be limited when the surgeon is concerned about disruption of the completed anastomosis; (2) the insetting is also facilitated by working with an ischemic flap, which frees the surgeon from the troublesome bleeding and engorgement that occur after revascularization; and (3) the position of the donor vessels becomes fixed after insetting, which eliminates the guesswork of setting the tension on the vascular pedicle [81].

3.13 Microvascular Anastomosis

After completing the flap inset and preparing the recipient and the donor vessels, the anastomosis is done using the operating microscope.

The anastomosis is started with the arterial system. The donor artery should match the caliber of the recipient artery. It should demonstrate a brisk pulsatile bleeding when the clasp is released. The anastomosis is done circumferentially using 9–0 or 10–0 interrupted nylon sutures. The venous anastomosis is then performed using circumferential sutures or a coupling device when possible.

The pedicle should lie in the neck without any tension or kinking. The head position should be accounted for. If the pedicle is redundant, the pedicle should be tagged to the underlying tissue to give it a gentle curve. The remaining inset can be completed at that time.

Careful attention to proper drainage of the neck is important to avoid hematoma formation or infections. Drainage should ensure evacuation of accumulated blood, exudate, or chyle which may lead to secondary infection. Open drainage system (Penrose) can be placed near the anastomosis, and closed drainage system (Jackson Pratt) can be placed in the dependent areas of the neck away from the anastomosis to prevent venous collapse and flap congestion.

3.14 Special Considerations

3.14.1 TMJ Reconstruction

The TMJ is a unique joint. It is a ginglymoarthrodial joint that produces both rotational and translational movements. Functional reconstruction of the TMJ is challenging. When oncologically sound, the TMJ and subcondylar stump should be preserved [82, 83]. If the resection involves the condyle, vascularized reconstruction is preferred with a goal to avoid complications such as malocclusion, difficulty in mastication, trismus, ankylosis, and loss of posterior mandibular height [35].

In resections that involve the condylar head, the proximal end of the fibula is rounded to simulate the shape of a condyle and inserted into the glenoid fossa (Fig. 3.24) [83]. Interposition of soft tissue into the joint space is important to prevent ankylosis [35]. A cuff of muscle is used to cover the neocondyle and act as an interposition graft. Other materials such as lyophilized dermis can be used as an interpositional graft [84]. To prevent “sag” of the neocondyle, suspension should be placed using Mitek sutures to the glenoid fossa or nonresorbable sutures to the zygomatic arch or temporal fossa. A pseudarthrosis develops that seems to be well tolerated and functional, although no translation of the neocondyle is possible [83]. Alloplastic materials such as prosthetic titanium implants, proplast, and silastic are mostly abandoned in oncological resections because of the high risk of complications such as erosion of the glenoid fossa [85], foreign body reaction, infection, and joint ankylosis [86]. Nonvascularized autogenous bone grafts such as costochondral bone and cartilage can undergo resorption, fracture, and hardware failure [35, 85, 87].

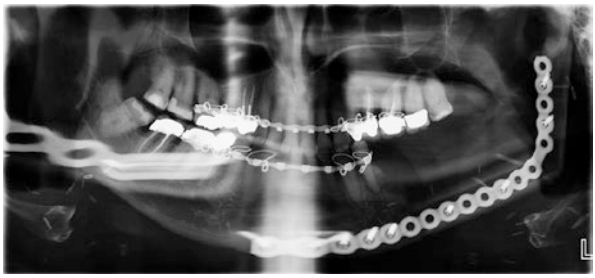

Fig. 3.24 Postoperative panorex after fibula free flap to reconstruct the TMJ/ramus complex. Temporary maxillomandibular fixation allows condylar positioning

3.14.2 Irradiated Patients

Patients with osteoradionecrosis and heavily irradiated wounds are at higher risk of wound healing complications. The feared complication in these patients is fistula formation and salivary contamination of the anastomosis and the carotid artery resulting in flap failure or carotid blowout, respectively. In high-risk patients, coverage of these vital vascular structures with a well-vascularized muscle is indicated. This may involve the incorporation of a segment of the latissimus dorsi muscle when using a scapular free flap (Fig. 3.12), or the use of the pectoralis major muscle separately for coverage in the neck.

3.15 Prosthodontic Rehabilitation

The final phase of mandibular reconstruction is restoring the dentition. The use of vascularized bone grafts provides a good platform for the placement of dental implants. Long-term success of dental implantation in fibula-based mandibular reconstruction has been well documented [88, 89]. It is important to realize that the goals to reconstruct the outline form of the lower third of the face and limited bone volume of the fibula can result in a significant height discrepancy with the native jaw. These factors for prosthetic rehabilitation are ameliorated with computer-assisted planning and implant framework design (Fig. 3.25).

Titanium implants can be placed immediately at the time of flap reconstruction or can be delayed after the reconstruction. Traditionally, implants were delayed 4–6 months after the initial reconstruction to allow healing of the wound, completion of radiation therapy and planning the prosthetic phase. Unless carefully planned, implants placed in the primary setting can lead to poor implant position and angulation making prosthetic restoration difficult if not impossible [88]. The decision for immediate placement and taking advantage of the blood supply prior to radiation therapy needs to be weighed against these considerations. Additionally, immediate implant placement cannot always be performed (e.g., the perforator surface is facing superiorly). Delayed implant placement has to be performed in such cases.

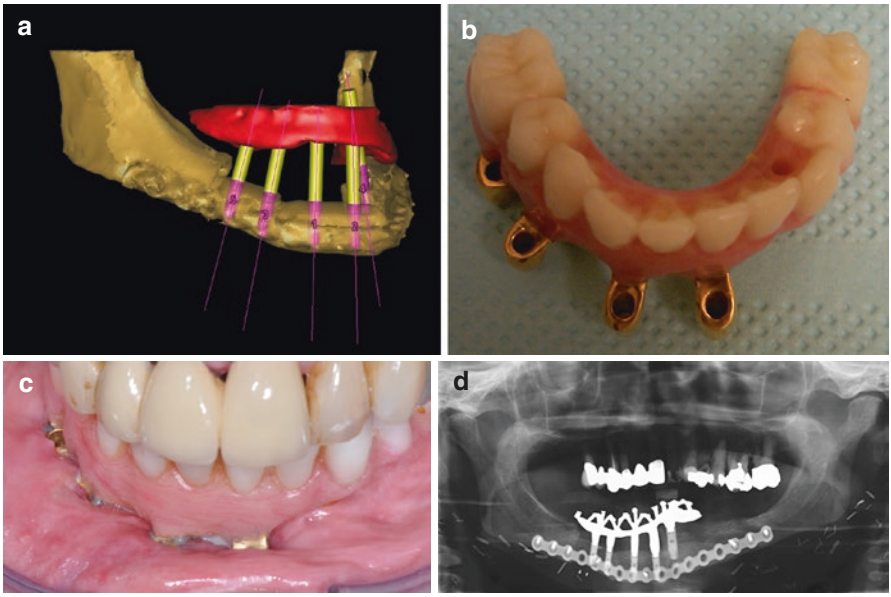

Fig. 3.25 (**a**) Three-dimensional reformation of mandible reconstruction with a fibula free flap. Scanning appliance (*in red*) identifies the position of the occlusal and facial surfaces of the teeth for virtual implant surgery and the fabrication of a CAD-CAM surgical template. (**b**) Definitive prosthesis with cantilevered framework to be fixed with screw retention. (**c**) Favorable mucosal reaction 1 week after insertion. The patient is restored to normal overbite and cross-bite relationship. (**d**) Panoramic view of fibula free flap reconstruction with four implants and one into native mandible supporting the framework of the definitive prosthesis. Note the location of the implants to plating screws determined on computer planning software (Courtesy of Dr. Devin Okay)

When planning the reconstruction of the complete dental arch with an implant-borne fixed prosthesis, a minimum of five or six implants with the greatest anterior-posterior spread is recommended to minimize the cantilever forces of the posterior extension of the prosthesis. Three to four implants are recommended for unilateral hemi-arch mandibular defects. As the defect crosses the midline, more implants are necessary to support the prosthesis [90]. No more than two implants are placed on any small fibula segment so as not to compromise perfusion of the bony segment or fracture of the segment [91].

In recent years, the use of computer-assisted planning has allowed prosthetic-guided treatment planning and implant placement. Computer-assisted planning provides a platform for prosthodontic treatment planning by using a radiographic scanning device worn by the patient during cone beam computerized tomography (CBCT). Virtual implant surgery and an opportunity to translate the planning to stage I surgery with CAD-CAM stereolithographic drilling templates achieve accurate, reproducible position and angulation of the implants in the immediate or delayed reconstructive setting (Fig. 3.26) [90, 92].

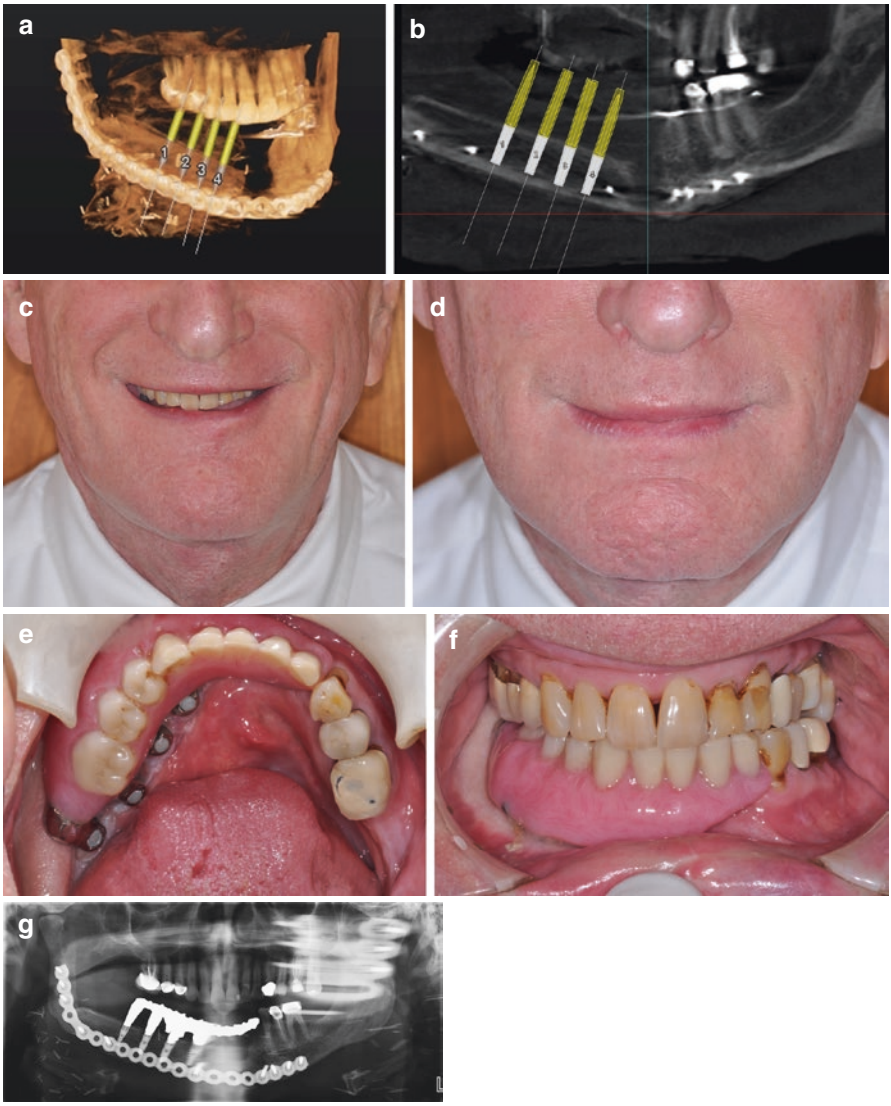

Fig. 3.26 (**a**) Computer-assisted planning for a 70-year-old gentleman after fibula reconstruction of the right mandible from angle to symphysis. (**b**) In anticipation for implant rehabilitation, reconstruction plate screws are placed away from implantable bone. (**c**, **d**) The marginal branch of the facial nerve was involved resulting in lip asymmetry. Support to the lower lip with an implant prosthesis can camouflage lip asymmetry. (**e**) The implant fixed dental prosthesis is screw retained for retrievability. (**f**) The occlusion is restored to bilateral contact. (**g**) Panoramic radiograph of completed reconstruction (Courtesy of Dr. Devin Okay)

3.16 Postoperative Care

Patients who undergo vascularized free flap oromandibular reconstruction routinely have a temporary tracheostomy to prevent airway compromise during the immediate postoperative period. The majority of patients can be decannulated within the first 5–7 days.

Many of the patients are nutritionally compromised preoperatively. Postoperative nutrition is important and essential to their general health, wound healing, and fast recovery. The severe edema and limited mouth opening prohibit the patient from oral feeding in the immediate postoperative period. Also oral feeding can have detrimental effects on the flap and wound breakdown when an intraoral skin paddle is used. Therefore, to ensure healing, minimize wound breakdown and salivary leak while maintaining the patient's nutritional needs, a feeding tube should be considered.

The use of perioperative antibiotics to cover the oral and cutaneous flora should also be considered. Deep venous thrombosis (DVT) chemoprophylaxis using low-dose heparin is essential to prevent postoperative DVT [93]. Antiplatelet therapy (asprin) is used to minimize pedicle thrombosis. These interventions do not seem to increase the incidence of postoperative hematoma when compared with the other anticoagulation agents [94, 95]. However, other data has demonstrated an increase in complications with the use of anticoagulation [96]. The flap is monitored according to the surgeon's preference. Doppler and pinprick at frequent intervals are used to check for the flap viability.

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References

1. Pogrel MA. Who was Andy Gump? J Oral Maxillofac Surg. 2010;68(3):654–7.
2. Steckler RM, Edgerton MT, Gogel W. Andy Gump. Am J Surg. 1974;128(4):545–7.
3. Whymper W. The gunner with the silver mask: being an extraordinary case of extensive destruction of the lower jaw by a shell, vol. 12. London: Medical Gazette; 1833. p. 705–9.
4. Kaufman MH, McTavish J, Mitchell R. The gunner with the silver mask: observations on the management of severe maxillo-facial lesions over the last 160 years. J R Coll Surg Edinb. 1997;42(6):367–75.
5. Ballingall SG. Cases and communications illustrative of subjects in military and naval surgery. Edinb Med Surg J. 1842;57:116–21.
6. Gillies HD. Plastic surgery of the face based on selected cases of war injuries of the face including burns. London: Henry Frowde Oxford University Press, Hodder & Stoughton; 1920.
7. Ivy RH, Epes BM. Bone grafting for defects of the mandible. Mil Surgeon. 1927;60:286.
8. Adams WM. Internal wiring fixation of facial fractures. Surgery. 1942;12:523–40.
9. Blocker Jr TG, Stout RA. Mandibular reconstruction, World War II. Plast Reconstr Surg (1946). 1949;4(2):153–6.
10. Siemssen SO, Kirkby B, O'Connor TP. Immediate reconstruction of a resected segment of the lower jaw, using a compound flap of clavicle and sternomastoid muscle. Plast Reconstr Surg. 1978;61(5):724–35.

11. Gullane PJ, Holmes H. Mandibular reconstruction. New concepts. Arch Otolaryngol Head Neck Surg. 1986;112(7):714–9.
12. Ivy RH. Bone grafting for restoration of defects of the mandible. Plast Reconstr Surg (1946). 1951;7(4):333–41.
13. Seward GR. A method of replacing the anterior part of the mandible by a bone graft. Br J Oral Surg. 1967;5(2):99–105.
14. Millard DR, et al. Interim report on immediate mandibular repair. Am J Surg. 1969;118(5):726–31.
15. Anlyan AJ. Immediate reconstruction of mandibular defects with autogenous bone chip grafts. Am J Surg. 1965;110(4):564–7.
16. Wersall J, et al. Split-rib graft for reconstruction of the mandible. Otolaryngol Head Neck Surg. 1984;92(3):271–6.
17. Schrag C, et al. Complete rehabilitation of the mandible following segmental resection. J Surg Oncol. 2006;94(6):538–45.
18. Disa JJ, Cordeiro PG. Mandible reconstruction with microvascular surgery. Semin Surg Oncol. 2000;19(3):226–34.
19. Spiessl B. New concepts in maxillofacial bone surgery. Anatomic reconstruction and functional rehabilitation of mandibular defects after ablative surgery. In: Spiessl B, Schmoker R, editors. New concepts in maxillofacial bone surgery. Berlin/Heidelberg: Springer; 1976.
20. Lavertu P, et al. The AO system for primary mandibular reconstruction. Am J Surg. 1994;168(5):503–7.
21. Chow JM, Hill JH. Primary mandibular reconstruction using the AO reconstruction plate. Laryngoscope. 1986;96(7):768–73.
22. Komisar A, et al. The use of osteosynthesis in immediate and delayed mandibular reconstruction. Laryngoscope. 1985;95(11):1363–6.
23. Wei FC, et al. Complications after reconstruction by plate and soft-tissue free flap in composite mandibular defects and secondary salvage reconstruction with osteocutaneous flap. Plast Reconstr Surg. 2003;112(1):37–42.
24. Spencer KR, et al. The use of titanium mandibular reconstruction plates in patients with oral cancer. Int J Oral Maxillofac Surg. 1999;28(4):288–90.
25. Kim MR, Donoff RB. Critical analysis of mandibular reconstruction using AO reconstruction plates. J Oral Maxillofac Surg. 1992;50(11):1152–7.
26. Schusterman MA, et al. Use of the AO plate for immediate mandibular reconstruction in cancer patients. Plast Reconstr Surg. 1991;88(4):588–93.
27. Tidstrom KD, Keller EE. Reconstruction of mandibular discontinuity with autogenous iliac bone graft: report of 34 consecutive patients. J Oral Maxillofac Surg. 1990;48(4):336–46; discussion 347.
28. Foster RD, et al. Vascularized bone flaps versus nonvascularized bone grafts for mandibular reconstruction: an outcome analysis of primary bony union and endosseous implant success. Head Neck. 1999;21(1):66–71.
29. Conley J. Use of composite flaps containing bone for major repairs in the head and neck. Plast Reconstr Surg. 1972;49(5):522–6.
30. Taylor GI, Miller GD, Ham FJ. The free vascularized bone graft. A clinical extension of microvascular techniques. Plast Reconstr Surg. 1975;55(5):533–44.
31. Taylor GI, Townsend P, Corlett R. Superiority of the deep circumflex iliac vessels as the supply for free groin flaps. Plast Reconstr Surg. 1979;64(5):595–604.
32. Sanders R, Mayou BJ. A new vascularized bone graft transferred by microvascular anastomosis as a free flap. Br J Surg. 1979;66(11):787–8.
33. Swartz WM, et al. The osteocutaneous scapular flap for mandibular and maxillary reconstruction. Plast Reconstr Surg. 1986;77(4):530–45.
34. Hidalgo DA. Fibula free flap: a new method of mandible reconstruction. Plast Reconstr Surg. 1989;84(1):71–9.
35. Bak M, et al. Contemporary reconstruction of the mandible. Oral Oncol. 2010;46(2):71–6.

36. Cordeiro PG, et al. Reconstruction of the mandible with osseous free flaps: a 10-year experience with 150 consecutive patients. Plast Reconstr Surg. 1999;104(5):1314–20.
37. Hidalgo DA, Pusic AL. Free-flap mandibular reconstruction: a 10-year follow-up study. Plast Reconstr Surg. 2002;110(2):438–49; discussion 450–1.
38. Urken ML, et al. Oromandibular reconstruction using microvascular composite flaps: report of 210 cases. Arch Otolaryngol Head Neck Surg. 1998;124(1):46–55.
39. Slaughter DP, Roeser EH, Smejkal WF. Excision of the mandible for neoplastic diseases; indications and techniques. Surgery. 1949;26(3):507–22.
40. Ward GE, Robben JO. A composite operation for radical neck dissection and removal of cancer of the mouth. Cancer. 1951;4(1):98–109.
41. Gurtner GC, Evans GR. Advances in head and neck reconstruction. Plast Reconstr Surg. 2000;106(3):672–82; quiz 683.
42. David DJ, et al. Mandibular reconstruction with vascularized iliac crest: a 10-year experience. Plast Reconstr Surg. 1988;82(5):792–803.
43. Boyd JB, et al. Classification of mandibular defects. Plast Reconstr Surg. 1993;92(7): 1266–75.
44. Blackwell KE, Buchbinder D, Urken ML. Lateral mandibular reconstruction using soft-tissue free flaps and plates. Arch Otolaryngol Head Neck Surg. 1996;122(6):672–8.
45. Deleyiannis FW, et al. Reconstruction of the marginal mandibulectomy defect: an update. Am J Otolaryngol. 2007;28(6):363–6.
46. Jewer DD, et al. Orofacial and mandibular reconstruction with the iliac crest free flap: a review of 60 cases and a new method of classification. Plast Reconstr Surg. 1989;84(3):391–403; discussion 404–5.
47. Urken ML, et al. Oromandibular reconstruction using microvascular composite free flaps. Report of 71 cases and a new classification scheme for bony, soft-tissue, and neurologic defects. Arch Otolaryngol Head Neck Surg. 1991;117(7):733–44.
48. Wei FC, et al. Double free flaps in reconstruction of extensive composite mandibular defects in head and neck cancer. Plast Reconstr Surg. 1999;103(1):39–47.
49. Boyd JB, et al. The free flap and plate in oromandibular reconstruction: long-term review and indications. Plast Reconstr Surg. 1995;95(6):1018–28.
50. Head C, et al. Microvascular flap reconstruction of the mandible: a comparison of bone grafts and bridging plates for restoration of mandibular continuity. Otolaryngol Head Neck Surg. 2003;129(1):48–54.
51. Urken ML, et al. The internal oblique-iliac crest osseomyocutaneous microvascular free flap in head and neck reconstruction. J Reconstr Microsurg. 1989;5(3):203–14; discussion 215–6.
52. Urken ML, et al. The internal oblique-iliac crest osseomyocutaneous free flap in oromandibular reconstruction. Report of 20 cases. Arch Otolaryngol Head Neck Surg. 1989;115(3): 339–49.
53. Urken ML, et al. The combined sensate radical forearm and iliac crest free flaps for reconstruction of significant glossectomy-mandibulectomy defects. Laryngoscope. 1992;102(5): 543–58.
54. Gibber MJ, et al. Subscapular system of flaps: an 8-year experience with 105 patients. Head Neck. 2014;37(8):1200–6.
55. Zlotolow IM, et al. Osseointegrated implants and functional prosthetic rehabilitation in microvascular fibula free flap reconstructed mandibles. Am J Surg. 1992;164(6):677–81.
56. Wei FC, et al. Fibula osteoseptocutaneous flap for reconstruction of composite mandibular defects. Plast Reconstr Surg. 1994;93(2):294–304; discussion 305–6.
57. Wei FC, Chuang SS, Yim KK. The sensate fibula osteoseptocutaneous flap: a preliminary report. Br J Plast Surg. 1994;47(8):544–7.
58. O'Leary MJ, Martin PJ, Hayden RE. The neurocutaneous free fibula flap in mandibular reconstruction. Otolaryngol Clin North Am. 1994;27(6):1081–96.
59. Kuo YR, et al. Free fibula osteocutaneous flap with soleus muscle as a chimeric flap for reconstructing mandibular segmental defect after oral cancer ablation. Ann Plast Surg. 2010;64(6):738–42.

60. Beppu M, et al. The osteocutaneous fibula flap: an anatomic study. J Reconstr Microsurg. 1992;8(3):215–23.
61. Wei FC, et al. Fibular osteoseptocutaneous flap: anatomic study and clinical application. Plast Reconstr Surg. 1986;78(2):191–200.
62. Wong CH, et al. Use of the soleus musculocutaneous perforator for skin paddle salvage of the fibula osteoseptocutaneous flap: anatomical study and clinical confirmation. Plast Reconstr Surg. 2007;120(6):1576–84.
63. Frodel Jr JL, et al. Osseointegrated implants: a comparative study of bone thickness in four vascularized bone flaps. Plast Reconstr Surg. 1993;92(3):449–55; discussion 456–8.
64. Rodriguez ED, et al. Near-total mandible reconstruction with a single fibula flap containing fibrous dysplasia in McCune Albright Syndrome. J Craniofac Surg. 2007;18(6):1479–82.
65. Moscoso JF, et al. Vascularized bone flaps in oromandibular reconstruction. A comparative anatomic study of bone stock from various donor sites to assess suitability for endosseous dental implants. Arch Otolaryngol Head Neck Surg. 1994;120(1):36–43.
66. Jones NF, et al. The "double barrel" free vascularized fibular bone graft. Plast Reconstr Surg. 1988;81(3):378–85.
67. Wallace CG, et al. Harnessing the potential of the free fibula osteoseptocutaneous flap in mandible reconstruction. Plast Reconstr Surg. 2010;125(1):305–14.
68. Horiuchi K, et al. Mandibular reconstruction using the double barrel fibular graft. Microsurgery. 1995;16(7):450–4.
69. Iizuka T, et al. Bi-directional distraction osteogenesis of the alveolar bone using an extraosseous device. Clin Oral Implants Res. 2005;16(6):700–7.
70. Schleier P, et al. Vertical distraction of fibula transplant in a case of mandibular defect caused by shotgun injury. Int J Oral Maxillofac Surg. 2006;35(9):861–4.
71. Bodde EW, et al. Donor-site morbidity after free vascularized autogenous fibular transfer: subjective and quantitative analyses. Plast Reconstr Surg. 2003;111(7):2237–42.
72. Sassu P, et al. Anatomy and vascularization of the flexor hallucis longus muscle and its implication in free fibula flap transfer: an anatomical study. Ann Plast Surg. 2010;64(2):233–7.
73. Babovic S, Johnson CH, Finical SJ. Free fibula donor-site morbidity: the Mayo experience with 100 consecutive harvests. J Reconstr Microsurg. 2000;16(2):107–10.
74. Boyd JB, Mulholland RS. Fixation of the vascularized bone graft in mandibular reconstruction. Plast Reconstr Surg. 1993;91(2):274–82.
75. Shaw RJ, et al. Comparison of miniplates and reconstruction plates in mandibular reconstruction. Head Neck. 2004;26(5):456–63.
76. Futran ND, et al. Rigid fixation of vascularized bone grafts in mandibular reconstruction. Arch Otolaryngol Head Neck Surg. 1995;121(1):70–6.
77. Ung F, Rocco JW, Deschler DG. Temporary intraoperative external fixation in mandibular reconstruction. Laryngoscope. 2002;112(9):1569–73.
78. Edwards SP. Computer-assisted craniomaxillofacial surgery. Oral Maxillofac Surg Clin North Am. 2010;22(1):117–34.
79. Kennady MC, et al. Stress shielding effect of rigid internal fixation plates on mandibular bone grafts. A photon absorption densitometry and quantitative computerized tomographic evaluation. Int J Oral Maxillofac Surg. 1989;18(5):307–10.
80. Jacobson AS, Smith M, Urken ML. Internal mammary artery and vein as recipient vessels in head and neck reconstruction. JAMA Otolaryngol Head Neck Surg. 2013;139(6):623–8.
81. Urken ML. Atlas of regional and free flaps for head and neck reconstruction. 1st ed. New York: Raven Press; 1955.
82. Nahabedian MY, Tufaro A, Manson PN. Improved mandible function after hemimandibulectomy, condylar head preservation, and vascularized fibular reconstruction. Ann Plast Surg. 2001;46(5):506–10.
83. Potter JK, Dierks EJ. Vascularized options for reconstruction of the mandibular condyle. Semin Plast Surg. 2008;22(3):156–60.
84. Khariwala SS, et al. Temporomandibular joint reconstruction using a vascularized bone graft with Alloderm. J Reconstr Microsurg. 2007;23(1):25–30.

85. Shenaq SM, Klebuc MJ. TMJ reconstruction during vascularized bone graft transfer to the mandible. Microsurgery. 1994;15(5):299–304.
86. Dolwick MF, Aufdemorte TB. Silicone-induced foreign body reaction and lymphadenopathy after temporomandibular joint arthroplasty. Oral Surg Oral Med Oral Pathol. 1985;59(5):449–52.
87. Bredell M, et al. Management of the temporomandibular joint after ablative surgery. Craniomaxillofac Trauma Reconstr. 2014;7(4):271–9.
88. Roumanas ED, et al. Reconstructed mandibular defects: fibula free flaps and osseointegrated implants. Plast Reconstr Surg. 1997;99(2):356–65.
89. Chiapasco M, et al. Clinical outcome of dental implants placed in fibula-free flaps used for the reconstruction of maxillo-mandibular defects following ablation for tumors or osteoradionecrosis. Clin Oral Implants Res. 2006;17(2):220–8.
90. Okay DJ, et al. Computer-assisted implant rehabilitation of maxillomandibular defects reconstructed with vascularized bone free flaps. JAMA Otolaryngol Head Neck Surg. 2013;139(4):371–81.
91. Wei FC, et al. Mandibular reconstruction with fibular osteoseptocutaneous free flap and simultaneous placement of osseointegrated dental implants. J Craniofac Surg. 1997;8(6):512–21.
92. Levine JP, et al. Jaw in a day: total maxillofacial reconstruction using digital technology. Plast Reconstr Surg. 2013;131(6):1386–91.
93. Clayburgh DR, et al. Prospective study of venous thromboembolism in patients with head and neck cancer after surgery. JAMA Otolaryngol Head Neck Surg. 2013;139(11):1143–50.
94. Chien W, et al. Effects of aspirin and low-dose heparin in head and neck reconstruction using microvascular free flaps. Laryngoscope. 2005;115(6):973–6.
95. Ashjian P, et al. The effect of postoperative anticoagulation on microvascular thrombosis. Ann Plast Surg. 2007;59(1):36–9; discussion 39–40.
96. Lighthall JG, et al. Effect of postoperative aspirin on outcomes in microvascular free tissue transfer surgery. Otolaryngol Head Neck Surg. 2013;148(1):40–6.

Current Concepts in Maxillary Reconstruction

4

Subramania Iyer and Krishnakumar Thankappan

4.1 Introduction

The concepts in maxillary reconstruction are still evolving when compared to the reconstruction of the mandible. Maxillary defects affect the functions of the speech, swallowing, and mastication and also cause cosmetic disfigurement. Rehabilitation of the maxillary defects is either possible by using an obturator prosthesis or by a surgical reconstruction. A variety of reconstructive methods are available. The classification systems are also many, none universally accepted. The oncologic safety of these procedures is still debated and conclusive evidence in this regard has not emerged yet. Management of the defects of the orbit associated with maxillectomy is an area yet to be solved. Tissue engineering, though thought to be one of the possible solutions for this reconstructive problem, has not come out with reliable and reproducible results yet. This chapter discusses the rationale and oncological safety of reconstructing the maxillary defects, critically analyzes the classification systems, and discusses the different reconstructive methods and controversies in this scenario. The management of the retained and exenterated orbit associated with maxillectomy is reviewed. The surgical morbidity, complications, and the recent advances in this field are also looked into. An algorithm, based on our experience, is presented.

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4.2 Obturator Versus Reconstruction

Maxillectomy defects traditionally were reconstructed using split-thickness skin grafts to line the cavity to facilitate a prosthetic obturator placement. After the cavity healing, an interim and later a permanent obturator was provided. The retention was achieved by anchoring to the remaining teeth [1]. To facilitate obturator placement in edentulous patients and in cases of bilateral maxillectomy, osseous integrated implants were used in the adjacent bony structures like the zygoma [2]. Obturation of the maxillary defects as a permanent definitive option is still practiced widely due to its relative safety and the lesser surgical time. This method has an advantage of immediately restoring the dentition, but the flap reconstructions require further procedures or dentures. It has been believed that permanent sealing of the maxillary cavity would hinder its inspection during follow-up for any recurrences. However, there are many disadvantages with the use of the obturator like the inadequacy in sealing leading to poor oronasal separation and instability of the prosthesis due to the lack of buttressing areas. This becomes more evident when the defect is wider and posteriorly placed [2, 3]. Quality of life studies (QOL) have shown low scores in patients using obturators when compared to the surgical reconstruction. Kornblith et al. [4] observed that patients with defects more than a third of the soft palate and a fourth of the hard palate had poor speech scores and obturator function. Rogers et al. [5] compared the QOL in a two similar groups of patients having either prosthetic or surgical obturation of maxillectomy cavities. These patients completed a postoperative semistructured interview with eight sets of questionnaires. No statistically significant differences were seen between the obturator and free flap groups. But they reported borderline trends for obturator patients being more self-conscious, concerned about their appearance, to have more pain and soreness in their mouths, more and less satisfied with their upper dentures and function. The problems with the use of obturator included larger soft or hard palatal resection, defects with facial skin or orbital contents, and the presence of trismus. Okay et al. noted that the stability of the prosthesis compromised as the size of the defect increased, resulting in poor obturator function and QOL. They concluded that the defects involve more than half of the hard palate or those with the defects of the premaxilla and both canines were poor candidates for prosthetic reconstruction [6]. The influence of the horizontal extent of the palatal defect in determining the success of the use of obturators was stressed by Moreno and Hanasono in their comparative study of 73 cases with obturation and 40 cases with free flap reconstruction. They found a statistically significant reduction in the speech and swallowing outcome with the use of obturators where the horizontal defect was large [7]. The superiority of free flaps in improving the QOL, even in small and medium defects of maxilla, was reported by Genden et al. [8]. Adjuvant radiotherapy can cause significant problems with obturator rehabilitation. The radiation can cause trismus and thereby the difficulty in insertion of the prosthesis and dryness and soreness of the mucosa [9]. Genden et al. noted that, in the group of patients who had undergone radiotherapy, there was pain and difficulty tolerating the prosthesis. They also needed frequent adjustment of the prosthesis [10]. The importance of surveillance

of the cavity for recurrences by keeping it open has been supported or negated by only very few studies. Moreno et al. [7] compared the average time of presentation of recurrence in two groups of patients who had undergone maxillectomy: one group had flap reconstruction and the other had patients with obturator. Each group was matched for cancer stage and histology. No statistically significant differences between the two groups could be detected. Also, they found that the diagnosis of recurrence was more frequently made by physical examination in both groups than by imaging with CT or MRI scans. But the number of cases included in this analysis was too small to reach any reliable conclusion. But the papers supporting reconstruction, without the support of any evidence, state that endoscopic examination and use of imaging modalities like CT and MRI scan can negate the necessity of keeping the cavity open.

4.3 Classification Systems

Various classification systems have tried to look at the defects, from their functional and/or esthetic effects. Some of them have looked at the reconstructive or rehabilitative considerations only. Brown et al. [11] initially classified maxillectomy defects into four, based on the vertical and horizontal defect components. The vertical divisions (Classes I–IV) denote the extent of unilateral involvement. The subclassifications into a–c qualify the defect horizontally, denoting the amount of palate and alveolus removed. The loss of the vertical component causes more of an esthetic problem, while the horizontal component loss results in greater functional deficits. The dental, masticatory, and the articulatory aspects are given by the horizontal component, and the esthetic and orbital aspects are highlighted by the vertical components. Recently, the authors modified the classification system [12], to include a class V defect, the orbito-maxillary defect, and class VI defect, the nasomaxillary defect. These two additions do not involve the ablation of the palate or the dental alveolus. Modification also included minimal changes in the horizontal classification into a–d.

Cordeiro et al. have suggested a four-part classification system [13–15]. They used this classification system to assess the surface area to volume requirement, the need for the palatal closure, and the need for orbital reconstruction. Triana et al. [16] classified the defects into (1) inferior partial maxillectomy, subdivided based on the extent of the palate lost, and (2) total maxillectomy subdivided depending on whether the orbit was removed and the amount of the malar bone and zygomatic arch lost. Okay et al. [6] have described a scheme based on the defect in the horizontal planes. This classification system mainly takes into account the obturator stability and the retention.

A classification system should be valid and reliable and should grade the defects according to the reconstructive difficulty. It should describe the defect with increasing loss of the reconstructive components and should be the guide to an ideal reconstructive method. It should serve as a means of documentation for the comparison of results and should identify the ability and deficits in achieving the reconstructive

goals. While other systems give much importance on the restoration of the soft issue and the bony components, the classification proposed by Okay et al. stressed on importance to the dental and alveolar restoration and rehabilitation. The extent of the palatal defect itself or the stability for successful obturator retention was given prime consideration in their classification. Moreno et al. [7] in their retrospective analysis pointed out that the success of denture obturator rehabilitation correlated very well when the defects were Type 3 as per Okay classification. They conclude that these defects are better covered with free flaps. Brown classification [12] also incorporates the horizontal extent of the defect, grading them a–c depending on the extent of resection of the hard palate and alveolus. But while considering the options in choosing the reconstructive choice of the flap, they stress on the vertical extent of the resection than on the horizontal extent. The vertical extent of the defect as well as the components involved have been the mainstay of the well-publicized classification systems proposed by Cordeiro [3, 17] and Brown. The four-part classification system proposed by Cordeiro and colleagues seems simple to follow and is based on the number of walls resected as well as whether the orbital contents were included in the resection. They used this classification system to assess the surface area to volume requirement, the need for the palatal closure, and the need for orbital reconstruction. They also tried to identify the best flap for a particular defect. But since they relied mostly on soft tissue reconstruction only especially with radial forearm, the guidance as to the ideal reconstructive choice based on their system of classification fails to serve in this purpose. Adding to the deficiencies of the system, this classification does not give much importance to the dental restoration. Cordeiro et al. [17] in their most recent modification added two subgroups based on whether less or more than 50 % of palate was resected but failed to substantiate this with any implications in the functional outcome.

The Brown classification is more sound in its principles both in terms of the description of the defects and the help rendered for planning the reconstruction and rehabilitation. This system does not quantify the amount of skin loss and skull base defect. Combining the Okay system palatal defect and the Brown classification as done in the series reported by Moreno et al. seems most encompassing but may be difficult to follow in all future studies.

4.4 Methods of Reconstruction

The reconstructive options described for maxillectomy defects can be regional flaps either soft tissue or bone containing flaps, free flaps with either soft tissue alone or with bone or combinations of soft tissue flaps and alloplastic implants. The regional soft tissue flaps used for reconstruction of these defects include temporalis myofascial flaps [15, 18], facial artery myomucosal flaps (FAMM) [19, 20], buccal pad of fat [21, 22], and reverse submental flaps [23, 24]. Of these, the buccal pad of fat flaps and the FAMM (Fig. 4.1a–c) flaps are found to be useful in small and lateral defects. The temporalis flap [25] (Fig. 4.2a–c) is still useful and popular. But the disadvantages of this flap include dehiscence in larger defects and trismus. The

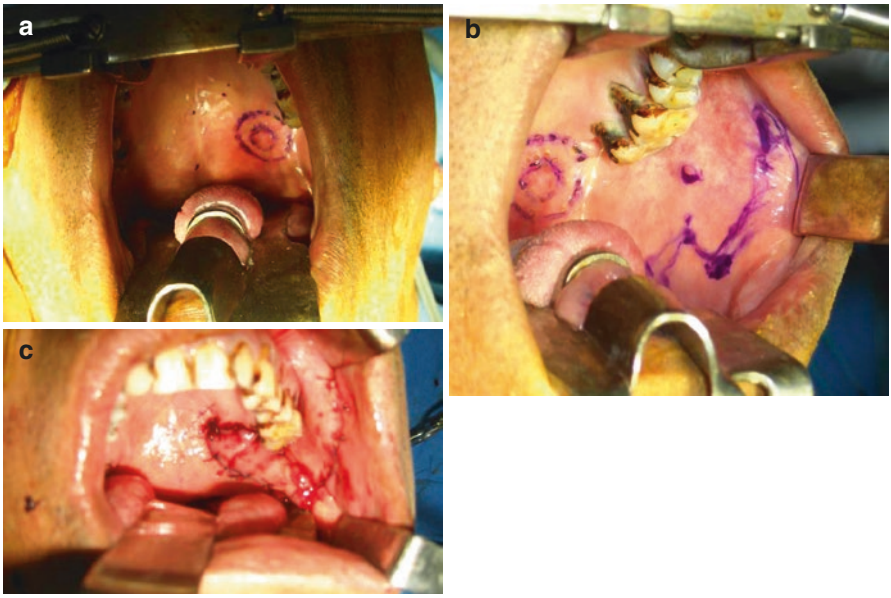

Fig. 4.1 (**a**) Facial artery myomucosal (FAMM) flap used for a lateral defect. The palatal lesion. (**b**) Flap marked. (**c**) FAMM flap sutured to the defect

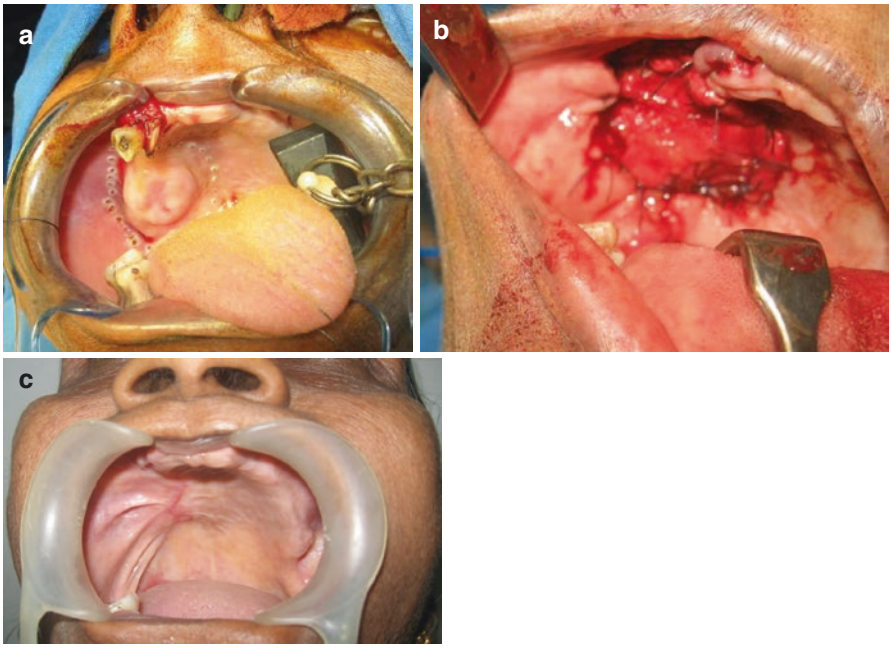

Fig. 4.2 (**a**) Tumor involving the posterior superior alveolar area. (**b**) Temporalis flap sutured to the defect. (**c**) Reconstructive outcome 2 years after surgery

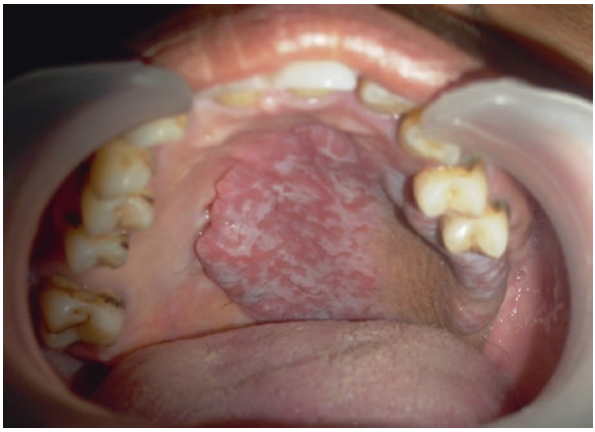

Fig. 4.3 Infrastructure maxillectomy defect reconstructed with free radial forearm flap

reverse submental artery flap based on the distal facial artery was reported to be successful in a series of 13 cases by Wang et al. [24]. The flaps were deepithelialized and used to cover inferior maxillectomy defects. These flaps undergo a phase of inflammation, granulation tissue re formation followed by epithelialization [26]. But all these flaps allowing epithelialization can lead to contraction and obliteration of the sulcus, making dental rehabilitation difficult.

The free soft tissue flaps described are radial forearm flaps [15], rectus abdominis [27], anterolateral thigh flap [28, 29], and deep inferior epigastric perforator (DIEP) flaps [30]. The main objective of reconstruction using these flaps is to seal the palatal defects. Hence, they are mainly used in cases of maxillectomy with preservation of the orbital floor. Figure 4.3 shows an infrastructure maxillectomy defect reconstructed with free radial fore arm flap. The advantage of these flaps includes their long pedicle that makes the vascular anastomosis in the neck easier [31]. The drawback of these flaps is their inability to address the need of orbital support, the inability to prevent hollowing of cheek, and the difficulty to place dental implants. Dental rehabilitation becomes difficult in these cases due to the insufficiency of the gingivo-buccal sulcus.

The disadvantages of lack of bony support to the orbit and the absence of skeletal support to the cheek, while using soft tissue flap alone, have been addressed in several reports by using implants or bone grafts along with them. Bianchi et al. reported successful use of iliac crest bone grafts along with both ALT [32] and vertical rectus abdominis flaps [33]. The number of cases reported was small, but they claimed the bone grafts withstanding postoperative radiation. Hashikawa et al. [34, 35] used titanium mesh for reconstruction of the floor of the orbit and radial forearm free flap for covering the titanium mesh and lining the cheek. Obturator prosthesis was used for palatal and dental rehabilitation. Sun et al. [36] also reported reconstruction of maxillary defects with titanium mesh and radial forearm free flap. Nakayama et al. [37] reported using soft tissue flaps like rectus abdominis muscle and ALT in

combination with titanium mesh for maxillectomy defect reconstruction. The soft tissue flaps were put both in front and behind the mesh to prevent its exposure. Dediol et al. [38] in a recent report used a prefabricated titanium mesh, for the orbital floor, the infraorbital rim, the zygomatic prominence, the anterior wall of maxilla, and the alveolus. The titanium mesh was bent intraoperatively on a three-dimensional skeletal model. They used ALT flaps in majority of cases for palatal obturation. Part of the flap was deepithelialized and used to cover the mesh from its anterior aspect.

Many bone flaps have been used in maxillary reconstruction. They provide (a) support for the orbital contents (b) alveolar reconstruction, and (c) prominence to the cheek. Few regional bone containing flaps have been used for this purpose, but most of the reports are those using free bone flaps. The use of the coronoid process of the mandible based on the temporalis muscle for orbital support was reported by Curioni [39] and Pryor et al. [40]. The coronoid process is harvested long enough into the ramus of the mandible enabling it to reach the medial nasal wall, where it is attached with the plate or wires. In the cases reported by Pryor et al. the maxillary cavity was covered with an obturator. Bilen et al. [41] described a superficial temporal artery (STA)- and vein-based calvarial bone flaps using its outer table. Without disrupting the integrity of the fascia and periosteum, the bone was separated into two segments. One segment of the bone was used to reconstruct the orbital floor and the other for reconstruction of the anterior maxillary wall. Out of the five cases, in two, large skin defects were also covered with lateral frontal skin supplied by the STA. Yang et al. [42] used the reverse submental deepithelialized flap to carry the lower border of the mandible for reconstructing the upper alveolar defect. They even used immediate dental implants in these cases successfully. The mandibular donor site was filled with a porous polyethylene surgical implant. The disadvantages of these pedicled flaps include difficulty in maneuvering them and the deficiency in soft tissue cover. The behavior of these flaps to radiotherapy is also unpredictable [43].

The literature is abundant on the use of free bone flaps for maxillary reconstruction. The flaps used include fibula osteocutaneous [44–47], scapula [48–50], iliac crest [51–53], radial forearm [54, 55], tensor facial lata (TFL)-iliac crest [56], rectus abdominis with ribs [57] and TFL-iliac crest with internal oblique [58], and medial femoral condyle flap [59]. The need of the bone in maxillary reconstructions is to (a) restore midface contour, (b) provide orbital floor support, (c) replace the missing alveolar bone, and (d) act as a base for the dental implants. The various bone flaps and the methods described utilizing these flaps achieve these goals to a widely variable extent. The radial forearm osteocutaneous flaps have the advantage of a long pedicle, large skin paddle for cheek or palatal lining, but with a small thin bony segment. Andrades et al. [55] used this flap for zygomatic maxillary buttress with the skin paddle used for covering the intraoral defect and the external skin defect. A mesh was used for the orbital support. Chepeha et al. [54] used the radial bone for orbital floor support and obturator for the palatal defect. In general, the use of it is limited in maxillary reconstruction.

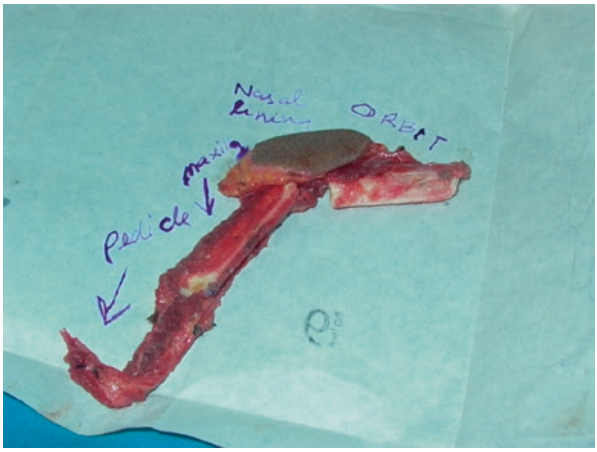

Fig. 4.4 Free fibula osteocutaneous flap with osteotomies and an intervening segment of bone removed to facilitate orbital and alveolar bone support

The advantages of the fibula flap include the sufficient bone length that allows multiple osteotomies to be made. This becomes important when separate bone segments are needed for alveolus and the orbital floor support. The intervening segment of the bone can be removed for this purpose (Fig. 4.4). But the greater advantage of the fibula is the long pedicle length, allowing a tension-free anastomosis in the neck. The skin paddle can be used for palatal obturation and the skin cover if needed. The disadvantages of the fibula include the lack of soft tissue to fill the maxillary cavity especially if a mesh is used for orbital floor reconstruction and the inability to contour it to the needs of orbital floor support. The deep circumflex iliac artery-based iliac crest flap was suggested as a better option by Brown et al. [60]. They oriented the iliac crest horizontally in their class II defects and vertically in the class III and class IV defects. The advantage of the iliac crest, when vertically placed for larger defects in restoration of the facial bone buttress, is the support to the nose and superior lip, and reconstruction of the orbital rim was stressed by Futran [61] and Bianchi [53]. The drawbacks of the iliac crest flap have been the short pedicle length and the donor side morbidity. The solutions for the short pedicle length are high dissection of the facial vessels in the cheek as the donor vessels or by extending the pedicle length by use of the ALT flap pedicle as an arteriovenous graft [53]. The scapula and parascapular flaps have been increasingly used in maxillary reconstruction [62, 63]. The advantages of the scapula include long pedicle length; the two pedicle systems that can be used to vascularize the bone, namely, the subscapular vessels and the angular artery from thoracodorsal system; and the availability of large amount of soft tissues with minimal donor site morbidity. The disadvantage of this flap includes the difficulty in harvesting the flap simultaneously, but Clark et al. [49] refute it by positioning the patient in such a way that they were able to harvest the flap without change of position, thereby reducing the time required in the harvest. The thin bone has been criticized for its aptness for implant placement [64].

Among the less commonly used free bone flaps, the medial femoral condyle based on the descending genicular vessels was reported to be useful in a case of small anterior or anterolateral alveolar defects by Kademani et al. [65]. In a single case report, Sekido et al. [57] harvested a DIEP flap, dissected the vessels through the rectus abdominis, and used the cranial part of the rectus muscle to vascularize the ninth and tenth ribs. They used these ribs for zygomaticomaxillary buttress reconstruction. We have described the use of the iliac crest-tensor fascia lata muscle with or without the overlying skin for maxillary reconstruction, where support of the globe was needed. Seven successful cases were reported, where the bone used was nourished by the attachment of the TFL muscle [66]. The authors reported further refinements on this technique, by combining it with the internal oblique muscle for orbital lining when orbital exenteration was done [58].

4.5 Maxillectomy with Orbital Floor Defects

Two types of defects can result depending on whether the orbital contents are preserved or not. When the orbital contents are preserved, the support of the globe becomes important. This will depend upon the amount of maxillary walls resected. Minimal loss of the orbital floor in a standard maxillectomy may not result in loss of support to the contents, since the periorbita will provide it. But when the loss is more, either in the mediolateral direction, especially when the lateral orbital walls is resected, or in the anteroposterior direction when entire floor of orbit is removed, support for the globe may be necessary. This situation also occurs when large area of the periorbita is excised for tumor clearance.

The use of soft tissue flaps alone in these situations may not be ideal. The number of cases with enophthalmos and hypophthalmos was higher in a series reported by Sampathirao et al. [70], when compared to bony reconstruction of the floor. Figure 4.5 shows a patient in whom rectus abdominis flap was used (Fig. 4.5a–d,). Provision for orbital floor support has been attempted by several methods [67] including the use of Prolene mesh, facial or musculofacial slings [68], titanium mesh in combination with other flaps [34, 37], free bone grafts along with soft tissue flaps [32, 33], pedicled calvarial [69] and coronoid flaps [39, 40], and free bone flaps. The free bone flaps suitable in these cases include the fibula [70], scapula [49], DCIA [51, 53], and TFL-IC flap [56]. The simplest solution for orbital support is the use of a titanium mesh that can be contoured to the defect very well (Fig. 4.6). The problem with using the mesh is its high extrusion rate with the postoperative radiation therapy. The importance of keeping the mesh posterior and not extending it to form the infraorbital rim in order to reduce the extrusion was stressed by Sarukawa et al. [71]. They also noted that, if a mesh had to be used, it should be straddled on all sides with a robust and vascular soft tissue. The use of other non-vascularized tissues is also debatable in view of the radiation therapy. In a recent article from MD Anderson group [72], out of the 246 cases, 59 needed orbital floor reconstruction. The majority of the cases (30 patients) had non-vascularized tissue or alloplast-titanium mesh; bone grafts were used in 20 patients,

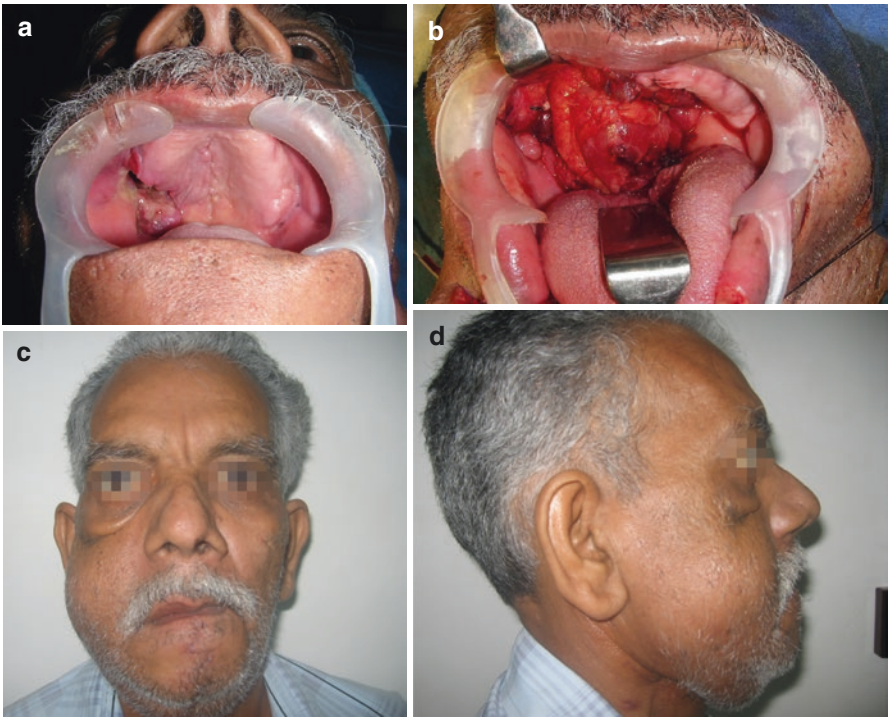

Fig. 4.5 (**a**) Palatal involvement by the tumor. (**b**) Rectus abdominis free flap used to fill the maxillectomy cavity and the palatal defect. (**c**) Reconstructive outcome 1 year after surgery and radiotherapy, frontal view. Note the sagging of the eye on the reconstructed side. (**d**) Reconstructive outcome 1 year after surgery and radiotherapy, lateral view

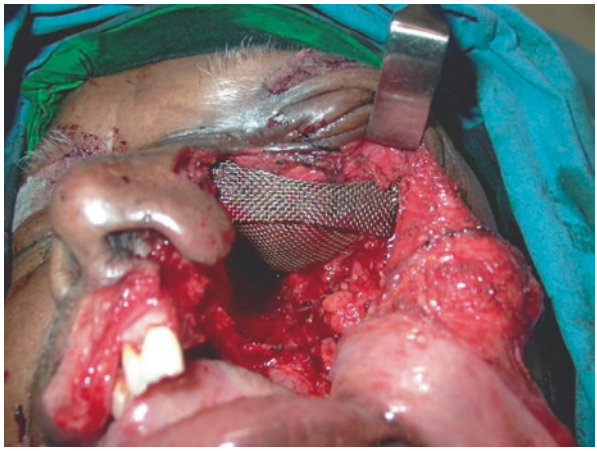

Fig. 4.6 Titanium mesh for orbital support

porous polyethylene in four patients, and a fascia lata graft in one patient. Four patients had bony free flaps. The implant exposure rate in their series of non-vascularized methods was very low. The implant got exposed in two cases of bone graft and in one case of titanium mesh. The authors' preference [70] is for a bone flap, either the fibula or TFL-iliac crest. Figure 4.7 shows a patient with maxillectomy defect with orbital floor loss, reconstructed with free fibula osteocutaneous

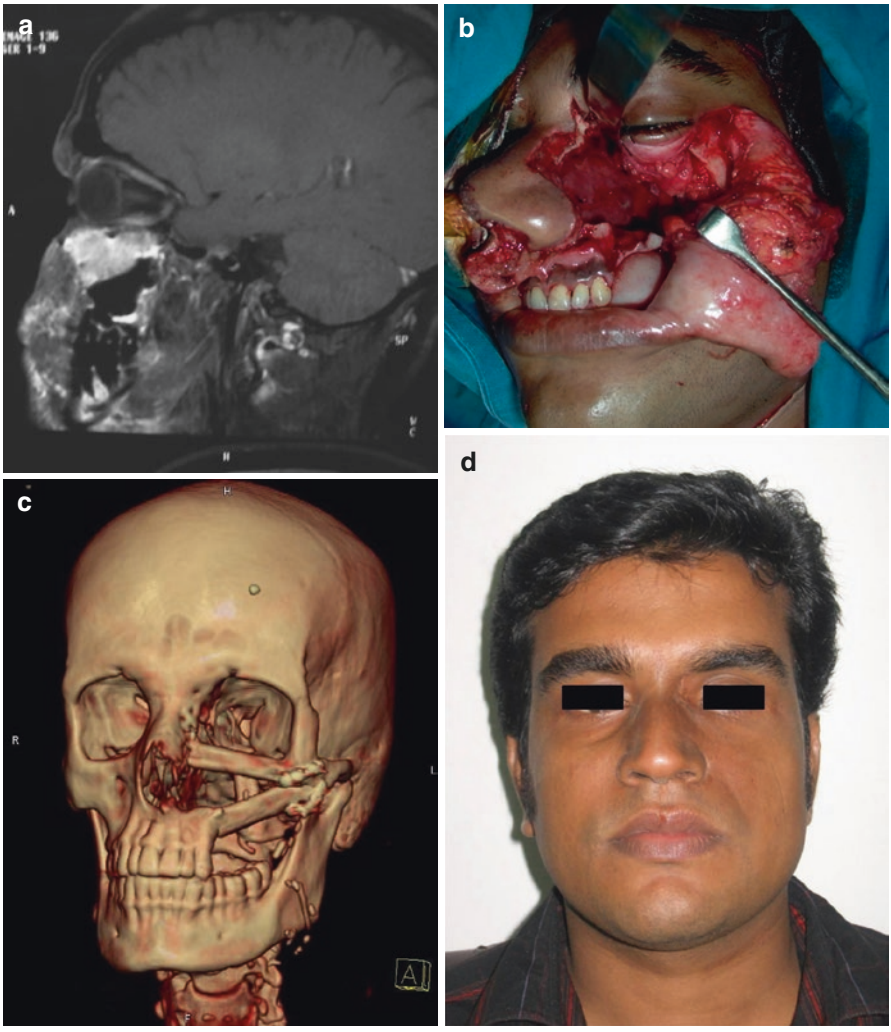

Fig. 4.7 (**a**) Computed tomography of a patient with maxillary tumor with orbital floor involvement. Sagittal view. (**b**) Total maxillectomy defect with orbital floor removed. Class IIIa per Brown classification. (**c**) Computed tomography, three-dimensional view showing free fibula flap used for reconstruction. (**d**) Reconstructive outcome 2 years after surgery and radiotherapy, frontal view

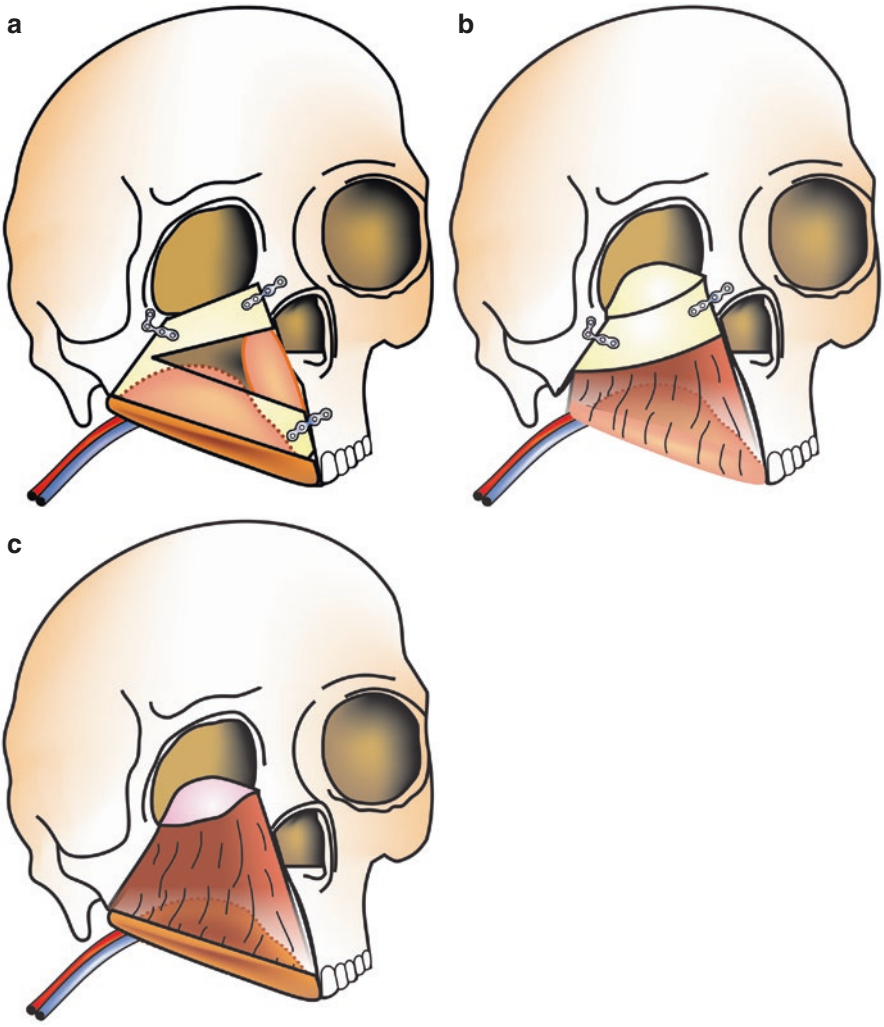

Fig. 4.8 (**a**) Line diagram showing the reconstruction with free fibula flap. (**b**) Line diagram showing the reconstruction with free tensor fascia lata with iliac crest flap. (**c**) Line diagram showing the reconstruction with a soft tissue flap, free rectus abdominis. The fascia of the flap (shown in *pink*) was used as a sling for the orbital contents

flap (Fig. 4.7a–d). Titanium mesh was used in the cases where the bone flap failed to provide the support, either due to the architecture of the defect or poor pedicle length, and in patients with the risk for long surgery due to systemic problems. Figure 4.8 shows a schematic representation of the three different options of reconstructing the orbital floor defects associated with maxillectomy with free flaps (Fig. 4.8a–c).

4.6 Maxillectomy with Orbital Exenteration Defects

When the orbital contents are exenterated along with a maxillectomy, the defect becomes complex with communication of the oral and nasal cavities with exterior and occasionally with the cranial cavity. Immediate goal in the reconstruction is achieved in such cases by a soft tissue flap like the rectus abdominis as suggested by Hanasono et al. [73] and Cordeiro et al. [15]. Figure 4.9 shows a patient with carcinoma of the maxillary sinus with orbital content involvement, who underwent orbital exenteration along with maxillectomy. Reconstruction was with free rectus abdominis flap (Fig. 4.9a–c). The orbital rehabilitation becomes difficult in this method of reconstruction as only a spectacle borne external prosthesis could be used. Though attempts have been to fit an ocular prosthesis in the cavity formed by a muscle flap, the fibrosis that sets in pushes out the ocular prosthesis. The use of conventional bone flaps like the DCIA flap, fibula flap, or scapula flap does not provide satisfactory reconstruction of the orbital cavity. The relative orientation of the bone, muscle, and the skin paddle is a restriction for this complex multiaxial reconstruction. A titanium mesh may be used for the orbital floor, combined with a free soft tissue flap. But technically it is difficult to cover the mesh on the orbital cavity side. Using two flaps like DCIA or fibula for the

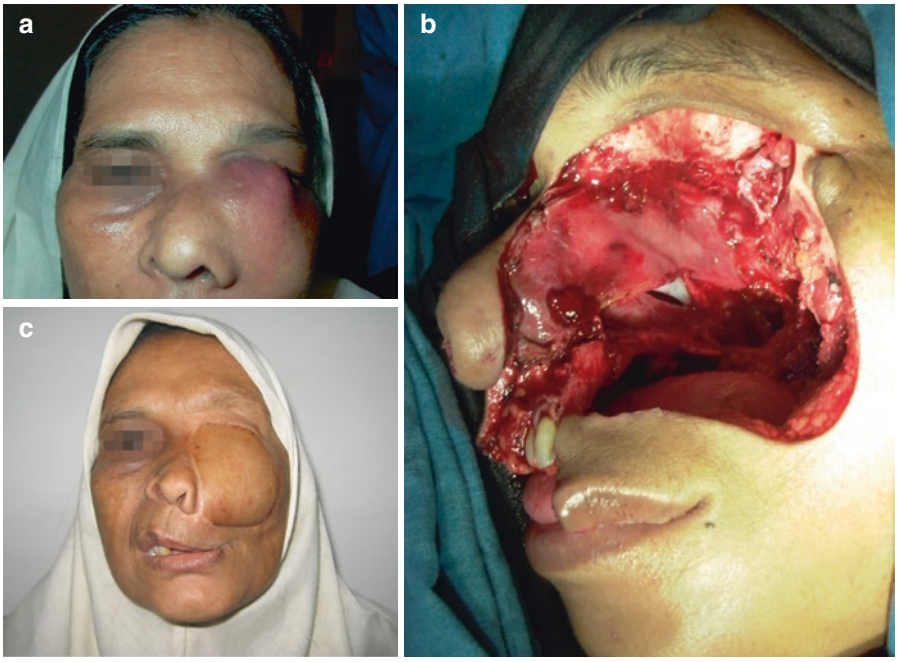

Fig. 4.9 (**a**) Patient with squamous cell carcinoma of the maxilla, preoperative frontal view. (**b**) Maxillectomy defect with orbital exenteration, Brown class IV. (**c**) Reconstructed outcome with free rectus abdominis flap, 2 years after treatment

suprastructure and a soft tissue flap like radial forearm flap for the palate may be considered. The authors described a new technique to address this issue by using a TFL-iliac crest-internal oblique (TFL-IC-IO) flap based on dual blood supply from the DCIA and TFL vessels [58] (Fig. 4.10a–c).

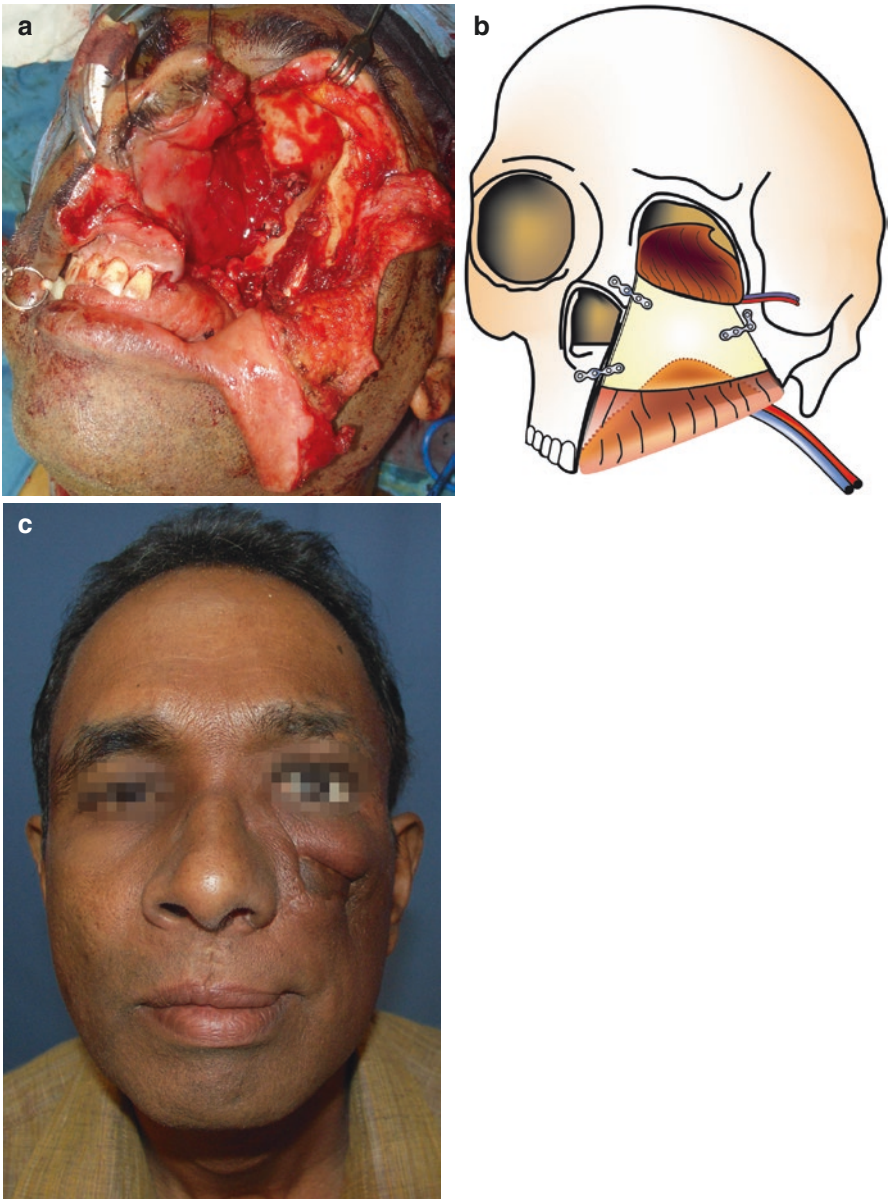

Fig. 4.10 (**a**) Maxillectomy with orbital exenteration defect. (**b**) Line drawing showing the reconstruction with tensor fascia lata-iliac crest-internal oblique flap (TFL-IC-IO) with dual anastomosis. (**c**) Reconstructed outcome 1 year after treatment, frontal view

4.7 Algorithmic Approach for Maxillary and Orbital Reconstruction

Based on different classification systems available and personal experience, different authors have put up algorithmic approaches for maxillary reconstruction. Brown [12] discusses the reconstructive options according to his earlier classification as well as its modification. He looked at the reconstructions reported till 2009 and, after reclassifying them, found that, in class I, radial forearm flap dominated the method of reconstruction. In classes II and III, more number of free bone flaps, especially the fibula, was used. Other bone flaps used included DCIA and scapular tip. In these defects, soft tissue flaps were also used: the radial forearm flap in class II and rectus abdominis in class III. In class IV, majority had either the rectus abdominis or latissimus dorsi. When bone flaps were used, DCIA predominated. He suggested either obturation or regional flaps or radial forearm flap for class I defects, bone flaps for classes II and III, and soft tissue flaps for class IV defects. The bone flap preferred was DCIA or scapula or scapular tip based on thoracodorsal vessels. Cordeiro and associates [15], based on their 15-year experience in maxillary reconstruction and based on their classification system, proposed an algorithm for maxillary reconstruction. Their preference was for the use of radial forearm flaps as single or double paddles or along with the radius bone as a sandwich flap, in majority of the cases. The rectus abdominis flap was used for defects requiring larger amounts of soft tissue. Okay [6] and associates after suggesting their classification guided by prosthodontic requirements suggested an algorithm. They suggested options similar to the ones by Brown et al. They preferred obturation, regional flaps, or soft tissue flaps for their type Ia defects, and all others were preferably reconstructed with bone flaps. Obturation could also be used in class II defects. They found bone flaps to be superior, since they suggested implant placement for proper dental rehabilitation. They did not specify the type of bone flaps to be used. While reporting one of the largest series of free flap reconstructions in the maxilla, Hanasono et al. [15] from MD Anderson group looked at the defects more exhaustively using both Brown and Cordeiro classification. The number of subclasses in their algorithm was more, but essentially the palato-alveolar, orbital floor, and orbital exenteration defects were the main considerations for choosing the method of reconstruction. In general they suggested bone flaps (free fibula osteocutaneous flap) for palate alveolar defects rather than soft tissue flaps, since they felt that dental rehabilitation was difficult with the latter, mainly due to the sagging of the flaps. They opted for alloplastic implants or bone grafts in combination, for the orbital floor defects and obliteration with soft tissue flaps for orbital exenteration defects. Sarukawa et al. [71] used the Cordeiro system and reconstructed only the class III and class IV defects with soft tissue flaps. For large palatal defects, they adopted the Brown classification [12] and suggested bony reconstruction using the fibula. Based on our experience of over 150 cases, we have evolved an algorithm as given in Fig. 4.11. We found the Brown classification [11, 12] to be more useful and reproducible. Our choice is regional or free soft tissue flaps or obturator for the type I defects. Free flaps, especially radial forearm flap, were preferred when the defect was larger transversely. In class II defects, our choice is the fibula, mainly for its long pedicle length and good bone

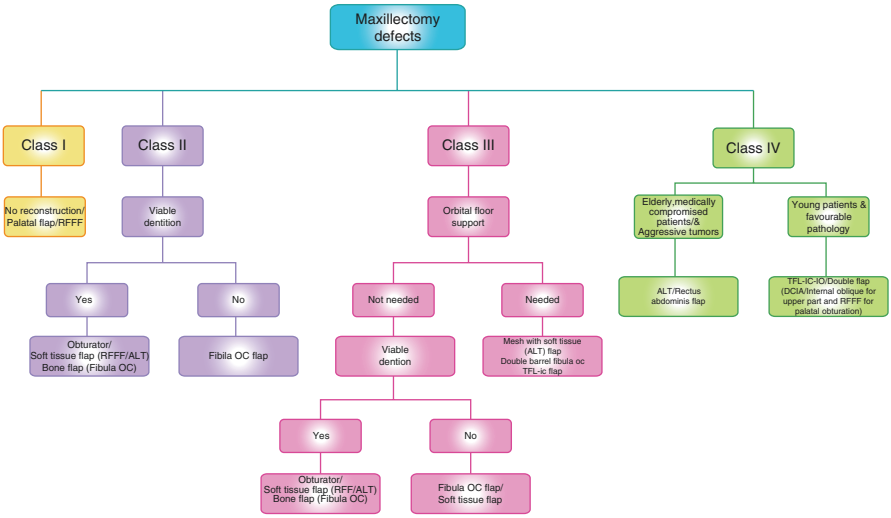

Fig. 4.11 Amrita algorithm for reconstructing the maxillectomy defects

support. The fibular skin paddle gives a satisfactory oronasal separation. In class III defects requiring orbital support, especially when the periorbita is removed or when the bone defect is large, the choice is debated. We still use the fibula but find it difficult to orient the orbital support segment properly in all cases. The other choice is TFL-iliac crest flap, especially when the skin defect also needs to be covered. We have found the DCIA also to be useful. The only limiting factor is the short pedicle length. The use of mesh has been found to be unsatisfactory due to their extrusion in majority of the cases where we have used it with the adjuvant radiation. In class IV defects, we prefer to provide a bony orbital floor and hence used the TFL-iliac crest-internal oblique flaps on the dual blood supply or double flaps with radial forearm providing the palatal cover and DCIA-internal oblique for the suprastructure defects.

4.8 Technical Difficulties and Surgical Morbidity

Maxillary reconstruction has been looked at with caution by many centers due to the perceived technical difficulties and the associated surgical morbidity. The pedicle length has been a problem for the novice in selecting the flap and by experienced to limit their flap choices to soft tissue flaps with long pedicles in the majority of situations [15]. The other alternative was to use superficial temporal vessels as a donor [74]. The length of facial artery available in the neck can be increased by dissecting it into the cheek, with a vertical incision on the face, the use of vein grafts, and the use of composite ALT arteriovenous grafts [53]. The flap loss in larger series has been between 3 and 7 %. Hanasono et al. [15] reported an overall complication rate of 37.8 %, which included wound infection, dehiscence, fistulae, and medical complications. Notable medical complication was pneumonia (6 %).

4.9 Distraction Osteogenesis

Distraction osteogenesis has been used for the maxilla and mandible in correcting bony deficiencies. Niu et al. [75] used this method in a case of maxillary ameloblastoma. During the initial surgery, an internal curvilinear distraction device was put in the residual zygoma. After a month, the wound was reopened; this distractor was replaced with another to achieve curvilinear distraction osteogenesis of the maxillary anterior alveolar process and straight distraction of the palate. After a couple of months, these distractors were removed and the small area of the residual defect was bridged with a bone graft. Though the final outcome was satisfactory, the authors concede that the procedure was lengthy and needed multiple procedures.

4.10 Tissue Engineering

This technique is considered as a possible solution to replace the complex reconstructive methods. But it has been hampered by the lack of adequate vascularization of the engineered constructs and the lack of clinically usable methods of engineering the constructs. Good manufacturing practices in cell culture and seeding have been available and have been reported [76] to be used successfully in segmental mandibular and maxillary reconstruction. The autologous cells are handled and prepared without animal-derived material; in good manufacturing practice (GMP) standard clean rooms, the cells can be considered safe for clinical cell therapy applications. Mesimäki et al. [77] described a novel method using tissue engineering methods. In a case of maxillectomy for a keratocyst, they harvested abdominal and adipose tissue stem cells. These cells were then isolated and expanded under GMP facilities. After 17 days, a titanium cage was inserted, filling it with mixture of auto-ASCs, beta-tricalcium phosphate, and bone morphogenetic protein into the rectus abdominis flap area. After 8 months of follow-up, the flap had developed mature bone structures and vasculature. This was then transplanted into the defect. Dental implants were successfully placed into the reconstruction subsequently. This method used the tissue engineering methods and utilized the microsurgical carrier for revascularizing the construct. The Helsinki group has performed ten cases, so far, for maxillary reconstructions using this method with three failures (personal communication). The computer-aided design is used for prefabricating the tray, which at present has been changed to biodegradable materials. The anterolateral thigh flap with the vastus lateralis is the preferred carrier for the construct now.

Conclusions

Maxillary reconstruction is still evolving. Considerable understanding and surgical advancement have been obtained in various aspects of reconstructing the maxillectomy defects. Level of evidence is not very high by which the role of obturation versus reconstruction can be defined, but general trend seems to be more toward accepting the superiority of reconstruction especially in larger defects. An ideal classification for the defects is still not agreed upon; but Brown classification seems to be gaining widespread acceptance. The algorithm for

reconstruction is again far from being universally agreed upon, and still reports claiming superiority of one flap over the other will be in vogue for some time. Strictly comparable studies will be difficult to carry out. Hence individual surgeon's choice or institutions practice may still persist. Orbital defects associated with the maxillectomy pose a greater challenge. Bony flap reconstruction appears to be better. Tissue engineering methods are yet to gain more acceptance and may develop novel methods in the near future.

References

1. Parr GR, Tharp GE, Rahn AO. Prosthodontic principles in the framework design of maxillary obturator prostheses. J Prosthet Dent. 1989;62:205–12.
2. Eckert SE, Carr AB. Implant-retained maxillary overdentures. Dent Clin North Am. 2004;48:585–601, v.
3. Cordeiro PG, Santamaria E, Kraus DH, Strong EW, Shah JP. Reconstruction of total maxillectomy defects with preservation of the orbital contents. Plast Reconstr Surg. 1998;102:1874–84; discussion 1885–1887.
4. Kornblith AB, Zlotolow IM, Gooen J, Huryn JM, Lerner T, Strong EW, et al. Quality of life of maxillectomy patients using an obturator prosthesis. Head Neck. 1996;18(4):323–34 [Internet]. [cited 2013 Nov 10].
5. Rogers SN, Lowe D, McNally D, Brown JS, Vaughan ED. Health-related quality of life after maxillectomy: a comparison between prosthetic obturation and free flap. J Oral Maxillofac Surg. 2003;61:174–81.
6. Okay DJ, Genden E, Buchbinder D, Urken M. Prosthodontic guidelines for surgical reconstruction of the maxilla: a classification system of defects. J Prosthet Dent. 2001;86:352–63.
7. Moreno MA, Skoracki RJ, Hanna EY, Hanasono MM. Microvascular free flap reconstruction versus palatal obturation for maxillectomy defects. Head Neck. 2010;32(7):860–8 [Internet]. [cited 2013 Nov 10].
8. Genden EM, Wallace DI, Okay D, Urken ML. Reconstruction of the hard palate using the radial forearm free flap: indications and outcomes. Head Neck. 2004;26(9):808–14.
9. Chigurupati R, Aloor N, Salas R, Schmidt BL. Quality of life after maxillectomy and prosthetic obturator rehabilitation. J Oral Maxillofac Surg. 2013;71(8):1471–8 [Internet]. [cited 2013 Nov 8].
10. Genden EM, Okay D, Stepp MT, Rezaee RP, Mojica JS, Buchbinder D, et al. Comparison of functional and quality-of-life outcomes in patients with and without palatomaxillary reconstruction: a preliminary report. Arch Otolaryngol Head Neck Surg. 2003;129(7):775–80 [Internet]. [cited 2013 Nov 10].
11. Brown JS, Rogers SN, McNally DN, Boyle M. A modified classification for the maxillectomy defect. Head Neck. 2000;22:17–26.
12. Brown JS, Shaw RJ. Reconstruction of the maxilla and midface: introducing a new classification. Lancet Oncol. 2010;11(10):1001–8 [Internet]. Elsevier Ltd; [cited 2013 Oct 7].
13. Cordeiro PG, Santamaria E. A classification system and algorithm for reconstruction of maxillectomy and midfacial defects. Plast Reconstr Surg. 2000;105(7):2331–46.
14. Santamaria E, Cordeiro PG. Reconstruction of maxillectomy and midfacial defects with free tissue transfer. J Surg Oncol. 2006;94(6):522–31.
15. Cordeiro PG, Chen CM. A 15-year review of midface reconstruction after total and subtotal maxillectomy: part I. Algorithm and outcomes. Plast Reconstr Surg. 2012;129(1):124–36 [Internet]. [cited 2013 Sep 24].
16. Triana RJ, Uglesic V, Virag M, Varga SG, Knezevic P, Milenovic A, et al. Microvascular free flap reconstructive options in patients with partial and total maxillectomy defects. Arch Facial Plast Surg. 2000;2(2):91–101 [Internet]. American Medical Association; [cited 2013 Nov 10].

17. McCarthy CM, Cordeiro PG. Microvascular reconstruction of oncologic defects of the midface. Plast Reconstr Surg. 2010;126(6):1947–59 [Internet]. [cited 2013 Nov 10].
18. Hanasono MM, Utley DS, Goode RL. The temporalis muscle flap for reconstruction after head and neck oncologic surgery. Laryngoscope. 2001;111:1719–25.
19. Caubet Biayna J, Iriarte Ortabe JI, Pueyo J. Reconstruction of a palatal defect with pedicled myomucosal flap of buccinator muscle. An Otorrinolaringol Ibero Am. 1998;25(3):263–70.
20. Van Lierop AC, Fagan JJ. Buccinator myomucosal flap: clinical results and review of anatomy, surgical technique and applications. J Laryngol Otol. 2008;122:181–7.
21. Amin MA, Bailey BMW, Swinson B, Witherow H. Use of the buccal fat pad in the reconstruction and prosthetic rehabilitation of oncological maxillary defects. Br J Oral Maxillofac Surg. 2005;43:148–54.
22. Rapidis AD, Alexandridis CA, Eleftheriadis E, Angelopoulos AP. The use of the buccal fat pad for reconstruction of oral defects: review of the literature and report of 15 cases. J Oral Maxillofac Surg. 2000;58:158–63.
23. You Y-H, Chen W-L, Wang Y-P, Liang J, Zhang D-M. Reverse facial-submental artery island flap for the reconstruction of maxillary defects after cancer ablation. J Craniofac Surg. 2009;20:2217–20.
24. Wang J-G, Chen W-L, Ye H-S, Yang Z-H, Chai Q. Reverse facial artery-submental artery deepithelialised submental island flap to reconstruct maxillary defects following cancer ablation. J Craniomaxillofac Surg. 2011;39:499–502.
25. Clauser L, Curioni C, Spanio S. The use of the temporalis muscle flap in facial and craniofacial reconstructive surgery. A review of 182 cases. J Craniomaxillofac Surg. 1995;23:203–14.
26. Cheung LK, Samman N, Tideman H. Temporalis myofascial flap in maxillofacial reconstruction: clinical and histological studies of the oral healing process. Br J Oral Maxillofac Surg. 1997;35:406–12.
27. Butler CE, Lewin JS. Reconstruction of large composite oromandibulomaxillary defects with free vertical rectus abdominis myocutaneous flaps. Plast Reconstr Surg. 2004;113:499–507.
28. Zaretski A, Wei F-C, Lin C-H, Cheng M-H, Tsao C-K, Wallace CG. Anterolateral thigh perforator flaps in head and neck reconstruction. Semin Plast Surg. 2006;20:64–72.
29. Rodríguez-Vegas JM, Angel PA, Manuela PR. Refining the anterolateral thigh free flap in complex orbitomaxillary reconstructions. Plast Reconstr Surg. 2008;121(2):481–6 [Internet]. [cited 2013 Nov 10].
30. Zhang B, Li D-Z, Xu Z-G, Tang P-Z. Deep inferior epigastric artery perforator free flaps in head and neck reconstruction. Oral Oncol. 2009;45:116–20 [Internet].
31. Chana JS, Wei F-C. A review of the advantages of the anterolateral thigh flap in head and neck reconstruction. Br J Plast Surg. 2004;57(7):603–9 [Internet]. [cited 2013 Nov 10].
32. Bianchi B, Ferri A, Ferrari S, Copelli C, Sesenna E. Maxillary reconstruction using anterolateral thigh flap and bone grafts. Microsurgery. 2009;29(6):430–6.
33. Bianchi B, Bertolini F, Ferrari S, Sesenna E. Maxillary reconstruction using rectus abdominis free flap and bone grafts. Br J Oral Maxillofac Surg. 2006;44(6):526–30.
34. Hashikawa K, Tahara S, Ishida H, Yokoo S, Sanno T, Terashi H, et al. Simple reconstruction with titanium mesh and radial forearm flap after globe-sparing total maxillectomy: a 5-year follow-up study. Plast Reconstr Surg. 2006;117:963–7.
35. Schubert W, Gear AJL, Lee C, Hilger PA, Haus E, Migliori MR, et al. Incorporation of titanium mesh in orbital and midface reconstruction. Plast Reconstr Surg. 2002;110:1022–30; discussion 1031–1032.
36. Sun G, Yang X, Tang E, Wen J, Lu M, Hu Q. Palatomaxillary reconstruction with titanium mesh and radial forearm flap. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108:514–9.
37. Nakayama B, Hasegawa Y, Hyodo I, Ogawa T, Fujimoto Y, Kitano H, et al. Reconstruction using a three-dimensional orbitozygomatic skeletal model of titanium mesh plate and soft-tissue free flap transfer following total maxillectomy. Plast Reconstr Surg. 2004;114(3):631–9.
38. Dediol E, Uglešić V, Zubčić V, Knežević P. Brown class III maxillectomy defects reconstruction with prefabricated titanium mesh and soft tissue free flap. Ann Plast Surg. 2013;71(1):63–7 [Internet]. [cited 2013 Nov 10].

39. Curioni C, Toscano P, Fioretti C, Salerno G. Reconstruction of the orbital floor with the muscle-bone flap (temporal muscle with coronoid process). J Maxillofac Surg. 1983; 11:263–8.
40. Pryor SG, Moore EJ, Kasperbauer JL, Hayden RE, Strome SE. Coronoid-temporalis pedicled rotation flap for orbital floor reconstruction of the total maxillectomy defect. Laryngoscope. 2004;114(11):2051–5.
41. Bilen BT, Kilinç H, Arslan A, Aslan S. Reconstruction of orbital floor and maxilla with divided vascularised calvarial bone flap in one session. J Plast Reconstr Aesthet Surg. 2006; 59:1305–11.
42. Ye J, Yang Z, Zhang D, Chen W, Zhou M. Maxillary functional reconstruction using a reverse facial artery–submental artery mandibular osteomuscular flap with dental implants. J Oral Maxillofac Surg. 2011;69(11):2909–14.
43. Choung PH, Nam IW, Kim KS. Vascularized cranial bone grafts for mandibular and maxillary reconstruction. The parietal osteofascial flap. J Craniomaxillofac Surg. 1991;19:235–42.
44. Chang DW, Langstein HN. Use of the free fibula flap for restoration of orbital support and midfacial projection following maxillectomy. J Reconstr Microsurg. 2003;19(3):147–52.
45. Nakayama B, Matsuura H, Hasegawa Y, Ishihara O, Hasegawa H, Torii S. New reconstruction for total maxillectomy defect with a fibula osteocutaneous free flap. Br J Plast Surg. 1994;47(4):247–9.
46. Yim KK, Wei FC. Fibula osteoseptocutaneous free flap in maxillary reconstruction. Microsurgery. 1994;15:353–7.
47. Futran ND, Wadsworth JT, Villaret D, Farwell DG. Midface reconstruction with the fibula free flap. Arch Otolaryngol Head Neck Surg. 2002;128:161–6.
48. Gilbert RW, Miles BA. Maxillary reconstruction with the scapular angle osteomyogenous free flap. Arch Otolaryngol Head Neck Surg. 2011;137(11):1130–5.
49. Clark JR, Vesely M, Gilbert R. Scapular angle osteomyogenous flap in postmaxillectomy reconstruction: defect, reconstruction, shoulder function, and harvest technique. Head Neck. 2008;30:10–20.
50. Granick MS, Ramasastry SS, Newton ED, Solomon MP, Hanna DC, Kaltman S. Reconstruction of complex maxillectomy defects with the scapular-free flap. Head Neck. 1990;12(5):377–85 [Internet]. [cited 2013 Nov 10].
51. Brown JS, Jones DC, Summerwill A, Rogers SN, Howell RA, Cawood JI, et al. Vascularized iliac crest with internal oblique muscle for immediate reconstruction after maxillectomy. Br J Oral Maxillofac Surg. 2002;40(3):183–90 [Internet]. [cited 2013 Oct 7].
52. Genden EM, Wallace D, Buchbinder D, Okay D, Urken ML. Iliac crest internal oblique osteomusculocutaneous free flap reconstruction of the postablative palatomaxillary defect. Arch Otolaryngol Head Neck Surg. 2001;127:854–61.
53. Bianchi B, Ferri A, Ferrari S, Copelli C, Boni P, Sesenna E. Iliac crest free flap for maxillary reconstruction. J Oral Maxillofac Surg. 2010;68(11):2706–13.
54. Chepeha DB, Moyer JS, Bradford CR, Prince ME, Marentette L, Teknos TN. Osseocutaneous radial forearm free tissue transfer for repair of complex midfacial defects. Arch Otolaryngol Head Neck Surg. 2005;131:513–7.
55. Andrades P, Rosenthal EL, Carroll WR, Baranano CF, Peters GE. Zygomatic-maxillary buttress reconstruction of midface defects with the osteocutaneous radial forearm free flap. Head Neck. 2008;30:1295–302.
56. Chatni S, Kuriakose MA, Iyer S. Free tensor fascia lata-iliac crest osteomusculocutaneous flap for reconstruction of combined maxillectomy and orbital floor defect. Ann Plast Surg. 2012;68(1):52–7.
57. Sekido M, Yamamoto Y, Makino S. Maxillary reconstruction using a free deep inferior epigastric perforator (DIEP) flap combined with vascularised costal cartilages. J Plast Reconstr Aesthet Surg. 2006;59(12):1350–4.
58. Iyer S, Thankappan K, Kuriakose MA, Sampathirao LMCSR, Mathew J, Sharma M. Tensor fascia lata-iliac crest-internal oblique free flap for composite orbito-maxillary defect with orbital exenteration. J Plast Reconstr Aesthet Surg. 2013;66(4):e116–8 [Internet]. [cited 2013 Oct 7].

59. Kademani D, Mardini S, Moran SL. Reconstruction of head and neck defects: a systematic approach to treatment. Semin Plast Surg. 2008;22:141–55.
60. Brown JS. Deep circumflex iliac artery free flap with internal oblique muscle as a new method of immediate reconstruction of maxillectomy defect. Head Neck. 1996;18(5):412–21 [Internet].
61. O'Connell DA, Futran ND. Reconstruction of the midface and maxilla. Curr Opin Otolaryngol Head Neck Surg. 2010;18:304–10.
62. Ilankovan V, Ramchandani P, Walji S, Anand R. Reconstruction of maxillary defects with serratus anterior muscle and angle of the scapula. Br J Oral Maxillofac Surg. 2011;49:53–7.
63. Mücke T, Hölzle F, Loeffelbein DJ, Ljubic A, Kesting M, Wolff K-D, et al. Maxillary reconstruction using microvascular free flaps. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;111:51–7.
64. Frodel JL, Funk GF, Capper DT, Fridrich KL, Blumer JR, Haller JR, et al. Osseointegrated implants: a comparative study of bone thickness in four vascularized bone flaps. Plast Reconstr Surg. 1993;92:449–55; discussion 456–458.
65. Kademani D, Salinas T, Moran SL. Medial femoral periosteal microvascular free flap: a new method for maxillary reconstruction. J Oral Maxillofac Surg. 2009;67(3):661–5 [Internet]. [cited 2013 Nov 10].
66. Iyer S, Chatni S, Kuriakose MA. Free tensor fascia lata-iliac crest osteomusculocutaneous flap for reconstruction of combined maxillectomy and orbital floor defect. Ann Plast Surg. 2012;68(1):52–7 [Internet]. [cited 2013 Oct 7].
67. Haug RH, Nuveen E, Bredbenner T. An evaluation of the support provided by common internal orbital reconstruction materials. J Oral Maxillofac Surg. 1999;57(5):564–70 [Internet]. [cited 2013 Nov 10].
68. Cinar C, Arslan H, Ogur S, Kilic A, Bingol UA, Yucel A. Free rectus abdominis myocutaneous flap with anterior rectus sheath to provide the orbital support in globe-sparing total maxillectomy. J Craniofac Surg. 2006;17(5):986–91.
69. Lee HB, Hong JP, Kim KT, Chung YK, Tark KC, Bong JP. Orbital floor and infraorbital rim reconstruction after total maxillectomy using a vascularized calvarial bone flap. Plast Reconstr Surg. 1999;104:646–53.
70. Sampathirao L, Thankappan K, Duraisamy S, Hedne N, Sharma M, Mathew J, et al. Orbital floor reconstruction with free flaps after maxillectomy. Craniomaxillofac Trauma Reconstr. 2013;06(02):099–106 [Internet]. Thieme Medical Publishers; [cited 2013 Nov 10].
71. Sarukawa S, Sakuraba M, Asano T, Yano T, Kimata Y, Hayashi R, et al. Immediate maxillary reconstruction after malignant tumor extirpation. Eur J Surg Oncol. 2007;33:518–23.
72. Hanasono MM, Silva AK, Yu P, Skoracki RJ. A comprehensive algorithm for oncologic maxillary reconstruction. Plast Reconstr Surg. 2013;131(1):47–60.
73. Hanasono MM, Lee JC, Yang JS, Skoracki RJ, Reece GP, Esmaeli B. An algorithmic approach to reconstructive surgery and prosthetic rehabilitation after orbital exenteration. Plast Reconstr Surg. 2009;123(1):98–105 [Internet]. [cited 2013 Oct 7].
74. Banks ND, Hui-Chou HG, Tripathi S, Collins BJ, Stanwix MG, Nam AJ, Rodriguez ED. An anatomical study of external carotid artery vascular territories in face and midface flaps for transplantation. Plast Reconstr Surg. 2009;123(6):1677–87.
75. Niu X-G, Zhao Y-M, Han X-X. Multiplanar and combined distraction osteogenesis for three-dimensional and functional reconstruction of unilateral large maxillary defects. Br J Oral Maxillofac Surg. 2009;47:106–10.
76. Sándor GK, Tuovinen VJ, Wolff J, Patrikoski M, Jokinen J, Nieminen E, et al. Adipose stem cell tissue-engineered construct used to treat large anterior mandibular defect: a case report and review of the clinical application of good manufacturing practice-level adipose stem cells for bone regeneration. J Oral Maxillofac Surg. 2013;71(5):938–50 [Internet]. [cited 2013 Nov 11].
77. Mesimäki K, Lindroos B, Törnwall J, Mauno J, Lindqvist C, Kontio R, et al. Novel maxillary reconstruction with ectopic bone formation by GMP adipose stem cells. Int J Oral Maxillofac Surg. 2009;38(3):201–9.

5 Functional and Aesthetic Reconstruction of Complex Maxillofacial Defects with the Prefabricated Fibula Flap

Dennis Rohner, Raquel Guijarro-Martínez, Peter Bucher, and Beat Hammer

5.1 Introduction

Several organs of multifunctional importance are compactly assembled in the cranio-maxillofacial region. Consequently, cancer resections with adequate safety margins are often significantly debilitating and call for complex primary or secondary reconstructive procedures [1]. Similarly, trauma or atrophy can also originate moderate to severe deficiencies in the hard and soft tissues. Regardless of the aetiology of the defect, the goal is the replacement of the lost hard and soft tissues together with the reestablishment of the patient's premorbid function and aesthetics. In order to achieve an optimal outcome, a comprehensive multidisciplinary team approach is needed. Indeed, all dimensions and stages of composite cranio-maxillofacial reconstruction require high precision and excellent coordination between the reconstructive surgeon, the prosthodontist and the maxillofacial technician [1–4].

Traditional reconstructive techniques often lead to suboptimal reconstructions due to inexact planning, poor communication between the resective and reconstructive teams [5] or surgical difficulties in adjusting a free flap and osteosynthesis plates into a three-dimensional (3D) defect without the help of any templates or surgical guides. However, the incorporation of CAD-CAM technologies has enabled the refinement of surgical and prosthodontic strategies. These novel technologies enable meticulous planning of the surgical and prosthetic phases and permit an effective transfer of the preoperative plan to the operating room. This becomes patent in complex reconstructions, particularly in the context of the prefabrication technique for the restoration of complex maxillofacial defects [6–9].

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Selection of the ideal flap depends on the patient's specific hard and soft tissue requirements, dental condition of the unresected jaw(s) and vascular condition of the potential donor sites [4]. Small (<4–6 cm) osseous defects may be reconstructed with non-vascularised bone grafts if there is well-vascularised peripheral soft tissue and an appropriate closure is feasible [10]. Larger and compound (bone and oral lining or skin) or composite (bone, oral lining and skin) defects are best reconstructed with vascularised flaps [1, 10–15]. In the latter cases, where substantial bone deficiency is present, the fibula, iliac crest and scapula are currently the preferred donor sites [5, 8, 11, 16–23].

5.2 The Free Vascularised Fibula Flap

Experience with the fibula flap in its osseous or osteoseptocutaneous versions has led the maxillofacial community to adopt it as the gold standard option for most reconstructions due to its significant anatomical *advantages* over other methods [1, 5, 12, 17, 19, 24]. These distinguishing features include the following [1, 13–15, 17, 19, 20, 25, 26]:

1. Unmatched supply of robust bone with sufficient length (22–26 cm in the adult) to reconstruct most maxillofacial defects.
2. Bicorticocancellous structure that is apt for dental implant osseointegration. The iliac crest is also suitable for implant placement. However, the more complex contour of the iliac crest in comparison to the fibula makes the three-dimensional (3D) reconstruction of the alveolar crest more complicated [4].
3. Sizable (2–3 mm in diameter) and lengthy (<15 cm) pedicle.
4. Reliable, thin, pliable and sizeable (22–25 cm in length) skin paddle that can be adapted to virtually any type of intraoral or extraoral defect.
5. Potential inclusion of a soleus muscle cuff for bulk.
6. Proximity to the sural nerve, which can be additionally harvested from the same donor site in order to provide sensitivity to the flap.
7. Donor site location, which allows for a two-team approach.
8. Acceptable donor site morbidity if the surgical technique and planning are meticulous.

Nevertheless, some *disadvantages* have also been reported, including the following [1, 5]:

1. Primary inadequacy of the skin paddle. Intraorally, the skin paddle used in association with the fibular bone in osteoseptocutaneous flaps is too thick and prone to inflammation in combination with dental implants [8, 9, 23, 26–28]. Consequently, flap shaping and debulking, vestibuloplasty and further soft tissue grafting procedures are necessary before installing an adequate implant-borne prosthetic rehabilitation. This delays the final restoration an average of 6 months [8], during which the patient is often very functionally and aesthetically impaired.

2. Limited height of the barrel. Anatomically, although the length of the fibula is usually sufficient to reconstruct most defects of the cranio-maxillofacial complex, the height of the barrel is limited to 13 mm [29]. In the context of mandibular reconstruction, placement of the fibula at the inferior border produces an excellent mandibular contour, but elongated prosthetic suprastructures are necessary to achieve occlusion, giving way to overloading of the implants due to excessive lever arm forces [1]. On the contrary, the placement of the fibula in continuity of the residual alveolar ridge yields an inharmonious inferior mandibular margin, which is particularly evident in anterior segment defects. In order to simultaneously restore alveolar height and mandibular contour, the double-barrel fibula flap [30] is routinely used.
3. Difficulty in performing multiple osteotomies. The definition of the configuration and number of osteotomies on the donor bone that will give the reconstruction its appropriate shape is often a demanding and time-consuming step. This disadvantage is a common drawback with other flaps as well. Ideally, surgical planning should comprise the detailed design of the number, shape and position of the osteotomised donor bone segments.
4. Length of the reconstructive procedure.

5.3 The Concept of Prefabrication

Maxillofacial reconstruction with prefabricated flaps entails a dramatic conceptual change in the conventional treatment workflow: The starting point is the desired end occlusion, in other words, the desired functional-aesthetic outcome. Based on this goal, which is absolutely patient-specific, the entire step-by-step reconstruction is designed and "prefabricated".

The prefabrication treatment algorithm involves two technical and two surgical steps. The first surgical step is, namely, the "flap prefabrication" stage. The selected donor site, most often the fibula, is approached. Dental implants are inserted, and a split-thickness skin graft is adapted around them in order to attain a stable epithelial soft tissue layer [7, 8]. This thin epithelial layer is essential for successful implant integration under stable long-term periimplant conditions [23, 24, 28, 31, 32]. After a healing period of 6–8 weeks to allow for implant osseointegration and revascularization of the skin graft, a second surgery is performed in order to harvest the graft, osteotomise the bone as necessary (using surgical guides and templates) for its adjustment to a pre-prepared prosthesis, and transfer the flap-prosthesis complex to the defect. The patient regains full function and aesthetics within 6–10 weeks.

5.4 Case Selection

The indication of a staged prefabrication-reconstruction procedure implies careful case selection. Two types of variables (defect and patient specific) must be considered:

1. *Defect-specific variables:*
   (a) Cause of the defect:
   Regarding the cause that originated the defect requiring reconstruction, an important distinction must be made between patients with head and neck cancer versus other pathologies:
      (i) *Non-cancer patients*:
      In general, the prefabrication technique finds its indications in patients with preexisting maxillary or mandibular defects, severe atrophy, benign osseous tumours, osteoradionecrosis or chronic osteomyelitis; in other words, conditions that allow for a staged approach.
      (ii) *Cancer patients*:
      The prefabrication technique is usually not recommended in patients with active malignant tumours of the head and neck. The need to urgently perform primary tumour resection and therapeutical or prophylactic neck dissection does not allow for a staged approach. However, cases of secondary reconstruction, after primary cancer surgery with curative intention (accompanied or not by coadjuvant therapy) and once the patient is proven to be disease-free, are excellent candidates for prefabrication [4]. In the case of maxillary cancer, the defect can be temporarily closed with an obturator during the period between primary resection and reconstruction.
   (b) Size of the defect:
   As with every microvascular free flap transfer, the particular dimensions of the maxillofacial defect to be reconstructed are crucial for the design of the ideal reconstructive strategy. The size of the defect must be of at least 2 cm, because vascularisation of small free flaps below this size is not predictable [4]. Hard tissue deficiencies below 2 cm can be reconstructed with free bone grafts provided that the peripheral soft tissue is sufficient in quantity and quality (in other words, well vascularised), or adequate soft tissue is transferred to the defect by means of local, rotational or free microvascularised flaps. On the other hand, big compound or composite defects must have a reasonable amount of residual healthy bone left, such that the transferred flap can be appropriately adapted and fixated to the recipient site [4].
   (c) Recipient vessels:
   In patients who have had previous neck dissection as part of their oncologic treatment, the status of the residual blood vessels in the recipient site must be specifically evaluated with appropriate imaging techniques. The length of the potential flap pedicle must be long enough to reach the recipient vessels, preferably without the need for intermediate vein grafts.
2. *Patient-specific variables:*
   (a) Age:
   In general, chronological age itself should not be considered an absolute contraindication for microvascular reconstruction. Rather, the specific health status and underlying diseases of the patient should be the determining factors for the selection of the reconstructive plan.

(b) Vascular anomalies and other comorbidities:
Peripheral vascular disease with complete or incomplete occlusion of the blood vessels in the donor site is considered a contraindication to microvascularised flap transfer. In the case of the fibula flap, the status of the peroneal vessels should be specifically assessed (e.g. by angiography, digital subtraction angiography (DSA), gadolinium magnetic angioresonance), especially in cases with abnormal pedal pulses or a significant history for leg trauma or surgery. Patients with a hypoplastic anterior tibial artery (with blood supply to the foot derived primarily from the peroneal artery via a perforating branch) must also be excluded for this flap.

Other medical contraindications include any underlying conditions that preclude an extended operative procedure or result in a hypercoagulable state that cannot be medically controlled. Relative contraindications include any disorders that have a potential impact on the patient's coagulation or healing capacity (e.g. severe obesity, connective tissue disorders, venous insufficiency, uncontrolled diabetes mellitus).

5.5 Workflow

Maxillofacial reconstruction with a prefabricated fibula flap entails a series of technical and surgical steps that are chronologically and logistically coordinated as follows [6–9, 33]:

1. *Technical stage one*: Prosthetic and surgical planning

The starting point of prosthetic planning is the desired end occlusion. In partially dentate patients, the ideal outcome is an implant-supported fixed partial denture. Hence, the starting point is the position of the future restored dentition in proper engagement with the opposing remaining dentition. Edentulous patients may be provided with either a fixed prosthesis if sufficient implants will be available, or with an implant-supported or implant-assisted overlay denture [4].

Impressions are taken with a trial denture. Maxillomandibular records are obtained and transferred to a semiadjustable articulator. These records are verified clinically together with speech and aesthetic parameters. According to these, the desired position of the restored teeth is established with respect to the residual dentition. At this point, the trial denture is duplicated and processed in resin, including strategically inserted radiopaque markings.

Subsequently, 3D polyamide stereolithographic models of the donor fibula and the skull are fabricated by rapid prototyping technology (Fig. 5.1). To this effect, high resolution computed tomography (CT) scans of the lower limbs and the skull are obtained. In the case of the latter, the patient is scanned with the trial denture in occlusion, and later an additional scan of the prosthesis alone is obtained. In partially dentate patients, a thin splint of radiotransparent material is fabricated in order to slightly increase the patient's vertical dimension and hence obtain a clear record

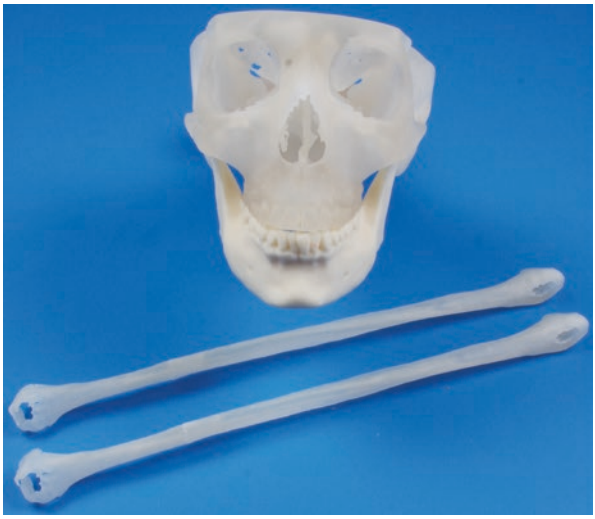

Fig. 5.1 3D stereolithographic models of the donor fibula and the skull

of the dental contours. This enables the precise superimposition of the scanned portion of the prosthesis within the defect thanks to the radiopaque markings.

The planned defect is created in the skull model (Fig. 5.2). The desired occlusion is then transferred to the skull model (Fig. 5.3). In partially dentate patients, an occlusal key is highly recommendable and will be very handy for graft positioning in the final surgical step (Fig. 5.4). The base of the trial prosthesis is reduced in order to leave enough space for the new alveolar ridge to be reconstructed with the fibular bone. Based on the desired occlusion, the ideal number of implants and location of the fibular osteotomy(ies) are marked (Fig. 5.5).

In the 3D model of the donor fibula, the outline of the fibular vessels is represented, for instance, by a red string. Pencil markings are made throughout the length of the bone on its posterior aspect (Fig. 5.6). These markings are subsequently carved with a round burr. A plaster cast is fabricated to keep exact control of fibular position. Former carvings are positivized in the plaster model, thereby maintaining the fibula in the exact same position on the plaster cast. Extra ink markings are drawn on the lateral aspect of the bone and continued on the plaster cast (Fig. 5.7). Hence, two marking systems are used to serve as a double check (Fig. 5.8).

Subsequently, the surgeon designs the number and configuration of the fibular osteotomies and their position in relation to the defect and fibular vessels (Fig. 5.9). After an impression of the whole reconstruction is taken with silicone putty, the occlusal splint together with the denture teeth and planned dentition-bearing bone segments are removed from the reconstruction. A duplication of the construct fibular bone dentition is fabricated (Fig. 5.10). The construct formed by the splint, the desired dentition and the dentition-bearing fibular segments is mounted on a plaster cast (Fig. 5.11). This plaster model represents the residual dentition with the stereolithographic fibular segments that will be used to restore the alveolar ridge. Following the drill markings on the occlusal splint, the preplanned implant position

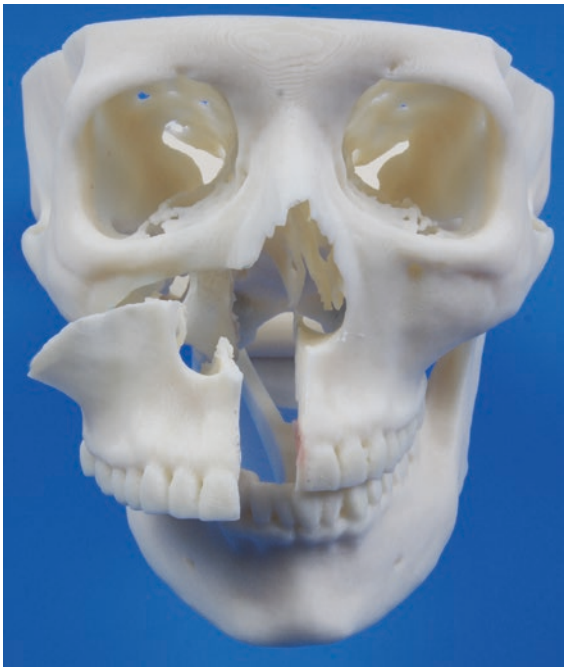

Fig. 5.2 Simulation of the anticipated defect

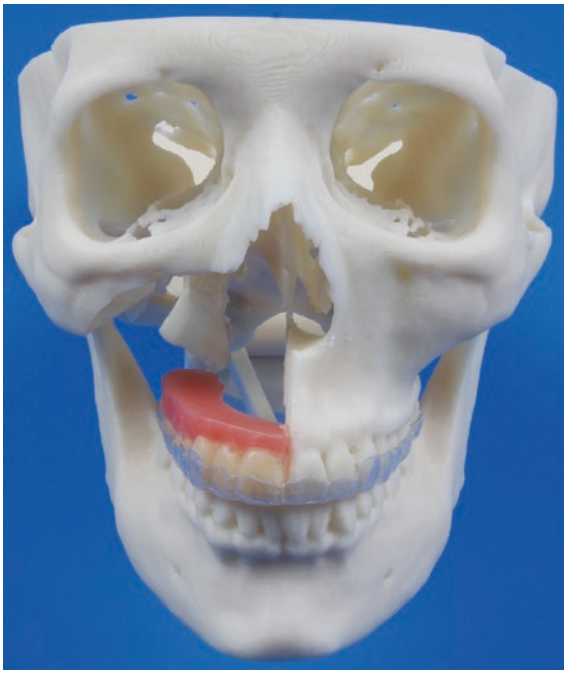

Fig. 5.3 Trial partial denture setup mounted on the stereolithographic model

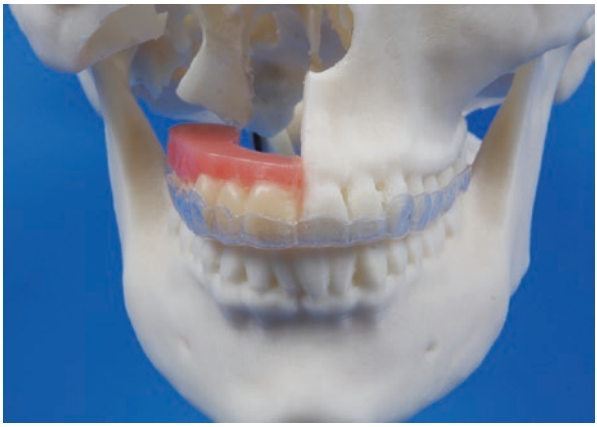

Fig. 5.4 Occlusal splint

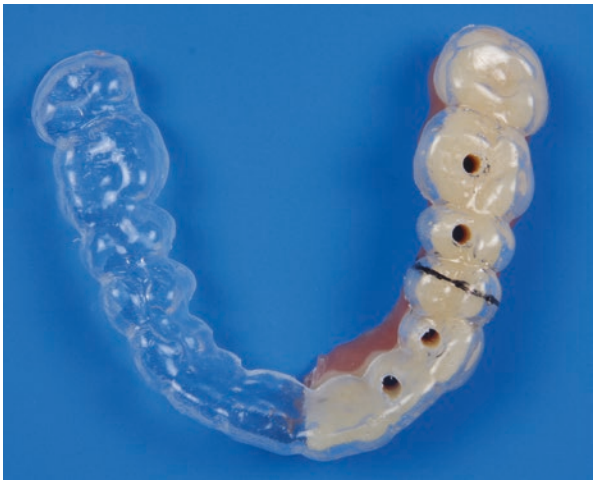

Fig. 5.5 Implant planning based on ideal teeth position: In this case, four implants are planned in two bone segments. The black line marks the exact location of the osteotomy

Fig. 5.6 3D stereolithographic model of the donor fibula: The left fibula is the first choice for the reconstruction of right maxillary defects. The outline of the fibular vessels is represented by a red string. Pencil markings are made throughout the length of the bone on its posterior aspect

Fig. 5.7 A plaster cast is fabricated to keep exact control of fibular position. Former carvings are positivized in the plaster model, thereby maintaining the fibula in the exact same position on the plaster cast. Extra ink markings are drawn on the lateral aspect of the bone and continued on the plaster cast. Hence, two marking systems are used to serve as a double check

Fig. 5.8 Close view of cast marks to accurately position the fibula: Positive code markings on the plaster shell corresponding to the posterior aspect of the bone and reciprocal ink marks on the bone and cast corresponding to the lateral aspect of the bone

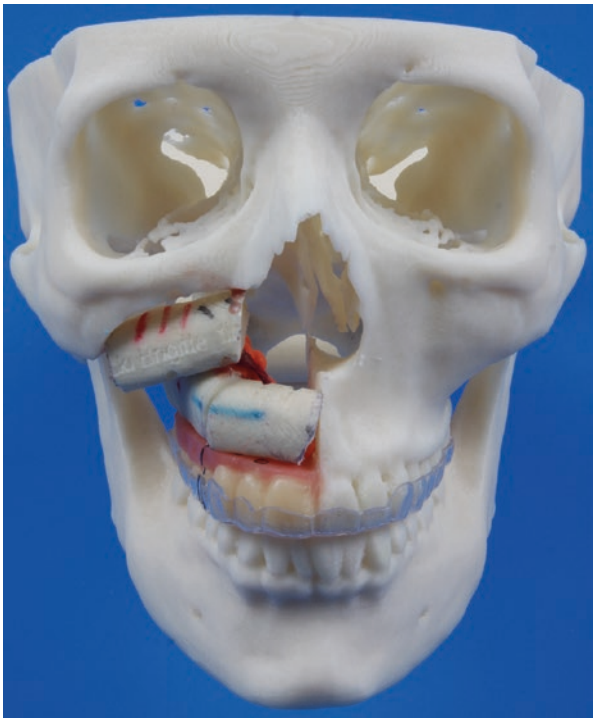

Fig. 5.9 Planned reconstruction with a three-segment fibular graft

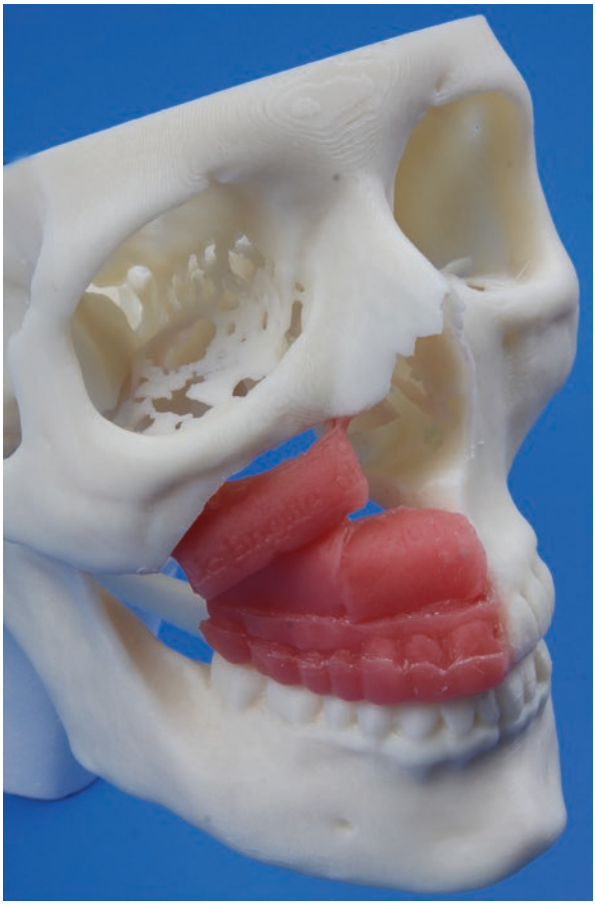

Fig. 5.10 Duplication of the construct fibular bone dentition

is transferred to the fibular bone (Fig. 5.12). The dentition-bearing fibular segments are easily remounted on the fibula plaster shell thanks to the markings on the bone and cast (Fig. 5.13). The technician then fabricates a surgical template to guide implant placement in the first surgical procedure (defining implant position and angulation) and osteotomy performance in the second surgical step (defining the number, position and angulation of the fibular osteotomies) (Fig. 5.14).

2. *Surgical stage one*: Flap prefabrication

The lateral aspect of the selected donor fibula is exposed through a standard approach. Particular attention is paid to periosteum preservation. The surgical template fabricated in technical stage one is mounted on the fibular bone in the exact preplanned position and fixed to it with the help of miniscrews (Fig. 5.15). Implant sites are prepared according to the drill guides of the template. After removal of the

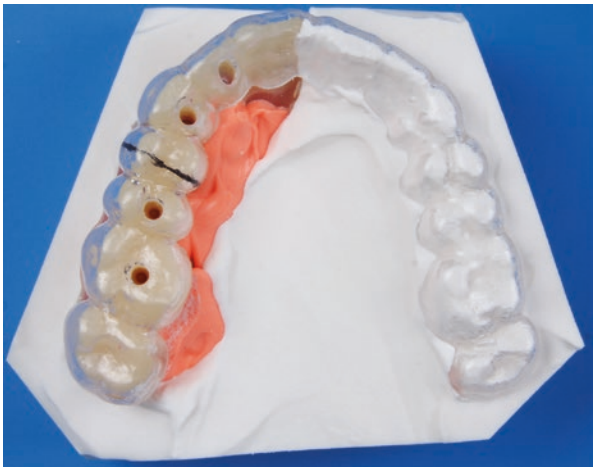

Fig. 5.11 The construct formed by the splint, the desired dentition and the dentition-bearing fibular segments is mounted on a plaster cast. The fibular segments are kept in place with the help of silicone material

template, the planned implants are inserted. Sterile pickup impression copings are connected, and an impression is taken with silicone material. During this procedure, the bone and implants are protected with a rubber dam. Subsequently, the polymerised impression together with the copings and rubber dam is removed, and implants are sealed with cover screws.

Subsequently, a 0.5 mm split-thickness skin graft is harvested, for example, from the anterior thigh. The graft is adapted over the fibula segment containing the implants, which adequately emerge above previously prepared holes (Fig. 5.16). Resorbable 4/0 polyglactin sutures are used to fix the skin graft in place, and the whole fibular segment is covered with an expanded polytetrafluoroethylene (PTFE) membrane (Fig. 5.17).

3. *Technical stage two*: Fabrication of the prosthesis

Implant fixture analogues are connected to the copings, and a master cast is fabricated (Fig. 5.18). The previously fabricated surgical template is secured to the cast via the implants. Subsequently, the cast is "osteotomised" along the vertical shields of the template just as if it was the fibular bone. The segments are then bent to the planned position in order to reproduce the contour of the maxilla. A plaster master cast is obtained from this. The previously prepared prosthesis is then connected to the implant analogues (Fig. 5.19), and a fixed partial denture is fabricated (Fig. 5.20). This new prosthesis is installed on the fibula model, and the construct can be then transferred to the defect of the stereolithographic model of the skull in proper occlusion. The surgeon is then able to plan graft fixation to the residual bone and to prebend the fixation plates (Fig. 5.21).

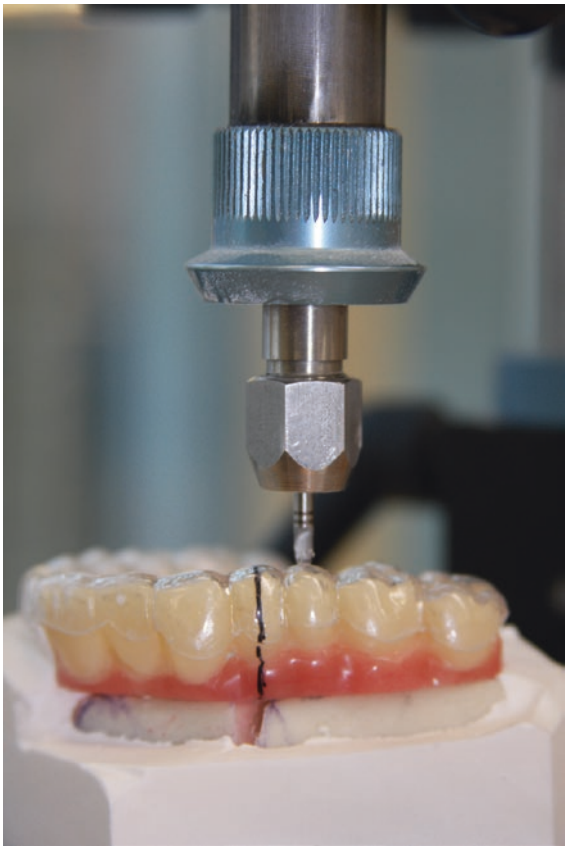

Fig. 5.12 Transfer of the preplanned implant position to the fibular bone segments following the drill markings (Fig. 5.5)

Fig. 5.13 The dentition-bearing fibular segments are easily remounted on the fibula plaster shell thanks to the markings on the bone and cast (Figs. 5.7 and 5.8)

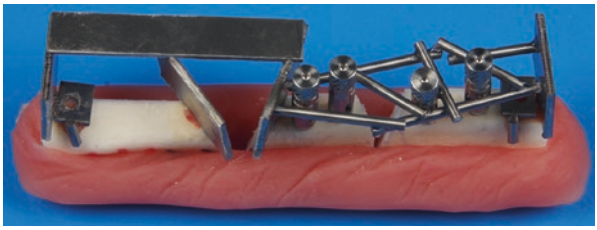

Fig. 5.14 Fabrication of surgical template to guide implant placement (first surgical step) and osteotomy performance (second surgical step)

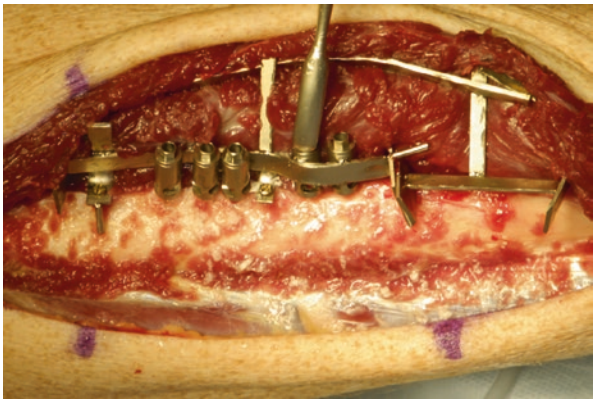

Fig. 5.15 Surgical template mounted on the planned fibular region and secured in place with four miniscrews

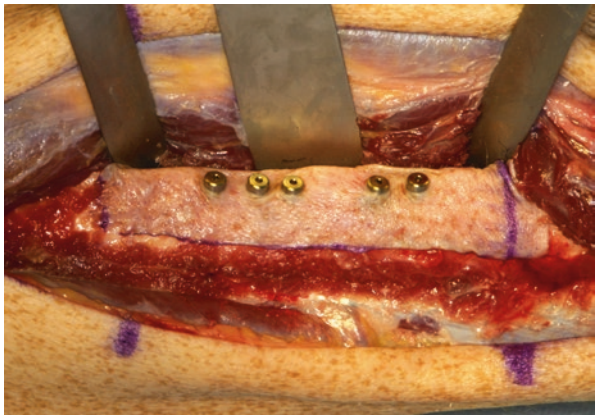

Fig. 5.16 Split-thickness skin graft placed over the lateral aspect of the fibula containing the implants. Adequate emergence of the caps is achieved by perforating the graft with a rubber dam plier

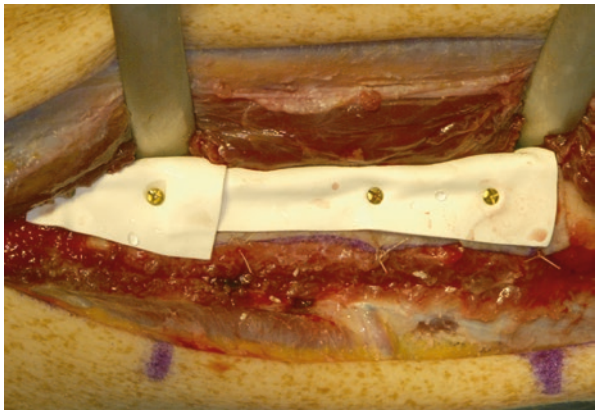

Fig. 5.17 The whole fibular segment is covered by a PTFE membrane which is secured in place with the help of three screws

Fig. 5.18 Plaster cast model fabricated using the impression taken during surgical stage one. Impression copings have been removed. In this case, the impression has been taken on multiunit level

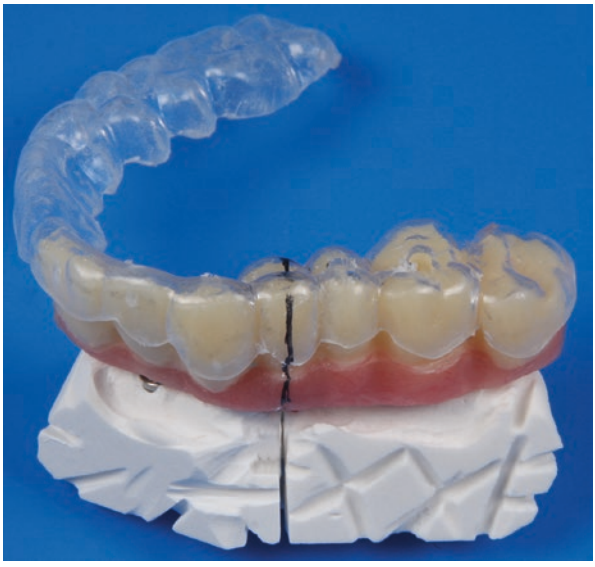

Fig. 5.19 Plaster cast model separated in two segments according to the plane determined by the surgeon. The two segments are repositioned into the occlusal splint

4. *Surgical stage two*: Final reconstruction

Six weeks after flap prefabrication, the fibula is reexposed. Removal of the barrier membrane reveals a newly formed epithelial tissue around the implants and along the lateral sides of the fibula, in other words, along the future alveolar ridge. The cover screws secured to the implants are removed, and the fibula is osteotomised distally and proximally. After clipping and releasing the vessels distally, the graft is dissected from distal to proximal. Prior to proximal vessel release, the

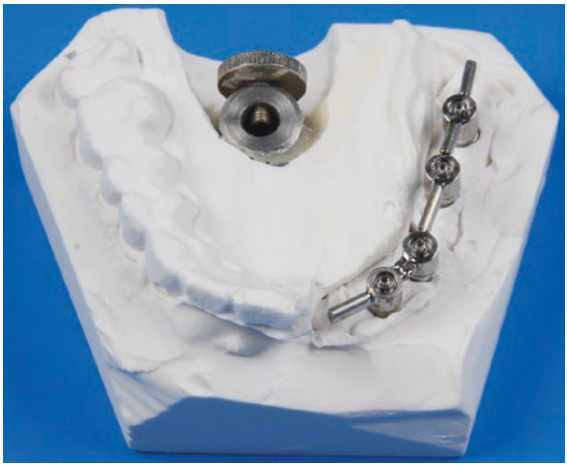

Fig. 5.20 Using a mini-parallelometer, the segments of the bar construction are placed and fixed in between the bar abutments using the technique of laser welding

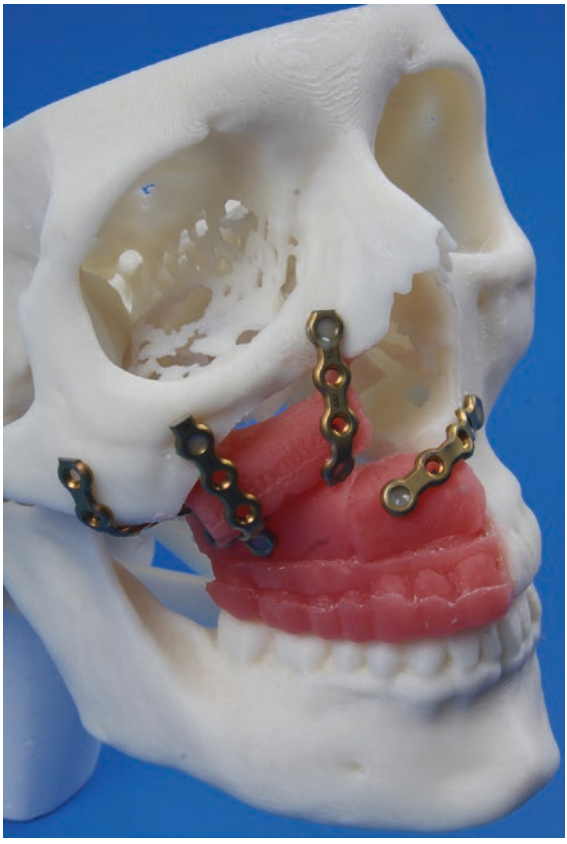

Fig. 5.21 Plate positioning and prebending on the skull model

surgical template is repositioned on the implants (Fig. 5.22), and the fibula is osteotomised as indicated by the vertical shields (Fig. 5.23). Proper configuration of the bone segments according to the preplanned contour is achieved by mounting the prosthesis onto the bone (Fig. 5.24). The vessels are then clipped proximally, and the prosthesis-fibula-muscle-vessel construct is transferred to the recipient site and positioned according to the occlusion dictated by the opposing dentition (Fig. 5.25). Intermaxillary fixation allows for the stabilisation of the construct in this position, while the prebent plates are used to fix the construct to the defect. Microvascular anastomoses are then performed.

Six months after the reconstructive procedure, the definitive acrylic prosthesis with a titanium scaffold is fabricated and installed with no need of further preprosthetic soft tissue procedures.

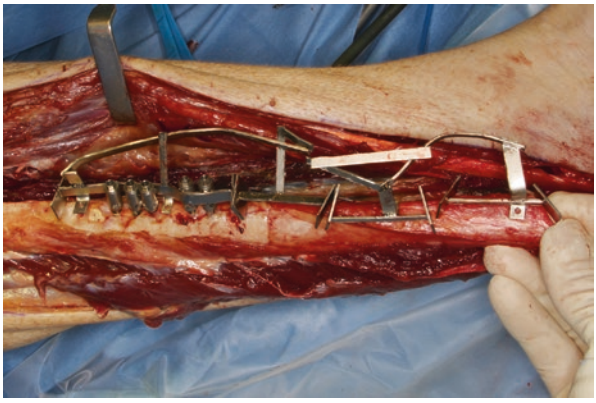

Fig. 5.22 Repositioning of the surgical guide on the fibula, prior to proximal vessel release

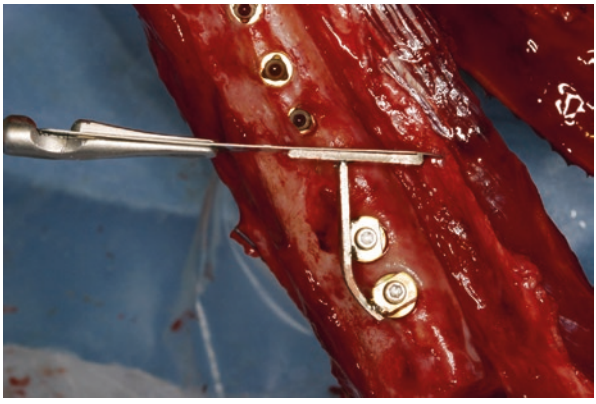

Fig. 5.23 Osteotomies are performed placing the saw exactly parallel to the vertical shields of the template

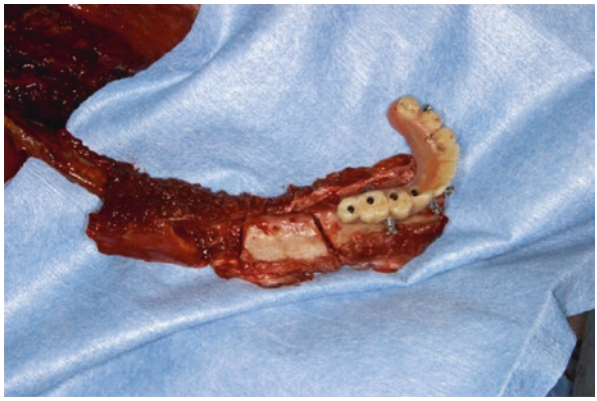

Fig. 5.24 Graft configuration according to the preplanned contour by mounting the prosthesis onto the bone while maintaining flap perfusion

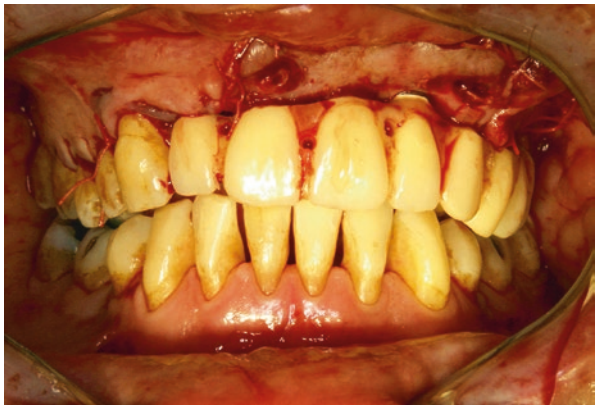

Fig. 5.25 Graft fixation according to the desired final occlusion

5.6 Clinical Examples

Case 1

A 40-year-old patient underwent a left hemimaxillectomy due to an adenoid cystic carcinoma of the palate. Six years later, a massive recurrence involving the skull base required radical resection of the left orbit. Taking into account the need for coadjuvant radiotherapy, the defect was reconstructed with cranial bone grafts and a free latissimus dorsi flap. After the end of the radiotherapy, the patient developed an osteoradionecrosis of the previously reconstructed anterior skull base and zygoma.

The starting point of the preoperative plan was the desired occlusion (Fig. 5.26). Four bone segments and additional muscle were planned in order to reconstruct the volume of the maxillary defect (Fig. 5.27). Six weeks after a first stage of prefabrication in which five implants were inserted and the future mucosal lining was prepared, the flap was transferred to the defect and fixated in proper occlusion with the opposing mandibular dentition (Fig. 5.28). The patient underwent an uneventful postoperative recovery. Six months after the reconstructive procedure, the definitive acrylic prosthesis was fabricated and installed with no need of additional soft tissue adjustments (Fig. 5.29).

Fig. 5.26 The starting point was the desired occlusion according to the residual dentition

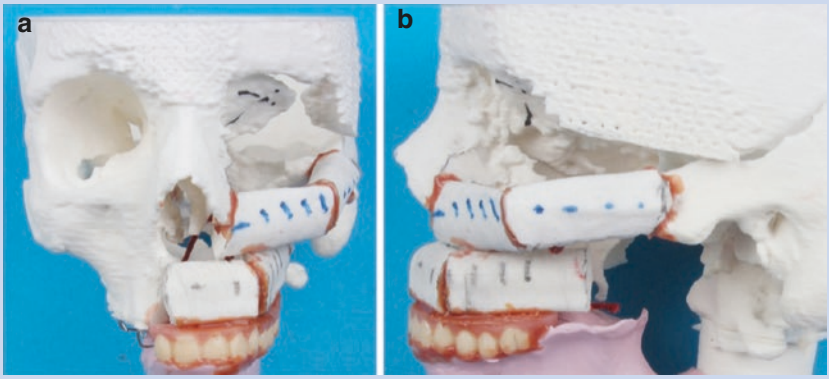

Fig. 5.27 Design of the number and configuration of the fibular osteotomies in order to reconstruct the maxilla and zygoma. (**a**) Front view. (**b**) Side view

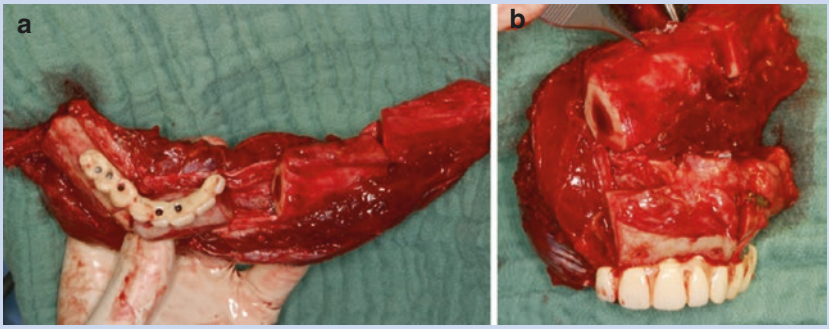

Fig. 5.28 (**a**) Conformation of the new alveolar ridge by mounting the prosthesis onto the bone while graft vascularity is still maintained. (**b**) After proximal vessel release, the construct was bent to its final configuration and transferred to the defect, where it was positioned according to the occlusion of the opposing dentition

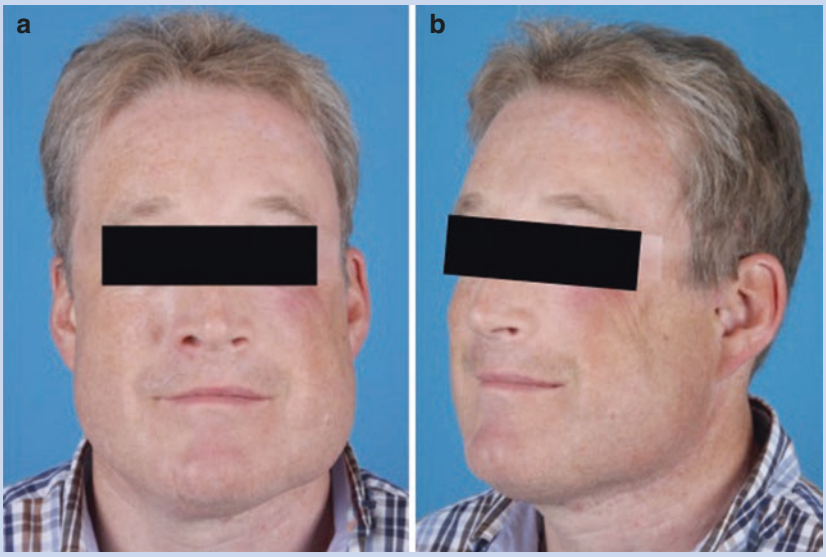

Fig. 5.29 Final result at 2-year follow-up. (**a**, **b**) Frontal and three quarters' view. An acceptable aesthetic outcome enables the patient to continue with his social and professional activities. (**c**) Stable occlusion with adequate bone and soft tissue support

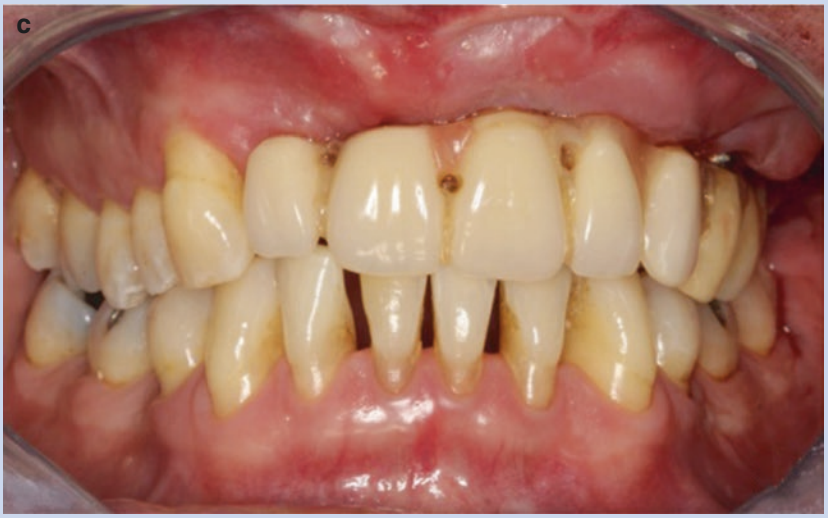

Fig. 5.29 (continued)

Case 2

A 72-year-old patient presented a segmental mandibular defect of the right body and ramus with malocclusion and persistent luxation of the right condyle (Fig. 5.30, top). He suffered from chronic mandibular osteomyelitis since 5 years. Several attempts of reconstruction with non-vascularised grafts had failed. Preoperative virtual planning with VoXim® software (IVS Technology GmbH, Chemnitz, Germany) (Fig. 5.30, bottom) allowed for the production of a solid stereolithographic model with the ideal occlusion and corrected mandibular position. Patient-specific templates were subsequently produced for the prefabrication and final reconstruction stages (Fig. 5.31). The patient underwent an uneventful postoperative recovery. Six months after the reconstructive procedure, the definitive acrylic prosthesis was installed on the implants with no need of additional soft tissue procedures (Fig. 5.32).

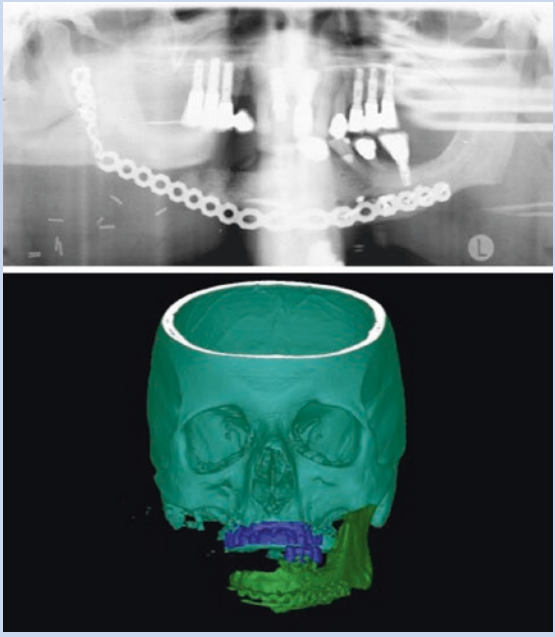

Fig. 5.30 *Top*: Segmental defect of the right mandible as a result of chronic osteomyelitis. *Bottom*: Virtual planning of the reconstruction with VoXim® software

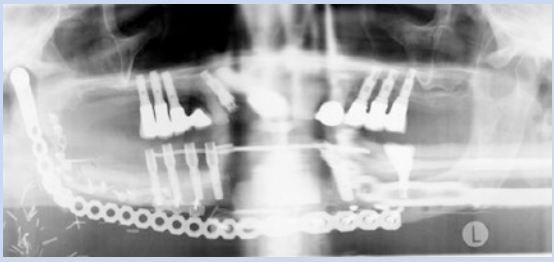

Fig. 5.31 Final reconstruction

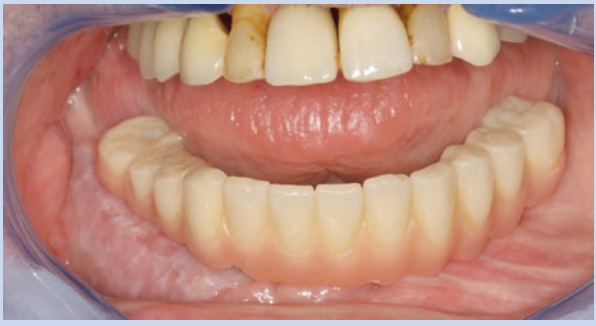

Fig. 5.32 Final prosthetic rehabilitation. The active metaplasia of the skin graft in the graft towards normal oral mucosa can be appreciated

5.7 Additional Remarks Apropos Maxillary Defects

In extended maxillary defects where a prefabrication approach is planned, an important distinction must be made between the palate and the alveolar ridge. Whereas the deficient alveolar ridge contour must be reconstructed with fibular bone in order to allow for adequate implant support, there is no need for a bony reconstruction of the hard palate. The latter, together with the soft palate, may be efficiently restored using an adequate muscle cuff attached to the fibula bone flap. As it happens with the temporalis muscle flap for the closure of oroantral and oronasal fistulas, the muscle cuff will initially react with hypergranulation and secondarily with metaplastic epithelialisation (Fig. 5.33).

The reconstruction of a maxillary defect often ends up having a long pedicle running along the ascending ramus of the mandible towards the neck. In some of these cases, an ossification of the pedicle may occur (Figs. 5.34 and 5.35). This

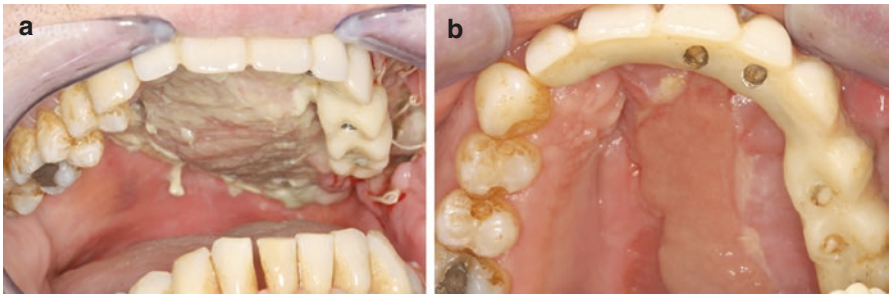

Fig. 5.33 Initial hypergranulation (**a**) that gradually transforms into stable metaplastic mucosa (**b**)

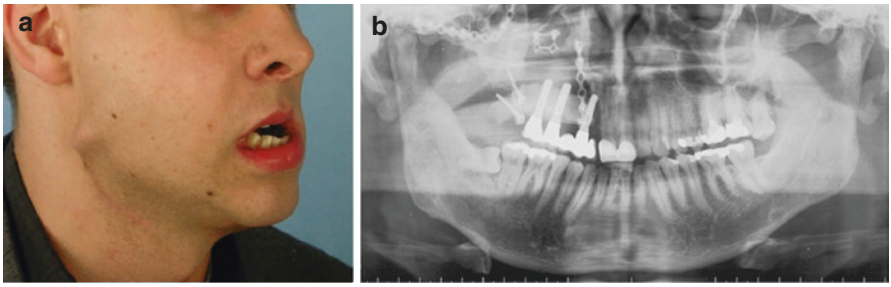

Fig. 5.34 Vascular pedicle ossification. Case example 1. Reconstruction of the right hemimaxilla after enucleation due to extensive fibrous dysplasia involvement. The ossification appeared 6 months after surgery. (**a**) Palpable cervical "string" corresponding to the ossified vessels and restricted mandibular motion. (**b**) Panoramic view of the reconstruction after excision of the calcified perivascular tissue

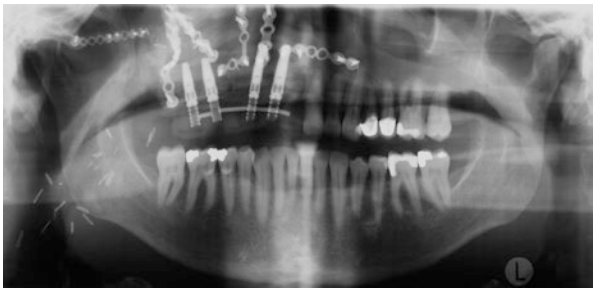

Fig. 5.35 Vascular pedicle ossification. Case example 2. Reconstruction of the right hemimaxilla after resection of a squamous cell carcinoma. The ossification appeared 5 months after surgery

calcification process of the vessels is most probably due to the presence of osteoconductive and/or osteoinductive cells around the vessels. These cells "follow" the course of the pedicle supported by the anterograde flow impulse within the pedicle vessels. At any rate, the ossification of the vascular pedicle may lead to an increasing limitation in the mandible's range of motion, which can require surgical dissection and removal of the calcifications.

5.8 Advantages of Prefabrication Over Traditional Reconstructive Procedures

Compared to conventional maxillofacial reconstruction with microvascular fibular grafts, prefabrication has the following advantages:

1. The starting point of preoperative planning is always the desired position of the restored dentition in adequate occlusion to the opposing healthy dentition or bone [4]. This ensures an optimal position of the flap that enables prosthetically ideal implant placement.
2. The future gingiva is prefabricated and thus incorporated into the flap. This mucosal lining is suitable for successful implant integration under stable long-term periimplant conditions [23, 24, 28, 31, 32] and spares the patient from secondary multistage soft tissue procedures prior to prosthetic rehabilitation [6–8, 33].
3. Operating room time, ischemia time and handling trauma to the graft are reduced. This is due to several factors: First, the position and design of the osteotomies are planned and transferred to a surgical guide that will aid the surgeon intraoperatively. Second, plates are prebent according to the stereolithographic simulation in order to further facilitate and speed up accurate graft fixation. Third, the need for additional hard or soft tissue augmentation procedures is foreseen in the 3D model and hence can be planned for specifically, leaving no space for intraoperative improvisation.

5.9 Conclusions and Future Perspectives

Proficient reconstruction of maxillofacial defects with microvascular techniques must be driven by the goal to achieve optimal, functional and aesthetic results. To this effect, an interdisciplinary design of the treatment plan is absolutely mandatory. Since the occlusion is the particular key point in maxillofacial reconstruction, the dental-trained specialist must necessarily be involved in the planning process from the beginning. Open communication between all involved specialists and the agreement on a uniform treatment strategy is essential for a successful outcome.

Prefabrication in its original form is only used in selected cases where a staged approach is feasible. However, a meticulous preoperative planning is mandatory in every case that needs bone resection and subsequent reconstruction. Therefore, the fabrication of drilling templates and cutting guides and the preparation of reconstruction plates should be considered state of the art in all types of maxillofacial reconstruction.

Efficient planning may be executed practically, using 3D models, or virtually, using 3D software tools. Both approaches are equally acceptable; the selection of either one depends on the availability of technical and infrastructural logistics in each individual setting. At any rate, both strategies must allow for the thorough evaluation of the 3D complexity of the anticipated defect, design of an accurate anatomical reconstruction plan, and achievement of optimal prosthetic rehabilitation. Currently, the workflow described in this chapter entails the fabrication of solid models, but the future goes in the direction of complete virtual simulation that includes implant planning. However, to date, a comprehensive virtual planning software tool that enables complete planning of the reconstruction and prosthetic rehabilitation is still lacking [33].

The contents in this chapter is based on the previous published work “Importance of patient specific intraoperative guides in complex maxillofacial reconstruction” published in the Journal of Cranio-Maxillofacial Surgery, Elsevier 2013.

References

1. Wallace CG, Chang YM, Tsai CY, Wei FC. Harnessing the potential of the free fibula osteoseptocutaneous flap in mandible reconstruction. Plast Reconstr Surg. 2010;125:305–14.
2. Roser SM, Ramachandra S, Blair H, Grist W, Carlson GW, Christensen AM, et al. The accuracy of virtual surgical planning in free fibula mandibular reconstruction: comparison of planned and final results. J Oral Maxillofac Surg. 2010;68:2824–32.
3. Eckardt A, Swennen GR. Virtual planning of composite mandibular reconstruction with free fibula bone graft. J Craniofac Surg. 2005;16:1137–40.
4. Beumer J, Marunick MT, Garrett N, Rohner D, Reintsema H, Abemayor E, et al. Rehabilitation of maxillary defects. In: Beumer J, Marunick MT, Esposito SJ, editors. Maxillofacial rehabilitation: prosthodontic and surgical management of cancer-related, acquired, and congenital defects of the head and neck. 3rd ed. Illinois: Quintessence; 2011. p. 155–212.

5. Hirsch DL, Garfein ES, Christensen AM, Weimer KA, Saddeh PB, Levine JP. Use of computer-aided design and computer-aided manufacturing to produce orthognathically ideal surgical outcomes: a paradigm shift in head and neck reconstruction. J Oral Maxillofac Surg. 2009;67:2115–22.
6. Rohner D, Kunz C, Bucher P, Hammer B, Prein J. New possibilities for reconstructing extensive jaw defects with prefabricated microvascular fibula transplants and ITI implants. Mund Kiefer Gesichtschir. 2000;4:365–72.
7. Rohner D, Bucher P, Kunz C, Hammer B, Schenk RK, Prein J. Treatment of severe atrophy of the maxilla with the prefabricated free vascularized fibula flap. Clin Oral Implants Res. 2002;13:44–52.
8. Rohner D, Jaquiery C, Kunz C, Bucher P, Maas H, Hammer B. Maxillofacial reconstruction with prefabricated osseous free flaps: a 3-year experience with 24 patients. Plast Reconstr Surg. 2003;112:748–57.
9. Jaquiery C, Rohner D, Kunz C, Bucher P, Peters F, Schenk RK, et al. Reconstruction of maxillary and mandibular defects using prefabricated microvascular fibular grafts and osseointegrated dental implants – a prospective study. Clin Oral Implants Res. 2004;15:598–606.
10. Pogrel MA, Podlesh S, Anthony JP, Alexander J. A comparison of vascularized and nonvascularized bone grafts for reconstruction of mandibular continuity defects. J Oral Maxillofac Surg. 1997;55:1200–6.
11. David DJ, Tan E, Katsaros J, Sheen R. Mandibular reconstruction with vascularized iliac crest: a 10-year experience. Plast Reconstr Surg. 1988;82:792–803.
12. Cordeiro PG, Disa JJ, Hidalgo DA, Hu QY. Reconstruction of the mandible with osseous free flaps: a 10-year experience with 150 consecutive patients. Plast Reconstr Surg. 1999; 104:1314–20.
13. Hidalgo DA. Fibula free flap: a new method of mandible reconstruction. Plast Reconstr Surg. 1989;84:71–9.
14. Yim KK, Wei FC. Fibula osteoseptocutaneous flap for mandible reconstruction. Microsurgery. 1994;15:245–9.
15. Yim KK, Wei FC. Fibula osteoseptocutaneous free flap in maxillary reconstruction. Microsurgery. 1994;15:353–7.
16. Forrest C, Boyd B, Manktelow R, Zuker R, Bowen V. The free vascularised iliac crest tissue transfer: donor site complications associated with eighty-two cases. Br J Plast Surg. 1992;45:89–93.
17. Hidalgo DA, Rekow A. A review of 60 consecutive fibula free flap mandible reconstructions. Plast Reconstr Surg. 1995;96:585–96; discussion 597–602.
18. Nakayama B, Matsuura H, Hasegawa Y, Ishihara O, Hasegawa H, Torii S. New reconstruction for total maxillectomy defect with a fibula osteocutaneous free flap. Br J Plast Surg. 1994;47:247–9.
19. Reychler H, Iriarte Ortabe J. Mandibular reconstruction with the free fibula osteocutaneous flap. Int J Oral Maxillofac Surg. 1994;23:209–13.
20. Shpitzer T, Neligan PC, Gullane PJ, Boyd BJ, Gur E, Rotstein LE, et al. The free iliac crest and fibula flaps in vascularized oromandibular reconstruction: comparison and long-term evaluation. Head Neck. 1999;21:639–47.
21. Thoma A, Archibald S, Payk I, Young JE. The free medial scapular osteofasciocutaneous flap for head and neck reconstruction. Br J Plast Surg. 1991;44:477–82.
22. Taylor GI, Miller GD, Ham FJ. The free vascularized bone graft. A clinical extension of microvascular techniques. Plast Reconstr Surg. 1975;55:533–44.
23. Vinzenz KG, Holle J, Wuringer E, Kulenkampff KJ. Prefabrication of combined scapula flaps for microsurgical reconstruction in oro-maxillofacial defects: a new method. J Craniomaxillofac Surg. 1996;24:214–23.
24. Chang YM, Santamaria E, Wei FC, Chen HC, Chan CP, Shen YF, et al. Primary insertion of osseointegrated dental implants into fibula osteoseptocutaneous free flap for mandible reconstruction. Plast Reconstr Surg. 1998;102:680–8.

25. Wei FC, Seah CS, Tsai YC, Liu SJ, Tsai MS. Fibula osteoseptocutaneous flap for reconstruction of composite mandibular defects. Plast Reconstr Surg. 1994;93:294–304; discussion 305–296.
26. Nazerani S, Behnia H, Motamedi MH. Experience with the prefabricated free fibula flap for reconstruction of maxillary and mandibular defects. J Oral Maxillofac Surg. 2008;66:260–4.
27. Chiapasco M, Biglioli F, Autelitano L, Romeo E, Brusati R. Clinical outcome of dental implants placed in fibula-free flaps used for the reconstruction of maxillo-mandibular defects following ablation for tumors or osteoradionecrosis. Clin Oral Implants Res. 2006;17:220–8.
28. Vinzenz KG, Holle J, Wuringer E, Kulenkampff KJ, Plenk Jr H. Revascularized composite grafts with inserted implants for reconstructing the maxilla – improved flap design and flap prefabrication. Br J Oral Maxillofac Surg. 1998;36:346–52.
29. Jones NF, Swartz WM, Mears DC, Jupiter JB, Grossman A. The "double barrel" free vascularized fibular bone graft. Plast Reconstr Surg. 1988;81:378–85.
30. Bahr W, Stoll P, Wachter R. Use of the "double barrel" free vascularized fibula in mandibular reconstruction. Op Tech Otolaryngol Head Neck. 1998;56:38–44.
31. Chang YM, Chan CP, Shen YF, Wei FC. Soft tissue management using palatal mucosa around endosteal implants in vascularized composite grafts in the mandible. Int J Oral Maxillofac Surg. 1999;28:341–3.
32. Warrer K, Buser D, Lang NP, Karring T. Plaque-induced peri-implantitis in the presence or absence of keratinized mucosa. An experimental study in monkeys. Clin Oral Implants Res. 1995;6:131–8.
33. Rohner D, Bucher P, Hammer B. Prefabricated fibular flaps for reconstruction of defects of the maxillofacial skeleton: planning, technique and long term experience. Oral Craniofac Tissue Eng. 2011;1:11–9.
34. Rohner D, Martínez RG, Bucher P, Hammer B. Importance of patient-specific intraoperative guides in complex maxillofacial reconstruction. Journal of CranioMaxillofacial Surgery. 2013; 41(5):382–90. https://doi.org/10.1016/j.jcms.2012.10.021.

Tongue and Floor of Mouth Defect Reconstruction

6

Hans C. Brockhoff II and Brent B. Ward

6.1 Introduction

The tongue and floor of the mouth represents an anatomically small compartment within the head and neck, but it is a complex collision of tissue types and function. This area is perhaps often overlooked in the hierarchy of importance due to the concealment of the overlying lips and maxillomandibular complexes, but nonetheless demands the utmost attention to the reconstructive surgeon. There are numerous tissues of distinct embryologic origins that interface with one another. Applying a thorough understanding of the relevant surgical anatomy, reconstructive options, and scientific information can lead to individually tailored approaches which optimize surgical outcomes. The focus of this chapter will be on reconstruction of the tongue and floor of the mouth defects that are compositely less than or equal to a hemiglossectomy. There will be a systematic and straightforward approach that both the neophyte and seasoned surgeon alike can glean from.

Early efforts at oral reconstruction were directed primarily at simply achieving closure of a defect with the avoidance of significant complications. A limitation of reconstructive options was partly attributable to this mentality. The emergence of new operative techniques led to a reexamination of these goals with an eye toward optimization of both form and function [1, 2]. Following an ablative procedure, considerations should be made toward reestablishing both mobility and soft tissue

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volume that are vital toward achieving the most optimal function in deglutition and intelligible speech. Current options employed for oral reconstruction include primary closure, skin grafting, pedicled flaps, and free flaps [1–5].

6.2 Quality of Life Considerations

Measuring success in oral reconstruction is not exclusive to flap survival or healing of a graft, but must take into consideration the reestablishment of presurgical function. Discussions regarding both functional and aesthetic outcomes should be a part of any preoperative workup. Clinical examination in conjunction with pertinent radiologic imaging should give indication of the anticipated location and size of the ablative defect. Gauging the patient's level of motivation and overall medical status will additionally help to include or exclude more surgically complex options such as a free tissue transfer.

The ability to maintain adequate swallowing function after surgery is a significant quality of life issue. During the oral phases of swallowing, tongue mass and mobility is critical for mastication. Coordinated movements off of the opposing dental alveolar arches lead to moistening, formation of a food bolus, and positioning the food more posteriorly. As the pharyngeal phase of swallowing takes over, the mass of the tongue (particularly the posterior third) aids in the generation of negative pressure in the hypopharynx, anterior elevation of the larynx, and prevention of aspiration [6].

Numerous studies of various designs have looked at functional outcomes in speech and tongue mobility following oral cancer surgery [7–9]. Lam et al. published a systematic review of the current research on the topic. A total of 21 articles qualified for their final review. They found that patients with resection and free flap reconstruction limited to either the oral tongue or base of tongue had significant decline in speech and swallowing function evident early in the postoperative phase but the majority recovered close to the preoperative level after 1 year. Resections involving the anterior tongue as well as the base of tongue demonstrated poorer speech and swallowing outcomes regardless of the type of free flap used for reconstruction. Lastly, multiple factors were influential including tumor size, location, method of reconstruction, and the use of adjuvant therapy.

Lee et al. recently reported long-term subjective tongue function following partial glossectomy without reconstruction. They concluded that patients who undergo partial glossectomy without reconstruction generally demonstrate good function on long-term follow-up (average 78.9 months with a range of 14–277). Additionally, subjective dysfunction was correlated with larger resection volume, older age, and shorter follow-up duration [7].

Another perhaps less investigated element contributing to quality of life is consideration toward the presence of obstructive sleep apnea (OSA) following head and neck cancer treatment [10, 11]. Nesse et al. found a prevalence of 12 % of OSA following surgery [10]. Gilat et al. reviewed their experience of patients who underwent radial forearm free flap reconstruction following oral cancer and noted disordered sleep was recorded on polysomnography in 73 % of their patients with 53 % meeting the criteria for diagnosis of OSA. Considerations toward screening and discussions concerning appropriate treatment of this comorbid condition may ensue.

6.3 Relevant Surgical Anatomy

6.3.1 Muscles of the Tongue

The mobile muscular organ, the tongue, can take on a variety of shapes and movements. The approximate length of the tongue is 12–14 cm. The anterior two thirds (anterior to the terminal sulcus) occupy the oral cavity proper, while the posterior one third (the terminal sulcus to the epiglottis) reside in the oropharynx. There are four paired extrinsic muscles (genioglossus, hyoglossus, styloglossus, and palatoglossus) comprising the tongue. The origins of these muscles are outside the tongue and are responsible mainly for overall movement with some alteration to the shape. The intrinsic muscles include the superior longitudinal, inferior longitudinal, and transverse and vertical muscles which comprise the core of the tongue and lend the tongue the ability to alter its shape (i.e., narrow, curl, flatten, etc.) [12–14].

6.3.2 Innervation

Four nerves are responsible for the overall innervation of the tongue. In regard to motor function, all muscles of the tongue are innervated by the hypoglossal nerve (CNXII), except for the palatoglossus which is innervated by the vagus (CNX). General sensation to the anterior two thirds of the tongue is provided by the lingual nerve (CN V_3). Special sensory to this same region is from the chorda tympani (CN VII) via the lingual nerve. The posterior third and vallate papilla acquire the majority of its general sensation and special sensory from the glossopharyngeal (CN IX). A small contribution to both general and special sensory derives from the internal laryngeal nerve, a branch off of the vagus (CN X) [12–14].

6.3.3 Blood Supply

The main blood supply to the tongue arises from the lingual artery, which is a branch from the external carotid. This artery arises at approximately the level of the hyoid bone in the Pirogoff triangle (whose triangular boundaries include the intermediate tendon of the digastric muscle, the posterior border of the mylohyoid muscle, and the hypoglossal nerve). As the lingual artery courses its way anteriorly, it passes deep to the hyoglossus muscle and superficial the middle pharyngeal constrictor before it divides into the deep lingual, dorsal lingual, sublingual, and suprahyoid arteries in the deep posterior portion of the tongue. The deep lingual is responsible for supplying blood to the anterior portion of the tongue, while the dorsal lingual to the posterior. The paired deep lingual arteries (terminal branch) will communicate with one another near the tongue apex forming a rich plexus. The dorsal lingual arteries are not privileged to this and are prevented from communicating by the lingual septum. The sublingual artery breaks off at the anterior border of the hyoglossus muscle and travels along the genioglossus and sublingual gland as it heads toward the anterior mandible. Smaller contributions of blood supply to the tongue

are derived from the ascending pharyngeal (branch off the external carotid) and tonsillar (branch off the facial) arteries [12–14].

The venous supply of the tongue may be slightly varied from their arterial counterparts. The deep lingual veins originate at the apex and drain into the sublingual vein or into the lingual vein, while the dorsal lingual veins will drain directly into the lingual vein. Eventually, tributaries from the sublingual veins, suprahyoid veins, dorsal lingual veins, and deep lingual veins will find their way into the internal jugular vein [12–14].

6.3.4 Floor of Mouth Anatomy

A thin drape of mucosa lines the floor of the mouth. Topographically the lingual frenulum divides the right and left sides. The sublingual papillae, which are located on either side of the frenulum, are the exit point of the submandibular ducts. The path of the submandibular duct creates the sublingual fold (plica), which is the continuation of the submandibular duct overlying the deeper positioned sublingual gland. Along the ridge will be numerous tiny openings of the sublingual ducts [12–14].

The mylohyoid is a broad triangular sheet of muscle forming the mobile diaphragm of the oral cavity. A median fibrous raphe exists delineating the right from left. Innervation arises from the mylohyoid nerve (a branch from V_3) that runs along the inferior belly of the muscle. The posterior free edge is where the submandibular gland resides. The geniohyoid is a narrow bellied muscle lying just on top of the mylohyoid. The innervation arises from the first cervical nerve that travels alongside the hypoglossal nerve. The relevant structures seen lateral to the hyoglossus muscle include the lingual nerve, hypoglossal nerve, venae comitantes of hypoglossal nerve, and the submandibular duct. The relevant structures that run medial to the hyoglossus muscle include the lingual artery, glossopharyngeal nerve, and stylohyoid ligament [12–14].

6.4 Considerations for Reconstruction Based on the Size/Location of Defect

When selecting the appropriate reconstructive option of an oral ablative defect, it is helpful to approach the problem by (1) describing the size of the defect in relation to the remaining tongue and (2) location of the defect (anterior two thirds versus base of tongue versus floor of mouth). As mentioned earlier, the focus of this chapter will be upon defects involving half the tongue (hemiglossectomy) and less, as well as defects of the floor of the mouth.

When the defect is confined to the anterior two thirds, or mobile tongue, and involves one fourth or less of the tongue, it is reasonable to do primary closure (Fig. 6.1a, b). There should be minimal scarring and contracture associated with this method, and a healthy enough bulk remains to not significantly impede overall function. Attention should be made at approximating the tongue in such a way that it does not unintentionally introduce rotation or distortion to the tongue.

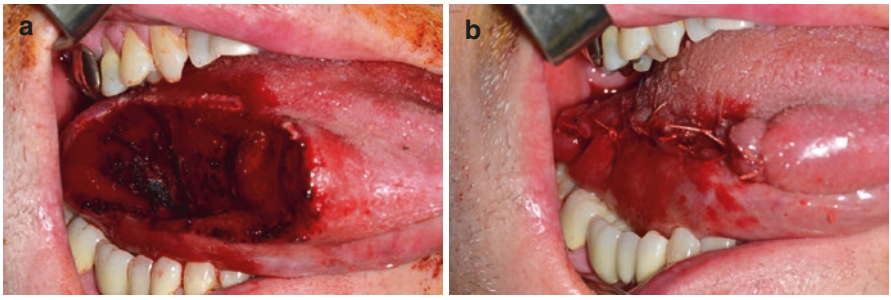

Fig. 6.1 (**a**) An isolated partial glossectomy of the mobile tongue with the total defect approximating one fourth of the overall volume. (**b**) Primary closure was accomplished with 3-0 Vicryl interrupted sutures

If the oral defect equates to less than one fourth of the tongue volume of the anterior tongue and involves the floor of the mouth, there is some leniency. If the floor of mouth component is minimal, once again primary closure is an option. Otherwise, the use of a split-thickness skin graft or allograph dermal matrix can be used to minimize scarring and contracture. Significant scarring of the floor of the mouth can lead to noticeable tethering of the tongue.

The base of tongue defect should be viewed differently than the anterior two thirds. When this area is involved, primary closure can be considered. However, if there is any significant rotation or distortion noted or anticipated, then it is wise to use a flap for reconstruction.

Lastly, when the size of the defect is between a hemiglossectomy and one fourth defect, the tendency is toward the use of a flap reconstruction. Certainly as the defect approaches a true hemiglossectomy, the decision is much easier to choose these more complex reconstructive modalities. Between these guidelines, patient preference, long-term functional goals, and defect location lead to discussions and treatments which are individualized and designed to optimize the risk/benefit ratios in favor of the patient.

6.5 Skin and Skin Substitute Grafts

Skin graft use in oral cavity reconstruction has been well documented and offers a simple way to reconstruct smaller ablative defects [15, 16]. Some clear advantages of their use includes reduction of contracture compared with healing by secondary intention, minimal operative time required, reduced postoperative hospitalization compared to free flaps, and minimal morbidity to the donor site.

6.5.1 Surgical Technique

The anterolateral thigh is the preferred donor site. This site is prepped and kept separated and sterile from the head and neck operative field. An indelible marking pen can be used to define the desired length of graft. A skin dermatome is used to harvest

the skin. 0.016–0.018 inches is the desired thickness of skin. A mineral oil is used to lather the thigh prior to harvest. When ready to harvest, the assisting surgeon will use a tongue blade to flatten the skin and soft tissue slightly ahead of the dermatome. A smooth continuous motion is employed to harvest the skin. The donor skin is then passed up toward the head. A simple Tegaderm dressing can be applied over the anterolateral thigh. The harvested skin is then appropriately trimmed to match the intraoral defect. It is critical to make sure that the recipient bed is hemostatic, thus reducing the likelihood of graft failure. 3-0 Vicryl interrupted suture is used to secure the graft along the periphery. Multiple horizontal mattress sutures should be placed in the central portion of the skin graft to secure it. Some surgeons advocate for a bolster to be applied especially if the defect involves the floor of the mouth. With small isolated tongue defects, it is reasonable to go without.

A second and similar option is to use donated skin, an allograph dermal matrix, or other skin substitute in place of a split-thickness graft. The graft is handled, trimmed, and secured in a fashion just described. The major advantage is the removal of morbidity associated with a second donor site (Fig. 6.2a, b).

6.6 Submental Island Flap

The submental island flap was originally described by Martin et al. in 1993 [17]. Since then its use in reconstruction following extirpation has been well documented with numerous variations both as a pedicled flap and a free flap [17–21]. It is a favorable selection in many regards due to its close proximity to the oral cavity, suppleness, concealment of donor site when included into a neck dissection, and ease of elevation. It can be used as a fasciocutaneous, myocutaneous, or osteomyocutaneous flap. Although hair-bearing skin may provide an excellent match for a cutaneous reconstruction, it may prove to be bothersome to a patient when used in oral reconstruction. Options for laser treatment can be offered to a patient following the postoperative healing period. A significant deterrent for its use by many is the setting of oral cavity malignancies where the lymphatic basin capturing the anterior

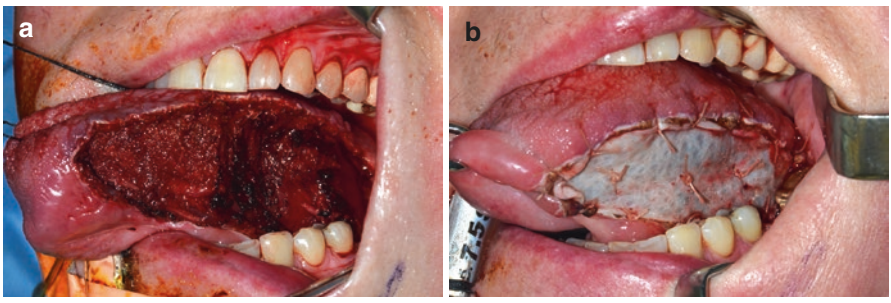

Fig. 6.2 (**a**) An isolated partial glossectomy of the mobile tongue extending onto the floor of the mouth with the total defect approximating one fourth of the overall volume. (**b**) AlloDerm graft that was placed was secured with 3-0 Vicryl suture

tongue and floor of the mouth (specifically level 1) is susceptible to experiencing regional metastasis to this node-bearing tissue. Therefore, when a neck dissection is indicated, a fastidious and meticulous effort should be implemented [18, 20]. A balance must be struck with thinning the flap and cleaning it of its fibrofatty tissue without compromising the vascular pedicle.

6.6.1 Surgical Technique

The patient is placed in the supine position with the head slightly extended. An indelible marking pen is used to mark out the inferior border of the mandible, hyoid, and location of the facial artery and vein (by use of a pen Doppler). The design of the skin paddle should be tailored to the size of the defect and anatomical limitations of the flap. The flap can be raised from mandibular angle to angle, with the width being determined by skin laxity that would enable primary closure ("pinch test") and not exceeding 18 cm (length)×7 cm (width) [18–22]. The upper limit of the flap is drawn within 1 cm of the inferior border of the mandible to avoid a visible scar. The inferior flap design is drawn to form an elliptical skin paddle based on the principles previously mentioned.

Begin with making the inferior skin incision. Continue the dissection down to the superficial layer of the deep cervical fascia. Raise the inferior skin flap in a subplatysmal plain to identify the intermediate tendon of the digastric muscle. Next make your superior skin incision, and identify the anterior belly of the digastric near its insertion point at the mandibular symphysis. Carefully dissect laterally to identify the facial artery and vein as they cross the inferior border of the mandible near the antegonial notch. Be mindful of the marginal mandibular branch of the facial nerve during this portion of the procedure which will lie superficial to your pedicle and can be identified with a nerve stimulator and thus protected. Starting distally, elevate the skin paddle toward the proximal in a plane superficial to the mylohyoid muscle. Continue raising the flap as the ipsilateral anterior belly of the digastric is encountered. The perforators may arise medially or laterally to the muscle, and thus care must be taken to avoid injury in this area. Divide the attachments of the anterior belly of the digastric muscle. You may choose to include a cuff of mylohyoid muscle deep allowing an additional layer of protection [23]. Once the anterior belly of the digastric with the mylohyoid have been divided, continue dissection over the underlying geniohyoid. Dissection of the submental vessels is completed by releasing the deep fascial attachments. Once adequate length has been achieved, create a generous pocket for the ease of transfer into the intraoral defect. Do not neglect the final pedicle geometry, which could inadvertently twist or kink during the transfer.

6.7 Platysma Flap

The platysma flap was originally described by Paul Tessier in 1970 [24]. It is a reliable, axial pattern, pedicled flap that can be utilized for oral reconstruction. Advantages include ease of access, minimal donor-site morbidity, thin, and versatile [25, 26]. There

are three variations of a platysma flap. The inferiorly based flap receives its arterial supply from the transverse cervical artery and does not have an application in oral reconstruction. Both the superiorly and posteriorly based flaps may be utilized for oral cavity reconstruction. Contraindications for these flaps include prior radiation and previous surgery in the neck which would have resulted in violation of the blood supply.

6.7.1 Surgical Technique

6.7.1.1 Posteriorly Based Flap

The occipital artery, which is located within the fascia at the anterior border of the sternocleidomastoid muscle (SCM), is the axial blood supply that a posteriorly based flap is designed from. Venous drainage is through the external jugular vein. The patient is placed in the supine position with the neck extended. The skin paddle design should be situated over the ipsilateral platysma in the submental region, elliptical, not crossing the midline, and with the long axis being perpendicular to the muscle fibers. The outlined skin paddle is incised, leaving the underlying platysma muscle layer intact. A horizontal incision is then carried posteriorly from the incised paddle, with care not to damage the underlying muscle. The horizontal incision is taken past the anterior border of the SCM. A superiorly based neck flap in the supraplatysmal plane is raised to approximately the level of the inferior border of the mandible. An inferiorly based neck flap can then be performed to gain more exposure of the underlying muscle and SCM. A minimum of 1 cm of muscle should be circumferentially around the skin paddle. The superior platysma is then transected anterior to posterior, just below, and parallel to the inferior border of the mandible. Similarly the platysma muscle is then horizontally excised on the inferior aspect (parallel to the superior incision) being sure to leave a minimum of a 4 cm width for survival of the pedicle. The flap is then carefully elevated anteriorly to posteriorly to be fully mobilized.

6.7.1.2 Superiorly Based Flap

The submental branch of the facial artery and vein are the dominant blood supply for the superiorly based platysma flap. Again, the patient should be placed in the supine position with the neck extended. The skin paddle is designed lower on the neck overlying the ipsilateral platysma muscle. There should be enough length to ensure it can be adequately rotated into the defect. It may be incorporated into a cervical incision for a neck dissection especially if placed slightly more caudal. The superior incision is made first, and then a dissection in a supraplatysmal plane is performed extending to the inferior border of the mandible (Fig. 6.3a). The platysma muscle is then transected horizontally 1 cm below the skin paddle to ensure a cuff of muscle is maintained. A subplatysmal plane of dissection is then carried out toward the inferior border of the mandible. Toward the proximal portion of the flap (near the inferior border of the mandible), attention should be paid to the facial artery perforators. The dissected plane should be slightly deeper here to include these perforators. Following the completion of both planes of dissection, the flap is transected vertically, anteriorly, and posteriorly in order to be mobilized. It can then be carried into the defect through a created pocket and subsequently inset (Figs. 6.3b and 6.4).

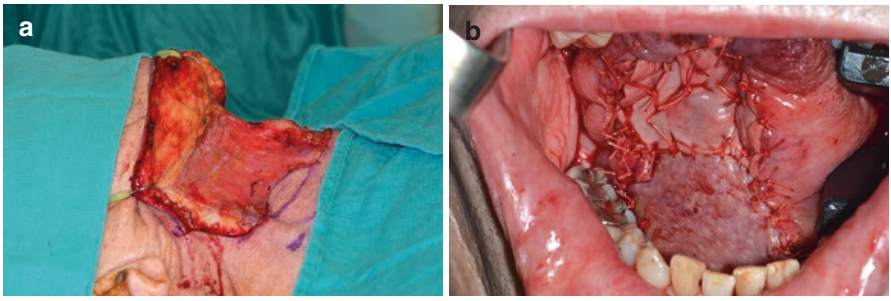

Fig. 6.3 (**a**) A superiorly based platysma flap following the elevation of the supraplatysma skin flap. The skin paddle to be used in reconstruction is marked out in an elliptical fashion. (**b**) The same platysma flap inset into a floor of mouth defect, while an AlloDerm skin graft was used to cover the tongue portion of the defect

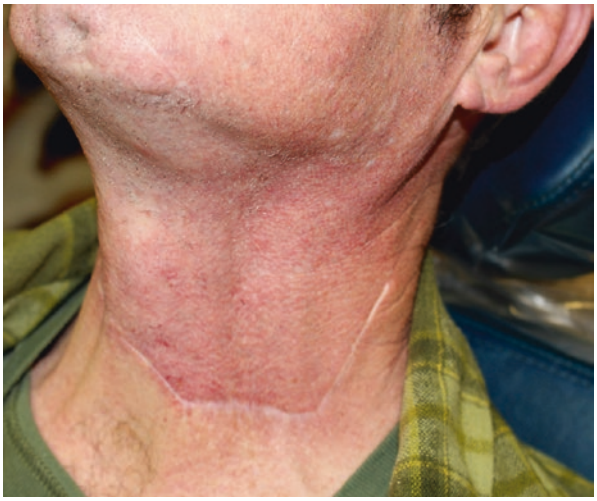

Fig. 6.4 Healed cervical incision following a superiorly based platysma flap incorporated into a simultaneous neck dissection. You should note that the incision is placed slightly caudal to where a classic cervical incision would be placed for a neck dissection

6.8 Radial Forearm Free Flap

The first flap described based off the radial artery was described by Taylor et al. in 1976 [27]. However, it wasn't until Yang et al. published their results in 1981 on 60 radial forearm free flaps as a fasciocutaneous graft that it began to gain momentum [28]. Since then, it has become a widely used flap for oral reconstruction, especially for the significant glossectomy defect [1–3]. Advantages include restoration of tongue volume, restoration of tongue mobility, pliability of skin, and opportunities to have a two-teamed approach to shorten operating room time. Numerous variations of the radial forearm free flap have been described including some proponents creating a sensate flap should the lingual nerve be sacrificed during the ablative portion of the procedure [29]. A beavertail modification has also been described by Seikaly et al., in which additional fat from the forearm can be included in the harvest and used for restoration of defects needing larger volumes of reconstruction (Fig. 6.5). This seems

to be particularly effective in base of tongue defects to help improve with the overall functional outcomes in speech and swallowing [30] (Fig. 6.5).

The complications associated with use of the radial forearm free flap can be numerous. The general complication risks increase with the increased medical comorbidities. Additionally, the patient will be subjected longer general anesthetic times. There is the possibility for flap failure, decreased grip strength, infection, and poor aesthetic outcome of the donor site.

6.8.1 Surgical Technique

An Allen test is performed preoperatively to verify that sufficient collateral circulation of the hand is present. The patient will be in the supine position with the arm positioned to expose the flexor side of the forearm. The cephalic vein and position of the radial artery are marked with the skin paddle centered over these structures. The size of the skin paddle should be commensurate with the reconstructive defect. The most distal aspect of the skin paddle should be at least 1 cm away from the wrist. A tourniquet is applied to the arm and inflated to 250 mmHg. The distal skin incision is made first to gain exposure of the radial artery and paired venae comitantes. The radial artery is then ligated and divided. Dissection may proceed either from the ulnar or radial direction. If begun from the radial direction, the first structure encountered will be the cephalic vein which is ligated and divided. The skin flap is then elevated to include the deep fascia to the level of the lateral intermuscular septum (border of the brachioradialis). The superficial branch of the radial nerve will be encountered and persevered as the plain of dissection is carried superficial (breaking the subfascial plane of dissection). The dissection should then move to the ulnar side. Elevation over the tendons of the flexor muscles should leave behind the paratenon to allow for skin grafting to the donor site. The dissection is then carried proximally by elevating the soft tissue flap with care to preserve the radial artery and venae comitantes within the fascial envelope connected to the flap. The brachioradialis and flexor carpi radialis muscles are retracted as the radial artery is traced

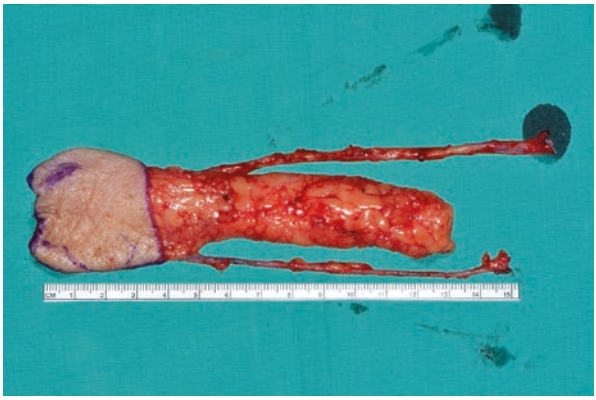

Fig. 6.5 Beavertail modification for the radial forearm free flap

proximally. A releasing incision in the skin is made at the proximal portion of the flap extending approximately 4 cm before the antecubital fossa. Skin flaps are elevated in a subcutaneous plane. The radial artery, cephalic vein, and venae comitantes are dissected to their takeoff point and ligated and divided. The flap can then be inset into the intraoral defect and the pedicle passed through a tunnel into the neck for microvascular anastomosis. The donor site is then closed primarily at the proximal aspect where the skin flaps were elevated. The distal site (where the skin paddle was harvested) can have a purse-string closure to reduce the size of the cutaneous defect and then will in most cases require a skin graft to facilitate the remainder of the closure or alternatively an advancement flap (Fig. 6.6).

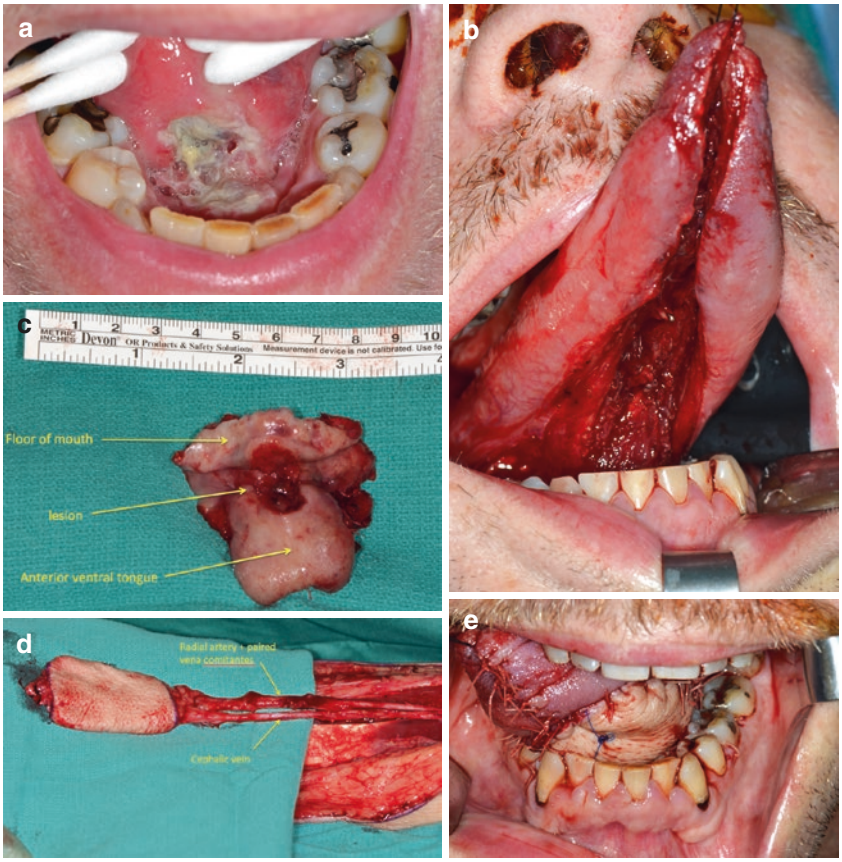

Fig. 6.6 (**a**) A 43-year-old male with a T2 squamous cell carcinoma of the anterior tongue and floor of the mouth. (**b**) The anterior tongue and floor of mouth defect following wide local excision of the lesion. (**c**) Specimen with anatomical structures labeled. (**d**) Left radial forearm free flap. (**e**) The tip of the tongue was closed primarily, and the radial forearm free flap was inset into the remainder of the defect. The blue 5-0 Prolene stitch on the skin paddle marks the site of the Doppler signal for a skin perforator

References

1. Urken ML, Moscoso JF, Lawson W, Biller HF. A systemic approach to functional reconstruction of the oral cavity following partial and total glossectomy. Arch Otolaryngol Head Neck Surg. 1994;120(6):589–601.
2. Urken ML, Weinberg H, Vickery C, Buchbinder D, Lawson W, Biller HF. Oromandibular reconstruction using microvascular composite free flaps: report of 71 cases and a new classification scheme for bony, soft tissue and neurologic defects. Ach Otolaryngol Head Neck Surg. 1991;117:733–44.
3. Bokhari WA, Wang SJ. Tongue reconstruction: recent advances. Curr Opin Otolaryngol Head Neck Surg. 2007;15(4):202–7.
4. Sieczka EM, Weber RV. Climbing the reconstructive ladder in the head and neck. Mo Med. 2006;103(3):265–9.
5. Smith RB, Sniezek JC, Weed DT, Wax MK. Utilization of free tissue transfer in head and neck surgery. Otolaryngol Head Neck Surg. 2007;137(2):182–91.
6. McConnell FM. Analysis of pressure generation and bolus transit during pharyngeal swallowing. Laryngoscope. 1988;98:71–8.
7. Lee DY, Ryu YJ, Hah JH, Kwon TK, Sung MW, Kim KH. Long-term subjective function after partial glossectomy. J Oral Rehabil. 2014;41(10):754–8.
8. Lam L, Samman N. Speech and swallowing following tongue cancer surgery and free flap reconstruction – a systematic review. Oral Oncol. 2013;49:507–24.
9. Pierre CS, Dassonville O, Chamorey E, Poissonnet G, Riss JC, Ettaiche M, Peyrade F, Benezery K, Chand ME, Leyssalle A, Sudaka A, Haudebourg J, Santini J, Bozec A. Long-term functional outcomes and quality of life after oncologic surgery and microvascular reconstruction in patients with oral or oropharyngeal cancer. Acta Otolaryngol. 2014;134(10):1086–93.
10. Nesse W, Hoekema A, Stegenga B, van der Hoeven JH, de Bont LG, Roodenburg JL. Prevalence of obstructive sleep apnoea following head and neck cancer treatment: a cross-sectional study. Oral Oncol. 2006;42(1):108–14.
11. Gilat H, Shpitzer T, Guttman D, Soudry E, Feinmesser R, Bachar G. Obstructive sleep apnea after radial forearm free flap reconstruction of the oral tongue. Laryngoscope. 2013;123:3223–6.
12. Moore K, Dalley A. Clinically oriented anatomy. 5th ed. Philadelphia: Lippincott William and Wilkins; 2006. p. 1003–9.
13. Brand R, Isselhard D. Anatomy of orofacial structures. St. Louis: Mosby; 2003. p. 300–15.
14. Strauss R, Kain N. Tongue flaps. Oral Maxillofacial Surg Clin N Am. 2014;26:313–25.
15. Schramm V, Myers E. Skin grafts in oral cavity reconstruction. Arch Otolaryngol. 1980;106:175–7.
16. Butler C. "Tongue Sandwich" bolster for skin graft immobilization. Head Neck. 2002;24(7):705–9.
17. Baudet D, Pascal J, Baudet J, et al. The submental island flap: a new donor site. Anatomy and clinical applications as a free or pedicled flap. Plast Reconstr Surg. 1993;92:867–73.
18. Parmar P, Goldstein D. The submental island flap in head and neck reconstruction. Curr Opin Otolaryngol Head Neck Surg. 2009;17:263–6.
19. Cheng A, Bui T. Submental island flap. Oral Maxillofacial Surg Clin N Am. 2014;26:371–9.
20. Howard B, Nagel T, Donald C, Hinni M, Hayden R. Oncologic safety of the submental flap for reconstruction in oral cavity malignancies. Otolaryngol Head Neck Surg. 2014;150(4):558–62.
21. Rahpeyma A, Khajehahmadi S. Submental artery island flap in intraoral reconstruction: a review. J Craniomaxillofac Surg. 2014;42(6):983–9.
22. Merten S, Jiang R, Caminer D. The submental artery island flap for head and neck reconstruction. Aust N Z J Surg. 2002;72:121–4.
23. Patel UA, Bayles SW, Hayden RE. The submental flap: a modified technique for resident training. Laryngoscope. 2007;117:186–9.

24. Tessier P, Matthews DC, Kamerer Jr D, Ciminello FS, Gargano F, Wolfe SA. Platysma-based myocutaneous clavicular island flap for intraoral reconstruction. Ann Plast Surg. 2011;67(6):S55–69.
25. Lafont Rufat M, Nadal Cristobal B, Saura Fillat E, Ruiz de la Cuesta Martín D. Platysma flap: an alternative to free flaps. J Maxillofac Oral Surg. 2014;13(2):84–6.
26. Baur DA, Williams J, Alakaily X. The platysma myocutaneous flap. Oral Maxillofac Surg Clin North Am. 2014;26(3):381–7.
27. Taylor GI, Ham FJ. The free vascularized nerve graft. A further experimental and clinical application of microvascular techniques. Plast Reconstr Surg. 1976;57:413.
28. Yang G, Chen B, Gao Y, et al. Forearm free skin flap transplantation. Natl Med J China. 1981;61:139.
29. Urken ML, Biller HF. A new design for the sensate radial forearm flap to persevere tongue mobility following significant glossectomy. Arch Otolaryngol Head Neck Surg. 1994;120:26–31.
30. Seikaly H, Rieger J, O'Connell D, Ansari K, Alqahtani K, Harris J. Beavertail modification of the radial forearm free flap in base of tongue reconstruction: technique and functional outcomes. Head Neck. 2009;31(2):213–9.

Total Glossectomy Defect Reconstruction

7

Vijay Pillai and Vikram D. Kekatpure

7.1 Introduction

Advanced tumours of oral tongue or base of the tongue have poor oncological outcome and are functionally debilitating. The procedure of total glossectomy for surgical management of such locally advanced disease of the tongue was described in 1950s by Kremer [1]. However, total glossectomy procedure with laryngeal preservation was associated with significant morbidity due to aspiration; therefore, this procedure often has been mentioned as a "morbid procedure for a morbid disease". Due to poor functional outcomes, it was relegated as a palliative procedure, and validity of such a procedure without laryngectomy was questioned [2, 3]. Due to the procedure-related morbidity, there was a trend towards organ preservation, and a variety of modalities such as chemoradiation and neoadjuvant chemotherapy followed by chemoradiation are now recommended for management of advanced carcinomas of oral and base of the tongue. However, many patients undergoing organ preservation treatment require surgical salvage for a residual or locally recurrent disease. Also, reports suggest unacceptable compromise with oncological outcome following organ preservation protocols. Recent development in microvascular reconstructive techniques has enabled better functional outcomes in patients undergoing total glossectomy [2, 4]. Therefore, in order to improve the oncological outcome without debilitating morbidity, there is renewed interest in considering total glossectomy as primary modality for management of advanced tongue tumours. The main factors that underlined this transition were better understanding of the dynamics associated with tongue reconstruction and availability of reconstructive options.

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7.2 Anatomical and Physiological Consideration

The management of advanced carcinomas of the tongue requires a consideration to entire anatomic subunit comprising the tongue, mandible, floor of the mouth with mylohyoid diaphragm, suprahyoid muscles and the hyoid-laryngeal complex along with the intervening neurovascular structures. This compartment concept is applicable to both the resection of tumour and subsequent reconstruction [5]. From the surgical standpoint, resection of these tumours needs removal of entire compartment for oncologic clearance. The tongue plays an important role in speech and swallowing function. Besides articulation, both oral and pharyngeal phases of swallowing are grossly affected following a total glossectomy. Absence of laryngeal elevation during swallowing leads to aspiration, which is one of the most dreaded complications of total glossectomy. Therefore, an optimal reconstruction should be based on the premise of recreating the anatomic and physiologic functions for optimal rehabilitation.

Swallowing involves four stages: (a) oral preparatory stage; (b) oral stage, these two stages ensure that the food bolus comes into contact with the occlusal surface; (c) pharyngeal stage; and (d) oesophageal stage. According to manofluorographic analysis of swallowing by Mc Connel et al., it proposed a concept of two pump systems consisting of a propulsion pump and a hypopharyngeal suction pump. The propulsive force is generated by the tongue which pushes the bolus towards laryngeal introitus. The hypopharyngeal suction force was the negative pressure generated at the level of the cricopharyngeus during laryngeal elevation [6]. Normal swallowing requires these four stages along with a laryngeal elevation and glottis closure to prevent aspiration.

Following total glossectomy, there is a defect in the oral and base of the tongue along with floor of the mouth diaphragm which separates oral cavity from the neck. The defect may be associated with a marginal or segmental loss of the mandible and associated dentition. These anatomical and physiological considerations form basis of functional reconstruction following total glossectomy.

7.3 Reconstruction of Total Glossectomy Defects

7.3.1 Anatomical Consideration of Post-ablative Defect

The resection of the intrinsic and extrinsic muscles results in loss of tongue bulk and dynamic structures. In addition, there is loss of innervation with sacrifice of hypoglossal nerves and sensation through lingual nerves. The loss of floor of the mouth with mylohyoid diaphragm impairs propulsion of food bolus into posterior oropharynx. Resection of suprahyoid muscles results in failure of laryngeal elevation and resultant loss of protective control of airway. Additionally, this may be associated with marginal or segmental mandibular defect. Resection may also result in a significant lining defect of the lateral pharyngeal wall and soft palate depending on the extent of resection for clear margins. Accordingly, following principles should form basis for total glossectomy reconstruction.

7.4 Principles of Glossectomy Reconstruction

1. Prevention of aspiration
2. Oral-neck separation
3. Restore tongue volume
4. Restore propulsive swallowing force
5. Laryngeal suspension
6. Restore clarity of speech

7.5 Selection of Reconstructive Options

A variety of flaps have been described for reconstruction of total glossectomy defects. The reconstructive armamentarium includes both regional and free flaps. The commonly used option includes free flaps such as the rectus abdominis flap, anterolateral thigh (ALT) flap, gracilis flap, latissimus dorsi flap, radial forearm flap, etc., and regional flaps such as the pectoralis major myocutaneous flap, lateral trapezius flap and latissimus dorsi flap [7–12]. At present, microvascular flaps are generally preferred over regional flaps due to superior swallowing and speech outcomes. A survey of body habitus helps to determine the flap with adequate bulk suitable for reconstruction.

The commonly used flaps for total glossectomy defects include ALT flap and rectus abdominis flap. Pectoralis major flap was extensively used prior to free flap era. The primary disadvantage with a pectoralis major myocutaneous flap is eventual loss of flap volume and downward traction of the pedicle that prevents palatal contact. Although most series report suboptimal outcome following pectoralis major myocutaneous flap, however, a study by Tiwari et al. has reported good functional outcomes with regional flaps [13].

7.5.1 Volume or Bulk of Restoration

The volume of tissue needed for glossectomy reconstruction varies according to the post-ablative defect. Hemiglossectomy or partial glossectomy defects can be reconstructed with fasciocutaneous flaps as these flaps are pliable and more importantly limit the tethering of the tongue. Here bulk is not a prerequisite as the residual tongue provides it and a thin flap is necessary for the mobility of the tongue.

In total glossectomy, bulk of reconstructed tongue is critical. The neotongue needs to come in contact with the palate. This serves a dual purpose of propelling food into oropharynx and also to reduce resonance to produce intelligible speech. Kimata et al. in their series of 30 glossectomy defects categorised neotongue shapes as protuberant, semiprotruberant and flat or recessed. The association between shape scores, speech scores and food scores was found to be statistically significant. The authors suggested the use of bulky flaps such as the anterolateral

thigh flap and the rectus abdominis to restore the height for the neotongue. In addition, a dimension in excess of 30 % of the defect width was essential to provide adequate contour [14]. A later series by Yun et al. reviewed patients who underwent total glossectomy, and reconstruction with anterolateral and rectus abdominis flap demonstrated a statistically significant correlation between speech and swallowing function and shape of the neotongue. This study also highlighted another crucial point of neotongue volume reduction over a period of time which needs to be considered [15]. Also, the flap bulk helps to divert the saliva and food into the lateral gutters minimising aspiration during swallowing [16].

7.6 Laryngeal Suspension

The issue of laryngeal suspension as an effective means of preventing aspiration in patients undergoing total glossectomy was initially advocated by Calcaterra and Goode in patients undergoing supraglottic laryngectomy [17, 18]. It significantly reduced the incidence of aspiration and facilitated deglutition as it effectively diverted food into the lateral gutters.

Weber et al. in their series of patients utilised the technique of laryngeal suspension in 12 patients with none of them developing aspiration as compared to the group of 15 patients who did not have laryngeal suspension. In the group without suspension, two patients had to undergo interval laryngectomy due to persistent aspiration pneumonia [19]. The technique as suggested by authors is to suspend the larynx from the anterior mandibular arch. However, if the arch has been resected, an alternative is to suspend it from the angle or the condyle [20].

Methods such as epiglottopexy, surgical closure of the glottis and laryngotracheal separation have been mentioned in literature to prevent aspiration but are not usually practised. The suspension of larynx projects it upwards and frontwards into an anatomical position required for swallowing.

7.7 Extended Resections

Mandibular resection: Resection of the mandible with total glossectomy adversely affects the chewing outcomes. The involvement of the mandible is also an adverse prognostic indicator. A series by Chang et al., however, showed no difference among patients undergoing segmental, marginal or no mandibulectomy along with total glossectomy and laryngeal preservation. The functional outcome was dependent on the extent of tongue resection wherein patients who underwent composite resection with hemiglossectomy had better functional outcome compared to those with total glossectomy [21]. It is important to consider bony and soft tissue reconstruction for segmental mandibular with total glossectomy defects.

Superior laryngeal nerve: Superior laryngeal nerve provides sensory innervation to larynx and pharynx. Preservation of the superior laryngeal nerve has

been emphasised in order to improve swallowing function. Many studies demonstrate significant aspiration in patients when superior laryngeal nerve is resected [22].

Supraglottis involvement: Total glossectomy with supraglottic resection has been demonstrated in studies to be a statistically significant marker of poorer functional and oncological outcome [23–25].

7.7.1 Motor and Sensory Innervation of Flap

As discussed a variety of flaps have been utilised for total glossectomy reconstruction. These include gracilis, rectus abdominis, latissimus dorsi and anterolateral thigh flap. Theoretically, it has been postulated that providing a sensate reconstruction enables detecting presence of food in the oral cavity which can be moved during mastication and then aids in deglutition [23, 26, 27]. However, these findings were questioned in a review by Dziegielewski et al. [28]. There is lack of data to compare benefits of motor innervation of flaps. Reanimation of muscle-containing flaps may contribute to the prevention of muscle atrophy rather than functional movement. However, the benefit of muscle innervation to overall functional outcome remains investigational.

Ozkan et al. in a small clinical series of six patients with advanced squamous cell carcinoma of the tongue, with a follow-up period of 35 months, reconstructed the defect with the anterolateral thigh flap and detailed a technique of both sensory and motor reinnervation [29]. In their study they harvested a chimeric anterolateral thigh flap with vastus lateralis muscle and nerve supply from the lateral femoral cutaneous nerve and motor nerve supply to the vastus lateralis muscle. Neural anastomosis was done to the hypoglossal nerve and lingual nerve.

However a key point in their technique is to suture the vastus lateralis muscle to the posterior border of the mandible and attach it anteromedially to the hyoid bone with 2–0 Prolene sutures. This reconstructs the suprahyoid musculature elevating the larynx during swallowing and is a technical variant from the conventional laryngeal suspension. The authors did not suspend larynx in any of their patients. Though the study was of a small sample size not aimed at demonstrating any statistical relationship between sensory recovery and motor functional outcome, it demonstrated the use of a chimeric anterolateral thigh flap for tongue reconstruction with nerve competition. The authors reported sensory recovery in all parameters in their patients and motor unit potentials in four patients when elevating the tongue during swallowing.

Bass et al. reviewed literature to analyse the improvement in tongue function with sensory reinnervation. The flaps analysed in their series were the radial forearm free flap, anterolateral thigh flap, rectus abdominis flap and tensor fascia lata flap. They demonstrated a superior sensory recovery in the radial forearm and anterolateral thigh flap series compared to other flaps but could not demonstrate any significant beneficial effects on tongue function [30].

7.8 Speech and Swallow Therapy

A key point in rehabilitation is postoperative speech and swallow therapy to improve the functional outcome following total glossectomy with laryngeal preservation. A study by Dziegielewski et al. reported superior speech and functional outcomes in patients who attended more than 80 % of swallowing and speech rehabilitation sessions [28].

7.9 Functional Outcomes Following Total Glossectomy

The current reconstructive options for total glossectomy defects mostly enable a static reconstruction, unlike a dynamic functional tongue. Therefore, a complete rehabilitation of dynamic functions like speech and swallowing remains a challenge. In pre-free flap era, the functional outcomes with regional flaps were poor. Most studies reported lower oral feeding and speech intelligibility rates ranging from 31 to 100 % and 60 to 100 %, respectively [9]. It is important to note that most reported series are single institutional experience with no standard outcome measures. The aspiration was a major problem due to lack of bulk and subsequent shrinkage. In order to prevent aspiration, procedures such as closure of laryngeal vestibule and interval laryngectomy were common. Palatal prostheses were commonly employed to reduce the oral volume to improve speech. A series by Tiwari et al. was an exception reporting a 100 % oral feeding and speech intelligibility rate [13].

With availability of free flaps, it is possible to transfer adequate tissue required for optimal reconstruction. As discussed, ALT and rectus abdominis are the commonly used flaps for glossectomy reconstruction. The reported oral feeding and speech intelligibility rates with free flaps range from 60 to 100 % and 80 to 100 %, respectively [9]. Decannulation rates as high as 90 % have been reported. Chang et al. have reported a large series of free flap reconstruction for glossectomy defects from the MD Anderson experience which included 28 subtotal and 24 total glossectomy patients and 13 total glossectomies with mandibulectomy. On multivariate analysis they demonstrated that smoking ($p=0.0018$), composite resections ($p<0.001$) and larger resections (total and subtotal glossectomies; $p<0.001$) were determinants for poor speech function. With regard to swallowing function, advanced age ($p=0.002$), radiation ($p=0.003$) and composite resections had worse swallowing function ($p<0.001$). Persistent tracheostomy was an independent variable affecting speech and swallowing ($p<0.001$) [21].

The authors developed an algorithmic approach to glossectomy reconstruction with total glossectomy defects being reconstructed with either an ALT free flap, transverse upper gracilis myocutaneous flap or rectus abdominis myocutaneous free flap. Further, the authors demonstrate a superior functional outcome in patients undergoing composite resection if two free flaps were used to reconstruct the defect.

This also characterises a paradigm in surgical management of advanced tumours with availability of superior reconstructive techniques. The authors have reported better speech and swallowing function with innervated flaps with the lingual or inferior alveolar nerve being the recipient nerve for coaptation.

Rihani et al. reviewed their series of 94 patients undergoing total glossectomy with laryngeal preservation from 1997 to 2012. They analysed both primary ($n=36$) and salvage cases after radiation or chemoradiation ($n=58$). They excluded patients with segmental mandibulectomy. Analysis of their reconstructive technique showed predominantly the use of rectus abdominis myocutaneous flap ($n=32$), pectoralis major myocutaneous flap ($n=35$), radial forearm flap ($n=21$), parascapular fasciocutaneous flap ($n=3$) and latissimus dorsi flap ($n=3$). All patients underwent a laryngeal suspension. The rate of tracheostomy tube dependence at 1 year was 16 % and gastric tube dependence was 71 %. There was no difference on the tube dependence outcomes based on the reconstruction type [24]. Noteworthy in this series is the disproportionately higher usage of radial forearm flap and pectoralis major pedicled flaps in their reconstruction, which may account for higher feeding tube dependence. However, the authors justify flap selection to higher adipose tissue bulk obtained from these sites for favourable reconstruction.

Dziegielewski et al. reported their functional outcomes at 1 year for all patients undergoing primary treatment by total glossectomy with laryngeal preservation followed by adjuvant radiation or chemoradiation from 2000 to 2010. Defects were reconstructed using an anterolateral thigh flap and laryngeal suspension in all cases. They had 12 eligible patients in their group with 8 evaluable at the end of 1 year. 50 % of these patients were gastric tube dependent at the end of 1 year and one had a tracheostomy for recurrent aspiration. Videofluoroscopic assessment showed doubled swallowing transit times. Speech intelligibility had decreased from preoperative scores of 78–66 %. However, at 1 year, QOL as measured by the EORTC 35 questionnaire had improved by a mean of 8.9 points [28].

Navach et al. reviewed survival and functional results in 37 patients with total glossectomy with laryngeal preservation from 2002 to 2011. The flaps used in their series included anterolateral thigh flap ($n=20$), gracilis free flap ($n=13$) and pectoralis major myocutaneous flap ($n=4$). They performed laryngeal suspension in all patients. In their series, all patients had retained intelligible speech, and 26 (70 %) were on an oral diet [31].

Sinclair et al. compared functional outcomes among patients undergoing total glossectomy with and without laryngectomy. They reported functional outcomes in 30 patients, 20 underwent total glossectomy with laryngeal preservation and had reconstruction with a free flap and laryngeal suspension. Eleven patients had been salvaged after failed radiation or chemoradiation. At last follow-up, 70 % patients were gastric tube dependent, 50 % were tracheostomy dependent and only 30 % had functional speech as measured subjectively [4].

A wide range of functional outcomes have been reported in literature. Since a variety of parameters have been used to report functional outcome, a comparison between various techniques is difficult. Also, the negative outcomes are usually not reported. Therefore, feeding tube removal, decannulation and speech intelligibility rates along with time to decannulation and resumption of oral feeding should form basis for functional evaluation following total glossectomy.

7.9.1 Summary of Technical Aspects of Post-ablative Total Glossectomy Defects

1. Flap selection: The neotongue requires bulk; therefore, flaps such as anterolateral thigh flap and rectus abdominis free flap are preferred choice. While regional flaps occupy an inferior rung in the reconstructive algorithm, regional flaps are to be considered only in view of extensive comorbidities and in the salvage setting for a free flap failure.
2. Design of the flap: The flap is designed to have a central mound that makes it approximately one third larger than required to compensate for tissue atrophy and fibrosis post-radiotherapy. This protuberant neotongue ensures palatoglossal contact during phonation and deglutition and also bolus propulsion during the pharyngeal phase of swallowing.
3. Laryngeal suspension: Circumhyoid sutures with 0 Prolene to drill holes in the mentum effectively suspend the larynx in an anterior and superior vector which is the normal physiologic direction of elevation of the larynx during swallowing.
4. Infrahyoid muscle release: If adequate suspension of the larynx is not achieved during reconstruction, consider an infrahyoid muscle release to facilitate the same.
5. Design for protrusion of the tongue by suturing the flap fascia to the intraoral mucosa: This enables good mucosalisation and provides for additional bulk (Fig. 7.1).

7.10 Summary

Total glossectomy is a procedure undertaken for advanced disease and may be associated with significant morbidity. The anatomical and physiological consideration is important for planning total glossectomy reconstruction. With availability of free flap reconstruction and application of technical points as detailed above, this procedure has an acceptable functional outcome.

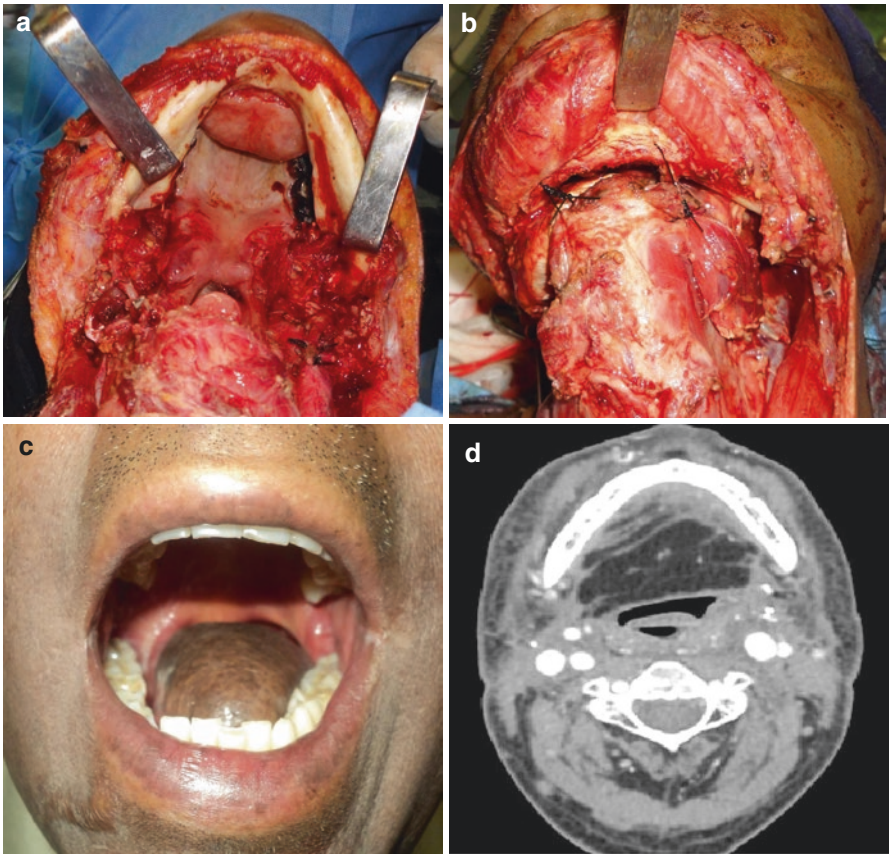

Fig. 7.1 (**a**) A typical total glossectomy defect with complete resection of the tongue and floor of the mouth with mandibular and laryngeal preservation. (**b**) Defect reconstructed with anterolateral thigh flap with laryngeal suspension using Prolene suture. (**c**) Reconstructed neotongue following radiotherapy. (**d**) Postoperative scan showing reconstructed tongue

References

1. Kremer AJ. A surgical technique for primary combined en bloc resection of tongue, floor of mouth and cervical lymphatics. Surgery. 1951;39:227–46.
2. Kreeft A, Tan IB, Van den Brekel MW, Hilgers FJ, Balm AJ. The surgical dilemma of 'functional inoperability' in oral and oropharyngeal cancer: current consensus on operability with regard to functional results. Clin Otolaryngol. 2009;34:140–6.
3. Sultan MR, Coleman JJ. Oncologic and functional considerations of total glossectomy. Am J Surg. 1989;158:297–302.

4. Sinclair CF, Carroll WR, Desmond RA, Rosenthal EL. Functional and survival outcomes in patients undergoing total glossectomy compared with total laryngoglossectomy. Otolaryngology Head Neck Surg. 2011;145:755–8.
5. Calabrese L, Giugliano G, Bruschini R, Ansarin M, Navach V, Grosso E, Gibelli B, Ostuni A, Chiesa F. Compartmental surgery in tongue tumors: description of a new surgical technique. Acta Otorhinolaryngol Ital. 2009;29:259–64.
6. Mc Connel FMS, Cerenko D, Mendlesohn MS. Manofluorographic analysis of swallowing. Otolaryngol Clin North Am. 1988;21:625–35.
7. Ariyan S. The pectoralis major myocutaneous flap. A versatile flap for reconstruction in the head and neck. Plast Reconstr Surg. 1979;63:73–81.
8. Haddock NT, Delacure MD, Saadeh PB. Functional reconstruction of glossectomy defects: the vertical rectus abdominis myocutaneous neotongue. J Reconstr Microsurg. 2008;24:343–50.
9. Vega C, Leon X, Cervelli D, et al. Total or subtotal glossectomy with microsurgical reconstruction: functional and oncological results. Microsurgery. 2011;31:517–23.
10. Lyos AT, Evans GR, Perez D, Schusterman MA. Tongue reconstruction: outcomes with the rectus abdominis flap. Plast Reconstr Surg. 1999;103:442–7.
11. Yu P, Robb GL. Reconstruction for total and near total glossectomy defects. Clin Plast Surg. 2005;32:411–9.
12. Haughey BH. Tongue reconstruction: concepts and practice. Laryngoscope. 1993;103:1132–41.
13. Tiwari R, Karim ABMF, Greven AJ, Snow GB. Total glossectomy with laryngeal preservation. Arch Otolaryngol Head Neck Surg. 1991;117:512–5.
14. Kimata Y, Sakuraba M, Hishinuma S, et al. Analysis of the relations between the shape of the reconstructed tongue and postoperative functions after subtotal or total glossectomy. Laryngoscope. 2003;113:905–9.
15. Yun IS, Lee DW, Lee WJ, et al. Correlation of neotongue volume changes with functional outcomes after long term follow up of total glossectomy. J Craniofac Surg. 2010;21:111–6.
16. Urken ML, Moscoso JF, Lawson W, Biller HF. A systematic approach to functional reconstruction of the oral cavity following partial and total glossectomy. Arch Otolaryngol Head Neck Surg. 1994;120:589–601.
17. Calcaterra T. Laryngeal suspension after supraglottic laryngectomy. Arch Otolaryngol. 1971;94:306–9.
18. Goode RL. Laryngeal suspension in head and neck surgery. Laryngoscope. 1976;86:349–55.
19. Weber RS, Ohlms L, Bowman J, et al. Functional results after total or near total glossectomy with laryngeal preservation. Arch Otolaryngol Head Neck Surg. 1991;117:512–5.
20. Krespi YP, Sisson GA. Reconstruction after total or subtotal glossectomy. Am J Surg. 1983;146:488–92.
21. Chang EI, Yu P, Skoracki RJ, Liu J, Hanasono MM. Comprehensive analysis of functional outcomes and survival after microvascular reconstruction of glossectomy defects. Ann Surg Oncol. 2015;22:3061–9.
22. Shedd DP, Scatliff JA, Kirchner JA. A cineradiographic study of postresectional alterations in oropharyngeal physiology. Surg Gynecol Obstet. 1960;110:69–89.
23. Gehanno P, Guedon C, Barry B, et al. Advanced carcinoma of the tongue: total glossectomy without total laryngectomy. Review of 80 cases. Laryngoscope. 1992;102:1369–71.
24. Rihani J, Lee MR, Lee T, Ducic Y. Flap selection and functional outcomes in total glossectomy with laryngeal preservation. Otolaryngol Head Neck Surg. 2013;149:547–53.
25. Kimata Y, Uchiyama K, Ebihara S, et al. Postoperative complications and functional results after total glossectomy with microvascular reconstruction. Plast Reconstr Surg. 2000;106:1028–35.
26. Davison SP, Grant NN, Schwarz KA, et al. Maximising flap inset for tongue reconstruction. Plast Reconstr Surg. 2008;121:1982–5.
27. Biglioli F, Liviero F, Frigerio A, et al. Function of sensate free forearm flap after partial glossectomy. J Craniomaxillofac Surg. 2006;34:332–9.
28. Dziegielewski PT, Ho ML, Rieger J, Singh P, Langille M, Harris JR, Seikaly H. Total glossectomy with laryngeal preservation and free flap reconstruction: objective functional outcomes and systematic review of the literature. Laryngoscope. 2013;123:140–5.

29. Ozkan O, Oozkan O, Derin AT, Bektas G, Cinpolat A, Duymaz A, Mardini S, Cigna E, Chen H–C. True functional reconstruction of total or subtotal glossectomy defects using a chimeric anterolateral thigh flap with both sensorial and motor innervation. Ann Plast Surg. 2015;74:557–64.
30. Baas M, Duraku LS, Corten EM, Mureau MA. A systematic review on the sensory functional benefits. J Plast Reconstr Aesthet Surg. 2015;68:1025–35. Epub ahead of print.
31. Navach V, Zurlo V, Calabrese L, Massaro MA, Bruschini R, Giugliano G, Ansarin M, Chiesa F. Total glossectomy with preservation of the larynx: oncological and functional results. Br J Oral Maxillofac Surg. 2013;51:217–23.

Reconstruction of Cheek Defects

8

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8.1 Anatomy of the Cheek

The cheek is a term loosely used to refer to the area of the face below the eyes and between the nose and the ears. It is a three-dimensional region which needs to be described in three planes – the anteroposterior, the superoinferior and the mediolateral. The anatomical boundaries are defined as the nasolabial and labio-mental crease anteriorly, the line extending from the lateral canthus to the superior border of the tragus superiorly, the tragus to the angle of the mandible posteriorly and the lower border of the mandible inferiorly. Intraorally, the buccal mucosal boundaries are defined as the commissure of the mouth anteriorly, the pterygomandibular raphe posteriorly and the upper and lower bucco-alveolar sulci superiorly and inferiorly, respectively [Fig. 8.1a, b – anatomic limits of cheek skin surface (1a) and mucosal surface (1b)].

Layers of the cheek From within outward, the cheek consists of the mucosa, submucosa, buccinator muscle, buccal pad of fat, SMAS, subcutaneous tissue and skin. It is important to appreciate that the branches of the facial nerve run horizontally between the buccinator muscle and SMAS layer. The facial artery and vein traverse lateral to the buccinator muscle in an anterosuperior direction. The parotid duct enters the buccal space lateral to the masseter and buccinator muscles, then passes through the buccinator and opens at the upper buccal sulcus in the region of the maxillary first molar tooth (Fig. 8.2: sectional anatomy of the cheek showing layers of the cheek and position of facial nerve branches and facial artery).

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Mucosa The mucosal layer of the buccal region is continuous anteriorly with the inner mucosal lining of the upper and lower lips; posteriorly with the mucosa of the retromolar trigone which then continues onto the anterior tonsillar pillar and the tonsillar fossa and further onto the posterior pharyngeal wall; and superiorly and inferiorly with the mucosa over the respective alveolar processes.

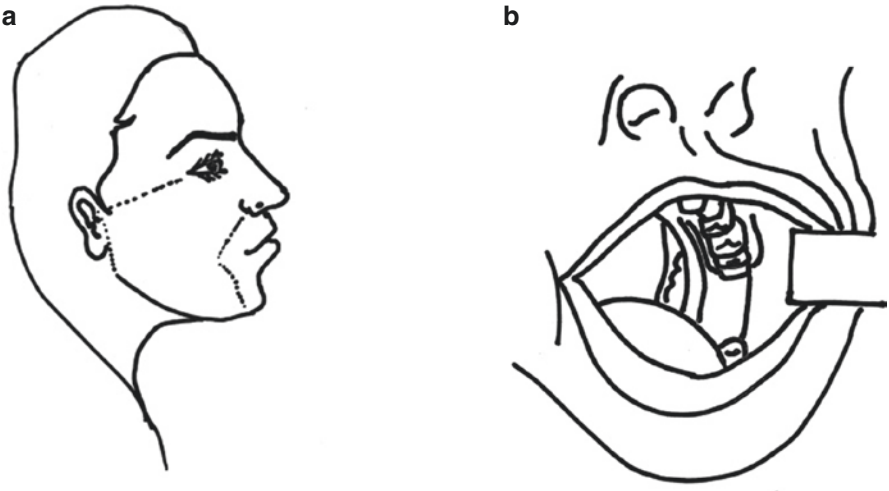


Fig. 8.1 (**a**) Extent of cheek and (**b**) intraoral extent of buccal mucosa

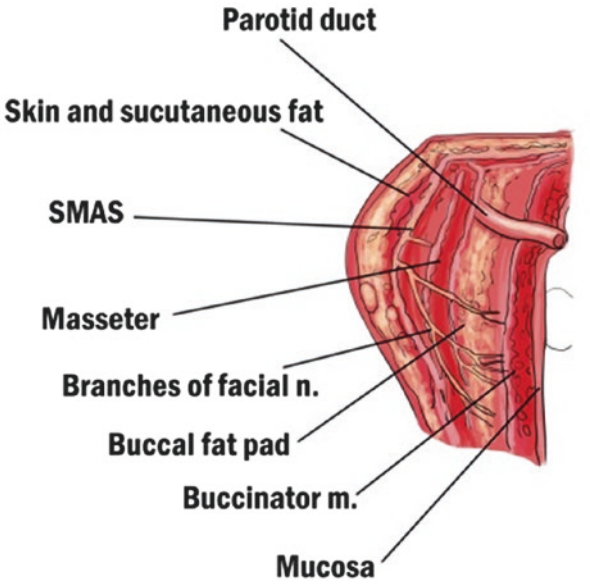


Fig. 8.2 Layers of the cheek

The mucosa consists of stratified non-keratinising squamous epithelial cells. Below the mucosa are the lamina propria and the submucosa, which contain numerous mucous minor salivary glands. There are also few ectopic sebaceous glands which appear as yellowish-white spots, called Fordyce granules. The opening of the parotid duct lies opposite to the crown of the upper second molar tooth. The mucosa is adherent to the deeper-lying muscle, the buccinator.

Fascial planes There are multiple fascial planes in the cheek. From inside out, they are the parotidomasseteric fascia, the superficial musculo-aponeurotic system (SMAS) and the subcutaneous fibroadipose tissue.

SMAS is a heterogeneous connective tissue plane that consists, variably across the face, of muscle fibres and fibrous or fibroadipose tissue. It is continuous inferiorly with the platysma, and it lies in the same plane as the superficial temporal fascia and the galea aponeurotica superiorly.

The parotidomasseteric fascia is a thin layer of fascia which is the superior continuation of the investing layer of the deep cervical fascia. Medially, it blends with the epimysium covering the buccinator and lies superficial to the buccal pad of fat which separates it from the buccinator. Laterally, it lies over the masseter as well as the branches of the facial nerve and the parotid duct.

Buccinator It is a thin, quadrilateral muscle that extends from the retromolar trigone to the commissure and from the upper to the lower alveolus. It forms the lateral wall of the vestibule and forms an important landmark in the cheek. Resection of tumours of the buccal mucosa which have not or have minimally breached this muscle is carried out in a plane lateral to the buccinator. When a tumour breaches the buccinator muscle through and through, there is no further barrier between the tumour and the skin, necessitating the inclusion of the skin in the resection specimen.

The buccinator arises from the posterior aspects of the alveolar processes of the mandible and the maxilla as well as the anterior margin of the pterygomandibular raphe posteriorly. This raphe is a condensed band of the buccopharyngeal fascia between the pterygoid hamulus and the posterior end of the mylohyoid line of the mandible. It also forms the anterior attachment of the superior pharyngeal constrictor, thus forming a continuous sheet of muscle from the lateral wall of the oral cavity up to the posterior pharyngeal wall. The raphe is also related posterolaterally to the medial pterygoid muscle. Its medial aspect is covered by the mucosa of the retromolar trigone.

Anteriorly, the fibres of the buccinator converge on the orbicularis oris at the commissure, with the central fibres decussating.

Relations The oral surface is covered by the mucosa and the submucosa. The lateral surface is covered by the buccopharyngeal fascia and lies deep to the buccal pad of fat, the mimetic muscles of the region and the parotidomasseteric fascia as well

as the branches of the facial nerve and vessels and the parotid duct. The parotid duct pierces the buccinator opposite the upper second molar tooth.

Neurovascular supply The buccinator is supplied by the branches of the facial artery and the buccal branch of the facial nerve and drained by a tributary of the facial vein.

Mimetic muscles The mimetic muscles in the cheek act mainly on the upper and lower lips, either elevating or depressing, retracting or everting them. The muscles acting on the upper lip include the levator labii superioris alaeque nasi, the levator labii superioris, the levator anguli oris and the zygomaticus major and minor. The muscles acting on the lower lip include the mentalis, the depressor labii inferioris and the depressor anguli oris. They are supplied by the zygomatic, buccal and marginal mandibular branches of the facial nerve.

Muscles of mastication These are the masseter, temporalis, medial and lateral pterygoid muscles. All of them participate in closing the mouth, except the lateral pterygoids which help in opening the mouth.

Masseter It is a bulky, three-layered muscle. Superiorly attached to the zygomatic arch, it passes postern-inferiorly to insert into the ramus and angle of the mandible. The parotid gland lies over the posterior margin of the muscle. It is supplied by branches of the maxillary, facial and superficial temporal arteries. Nerve supply is via the masseteric branch of the anterior division of the mandibular division of the trigeminal nerve.

Temporalis It is a fan-shaped muscle attached superiorly to the bones forming the temporal fossa up to the inferior temporal line. These muscle fibres then converge to form a tendon which passes deep to the zygomatic arch to insert into the coronoid process and the anterior border of the ramus of the mandible. It is supplied by the deep temporal branches of the maxillary artery. Nerve supply is by the deep temporal branch of the anterior division of the mandibular division of the trigeminal nerve.

Infratemporal fossa and masticatory space The infratemporal fossa lies posterior to the retromolar trigone. It is a region commonly invaded by locally advanced buccal mucosa carcinoma and hence may form part of the defect. Thus, an understanding of the anatomy of this region is vital to carry out both resections as well as reconstruction of the cheek.

The infratemporal fossa is a three-dimensional space bounded by the inferior surfaces of parts of the temporal bone and the greater wing of the sphenoid superiorly, the ramus of the mandible laterally and the lateral pterygoid plate with the

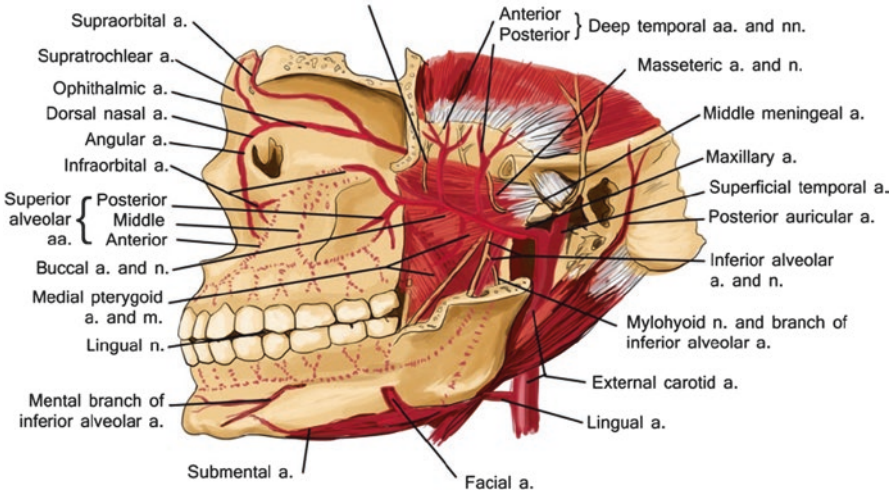


Fig. 8.3 Anatomy of the infratemporal fossa

posterolateral pharyngeal wall medially. It is continuous with the temporal fossa superiorly and the pterygopalatine fossa medially.

Contents Medial and lateral pterygoid muscles, mandibular division of the trigeminal nerve and its branches, chorda tympani branch of the facial nerve, the otic ganglion, the maxillary artery and the pterygoid plexus of veins (Fig. 8.3).

Buccal pad of fat It shall be described in detail later.

Facial vessels The facial artery is a branch of the external carotid artery. It arises in the neck. It lies deep to the platysma. It crossed into the submandibular region deep to the posterior belly of the digastric, lying in close proximity to the submandibular gland before passing into the face near the inferior aspect of the anterior border of the masseter. In the face, it lies superficial to the buccinators and the parotidomasseteric fascia. It courses superomedially, giving branches to supply the lower and upper lips, and pursues a tortuous course in the direction of the medial canthus of the eye before terminating in the levator labii superioris alaeque nasi. It supplies the muscles and the skin of the face as well as the lips.

The facial vein is formed by the union of the supraorbital vein and the supratrochlear vein near the medial canthus of the eye.

It lies with the facial artery in the face. In the neck, it usually crosses superficial to the posterior belly of the digastric to enter the carotid triangle. Here, the anatomy is variable. It usually terminates in the internal jugular vein, but is also known to join the external jugular or rarely even the anterior jugular veins.

Facial nerve It is the seventh cranial nerve. It can be divided into six segments – the intracranial, meatal, labyrinthine, tympanic, mastoid and extratemporal. We are concerned here with the extratemporal segment.

The extratemporal segment of the nerve begins as the nerve exits the temporal bone at the stylomastoid foramen. It immediately gives branches to supply the stylohyoid muscle, the posterior belly of the digastric muscle, the occipital belly of the occipitofrontalis muscle and some of the auricular muscles.

It then enters the parotid gland at its posteromedial surface. Within the substance of the gland, it gives off the superior and inferior trunks which usually give five terminal branches – the temporal, zygomatic, buccal, marginal mandibular and cervical branches. There is wide variation in the anatomy as well as considerable interconnections between the branches both within the parotid and externally. They usually arise within the gland and exit it separately at the anteromedial surface.

The facial nerve provides motor supply to the mimetic muscles of the face and sensory supply to the auricular and post-auricular regions as well as the conchal depression and over its eminence.

8.2 Classification of Defects of the Cheek

Any system to classify post-ablative head and neck defects has to consider the three-dimensional nature of the defect to aid in planning reconstruction and to determine the potential functional and aesthetic morbidity. In all the three planes, there are important structures affecting functional and aesthetic outcomes and hence the plan of reconstruction. Therefore, the authors propose the following classification system which classifies the defect in three different planes, the combination of which gives the exact description of any defect that may assist surgeons to choose a specific reconstructive technique.

1. Thickness of the defect
   P: Partial-thickness defects – the skin and subcutaneous planes are intact.
   F: Full-thickness defects – the overlying skin has been resected.
2. Supero-inferior plane
   I. Limited buccal defect without bony resection
      (a) <3 cm in greatest dimension
      (b) >3 cm in greatest dimension
   II. Minimal bone resection – upper alveolectomy and/or marginal mandibulectomy, no palatal or floor of the mouth defect
   III. Defect involving segmental mandibulectomy with or without subtotal maxillectomy below the zygomatic arch
   IV. Extensive bone defect with segmental mandibulectomy and subtotal/total maxillectomy extending above the zygomatic arch

3. Anteroposterior plane
   A. Limited buccal defect without involvement of commissure, infratemporal fossa (ITF) or masticatory space
   B. Anterior defect with involvement of commissure ± lip, but not ITF or masticatory space
   C. Posterior defect with involvement of ITF or masticatory space with or without posterior pharyngeal wall defect without commissure involvement
   D. Defect extending from lip to ITF or masticatory space with or without posterior pharyngeal wall (Figs. 8.4, 8.5, 8.6. 8.7, and 8.8).

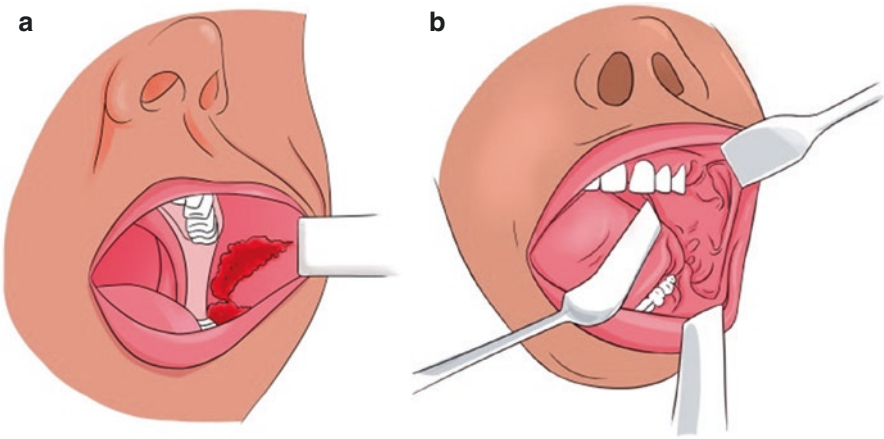


Fig. 8.4 Type I and type A defects. (**a**) PIaA defect, (**b**) PIbA defect

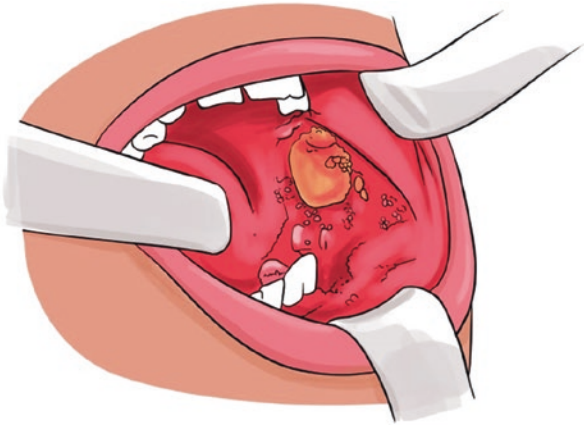


Fig. 8.5 Type II defect: PIIA defect

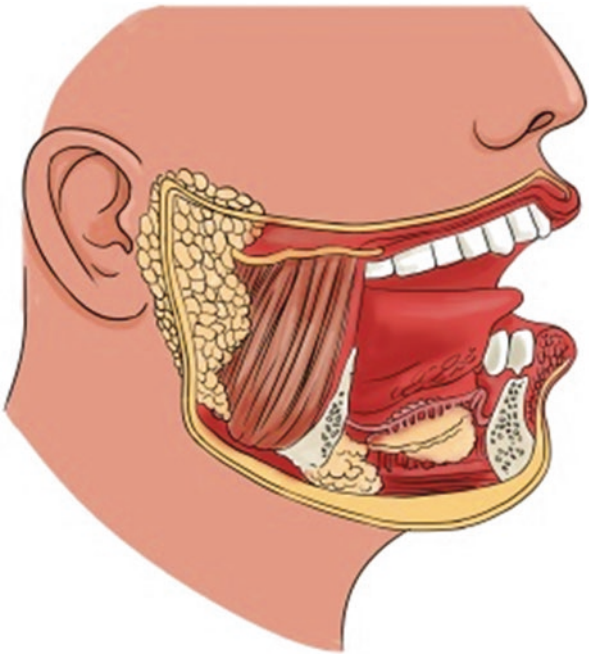


Fig. 8.6 Type III defect: FIIIB defect

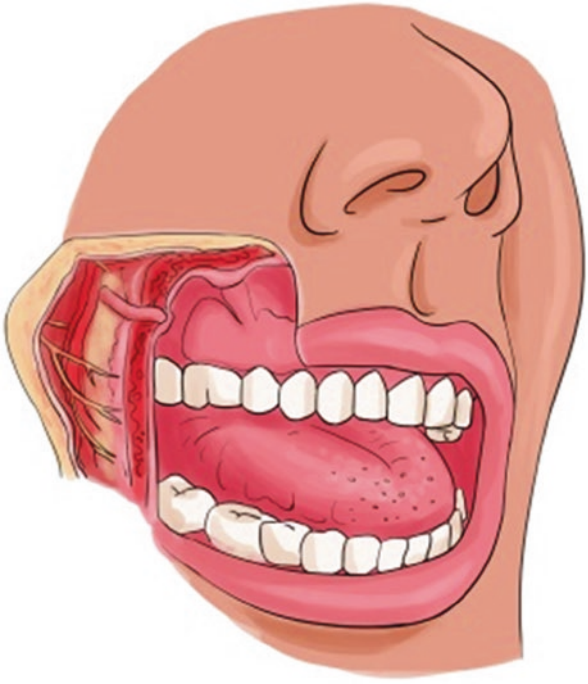


Fig. 8.7 Type B defect: FIbB defect

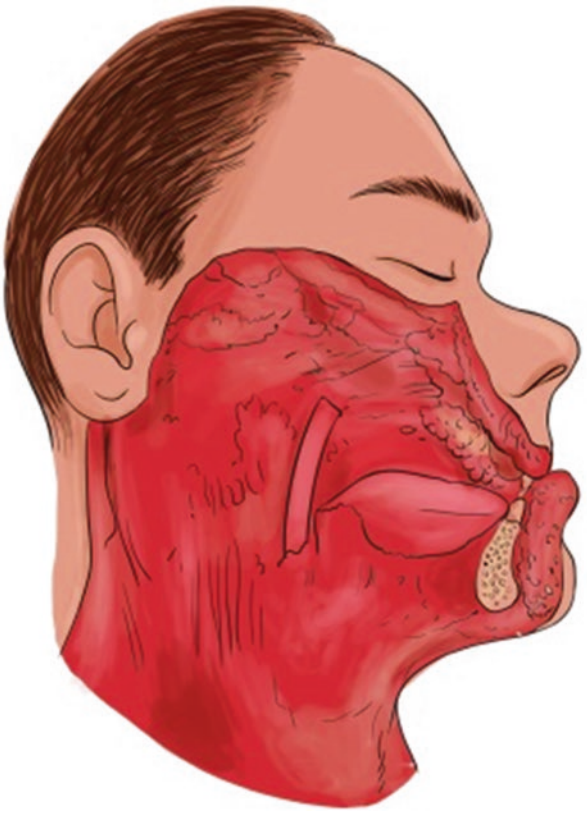


Fig. 8.8 Type IV and type D defect: FIVD defect

8.3 Objectives of Reconstruction

Objectives of reconstruction of buccal mucosal defects:

1. Orocutaneous separation
2. Separation of the oral cavity from the neck
3. To provide and/or maintain adequate mouth opening
4. To provide oromotor competence
5. To facilitate chewing and swallowing
6. To restore facial form as best as possible

8.4 Considerations

Considerations to select appropriate mode of reconstruction:

1. Primary closure vs. soft tissue reconstruction
   The most important functions to consider in oral cavity reconstruction are facilitation of intake of food, its mechanical breakdown by chewing to form a bolus and facilitation of swallowing without aspiration. Therefore, the first step is to provide adequate mouth opening in order to facilitate intake of food. Mouth opening is affected by the quality and quantity of buccal tissue from the commissure up to the infratemporal fossa.

   Any fibrosis or excessive scarring of the buccal mucosa anterior to the retromolar trigone and infratemporal fossa causes trismus. Hence, in type Ia A and B defects, it is possible to consider primary closure without compromising the mouth opening. In larger defects, contracture and scarring can occur [1]. There is no clear cut-off mentioned in literature, but in the authors' experience, defects more than 3 cm need additional tissue cover in order to prevent trismus.
2. Soft tissue versus bony reconstruction
   Composite type II, III and IV defects have both bony and soft tissue components. Hence, it is important to understand the indications for bony reconstruction.

   In type II defects, the bony continuity is maintained, but only the alveolar processes are resected. Hence, bony reconstruction is not necessary, and a soft tissue reconstruction usually suffices. In type III A and B defects that involve a segment of the mandible or a significant part of the maxilla with a part of the buccal mucosa but not the muscles of the infratemporal fossa, a bony reconstruction would be an ideal option. The requirement of soft tissue is limited, and also a segmental defect of the mandible can cause deviation of the remnant mandible and distortion of occlusion if not corrected. Dental rehabilitation may also be carried out if the bony segment is reconstructed [2–5].

   Buccal tumours, in advanced stages, may involve the masticator space, causing varying degrees of trismus. Following resection of the tumour along with a segment of the mandible as well as the muscles of the infratemporal fossa, the mouth opens up, and a type III or IV C and D defect is created. In order to maintain the mouth opening, it is of paramount importance to have adequate soft tissue to obliterate the dead space created, failing which there may be extensive fibrosis and compromised mouth opening. Also, healing in the immediate postoperative period may be affected due to serous collection, hematoma and infection of the dead space [6, 7]. At the same time, there may be occlusal distortion and inability to chew if the bony segment is not reconstructed, leading to poor quality of life. Hence, there is dilemma over which flap is ideal. An ideal flap would be one that provides a good strut of bone with plenty of soft tissue. Such a flap, however, does not exist. In such a setting, it

is advisable to prioritise soft tissue over bony reconstruction as long as the mandibular arch is uninvolved [7–9].

A reconstructive plate with soft tissue flap has been tried, but the rate of complications such as plate exposure, infection, fracture and deformity were found to be high. Hence, such an approach is not recommended [2, 10, 11].

An osteo-fasciocutaneous fibula flap provides an excellent segment of the bone; however, the soft tissue component is neither adequate nor pliable enough to be manoeuvred into the space of the infratemporal fossa [2, 4, 5, 12].

A soft tissue flap such as pectoralis major myocutaneous flap, anterolateral thigh flap or rectus abdominis flap can offer only soft tissue bulk to obturate the defect without providing bony support of the segmental mandibular defect.

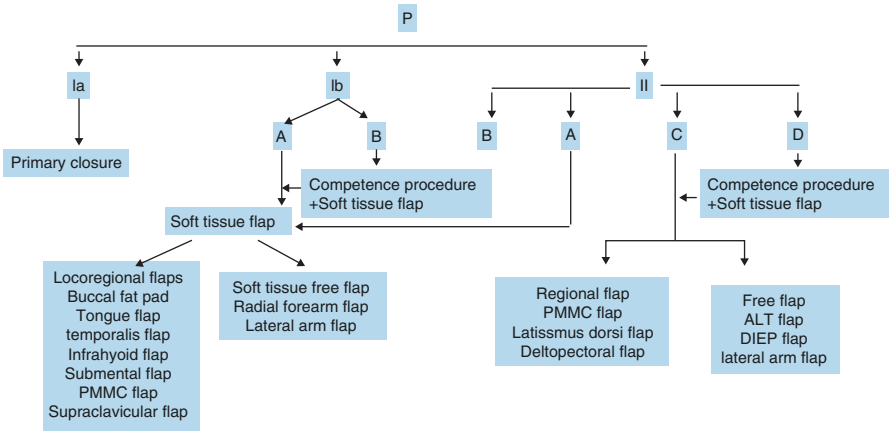
A scapular osteo-fasciocutaneous flap has been suggested as a middle ground, a flap which provides a long segment of the bone as well as plenty of soft tissue that can be used to fill the infratemporal fossa cavity. This flap isn't without limitations. Up to 14 cm of the bone can be harvested to provide bone continuity and prevent mandibular deviation. But the bone is thin and the quality often poor. Hence, dental rehabilitation with implant placement is not possible. Also, a two-team approach with simultaneous harvest of the flap is not possible due to the need for a change in the patient's position intraoperatively. This increase in operating time is not advisable in older patients or those unfit for prolonged anaesthesia [2, 5].

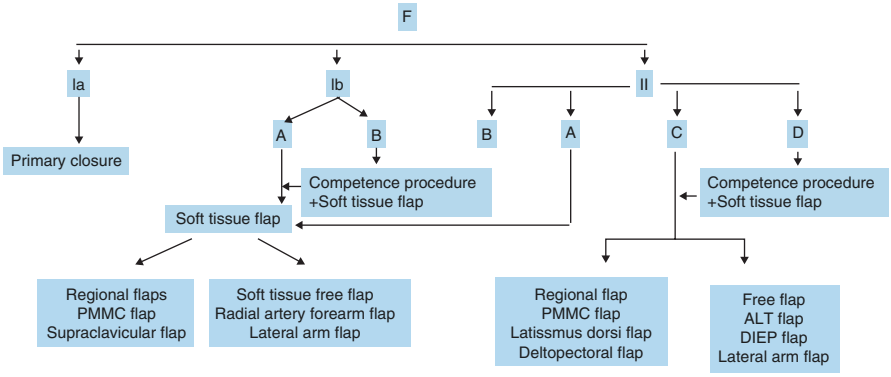
A deep circumflex iliac artery (DCIA) flap is another flap that provides a long segment of the bone with adequate soft tissue. But there are some important disadvantages of this flap. The first is that the soft tissue is adherent to the bone and cannot be manoeuvred to fill the defect in the infratemporal fossa. The lack of segmental perforators makes it risky to osteotomise the bone. Another problem to be considered is donor site morbidity. Incisional hernias and numbness over hip following rectus sheath harvest are reported to be significant. Higher incidences of gait disturbances were also reported with DCIA than fibula flap. Thus, especially in young patients, these complications may be considered a deterrent for the use of the flap [2, 13].

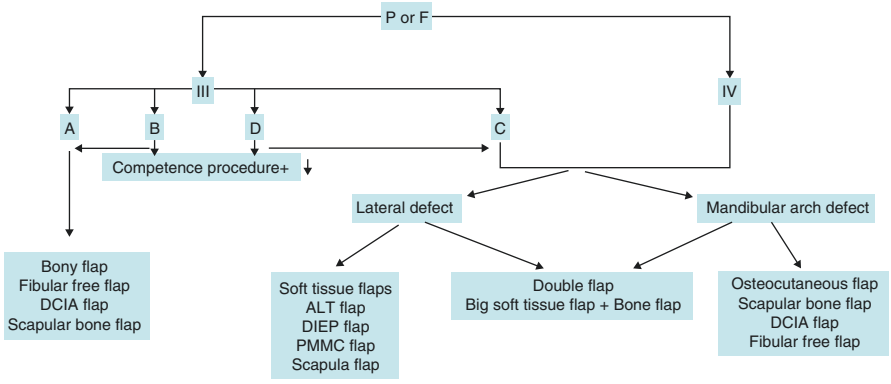
In ideal circumstances, a double flap would be the perfect reconstructive option. A free fibular bone flap with a soft tissue flap such as anterolateral thigh flap [14] or pectoralis major myocutaneous flap [15] provides excellent soft tissue cover as well as good quality of the bone to maintain occlusion and place implants for dental rehabilitation. However, the operating time is increased drastically and is not advisable in patients with poor general condition, which is fairly common among cancer patients [5, 9, 16, 17].

To summarise, there is no ideal, all-encompassing mode of reconstruction, and both defect and patient factors as well as the experience of the operating surgeon need to be considered while planning reconstruction of individual patients.

8.5 Reconstruction Algorithm







8.6 Reconstructive Options

With the above considerations in mind, the following section reviews the reconstructive options available to date for each defect defined by the proposed classification system.

8.6.1 Partial-Thickness Defects with Limited or No Bone Defects

These include PIa, PIb and PII defects. These defects do not need bony reconstruction; hence, soft tissue flaps are the method of choice. The options to consider are decided by the size, location and structures involved by the defect.

PIa: These defects are almost always type A defects, or rarely type B. The smallest of buccal defects is classified in this category. The depth of these defects is either mucosal or up to the buccinator. These defects may be closed primarily without any compromise of function.

PIb and PII: PIb defects are larger defects that may be type A or B. PII defects maybe types A, B, C or D. These defects are too big to be closed primarily without compromise of function [1].

PIb A and PII A: These are the defects most amenable to local flap reconstruction. The flap of choice depends on the size and location of the defect.

8.7 Local and Regional Flap Options

Buccal fat pad A pad of fat, described by Bichat in 1801, lies between the masseter and the buccinator posterior to the site where the latter is pierced by the Stensen's duct. It has an average volume of about 10 ml and is reported to be able to cover about 10 cm [3], although this varies between individuals. It has a rich blood supply from branches of maxillary and superficial temporal arteries. The increased vascularity has been ascribed to the intermittent high pressure it is subjected to. The main function of the fat pad is cushioning [18].

The buccal fat pad can be teased out into the oral cavity to cover small to moderate type A and B defects. Care should be taken to maintain a wide base in order to keep the blood supply intact. Mucosalisation occurs within the first 3 days, and adequate reconstruction is achieved with no functional or cosmetic adverse effects on the donor site. The limitation of this flap is the limited size of defects it can cover [18].

Tongue flaps Lateral, single-door or double-door tongue flaps are easy, reliable reconstructive options for small type A or B buccal defects. Potential complications include speech issues, deformity of the tongue and premature flap detachment and failure. This flap is also limited by size and reach [19].

Temporalis flap A temporalis myofascial flap based on the deep temporal arterial branches has been reported for buccal reconstruction. This flap can be used in medium-sized defects. The muscle along with the fascia is harvested based on the anterior and posterior deep temporal vessel which enters the muscle on the medial (deep) aspect. Care should be taken to preserve the blood supply during harvest. The flap can be brought into the oral cavity through the retromolar trigone region. Problems with the flap include fibrosis causing trismus which requires intense physiotherapy and a significant hollowing at the donor site causing a cosmetic defect, although use of alloplastic material has been reported to cover this defect. Another problem is getting the flap into the oral cavity when the upper teeth are intact. Also, it is not feasible in large resection due to compromise of the potential flap's blood supply and also the lack of bulk the flap can provide. There is also a chance of injury to the zygomatic branch of the facial nerve during harvest. Due to these reasons, it is not routinely used and can be considered only in the absence of better options [20, 21].

Infrahyoid flap It is based on the superior thyroid artery, which provides perforators to supply the strap muscles and the overlying skin. It provides reliable, pliable, non-hair-bearing skin. The flap has to be planned in advance so as not to disturb the perforators supplying the skin while raising a subplatysmal flap for neck dissection. The limitations of the flap include size, reach and a scar over the neck. It is a good option to consider in selected buccal defects where prolonged surgery is not advisable or a free flap is not feasible for any other reason [22, 23].

Submental flap It is based on the submental branch of the facial artery. Its use in reconstruction of buccal defects up to 15x8 cm is well documented in literature. It provides a reliable flap with good reach and minimal donor site morbidity [24–26]. While some authors have reported the flap to be oncologically safe in cases of carcinoma [25], others have their reservations since it includes the fibro-fatty tissue which is usually cleared as part of the level I lymph node station in neck dissections [26]. Hence, due to the availability of better options, it is not routinely advocated in carcinoma defects.

Nasolabial flap It is a time-tested flap in the reconstruction of oral defects, especially medium-sized buccal mucosa defect. Traditionally it is raised as a random pattern flap either superiorly or inferiorly based in the nasolabial crease. This reduces the mobility and arc of rotation, which in turn limits its reconstructive capability. Hence, islanded nasolabial flaps based on the facial artery and its perforator have been reported. Even in cases where facial artery needs to be sacrificed, one can base this flap on the transverse branch of maxillary artery [27]. It is useful in reconstruction of defects that involve more than one-third of either lip [28]. Problems with the flap include possible compromised blood supply, unavailability in case of extensive resection, limited size and a scar over the face. With the availability of better options, this flap should be used sparingly in buccal reconstruction.

Pectoralis major myocutaneous flap (PMMC) It is the workhorse of head and neck reconstruction. It is based on the pectoral branch of the thoracoacromial artery. One of the most widely used flaps, it provides reliable, good quality skin with adequate

soft tissue. It is easily raised with minimal donor site morbidity. It can be used to reconstruct small to large defects up to the zygoma. Due to a bulky soft tissue component, it is not preferred in very small defects. But in medium to large defects of the buccal mucosa where a free flap is either contraindicated or not feasible for any reason, it is the flap of choice. It is also useful as a salvage flap following failure of a free flap [29, 30]. Drawbacks of the flap include limit of reach above the zygoma, bulk in ladies due to breast tissue and chance of dehiscence, partial skin paddle loss and wound infection, especially in salvage setting [30, 31].

Deltopectoral flap It is another reliable flap based on the second and third perforators of the internal mammary artery. It provides thin pliable skin ideal for medium buccal defects. Conventionally, the need for a second-stage procedure to divide the pedicle was required, but an islanded technique after de-epithelialisation has been reported [32]. It is a useful flap to have in one's armamentarium although its use is uncommon in the present day.

Supraclavicular flap It is based on the supraclavicular branch of the transverse cervical artery. It provides reliable thin, pliable skin for medium-sized buccal mucosal defects. However, it cannot be used after radical/functional neck dissection if the vascular pedicle has been ligated [33]. Also, the reach and lack of bulk are limiting factors for its use in large soft tissue defects. For selected patients, it is a useful regional flap to use when free flaps are not feasible.

Forehead flap It is a rotational flap based on the anterior branch of the superficial temporal artery. It is usually performed in two stages, with a second procedure required to detach the pedicle. It is more useful in reconstructing skin defects, especially around the nose, rather than intraoral mucosal defects. It can also be used in full-thickness defects to cover the skin defect. However, due to poor cosmetic result at the donor site, a chance of injury to the zygomatico-frontal branch of the facial nerve as well as the need for a second stage, other, simpler flaps are preferred for intraoral defects (Figs. 8.9, 8.10, 8.11, 8.12, and 8.13).

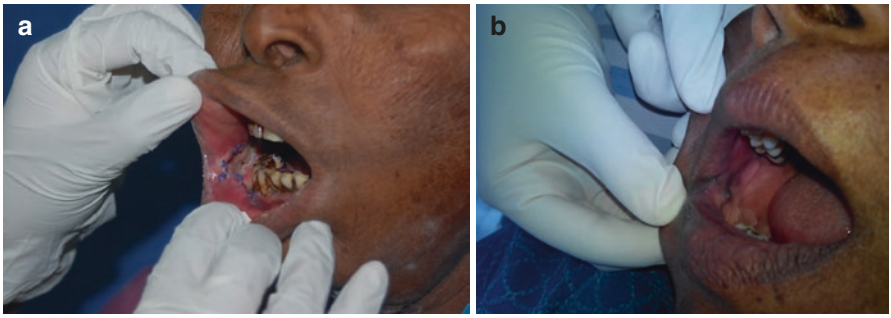


Fig. 8.9 Buccal fat pad. (**a**) Immediate post-op. (**b**) Mucosalisation seen on follow-up

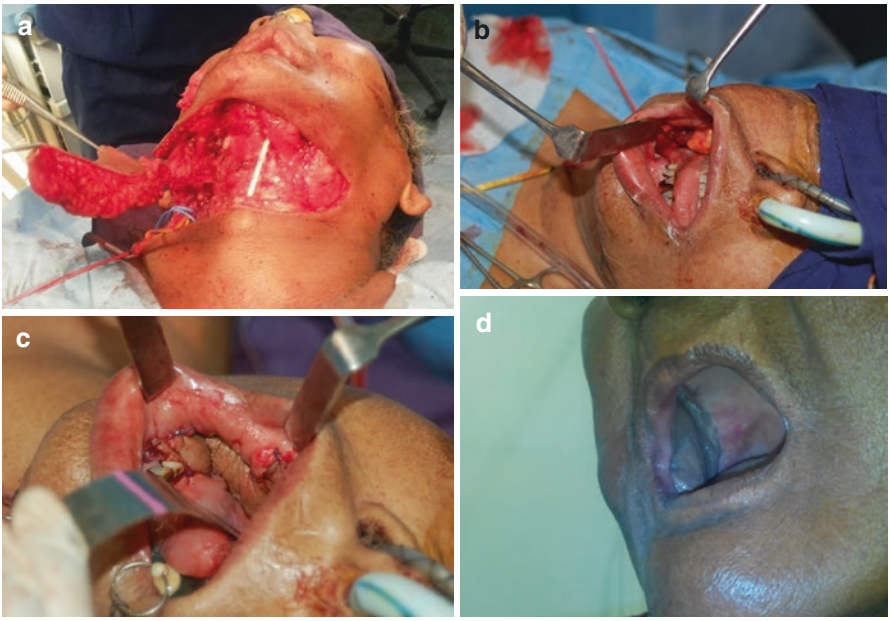


Fig. 8.10 Submental flap. (**a**) The harvested submental flap; (**b**) the defect – PIIA; (**c**) flap after insetting; (**d**) the flap after 1 month

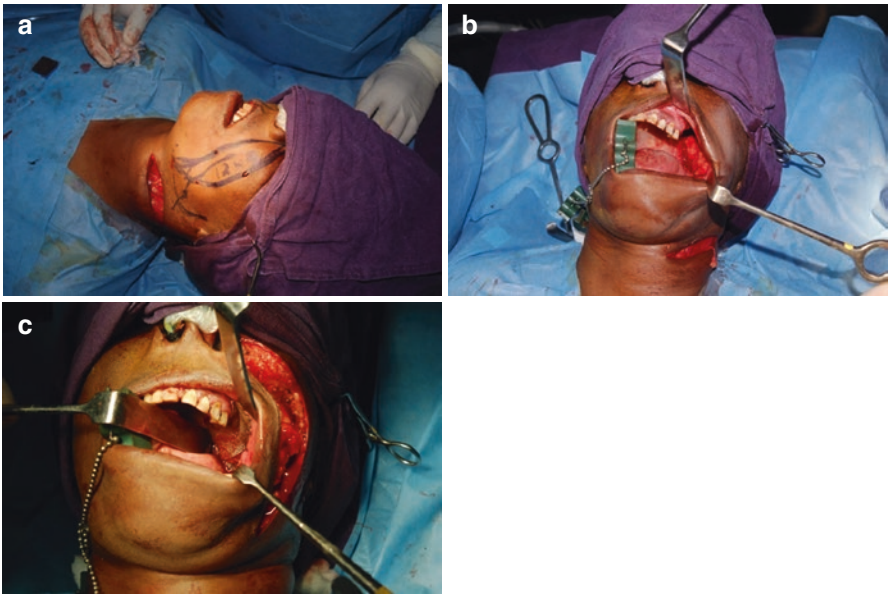


Fig. 8.11 Nasolabial flap. (**a**) Marking of the flap; (**b**) the defect – PIIA; (**c**) flap after insetting

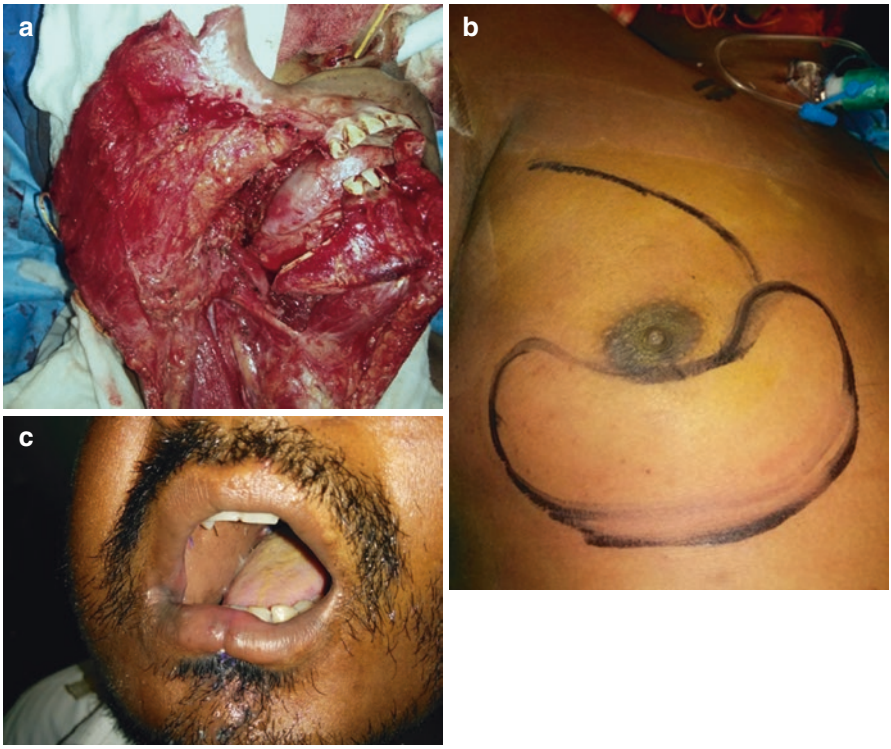


Fig. 8.12 Pectoralis major myocutaneous flap. (**a**) The defect – PIIIC; (**b**) marking of the flap; (**c**) the inset flap

8.8 Free Flap Options

Radial artery forearm flap It is a fasciocutaneous flap based on the radial artery and cephalic vein. It is a reliable flap that provides pliable skin, which may be harvested as single or multiple paddles. It also provides consistent, reliable and long vascular pedicle. It is always easily harvested with minimal functional donor site morbidity in experienced hands. It is the ideal flap to reconstruct type A or B defects. It can even be bi-paddled to cover full-thickness defects, including the commissure [34, 35]. The only drawbacks are a scar over the volar aspect of the forearm and a lack of bulk which makes it unsuitable for type C and D defects.

Lateral arm flap It is a fasciocutaneous flap based on the posterior radial collateral artery. It is a reliable flap in buccal reconstruction. Donor morbidity is minimal, and primary closure is often achieved [36]. The disadvantage compared to the radial forearm is the smaller calibre and length of the vascular pedicle as well as decreased pliability of the skin which is thicker than the skin over the forearm. In experienced

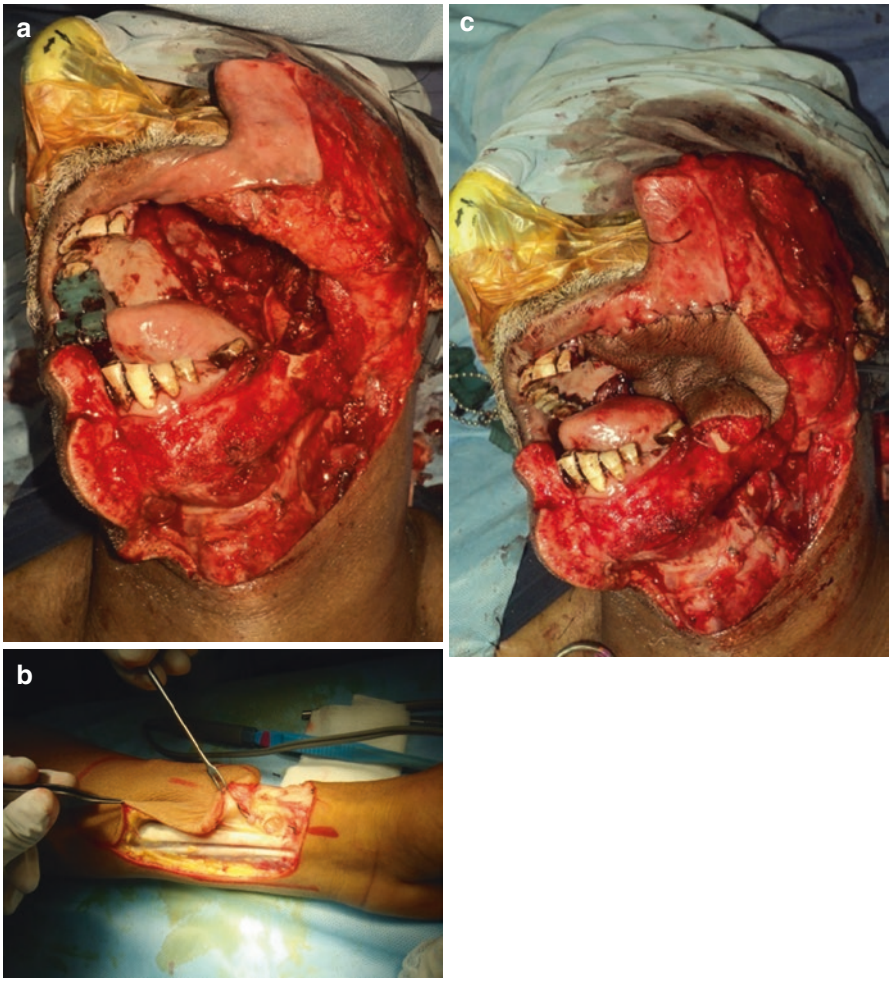


Fig. 8.13 Radial artery forearm flap. (**a**) The defect – PIIC; (**b**) the flap being harvested. The ligated distal end of the radial artery seen; (**c**) the flap inset to defect

hands, it can be used to cover even large defects requiring plenty of soft tissue, including full-thickness defects [37].

PIb B and PII B These defects are similar to the type A defects described above, except for the involvement of the commissure with or without lip involvement. Hence, they require additional measures to ensure oromotor competence. Limited lip involvement (less than one-third of one lip) may be closed primarily, followed by any of the previously mentioned flaps as required by the rest of the defect. If, however, there is extensive lip resection, then a separate flap such as an Abbe-Estlander flap, a bilateral Karapandzic flap or a nasolabial flap may be required. When there

is a large buccal component, then a single flap such as radial artery forearm flap [35], anterolateral thigh flap with fascia lata [38] or a temporalis flap may be used with a mechanical fascial sling to prevent drooping of the commissure. Detailed description of the reconstruction of the lip is given in the chapter on lip reconstruction.

PII C and D These are defects with a large soft tissue component with minimal bone defect. They require large soft tissue flaps such as PMMC, ALT, DIEP or TRAM.

Antero lateral thigh flap The anterolateral thigh flap is based on the descending branch of the circumflex femoral branch of the profunda femoris. It may be fasciocutaneous, myofasciocutaneous or even chimeric flap depending on the requirement of soft tissue mass as well as availability of a reliable perforator. It is a reliable flap that can provide a large skin paddle and abundant soft tissue and hence is ideal for large buccal defects. Donor site morbidity is minimal, and even large donor defects may be closed primarily, with split-skin grafts rarely required [39]. One disadvantage is a wide variability of the vascular anatomy [39, 40]. Also the bulk of the soft tissue component makes it unsuitable for type A and B defects. Some authors have reported methods to reduce the bulk by trimming the excess fibro-fatty tissue, but this can lead to compromise of the vascularity of the flap leading to increased incidents of complications [41]. A thorough knowledge of the vascular anatomy as well as meticulous dissection technique is required to have success with this flap.

Deep inferior epigastric perforator flap Deep inferior epigastric perforator (DIEP) flap is a fasciocutaneous flap based on the perforators from the deep inferior epigastric artery, a branch of the external iliac artery. It is a reliable alternative to the ALT flap, which provides adequate soft tissue with a large skin paddle [42]. It carries a small risk of abdominal complications such as wall weakness and hernia [43, 44]. Hence, the authors prefer the ALT flap which provides similar tissue with no functional donor *morbidity.*

Transverse rectus abdominis muscle flap Transverse rectus abdominis muscle flap is similar to the DIEP but includes harvest of the rectus abdominis muscle. This flap is more robust than DIEP with fewer reported flap-related complications but higher donor site morbidity [45]. Hence, it is not the preferred option in head and neck reconstruction.

8.9 Partial-Thickness Defects with Extensive Bone Defects

These include PIII and PIV defects. PIII defects may have limited soft tissue component (A or B) or large soft tissue component (C or D), whereas PIV defects almost always have large soft tissue component.

PIII A and B These are common in benign tumours or cysts of the mandible, where there is a large bone defect with limited soft tissue disruption. The reconstructive options revolve around restoration of bony continuity. The flap of choice in these defects, unless contraindicated, is the fibular free flap. It provides a long segment of high-quality bone with segmental blood supply and a reliable length of vascular pedicle which may be harvested with minimal donor site morbidity. If contraindicated due to peronea magna or previous fractures, then other flaps such as deep circumflex iliac artery flap with iliac crest bone or a scapula flap with the lateral border of the scapula may be considered. These, however, are inferior to the fibular flap either due to poor quality of the bone strut or high donor site morbidity [4, 5].

PIII C and D These include segmental mandibular defects with extensive soft tissue resection. The dilemma of whether to reconstruct the bone or not arises. The decision regarding need for bony flap can be taken based on the location and extent of the bone defect. Lateral defects which spare the mandibular arch do not warrant bony reconstruction [7–9]. But when the defect extends up to the midline beyond the genial tubercle, restoration of bony continuity, preferably with a fibular flap, is highly desirable [2, 5]. This is because the anterior attachment of the tongue is lost, which causes it to fall back onto the oropharynx, thus obstructing the oropharyngeal airway. It is imperative to provide anterior support to the tongue to prevent airway obstruction.

An ideal option would be to do a double flap including a large soft tissue flap to complement a fibular flap in these defects [5]. However, it is not always feasible due to time and resource constraints. In such a scenario, large soft tissue flaps such as the ALT, rectus abdominis or even a large PMMC flap should be preferred in lateral defects [7] while fibular flap should be reserved for defects involving the mandibular arch.

PIV These are some of the largest defects one could come across in the cheek. They almost always have large bony and soft tissue components. Since they extend beyond the mandible, regional flaps such as the PMMC do not reach the superior aspect of the defect and hence are not feasible. The ideal option is a double flap as described above. When not feasible, a large soft tissue flap should be preferred unless the arch of the mandible is involved [7]. The floor or the orbit may be reconstructed with a titanium plate or a strut of bone when feasible. Details of orbital reconstruction are covered in another chapter.

8.10 Full-Thickness Defects

Resection of skin often has a bearing on the reconstruction. Small skin defects can be closed primarily. However, defects bigger than 3 cm need flap or graft cover. A skin defect should preferably be covered by skin and hence rules out fascia-only

flaps. It also increases the size of the skin paddle required, and hence a large skin defect also rules out flaps with size limitations. Outside of these limitations, full-thickness defects can be reconstructed similar to their partial-thickness counterparts. Bi-paddled free flaps are ideal in reconstruction of full-thickness defects, with the choice of flap depending on the bulk of soft tissue required (Figs. 8.14, 8.15, 8.16, and 8.17).

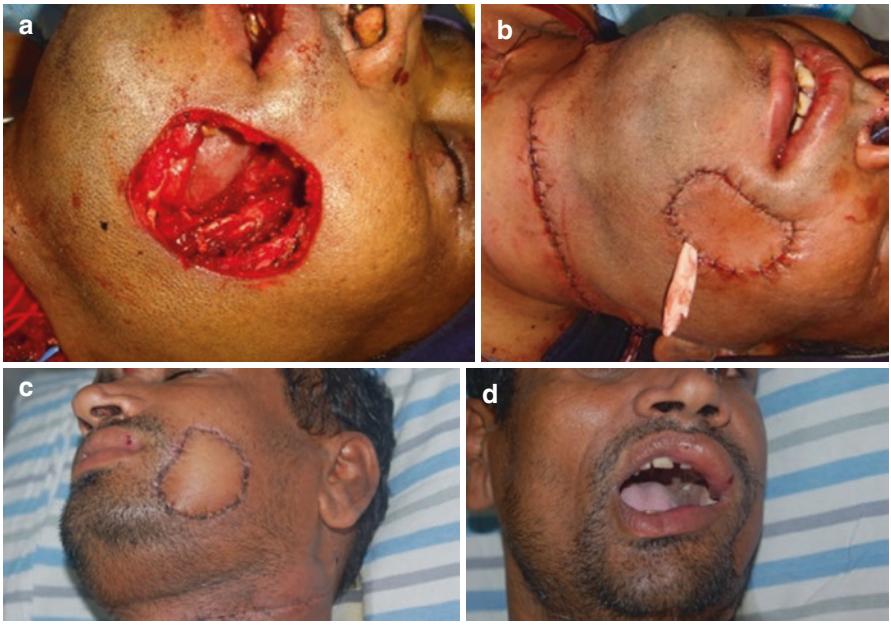


Fig. 8.14 Radial artery forearm flap for small full-thickness defects.(**a**) The defect – FIIA; (**b**) the flap after inset; (**c**) and (**d**) the flap on post-op day 10

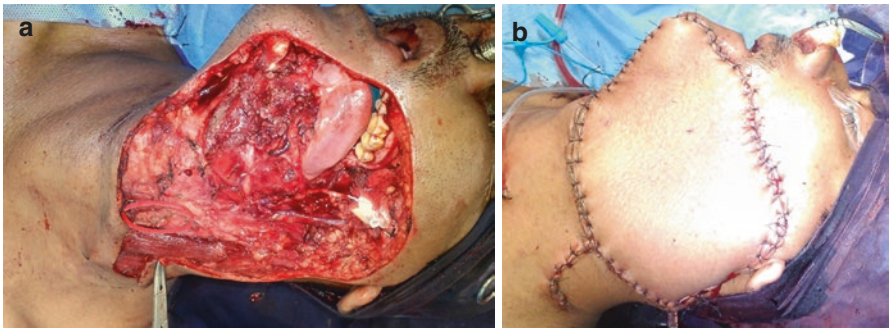


Fig. 8.15 Anterolateral thigh flap for full-thickness defect. (**a**) The defect – FIVC; (**b**) ALT flap after insetting

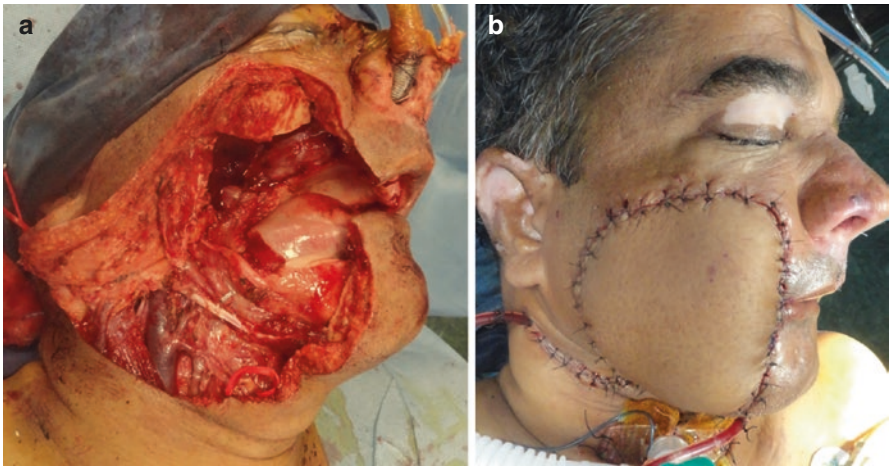


Fig. 8.16 Anterolateral thigh flap with fascia lata for full-thickness defect with commissure involvement. (**a**) The defect – FIVD; (**b**) the ALT flap on post-op day 1

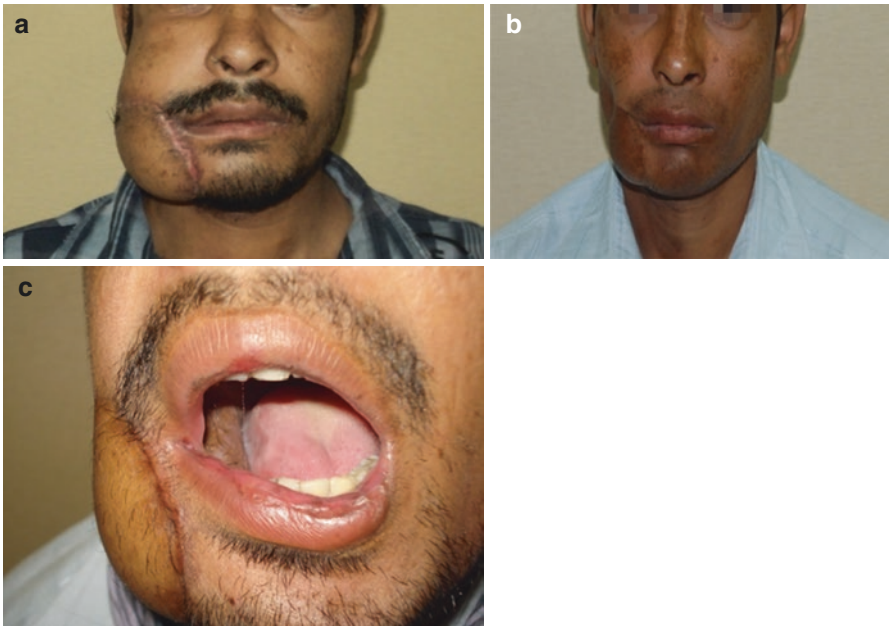


Fig. 8.17 Long-term results of full-thickness defect reconstructed with ALT flap. (**a**) Post-op day 10. (**b**) and (**c**) 1 year after treatment. Comparison of (**a**) and (**b**) shows flap shrinkage after radiotherapy and with time. (**c**) Shows adequate mouth opening and competence of the commissure

8.11 Summary

Cheek defects are complex and involve important structures that affect functions related to eating and speaking. The reconstructive plan needs to consider the three-dimensional nature of the defect and the functional outcomes desired. The aim is to provide adequate mouth opening, a competent stoma and dental rehabilitation whenever possible with acceptable aesthesis. Reconstruction should be individualised; however, some principles can be defined. Any defect more than 3 cm needs a flap. Bony defects with limited soft tissue component need osseous flaps. When the soft tissue defect is large and involves the masticatory space, soft tissue bulk takes precedence unless the arch of the mandible is involved. Also, patient factors such as age, comorbidities and resources need to be taken into consideration before the final plan is formulated.

References

1. Neuhaus RW, Baylis HI, Shorr N. Complications at mucous membrane donor sites. Am J Ophthalmol. 1982;93:643.
2. Disa JJ, Cordeiro PG. Mandible reconstruction with microvascular surgery. Semin Surg Oncol. 2000;19(3):226–34.
3. Urken ML, Buchbinder D, Costantino PD, Sinha U, Okay D, Lawson W, Biller HF. Oromandibular reconstruction using microvascular composite flaps: report of 210 cases. Arch Otolaryngol Head Neck Surg. 1998;124(1):46–55.
4. Ferri J, Piot B, Ruhin B, Mercier J. Advantages and limitations of the fibula free flap in mandibular reconstruction. J Oral Maxillofac Surg. 1997;55(5):440–8; discussion 448–9.
5. Takushima A, Harii K, Asato H, Momosawa A, Okazaki M, Nakatsuka T. Choice of osseous and osteocutaneous flaps for mandibular reconstruction. Int J Clin Oncol. 2005;10(4):234–42.
6. Wong CH, Wei FC. Microsurgical free flap in head and neck reconstruction. Head Neck. 2010;32(9):1236–45.
7. Kekatpure VD, Manjula BV, Mathias S, Trivedi NP, Selvam S, Kuriakose MA. Reconstruction of large composite buccal defects using single soft tissue flap--analysis of functional outcome. Microsurgery. 2013;33(3):184–90.
8. Mosahebi A, Chaudhry A, McCarthy CM, Disa JJ, Mehrara BJ, Pusic AL, Hu Q, Cordeiro PG. Reconstruction of extensive composite posterolateral mandibular defects using nonosseous free tissue transfer. Plast Reconstr Surg. 2009;124(5):1571–7.
9. Kroll SS, Robb GL, Miller MJ, Reese GP, Evans GR. Reconstruction of posterior mandibular defects with soft tissue using the rectus abdominis free flap. Br J Plast Surg. 1998;51(7):503–7.
10. Wei FC, Celik N, Yang WG, Chen IH, Chang YM, Chen HC. Complications after reconstruction by plate and soft-tissue free flap in composite mandibular defects and secondary salvage reconstruction with osteocutaneous flap. Plast Reconstr Surg. 2003;112(1):37–42.
11. Blackwell KE, Buchbinder D, Urken ML. Lateral mandibular reconstruction using soft-tissue free flaps and plates. Arch Otolaryngol Head Neck Surg. 1996;122(6):672–8.
12. Yilmaz M, Vayvada H, Menderes A, Demirdover C, Kizilkaya A. A comparison of vascularized fibular flap and iliac crest flap for mandibular reconstruction. J Craniofac Surg. 2008;19(1):227–34.

13. Ling XF, Peng X, Samman N. Donor-site morbidity of free fibula and DCIA flaps. J Oral Maxillofac Surg. 2013;71(9):1604–12.
14. Wei FC, Celik N, Chen HC, Cheng MH, Huang WC. Combined anterolateral thigh flap and vascularized fibula osteoseptocutaneous flap in reconstruction of extensive composite mandibular defects. Plast Reconstr Surg. 2002;109(1):45–52.
15. Chen HC, Demirkan F, Wei FC, Cheng SL, Cheng MH, Chen IH. Free fibula osteoseptocutaneous-pedicled pectoralis major myocutaneous flap combination in reconstruction of extensive composite mandibular defects. Plast Reconstr Surg. 1999;103(3):839–45.
16. Wei FC, Demirkan F, Chen HC, Chen IH. Double free flaps in reconstruction of extensive composite mandibular defects in head and neck cancer. Plast Reconstr Surg. 1999;103(1):39–47.
17. Balasubramanian D, Thankappan K, Kuriakose MA, Duraisamy S, Sharan R, Mathew J, Sharma M, Iyer S. Reconstructive indications of simultaneous double free flaps in the head and neck: a case series and literature review. Microsurgery. 2012;32(6):423–30.
18. Tostevin PM, Ellis H. The buccal pad of fat: a review. Clin Anat. 1995;8(6):403–6.
19. Strauss RA, Kain NJ. Tongue flaps. Oral Maxillofac Surg Clin North Am. 2014;26(3):313–25.
20. Abubaker AO, Abouzgia MB. The temporalis muscle flap in reconstruction of intraoral defects: an appraisal of the technique. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2002;94(1):24–30.
21. Cordeiro PG, Wolfe SA. The temporalis muscle flap revisited on its centennial: advantages, newer uses, and disadvantages. Plast Reconstr Surg. 1996;98(6):980–7.
22. Deganello A, Manciocco V, Dolivet G, Leemans CR, Spriano G. Infrahyoid fascio-myocutaneous flap as an alternative to free radial forearm flap in head and neck reconstruction. Head Neck. 2007;29(3):285–91.
23. Peng H, Wang SJ, Yang X, Guo H, Liu M. Infrahyoid myocutaneous flap for medium-sized head and neck defects: surgical outcome and technique modification. Otolaryngol Head Neck Surg. 2013;148(1):47–53.
24. Parmar PS, Goldstein DP. The submental island flap in head and neck reconstruction. Curr Opin Otolaryngol Head Neck Surg. 2009;17(4):263–6.
25. Howard BE, Nagel TH, Donald CB, Hinni ML, Hayden RE. Oncologic safety of the submental flap for reconstruction in oral cavity malignancies. Otolaryngol Head Neck Surg. 2014;150(4):558–62.
26. Pistre V, Pelissier P, Martin D, Lim A, Baudet J. Ten years of experience with the submental flap. Plast Reconstr Surg. 2001;108(6):1576–81.
27. Lazaridis N, Tilaveridis I, Karakasis D. Superiorly or inferiorly based “islanded” nasolabial flap for buccal mucosa defects reconstruction. J Oral Maxillofac Surg. 2008;66(1):7–15.
28. Tan NC, Hsieh CH, Riva FM, Jeng SF. The nasolabial flap as a one-stage procedure for reconstruction of intermediate-to-large lip defects with functional and aesthetic assessments. J Plast Reconstr Aesthet Surg. 2013;66(3):352–7.
29. Patel K, Lyu DJ, Kademani D. Pectoralis major myocutaneous flap. Oral Maxillofac Surg Clin North Am. 2014;26(3):421–6.
30. Gadre KS, Gadre P, Sane VD, Halli R, Doshi P, Modi S. Pectoralis major myocutaneous flap–still a workhorse for maxillofacial reconstruction in developing countries. J Oral Maxillofac Surg. 2013;71(11):2005.
31. Vartanian JG, Carvalho AL, Carvalho SM, Mizobe L, Magrin J, Kowalski LP. Pectoralis major and other myofascial/myocutaneous flaps in head and neck cancer reconstruction: experience with 437 cases at a single institution. Head Neck. 2004;26(12):1018–23.
32. Mortensen M, Genden EM. Role of the island deltopectoral flap in contemporary head and neck reconstruction. Ann Otol Rhinol Laryngol. 2006;115(5):361–4.
33. Granzow JW, Suliman A, Roostaeian J, Perry A, Boyd JB. The supraclavicular artery island flap (SCAIF) for head and neck reconstruction: surgical technique and refinements. Otolaryngol Head Neck Surg. 2013;148(6):933–40.

34. Savant DN, Patel SG, Deshmukh SP, Gujarati R, Bhathena HM, Kavarana NM. Folded free radial forearm flap for reconstruction of full-thickness defects of the cheek. Head Neck. 1995;17(4):293–6.
35. Valentini V, Saltarel A, Cassoni A, Battisti A, Egidi S. One-stage reconstruction of a defect of the oral commissure and of the cheek with a radial forearm free flap. J Craniofac Surg. 2008;19(6):1508–11.
36. Marques Faria JC, Rodrigues ML, Scopel GP, Kowalski LP, Ferreira MC. The versatility of the free lateral arm flap in head and neck soft tissue reconstruction: clinical experience of 210 cases. J Plast Reconstr Aesthet Surg. 2008;61(2):172–9.
37. Chen IC, Lin CY, Yen RS, Ou LF, Tan YW. The extended lateral arm flap in head and neck reconstruction. J Chin Med Assoc. 2003;66(9):544–50.
38. Kuo YR, Jeng SF, Wei FC, Su CY, Chien CY. Functional reconstruction of complex lip and cheek defect with free composite anterolateral thigh flap and vascularized fascia. Head Neck. 2008;30(8):1001–6.
39. Wong CH, Wei FC. Anterolateral thigh flap. Head Neck. 2010;32(4):529–40.
40. Lakhiani C, Lee MR, Saint-Cyr M. Vascular anatomy of the anterolateral thigh flap: a systematic review. Plast Reconstr Surg. 2012;130(6):1254–68.
41. Agostini T, Lazzeri D, Spinelli G. Anterolateral thigh flap thinning: techniques and complications. Ann Plast Surg. 2014;72(2):246–52.
42. Masià J, Sommario M, Cervelli D, Vega C, León X, Pons G. Extended deep inferior epigastric artery perforator flap for head and neck reconstruction: a clinical experience with 100 patients. Head Neck. 2011;33(9):1328–34.
43. Futter CM, Webster MH, Hagen S, Mitchell SL. A retrospective comparison of abdominal muscle strength following breast reconstruction with a free TRAM or DIEP flap. Br J Plast Surg. 2000;53(7):578–83.
44. Guerra AB, Metzinger SE, Bidros RS, et al. Bilateral breast reconstruction with the deep inferior epigastric perforator (DIEP) flap: an experience with 280 flaps. Ann Plast Surg. 2004;52:246–52.
45. Man LX, Selber JC, Serletti JM. Abdominal wall following free TRAM or DIEP flap reconstruction: a meta-analysis and critical review. Plast Reconstr Surg. 2009;124(3):752–64.

Lip Reconstruction

9

Can Ozturk, Cemile Nurdan Ozturk, and Oguz Cetinkale

The lips have a unique functional and aesthetic importance for human beings. It is the essential subunit of the face for expressing facial mimics. As a functional unit, it maintains the oral competence and assists speech and feed. In general, the etiology of lip defects could be congenital or acquired. Acquired deformities may be broadly grouped as traumatic injuries and cancer resections. In this chapter, we focus on the surgical reconstruction strategies for acquired deformities commonly seen after cancer resections. Squamous cell carcinoma (SCC) is the most common malignancy affecting the lip, unlike the rest of the facial skin where basal cell cancer is predominant. The UV (ultraviolet) radiation and tobacco exposure are the most common environmental factors that cause lip cancer. About 90 % of the lip malignancies are located in the lower lip. The other malignancies and diseases involving the lips are Merkel cell carcinoma, microcystic adnexal carcinoma, hemangiomas, nevi, cheilitis, melanotic macules, and infectious processes like noma [1]. The pathology of the disease is important for planning the margins of resection and final defect size [2].

9.1 Historical Context

One early report from Hindu literature, the Sushruta Samhita, exemplifies the local and regional flaps for the reconstruction of the lip defects dating back to 600 BC. The other early report is De Medicina by Celsus [3]. In recent centuries, Dieffenbach described the bilateral cheek advancement flaps for lower lip

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reconstruction in 1829 [4]. Despite the attribution to Abbe and Estlander, Sabattini was the first who described and reported the cross-lip flap from lower lip to reconstruct a philtrum defect [5]. In 1853, Bernard defined the technique of full-thickness wedge excision paired with cheek advancement flaps for lower lip repair [6]. Estlander, in 1872, described the upper to lower lip transfer at the commissure, as Abbe reported the central cross-lip flap in 1898 for cleft lip defects [7, 8]. The cheek rotation fan flap was described by Gilles in 1920, Webster's modification to the Bernard cheek advancement flap was described in 1960, and other pioneers such as Karapandzic, Mc Gregor, Spira, and Hardy proposed several modifications to prior techniques and described new surgical approaches [9–13]. More recently, buccal mucosal flaps by Rayner and Arscott and the facial artery musculomucosal flap (FAMM) by Pribaz were described [14, 15]. The first reported microvascular free tissue transfer was by Harii and Ohmari in 1974 for total lip reconstruction [16]. In 2005, the world's first partial facial transplantation was done in Lyon, France, by Devauchelle and Dubernard for reconstruction of the lips and central face after a dog bite injury [17].

9.2 Anatomy

Understanding the complex anatomy of the lip is crucial to accurately restore function after reconstruction. The lips are centrally located at lower third of the face and consist of three layers: outer layer with skin and vermillion, muscular layer, and inner layer of mucosa. The upper lip extends from the columellar base and nostrils superiorly to the nasolabial folds laterally and vermillion inferiorly. The central part of the upper lip, philtrum, is bordered by philtral columns laterally and the Cupid's bow inferiorly. The lower lip is defined inferiorly by labiomental crease, laterally by nasolabial folds, and superiorly by the vermillion. Both lips extend to gingivolabial sulcus intraorally. The other important landmarks are the "white roll" that is the transition zone between facial skin and vermillion, and the "red line" which is the transition zone of the dry and wet portion of the vermillion. Intermediate layer consists of muscular support structures, including 21 muscles: elevators (levator labii superioris, levator labii superioris alaeque nasi, levator anguli oris, zygomaticus major and minor muscles), depressors (depressor labii inferioris and depressor anguli oris muscles), protrusion (mentalis muscles), buccinator and risorius muscles. These muscles with circumferentially oriented orbicularis oris muscle form a circular complex that maintains the oral competence and performs rest of the functions. The understanding of the anatomy of circular complex is critical to determine the final lip defect after disruption of the muscle continuity, as disrupted edges contract laterally, exaggerating the amount of actual lip defect. Most of these muscles insert or originate to a fibrous structure, named as modiolus which is located at the deep layer of skin at commissures. Arterial blood supply comes from the superior and inferior labial arteries, distal branches of the facial artery. These branches arise from facial artery deep to the modiolus and course horizontally and posterior to

orbicularis oris muscle. The knowledge of axial course and the location are essential during dissection of cross-lip flaps. The venous system consists of multiple interconnected vessels that drain into facial vein. There is rich lymphatic drainage at the lips. The central part of the lower lip drains into submental, submandibular, and jugular nodes, whereas the lateral parts of the lower lip and whole upper lip drain into submandibular nodes directly. The sensory nerve supply of the upper lip is from the infraorbital division of the trigeminal nerve, whereas the mental branch division provides lower lip sensation. The motor nerve supply is provided by zygomatic, buccal, and marginal mandibular branches of the facial nerve. With the exception of mentalis, buccinator, and levator anguli oris, the perioral muscles are innervated from their deep surface.

9.3 Part I: Planning of Lip Reconstruction

The primary goal of lip reconstruction is to restore function with the best possible aesthetic outcome. To achieve these goals the assessment of the defect is critical. The location (upper/lower lip, central/lateral/commissure), thickness (partial/full), dimensions of the defect and patient status should be considered in the operative plan. A multitude of flaps have been described in the literature to reconstruct these defects [1–21].

9.3.1 Small Defects (Up to One-Third)

Up to one-fourth of the upper lip and one-third to one-half (depending on the laxity and location) of the lower lip, full-thickness defects can be reconstructed with vertically oriented closure. To achieve this closure, the wedge resection should be designed as a V, W, single-barrel, or double-barrel pattern (Fig. 9.1) [18, 19]. However, vertically oriented linear closure of the central part of the upper lip, including philtrum and Cupid's bow, often results in distortion of these structures. To avoid this problem, a cross-lip flap (Abbe) from lower central lip should be used for reconstruction of this area (Fig. 9.2). All of these techniques consist of three layers of closure including mucosa, muscle, and skin. For the upper lip defects, perialar excisions may be considered to facilitate the reconstructive goal (Fig. 9.3). Meticulous alignment of the orbicularis muscle particularly at lower lip and vermillion white roll is critical to avoid functional and aesthetic morbidities.

9.3.2 Moderate to Large Defects

Upper lip defects greater than one-fourth of the upper lip or lower lip defects greater than one-half of the lower lip require more complex surgical closure, such as local flaps and/or free flaps. For partial-thickness moderate size defects, V-Y advancement, nasolabial transposition, lip advancement, and a combination of these flaps are usually the first-line options for reconstruction (Figs. 9.4 and 9.5). For the upper

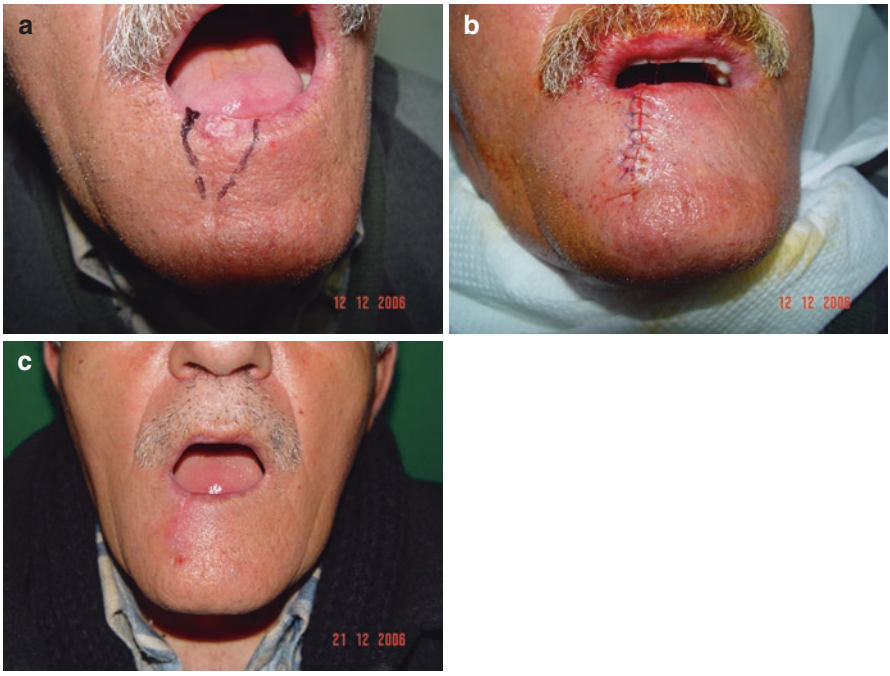

Fig. 9.1 (**a**) Recurrent SCC of the lower lip. V-shaped excision is planned. (**b**) Primary closure of the defect. (**c**) Postoperative view demonstrating mouth opening

lip central defects, central cross-lip flap (Abbe) from the lower lip is an excellent option. Abbe flap and nasolabial flaps can be used for the reconstruction of large upper lateral lip defects. For lateral defects that involve commissure, lateral cross-lip flap (Estlander) is the preferred option (Fig. 9.6). The details of these flaps are discussed below in Part II.

For large lower lip defects, cross-lip flaps (Abbe and Estlander) from upper lip, nasolabial flap, local composite flaps (Bernard, Gilles, Webster, and various modifications of the local lip flaps), and innervated composite flaps, such as Karapandzic flap (discussed below), are the main reconstructive options (Figs. 9.7 and 9.8).

9.3.3 Total Lip Defects

In general, if local tissue is available, Bernard-Webster cheek advancement flaps with/without cross-lip flaps remain an option for the reconstruction of the near-total lip defects. Cheek advancement flaps result in good color match providing similar thickness and contour. Most importantly, they provide sensate and functional tissue; however, donor site scars, blunting of facial creases due to aggressive advancement, microstomia, and lower lip collapse into the oral mucosa are the major disadvantages. When there is a lack of local tissue, distant flaps such as submental and

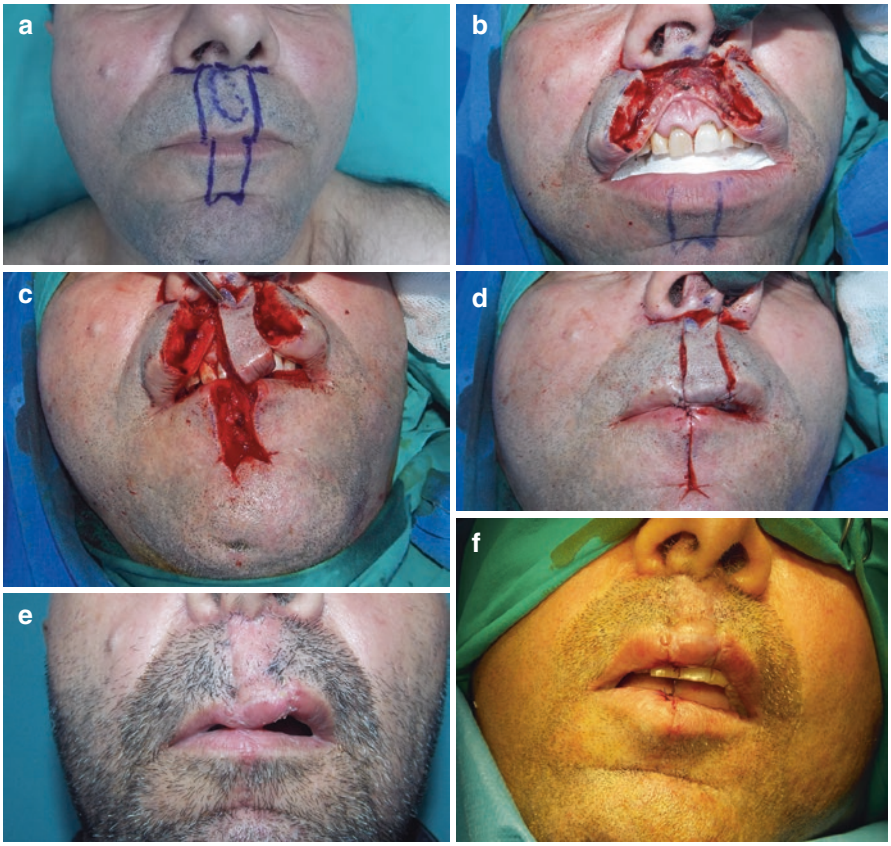

Fig. 9.2 (**a**) Hidradenocarcinoma of the upper lip. (**b**) Upper central lip defect after resection. Abbe flap was planned from the lower lip. (**c**, **d**) Transposition and inset of Abbe flap. (**e**) Flap is seen prior to division of pedicle. (**f**) Final result after division of flap pedicle

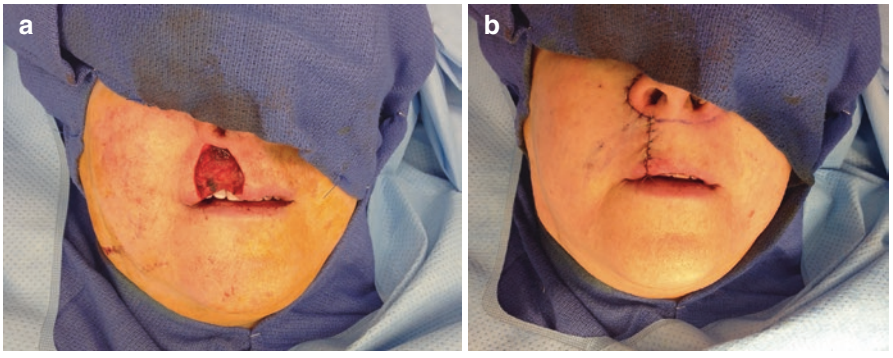

Fig. 9.3 (**a**) Partial upper lip defect after skin cancer removal. (**b**) Cheek was undermined in the subcutaneous plane lateral to the defect, and a perialar cresentic excision was made to facilitate advancement of cheek skin towards the upper lip

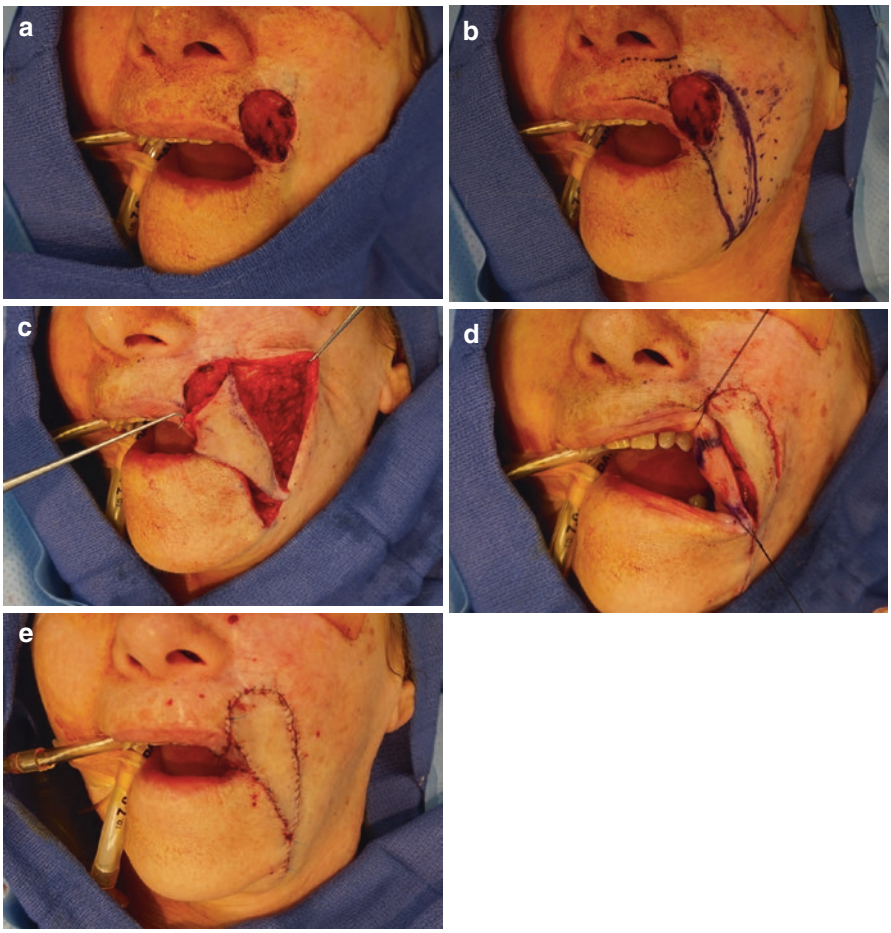

Fig. 9.4 (**a**) Partial-thickness upper lip defect after excision of recurrent skin cancer. (**b**) V-Y advancement flap design to reconstruct the defect. (**c**) As lateral cheek skin is undermined, care is taken to preserve subcutaneous pedicle to the V-Y flap. (**d**) Mucosal advancement is planned to recreate the missing vermillion. (**e**) Final closure

temporoparietal flap options should be considered. If neither local flaps nor regional flaps exist, the next step will be utilization of free flaps including radial forearm, gracilis, and anterolateral thigh flaps (Fig. 9.9). Recently, for providing oral competency and achieving a better functional outcome, functional muscle transfers and composite free flaps have been described. Finally, at last decade, in 2004 Dubernard et al. performed first lip transplantation as a part of lower face transplantation in a middle-aged female patient who lost her lip due to an animal bite. It was reported that the patient had almost normal sensorial recovery and satisfactory motor function at 10 months after surgery [17]. This successful surgery opens a new era in reconstructive plastic surgery and expands the armamentarium of the surgeon for challenging cases.

9.3.4 Complications

The potential complications with lip reconstruction include impaired oral competence, vermillion notching, microstomia, drooling, lip droop, impaired functional activity, scars, etc. Serial revisional surgeries may be needed to improve these problems. By far, the worst outcomes are inadequate nutrition intake and impaired speech due to microstomia most commonly seen after total lip reconstruction.

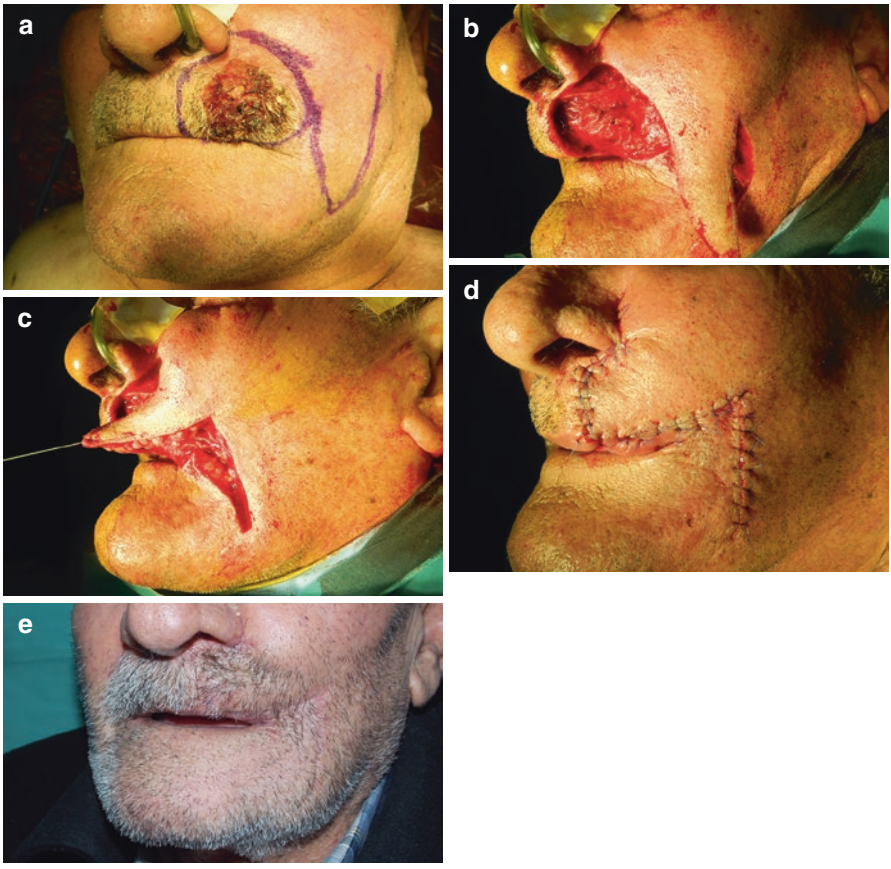

Fig. 9.5 (**a**) BCC of the upper lip and planning of a transposition flap. (**b**) Partial-thickness upper lip defect and elevation of the transposition flap. (**c**) Flap is transposed into the defect. (**d**) Final closure. (**e**) Postoperative result

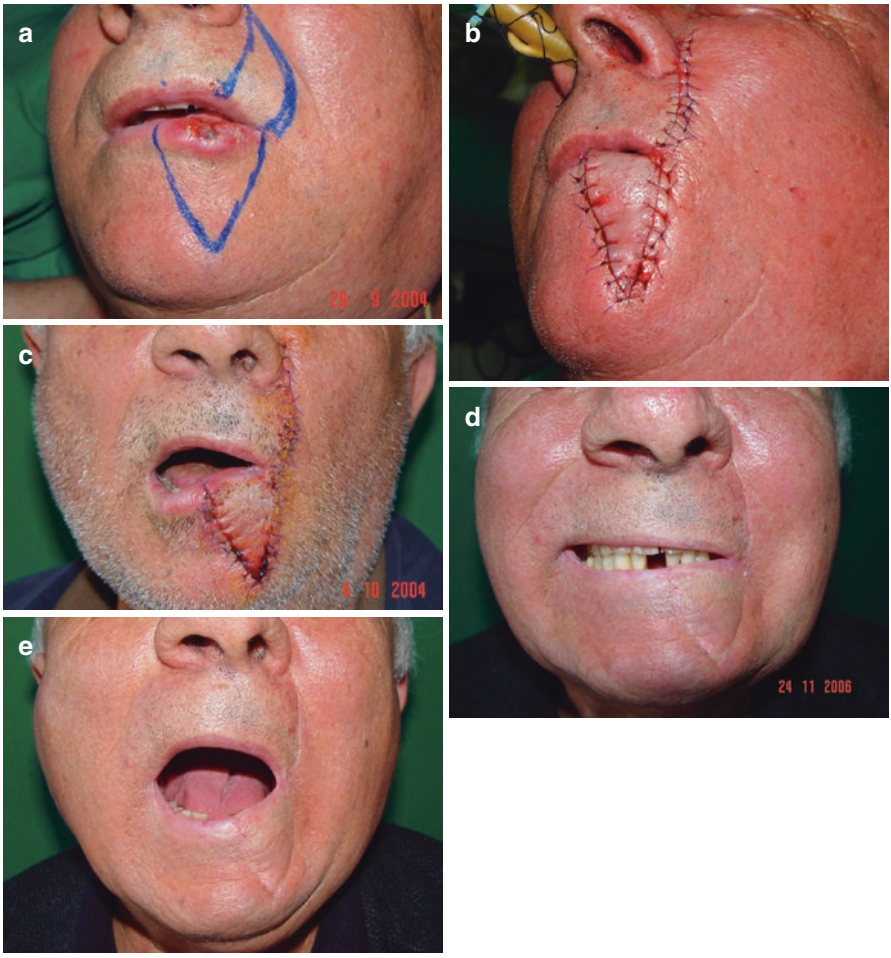

Fig. 9.6 (**a**) SCC of the lower lip and planning of Estlander flap. (**b**) Intraoperative view after transposition of flap. (**c**) Early postoperative result. (**d**, **e**) Late postoperative result demonstrating mouth opening

9.4 Part II: Surgical Techniques

9.4.1 Primary Repair

Small full-thickness defects, not extending beyond the one-fourth to one-third of the lip, may be closed primarily. The commonly used treatment technique is a V-shaped full-thickness excision and primary closure of the defect (Fig. 9.1). However, a W-shaped or pentagonal excision technique can also be performed. The closure of

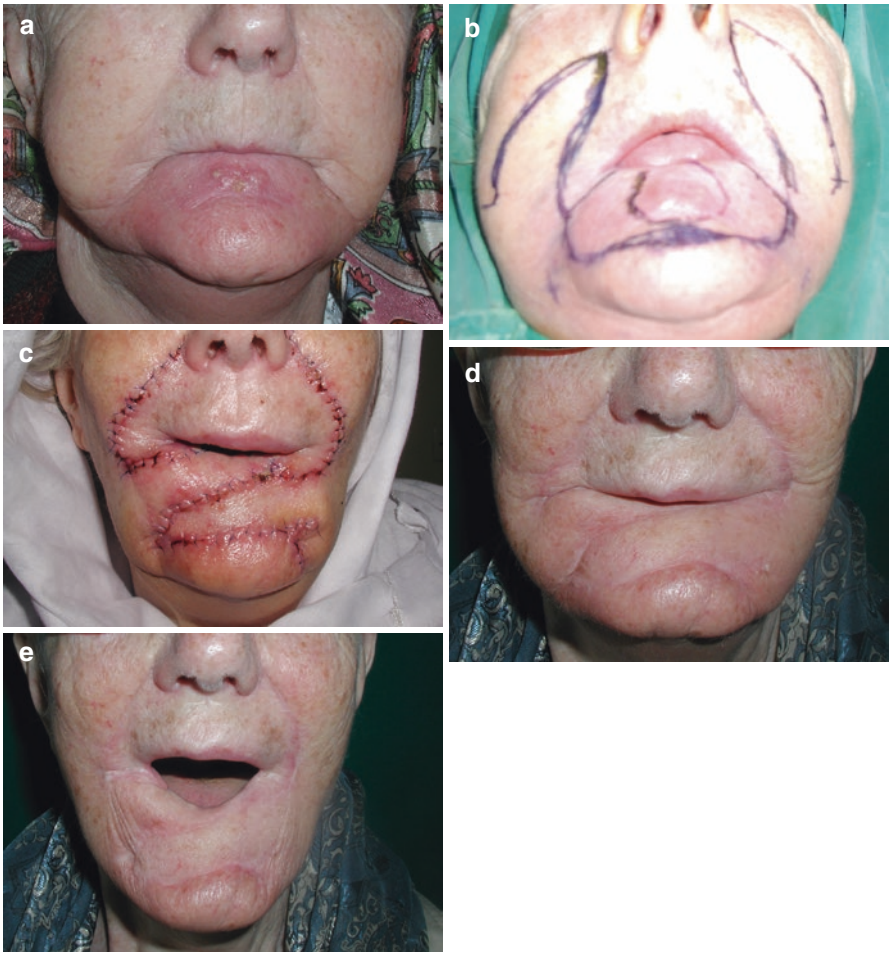

Fig. 9.7 (**a**) Recurrence of lower lip cancer after radiation therapy. (**b**) Bilateral nasolabial flaps are planned for total lip reconstruction. (**c**) Early postoperative result after reconstruction. (**d**, **e**) Late postoperative result demonstrating mouth opening

these defects should be oriented parallel to the relaxed skin tension lines (RSTLs) of the lip. For central excisions, vertical orientation is preferable; however, for lateral regions of the lip, more laterally angulated excision match better with RSTLs. Before the local anesthetic injection and excision, the white roll, junction point between vermillion and lip skin, should be marked for proper orientation of the two separated edges during final closure. After excision, the approximation of the mucosa, muscle, dermis, and skin should be performed properly. Accurate repair of the orbicularis muscles reduces development of depressed, notched, and retracted lip scars. A tongue-in-groove method on the vermillion also helps prevent notching along the suture lines.

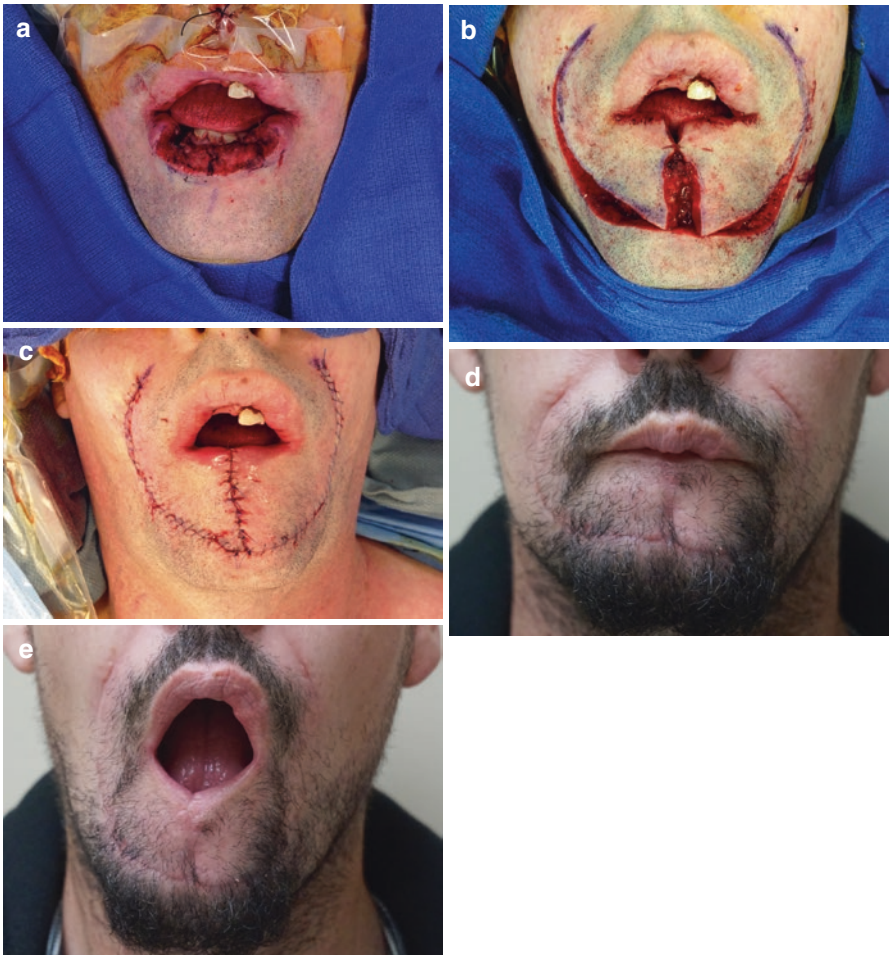

Fig. 9.8 (**a**) Near total full-thickness lower lip defect after resection of SCC. (**b**) Bilateral Karapandzic flaps are dissected (**c**) Intraoperative view after closure. (**d**, **e**) 2 months after reconstruction

9.4.2 Cross-Lip Flaps

9.4.2.1 Abbe Flap

This flap was first described by Sabattini in 1838 for closure of a full-thickness lip defect [5]. In 1898, Abbe designed transfer of a triangular full-thickness lip tissue from lower lip to upper lip [8]. The labial artery and small veins are the main vascular blood supply of Abbe flap. The flap is designed as a reverse triangle shape with its base on the vermillion, and width of the flap should be slightly smaller than the width of the defect (Fig. 9.2). The vertical length of the flap generally matches with

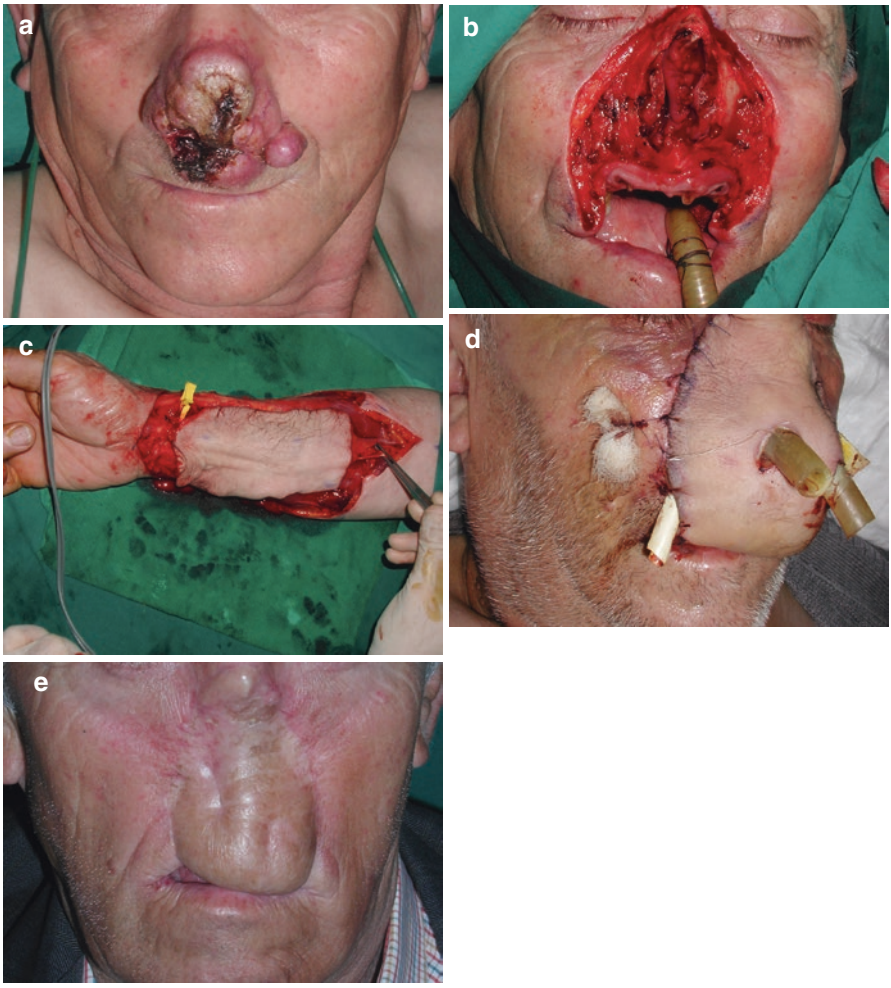

Fig. 9.9 (**a**) Skin cancer encompassing the nose and upper lip. (**b**) Extensive defect of nasal and upper lip regions. (**c**) Free radial forearm is planned for reconstruction. (**d**) Early postoperative result. (**e**) Flap after revisions and debulking

that of the defect. The one-side labial artery should be preserved during flap dissection as the main arterial blood source. Once dissection is completed, the flap is pivoted almost 180° on its pedicle towards the opposing lip defect and sutured. This is a two-staged procedure and requires division of the pedicle usually 2–3 weeks later. Meticulous repair of mucosal, muscle, and lip layers is essential for better functional and cosmetic outcomes. Inadequate repair may result in trap door deformities and poor scarring and function. Besides the standard reverse triangle design, variations of V, W, and other configurations may be done according to the missing tissues and defect size. For larger defects, Abbe flap may not be sufficient and combination of other flaps such as unilateral or bilateral advancement flaps might be indicated. Note that Abbe flap does not violate the commissures.

9.4.2.2 Estlander Flap

Similar to Abbe flap, Estlander flap is a cross-lip flap that involves ipsilateral commissure and provides full-thickness reconstruction of moderately sized opposing lip defect (Fig. 9.6). The labial artery is the main vascular pedicle of this laterally based flap and once the flap is harvested, it is transposed around the commissure to restore the ipsilateral lip defect. It can be performed as a single-stage procedure, but may require revisional surgeries to improve the rounded edge of the commissure.

9.4.3 Karapandzic Flap Technique

This flap was first described by Karapandzic in 1974 [11]. It is a single-stage technique designed for reconstruction of full-thickness defects of central lower lip but also can be modified for upper lip defects (Fig. 9.8). The technique includes rotation advancement flaps that preserve the neurovascular bundle intact, maintaining lip mobility and sensivity. Incisions are made semicircumferentially from the defect and may be extended to the superior border of nasolabial folds. Following the skin incision, muscle fibers are mobilized by blunt dissection in order to preserve the neurovascular bundle. The width of the flap should be equal to vertical height of the lip defect. Additional incisions of the mucosa may be needed to reapproximate the mucosal edges. This technique allows reconstruction of up to 80% of the lower lip defects. The main disadvantage is the reduction in the size of oral aperture, which can improve in time.

9.4.4 Gilles Fan Flap

Gilles fan flap is a modification of the cross-lip technique that includes the portion of opposing ipsilateral lip segment and the remaining lip segment. For reconstruction of lower lip, a "fan"-shaped flap is designed and a full-thickness incision starts from the inferior border of the defect, extends laterally around the ipsilateral commissure, curves superiorly to the nasolabial fold, and turns towards to the superior vermillion. As a main vascular source, contralateral superior labial artery should be preserved. After completing the incisions and release of the attachments, the flap is rotated and advanced into the defect. Because this technique uses more tissue, it results in less microstomia. However, oral incompetence may occur due to incomplete dissection, release, and advancement of orbicularis muscle.

McGregor flap is a modification of Gilles flap for reconstructing the upper lip defects using melolabial tissue. The McGregor flap can be used bilaterally for large defects of the upper lip.

9.4.5 Bernard-Webster Technique

This technique does not require presence of lip tissue to reconstruct the lip defects. Although it is possible to reconstruct near total lip defects using bilateral Bernard-Webster flaps, best results may be obtained in defects that are one-thirdto two-third

of total lip. A horizontal full-thickness incision that extends laterally from the commissure is done. Burow's triangles at the superior and inferior aspects of the cheek tissue are excised and remaining cheek tissue is advanced medially to reconstruct the defect. A tongue flap or buccal mucosa flap can be used to reconstruct the vermillion. This flap does not provide dynamic restoration.

9.4.6 Tongue Flap

The tongue flap provides sufficient amount of tissue to reconstruct small to moderate size vermillion defects. The flap is raised from ventral or dorsal surface depending on the location of defect. The appropriate amount of tongue tissue is cut, unrolled, and transferred to the lip defect. The flap consists of partial thickness tongue tissue that allows primary closure of the donor site. It is a two-stage procedure and requires division of the pedicle and final inset which are usually performed 2–3 weeks after initial surgery. During this period, the patient must be aware of not biting through the pedicle site. The multistage approach and bulky tissue are the main disadvantages of this procedure. However, the reconstruction using tongue flap usually provides good outcomes due to excellent blood supply, mobility, and color match with vermillion and mucosa.

9.4.7 Free Flaps

Free flaps may be needed for restoration of large lip defects. The most commonly used free flap is the radial forearm fasciocutaneous flap that is usually transferred with palmaris longus tendon for lip support (Fig. 9.9). The skin is usually folded on itself to reconstruct the existing lip defect and oral mucosa. The palmaris longus tendon is anchored to modiolus, orbicularis oris muscle, malar periosteum, or zygomatic arch for suspension of the flap to provide static oral competence. Usually facial artery and vein are chosen as a recipient vessel for microvascular anastomosis; however, external carotid artery branches and external jugular vein can be used if needed. The gracilis and anterolateral thigh free flaps are the other free flap options for reconstruction. The gracilis flap can be transferred as a functional flap by a neurorrhaphy of the obturator nerve to the marginal branch of facial nerve. These free flaps may also be combined with temporalis muscle flap for reconstruction of lower lip defects that involves the oral commissure. The potential complications are free flap loss, scar, donor site morbidity, sensorial loss, microstomia, loss of oral competence, and loss of gingivobuccal sulcus and oral mucosa.

Conclusion

The lip has unique properties that make the reconstruction challenging. Proper surgical planning, meticulous technique, detailed knowledge of anatomy, and restoration of appropriate form and function are essential for achieving good outcomes.

References

1. McCarn KE, Park SS. Lip reconstruction. Facial Plast Surg Clin North Am. 2005;13:301.
2. Anvar BA, Evans BC, Evans GR. Lip reconstruction. Review. Plast Reconstr Surg. 2007;120(4):57e–64.
3. Hauben DJ. History of lip reconstruction. Cheiloplasty Acta Chir Plast. 1985;27:129.
4. Dieffenbach JF. Chirurgische Erfahrungen, bensonders uber die Wiederherstellung Zerstoerter Theile des Menschlichen Koerpers nach Neuen Methoden. Berlin: TCF Enslin; 1829.
5. Sabattini P. Cennestorico dell'origine e progressi della rhinoplastica e cheiloplastica. Italy: Bella Arti. Bologna; 1938.
6. Bernard C. Cencer de la levre inferieure; restauration a l'aide de lambeaux quadrataires-latereaux. Scalpel. 1852;5:162–5.
7. Estlander JA. A method of reconstructing loss of substance in one lip from the other lip. Arch Klin Chir. 1877;14:622.
8. Abbe R. A new plastic operation for the relief of deformity due to double hairlip. Med Rec. 1898;53:477.
9. Gilles HD. Plastic surgery of the face. London: Hodder and Stoughton; 1920.
10. Webster RC, Coffey RJ, Kelleher RE. Total and partial reconstruction of the lower lip with innervated muscle-bearing flaps. Plast Reconstr Surg. 1960;25:360.
11. Karapandzic M. Reconstruction of lower lip defects by local arterial flaps. Br J Plast Surg. 1974;27:93.
12. McGregor IA. Reconstruction of the lower lip. Br J Plast Surg. 1983;36:40.
13. Spira M, Hardy SB. Vermillionectomy. Review of cases with variations in technique. Plast Reconstr Surg. 1964;33:39.
14. Rayner CR, Arscott GD. A new method of resurfacing the lip. Br J Plast Surg. 1987;40:454.
15. Pribaz JJ, Meara JG, Wright S, et al. Lip and vermillion reconstruction with the facial artery musculomucosal flap. Plast Reconstr Surg. 2000;105(3):864–72.
16. Harii K, Omori K, Omori S. Successful clinical transfer of ten free flaps by microvascular anastomoses. Plast Reconstr Surg. 1974;53(3):259–70.
17. Devauchelle B, Badet L, Lengelé B, et al. First human face allograft: early report. Lancet. 2006;368(9531):203–9.
18. Carty MJ, Pribaz JJ. Lip and cheek reconstruction. In: Siemionow M, Eisenmann-Klein M, editors. Plastic and reconstructive surgery. London: Springer-Verlag London Limited; 2010.
19. Renner GJ. Reconstruction of the lips. In: Baker SR, editor. Baker local flaps in facial reconstruction. 3rd ed. St. Louis: Elsevier Saunders; 2014.
20. Neligan PC. Strategies in lip reconstruction. Clin Plastic Surg. 2009;36:477–85.
21. Baumann D, Robb G. Lip reconstruction. Semin Plast Surg. 2008;22:269–80.

Reconstruction of Face and Scalp Defects with Local Flaps

10

Paul Tomljanovich and Cemile Nurdan Ozturk

10.1 Introduction

With increasing incidence of cutaneous malignancies of the face and scalp, the need for reconstructive surgery is steadily increasing. Aesthetics is a major requirement of facial defect reconstruction. Because of the reliability, convenience, and aesthetic outcome, local flaps are often the reconstructive choice for facial and scalp skin defects.

When we encounter facial skin defect, the following questions may pass through our mind. Can we close the wound with a local flap or maybe a skin graft? Do we leave the wound open? In certain areas, the wound will heal better by secondary intention than any surgical procedure. In other instances, leaving the wound open for a near future closure in the operating room with more extensive surgery (distant flaps, microsurgical flaps) will be required. Another reason to delay the reconstruction is to wait for permanent pathology report. Tumors in certain areas of the face have a tendency to recur or extend deeper than expected such as the medial canthus of the eye and around the base of the nasal ala [1] (Fig. 10.1). Re-excision for recurrences can be difficult and mutilating and reconstruction quite challenging. Thus, if there is uncertainty regarding surgical margins, it is preferred to carry out the reconstruction after the final pathology report. Leaving wounds open is a very often a good decision. Some areas of the face will heal better unattended as long as the vital structures are covered. Areas of the medial canthus of the nose and small defects of the nose and cheek heal very well with secondary intention [2] (Fig. 10.2). Wounds, when left open, often contract to a pin point defect in a course of several weeks. Open wounds of the face and scalp do not get infected easily due to presence of abundant blood supply.

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The defects of the face and scalp can be reconstructed with local tissue depending on availability of the surrounding tissues that often will be used as donors. Some areas are classic donor sites such as glabella, mid-forehead, and nasolabial fold. The neck and the preauricular area are also preferred due to good quality skin and sufficient laxity. A reconstructive ladder was devised to describe our process of thinking (Fig. 10.3). The simple procedures are lower in the ladder and the more involved procedures are at the top [3]. Usually, surgeons go from simple to more complex procedures in reconstructing soft tissue defects. It is also wise to have a backup plan, in case the first-line reconstruction option fails or is not feasible.

Most of the local flaps have been developed by surgeons in the last 200 years and a few even longer. Almost like Leonardo da Vinci, surgeons thought of all these procedures, but they could not achieve the results because of lack of anesthesia and technology. Patients had to be very brave and motivated to undergo reconstruction of the nose with local flaps in India 2000 years ago or distant flaps as described by Gaspare Tagliacozzi. Reconstructive procedures are all based on basic principles that are modified and polished through the years to make them more stylized more geometrical. A good eye and a good knowledge of geometry help a lot.

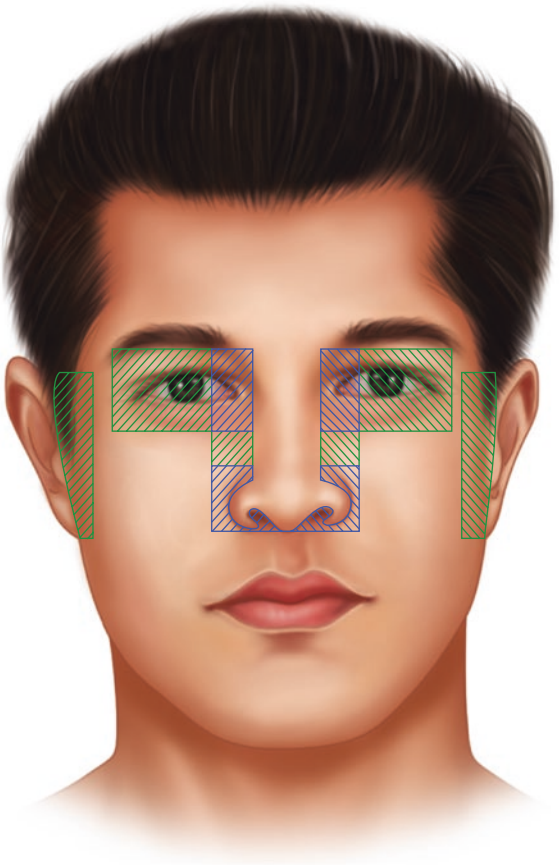

Fig. 10.1 Tumors in certain areas of the face have a tendency to recur or extend deeper than expected

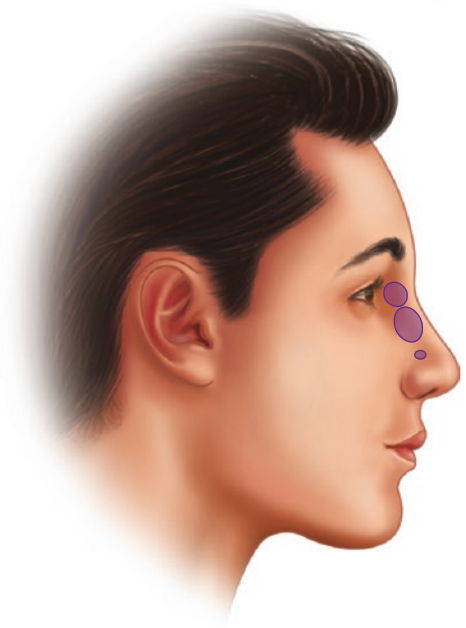

Fig. 10.2 Areas of the medial canthus, small defects of the nose and cheek heal well with secondary intention

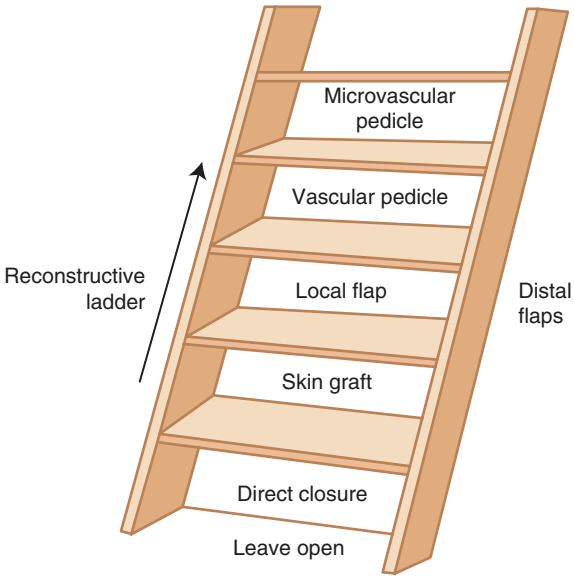

Fig. 10.3 In a reconstructive ladder, the simple procedures are lower in the ladder versus the more complex procedures at the *top*

A basic advancement flap is unidirectional and has limited stretch which depends on the characteristic of skin at a given location (Fig. 10.4). With such procedures, we are taking advantage of the elasticity of skin. Closing skin under tension by applying sutures and giving 5–10 min for the skin to stretch will advance the tissues.

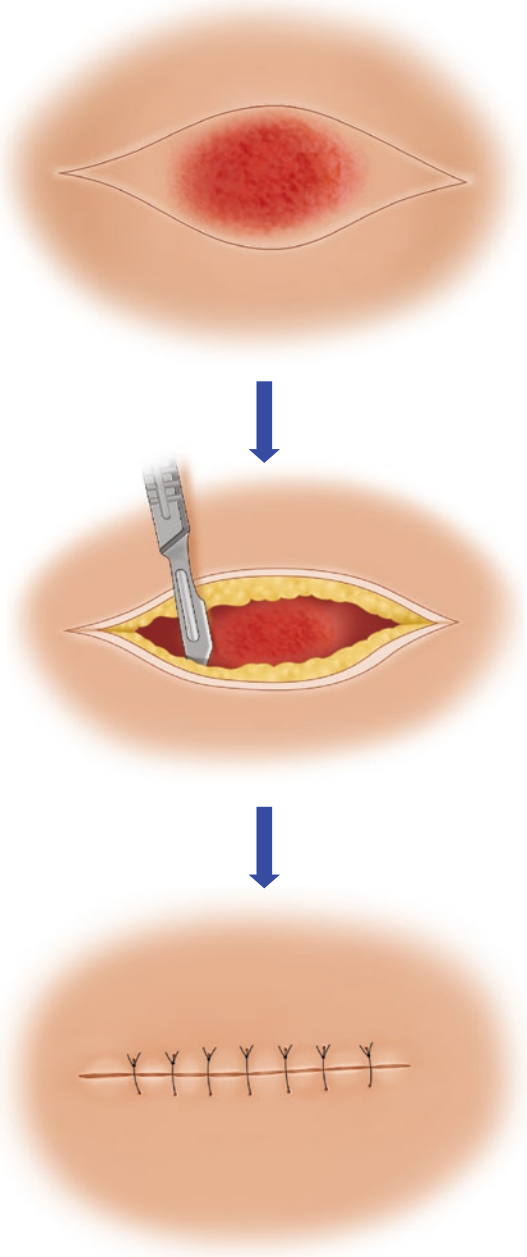

Fig. 10.4 A basic advancement flap is pulled in one direction and has limited stretch which depends on the characteristic of skin at a given location

This is called rapid expansion. The sutures are placed laterally and medially until the last stitch is easily applied in the middle. This technique probably dates back to the original surgeons who applied sutures under tension for reconstruction. With advancement of techniques, surgeons started to consider pulling the skin in multiple directions, stretching the skin at different angles. They developed transposition flaps at 60° or 90° angles (Fig. 10.5). A classic example is the rhomboid flap which is

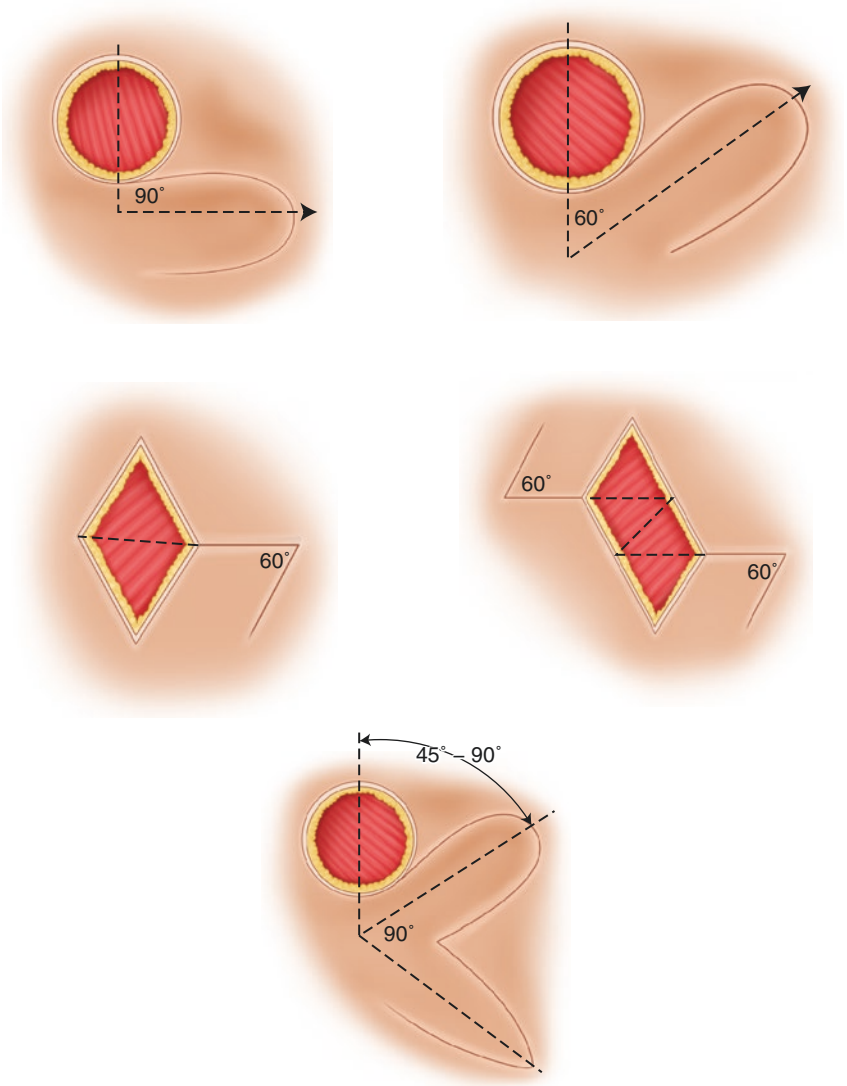

Fig. 10.5 Transposition flaps of 60° angle and 90° angle are shown. Utilization of multiple flaps such as the bilobe flap distributes the tension in three directions

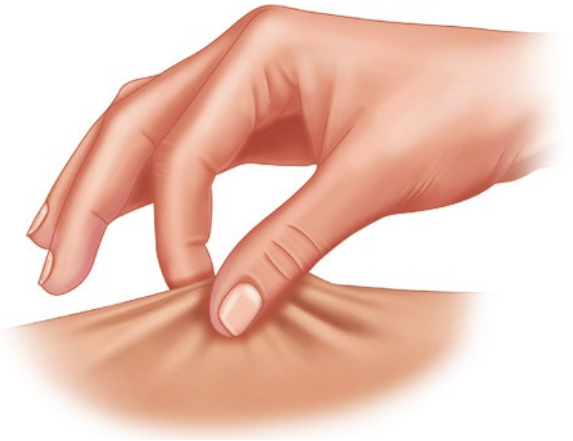

Fig. 10.6 Pinching the skin to see if there is laxity is a good test before planning flaps

designed in 60°–120° angles. It is critical to undermine skin widely to facilitate closure, specifically at the donor site. Utilization of multiple flaps such as the bilobed flap is a smart way to distribute the tension in three directions (Fig. 10.5). With a large surface area of rotation or advancement, it is possible to distribute tension over a large area, always looking for an area of loose skin. Fortunately, human skin does forgive some errors, but we have to examine and execute with precision in certain areas, especially if there is limited laxity of the tissues. We are very often working with elderly patients whose skin is loose – but not always. Pinching the skin to see if there is laxity is a good test before planning flaps (Fig. 10.6). Sometimes the skin is fibrous and can be deceiving.

10.2 Scalp Reconstruction

The scalp is a spherical surface with minimal or no laxity. The greatest amount of mobility is in the temporoparietal region. The vertex has the least mobility and most of the time requires extensive undermining and larger flaps. It can be difficult to close a defect over 5 cm. Skin grafts will heal well if the pericranium is intact. Flap coverage is required for denuded bone, for areas of bone resection or where a hardware is present.

Primary closure (with/without rapid intraoperative expansion, as described above) is only possible if the defect is less than 2 cm^2 [4]. Medium defects of 2–25 cm^2 can be successfully reconstructed with a variety of flaps such as pinwheel flaps, bilobed flaps, rhomboid flaps, or rotation flaps [4] (Fig. 10.7a, b). Large rotation and advancement flaps are often necessary to cover defects greater than 25 cm^2. Scoring of the galea is a useful adjunct technique to release tension (Fig. 10.8). When a large scalp rotation flap is performed, the pericranium is preserved at the donor area in preparation for a skin graft. Large flaps are planned along vascular pedicles to make sure blood will reach the end of the flap that is often under the greatest tension. Multiple flaps can be necessary, as we are working on a sphere

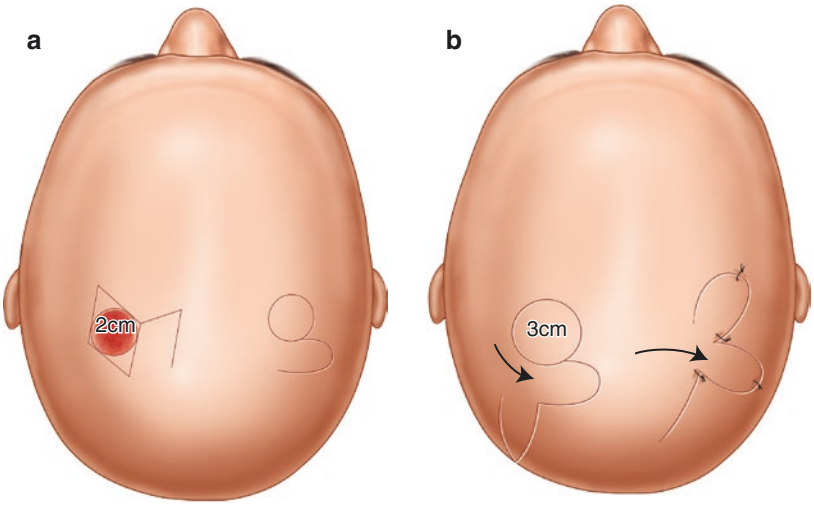

Fig. 10.7 Reconstruction of medium-sized defects. (**a**) Rhomboid flaps, (**b**) Bilobed flaps

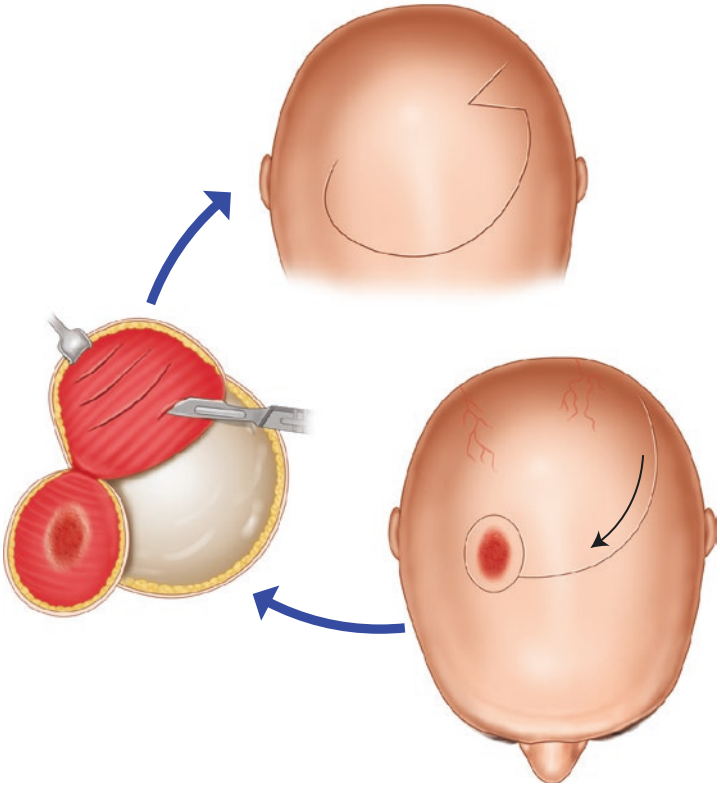

Fig. 10.8 Galeal scoring in direction of flap mobilization releases the tension

where the flaps have to be longer to reach [5] (Fig. 10.9). Care should be taken to avoid crossing the hairline and the forehead.

If one is not pressed for time, the ideal operation for scalp reconstruction is using a tissue expander. At the time of the initial surgery, one or two expanders are placed under the hair bearing skin of the scalp (Fig. 10.10). The expander is stretched over many weeks injecting the valve with saline and a syringe with a thin needle. It starts slowly, 5–10 cc at a time, and then it goes faster when the skin is stretched. At the second stage, the expander is removed and the scalp is advanced to close the defect. The only residual deformity will be the scar, and sometimes the direction of the hair. Exposure of the implant is a well-known complication, which could force one to conclude the reconstruction with the flap sooner than planned.

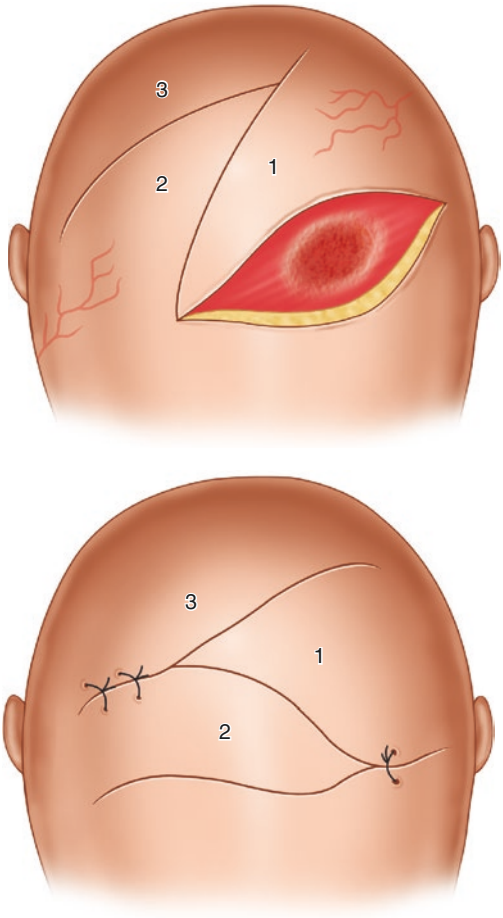

Fig. 10.9 Multiple flaps can be necessary depending on the size of the defect

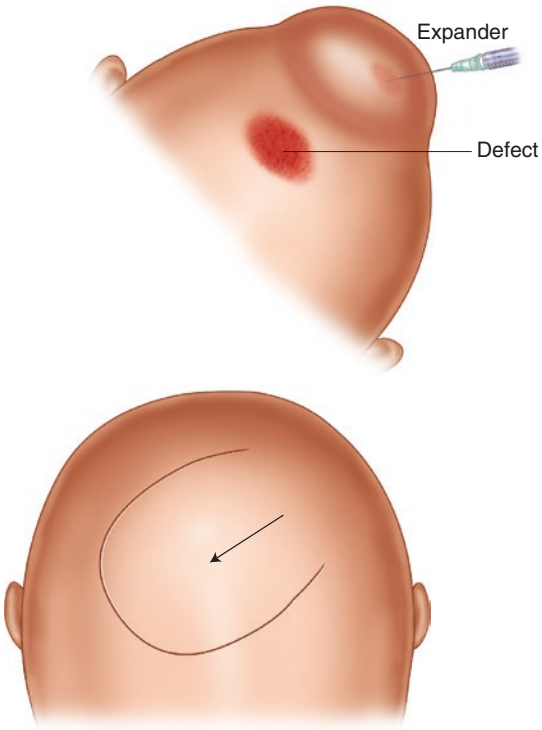

Fig. 10.10 Tissue expanders are the ideal choice for reconstruction of hair bearing scalp

10.3 Forehead Reconstruction

The location of the hairline is critical and should be preserved if possible. Also of concern is the eyebrow position which should not be elevated. Incisions heal better along the relaxed skin tension lines and scars are less visible if they are horizontal. However, such primary closure techniques unfortunately will raise the eyebrow. Incisions that are adjacent to the eyebrow result in a more permanent elevation and the possibility of compromised aesthetics should be discussed with the patient ahead of time. In an effort to avoid eyebrow malpositioning, bilobed or rhomboid flaps could be utilized (Fig. 10.11a, b). Eventual scar is cosmetically more acceptable with rhomboid flaps. For large defects, any type of advancement or rotation flap could be used in the forehead as long as they are positioned according to the forehead skin lines (Fig. 10.12).

In some cases, skin grafts might yield a more acceptable result than primary closure with malpositioned eyebrows [6]. A skin graft on the forehead is more acceptable when laterally located (Fig. 10.13a). This can be removed later with serial excision (Fig. 10.13b). Scars of the forehead usually heal well and keloids are

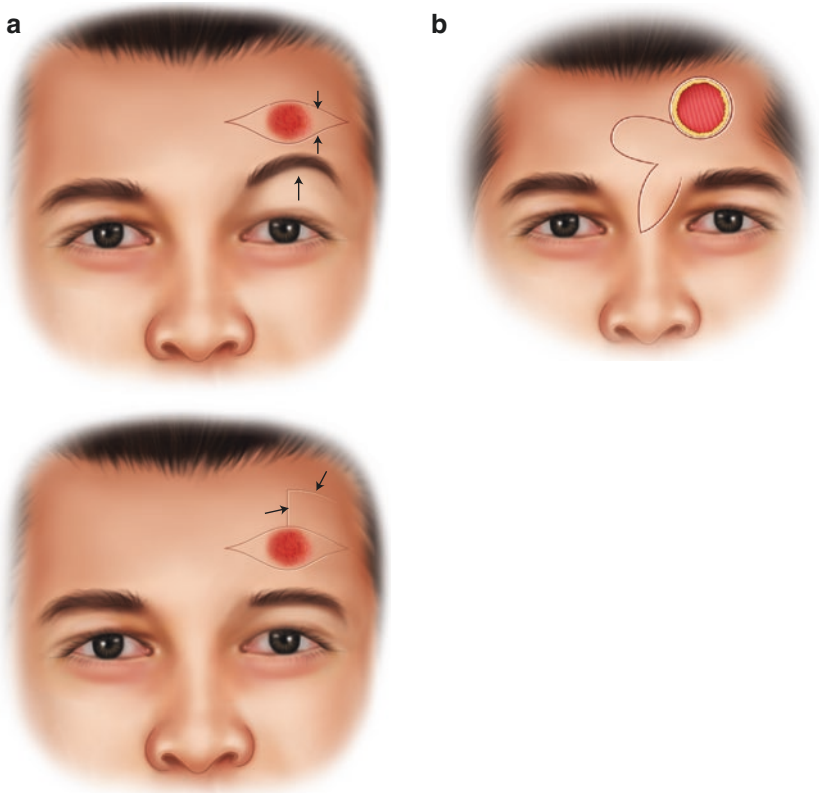

Fig. 10.11 (**a**) Rhomboid flap and (**b**) bilobed flap are demonstrated for reconstruction of forehead defects

unknown in this area, but this is a very visible part of the face and revisions may be requested by patients.

10.4 Cheek Reconstruction

The cheek is the largest aesthetic subunit of the face and its borders extend from the nasal-facial junction and the nasolabial fold to the ear, from the inferior orbital rim and zygomatic arch to the jawline [7] (Fig. 10.14). Neck and the retroauricular area are a good match to replace the skin of the face. Lip and ear lobule can tolerate slight tension; however, the lower eyelid closure should be tension free. Flaps or grafts should be utilized instead of primary closure in the vicinity of the lower eyelid area to prevent ectropion (Fig. 10.15).

The triangle below the eyelid can be reconstructed with a rotation flap from lateral face called Mustarde flap [8] (Fig. 10.16a, b). The superior flap border is

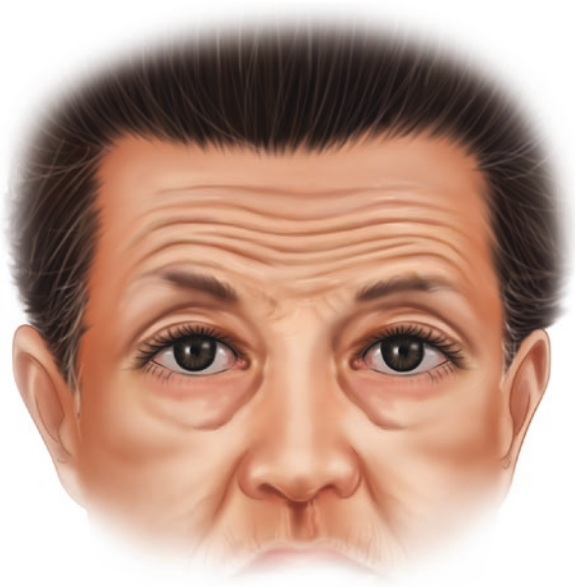

Fig. 10.12 Relaxed skin tension lines are horizontal in the upper face

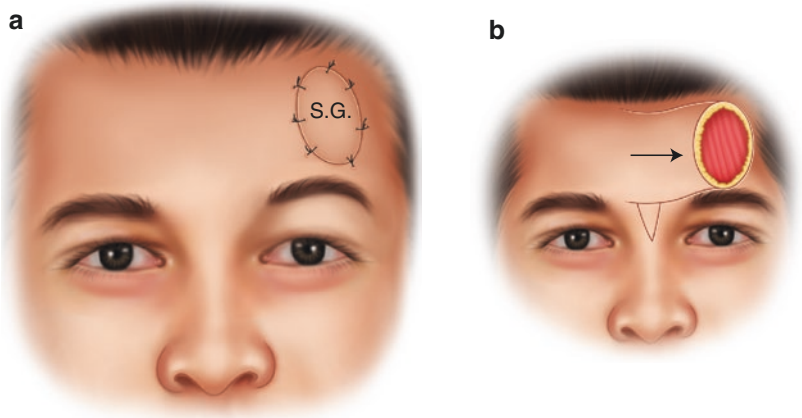

Fig. 10.13 (**a**) A skin graft acceptable when defect is laterally located. (**b**) This can be removed later with serial excision

designed high lateral to lateral canthus of the eye and above the zygomatic arch to avoid tension on the lower lid. The incision then continues inferiorly to the anterior ear with an extension in the neck, as necessary. The rotation point is on the nasolabial fold, close to the corner of the mouth.

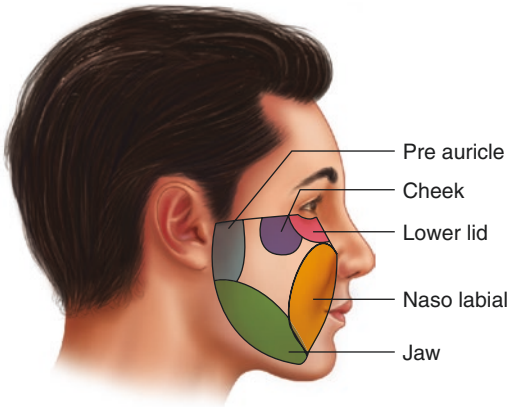

Fig. 10.14 The borders of the cheek (lateral face) is demonstrated

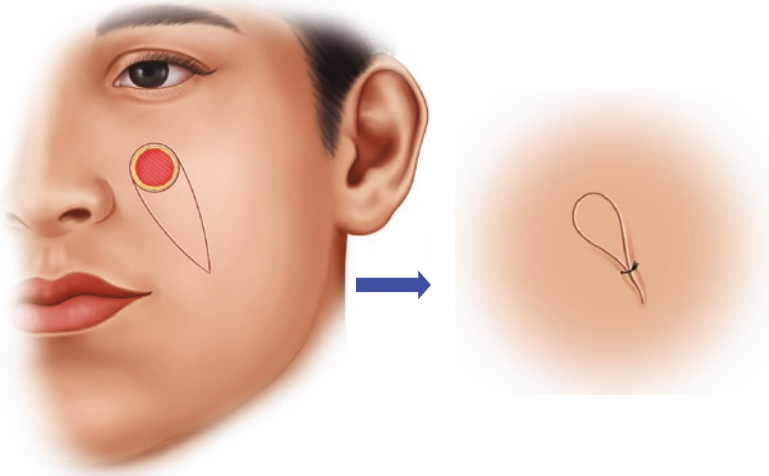

Fig. 10.15 A V-Y flap is demonstrated which was utilized for coverage to avoid ectropion

Soft tissue defects anterior to the ear can be closed by advancing the skin of the face as in a face lift (Fig. 10.17). In addition, flaps from cervical or retroauricular area can be used as flaps to aid in closure [9] (Fig. 10.17). Over the zygoma, defects can be closed easily with local flaps, but the scars are very visible and should be meticulously placed (Fig. 10.18). Careful planning is essential to avoid tension on the lower eyelid. The jaw line is the area where the skin tension lines lie in a superior to inferior direction. Inferiorly based cervical transposition flaps can be used and rotated 90° degrees (Fig. 10.19a). This will position the flap ideally along the relaxed skin tension lines (Fig. 10.19b).

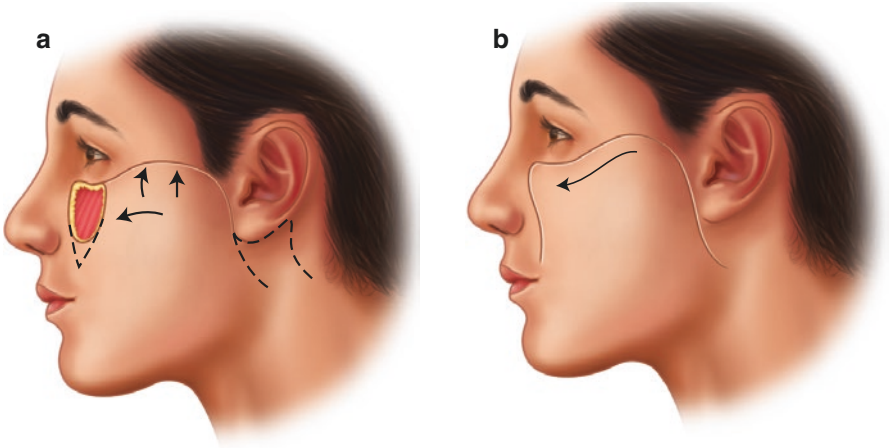

Fig. 10.16 (**a**, **b**) Cheek rotation advancement flap can be utilized for defects of the upper cheek

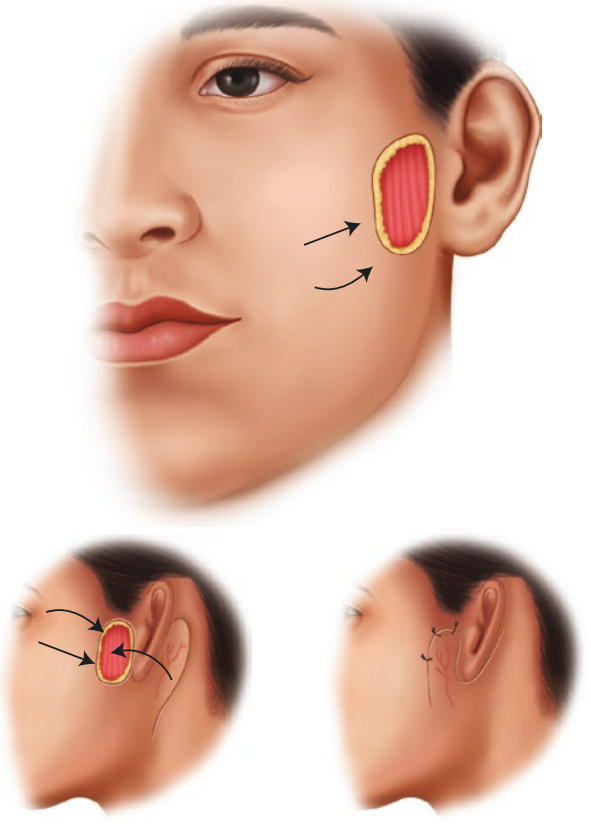

Fig. 10.17 Cheek skin can be undermined and advanced for preauricular defects. In addition, cervical skin or retroauricular skin could be transposed as necessary

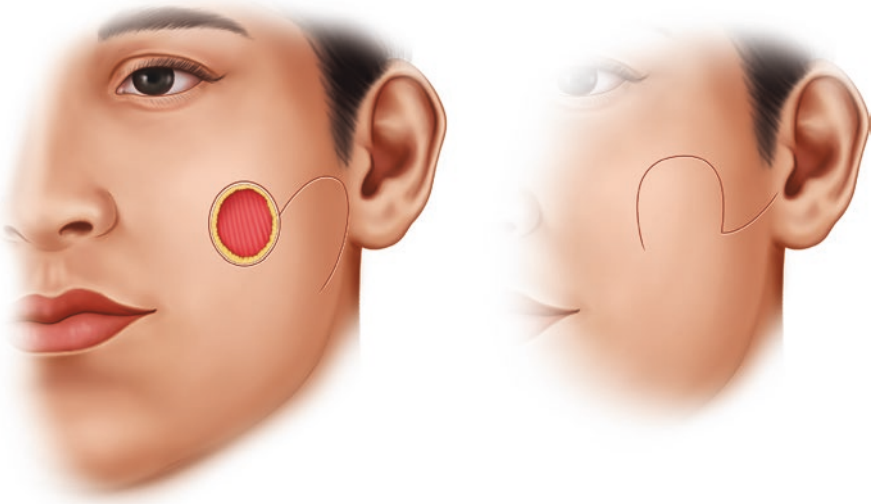

Fig. 10.18 A transposition flap is shown for reconstruction of a soft tissue defect over the zygoma

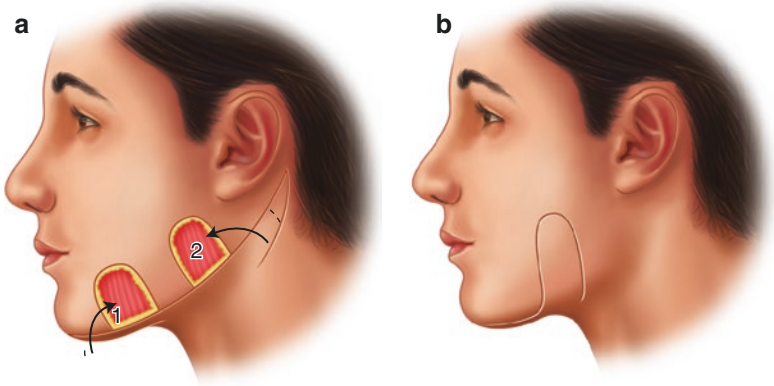

Fig. 10.19 (**a**) Cervical transposition flaps for jaw line reconstruction. (**b**) Once transposed, the flap lies ideally along the relaxed skin tension lines

10.5 Nasal Reconstruction

Skin of the lower third of the nose is adherent to the cartilaginous structure and is not mobile and cannot be rotated. Skin of the upper third is the most mobile and is often utilized as a donor site. Central nose also has some mobility, and closure techniques depend on the direction of the defect. Ideally, scars should be positioned at the borders of the subunits and adjacent normal tissue may need to be discarded for optimal cosmetic outcome [10]. Typical donor sites for nasal reconstruction are

nasolabial area, forehead, upper lateral nose, or glabella (Fig. 10.20). Large noses are wonderful to work on because they have ample surface for donor site. Young, small noses are challenging as the skin is tight and very often skin grafts are needed.

When there is a vertical defect in the upper or central nose, advancing the skin of the side of the nose may be sufficient with two z-plasties (Fig. 10.21). For

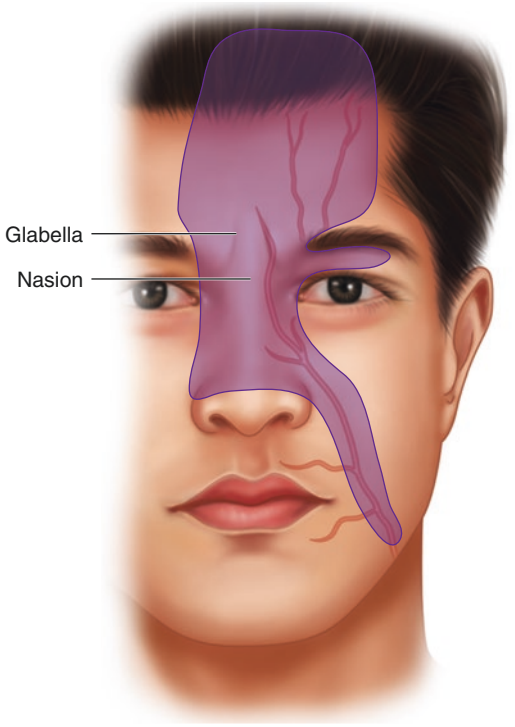

Fig. 10.20 Shaded area demonstrates typical donor sites for nasal reconstruction

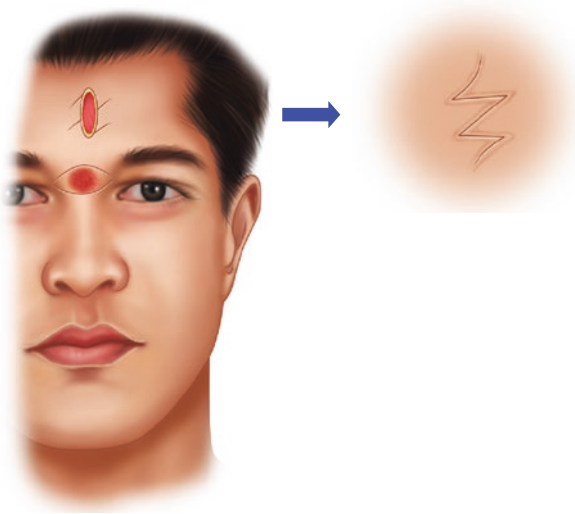

Fig. 10.21 Z-plasties are a practical method of mobilizing skin laterally

round defects of upper and central nose, flaps from the glabella such as rotation, bilobed, or rhomboid are utilized (Fig. 10.22a, b). In the lower third of the nose, direct closure does not work well because it causes distortion of the ala and tip. Superiorly based nasolabial flap is a good choice for resurfacing a defect of the lower third of nose, specifically in the vicinity of the alae [10, 11] (Fig. 10.23a–c). Skin grafts and cartilage grafts may be necessary to prevent contracture. A dorsal nasal flap is ideal for defects located low in the midline (Fig. 10.24). Local flaps can result in a trap door (pincushion) deformity which may require secondary revision procedures.

Bilobed flaps are designed along the vertical axis of the nose and are rotated after wide undermining (Fig. 10.25). When designing bilobed flaps, the first donor flap is

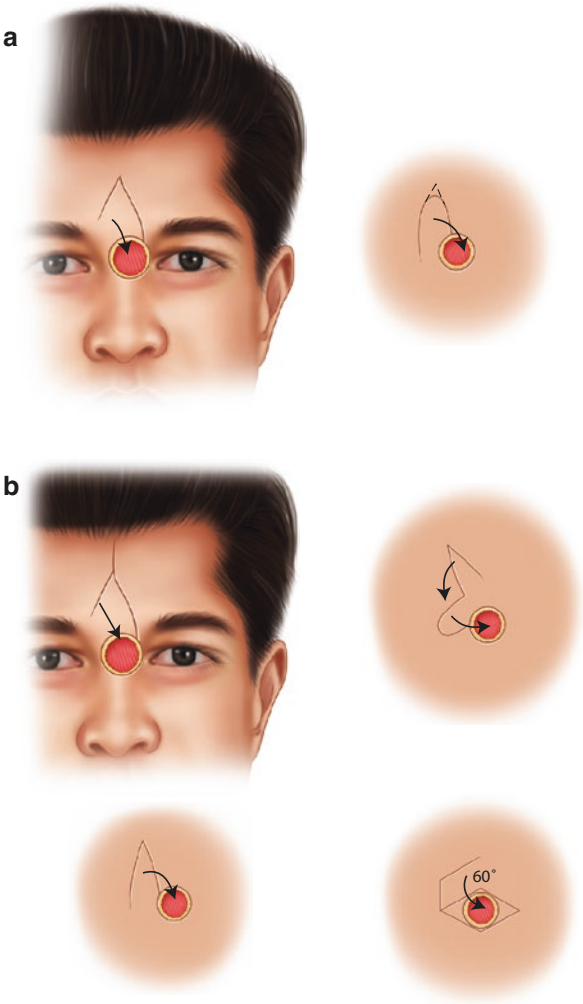

Fig. 10.22 (**a**, **b**) For central and upper nose reconstruction, flaps from the glabella such as rotation, bilobed, or rhomboid are utilized

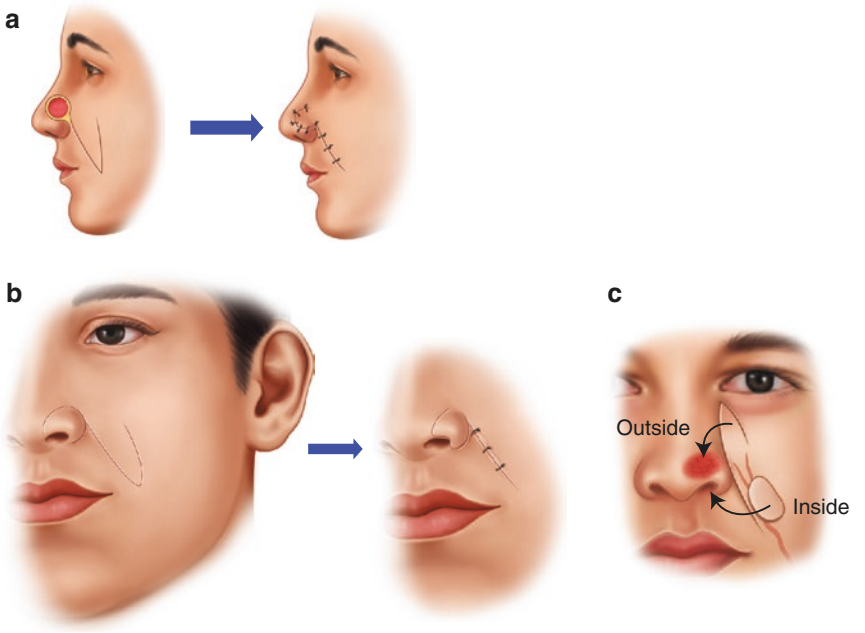

Fig. 10.23 (**a**, **b**) A superiorly based nasolabial flap is a common choice for alar reconstruction. (**c**) Skin grafts may be necessary for inner lining reconstruction

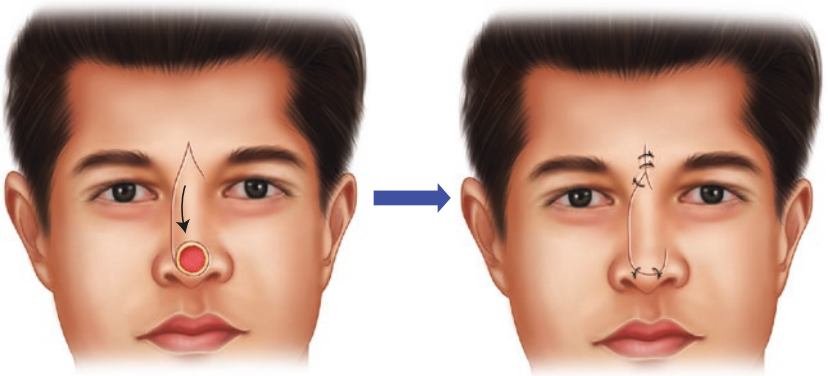

Fig. 10.24 A dorsal nasal flap is usually used for reconstruction of the lower third of nose

made narrower than the defect making it more oval. The second donor flap is even narrower, ending in a point, with a variable angle [12, 13].

The workhorse flap in reconstruction of the nose is the paramedian forehead flap, which is done in two stages. It is not the original Indian flap of 2000 years ago, but the one which was described in 1800 by a visiting British colonial in India and

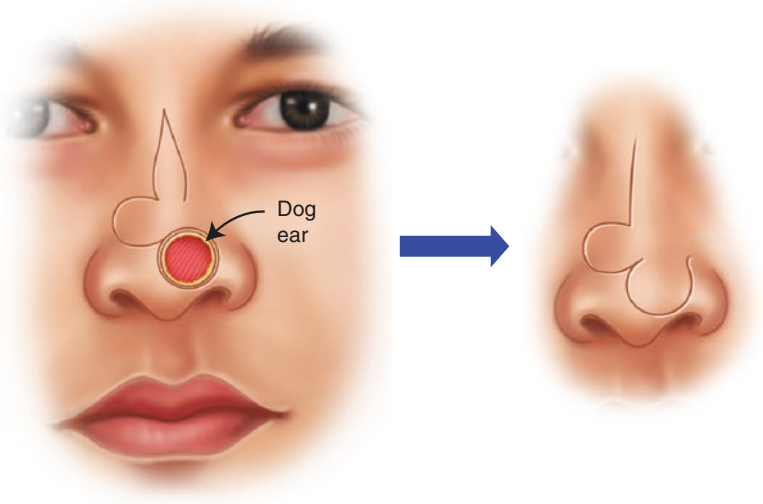

Fig. 10.25 Bilobed flaps. The first donor flap is made narrower than the defect and the second donor flap is even narrower, ending in a point

brought to England [14, 15]. The flap is designed based on the supratrochlear vessels (Fig. 10.26a). The pedicle is left attached for a minimum of 2 weeks or more for vascularization of the flap (Fig. 10.26b, c). If there is uncertainty about vascularization, the division can be delayed or performed as a partial separation. There may be a need for a third surgery, for final trimming and shaping.

10.6 Lip Reconstruction

There are a multitude of local flaps described for lip reconstruction. The choice depends on the structures involved (i.e., vermillion, commissure, skin) and size of the defect. Perioral reconstructions must attempt to restore both appearance and function. It is critical to reapproximate orbicularis muscle for normal lip motion and the white roll must be accurately aligned. The lower lip is more mobile and tolerates primary closure for the majority of defects. For this reason, superficial defects that are less than 1/3–1/2 of the lip are usually treated as full-thickness defects [16]. Full-thickness excisions are typically performed in a wedge or W pattern (Fig. 10.27). It is important not to violate the chin-lip crease and the tail of the pattern should be adjusted accordingly. Rectangular excision followed by bilateral incisions along the chin-lip crease to advance skin may be necessary to avoid crossing this natural fold. Rhomboid or nasolabial flaps based inferiorly are among other choices (Fig. 10.28). Cervical transposition flaps to move tissue from underneath the chin can also be used, if the defect is located low (Fig. 10.28). Finally, lip switch or cheek advancement techniques could be employed for larger defects encompassing more than 2/3 of the lip.

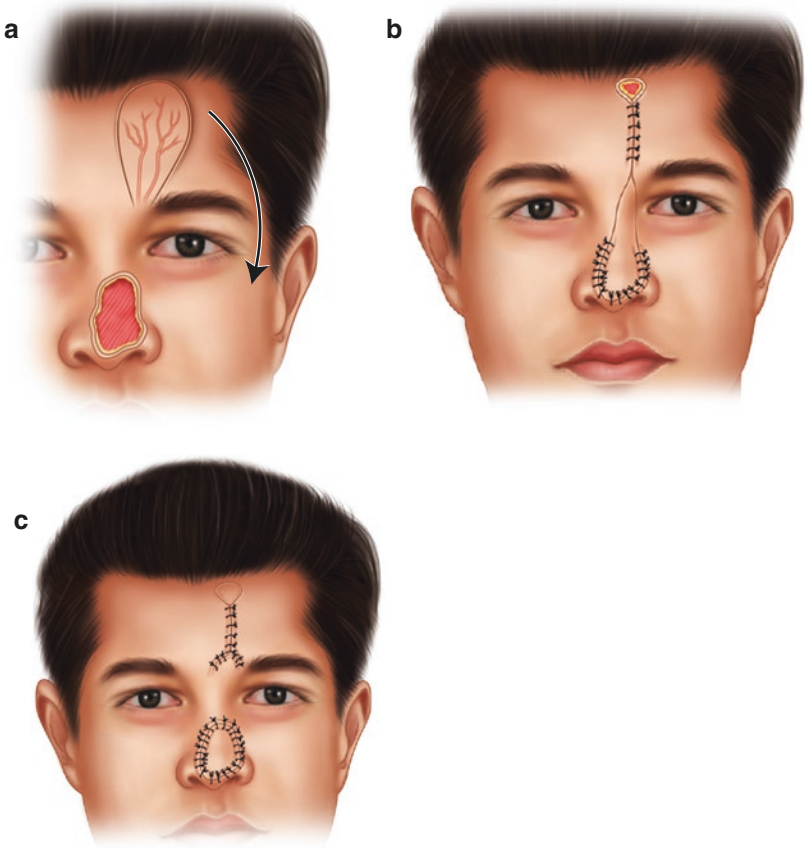

Fig. 10.26 (**a**) Paramedian forehead flap is based on the supratrochlear vessels. (**b**) The flap is transposed and the donor site is primarily closed or left for secondary intention healing. (**c**) The pedicle remains attached for 2–3 weeks after which it is divided and inset

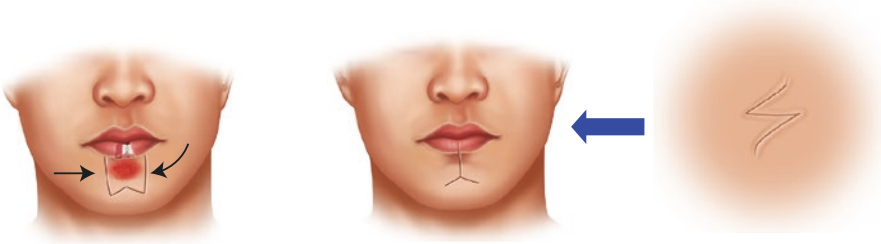

Fig. 10.27 A lower lip lesion could be excised in W fashion and primarily closed with advancement of lateral lip elements

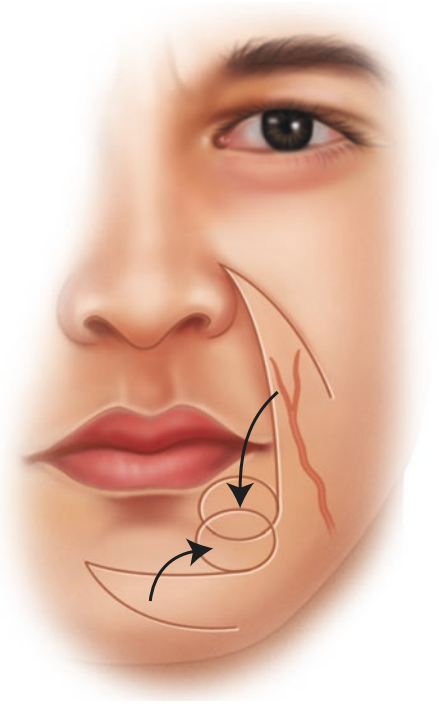

Fig. 10.28 Nasolabial flap and cervical transposition flap are demonstrated for a lower lip skin defect

Upper lip is less tolerant for tension and defects up to 1/3–1/4 will do well with primary closure [16]. This will usually require perialar crescentic excisions to mobilize lateral lip tissue [17] (Fig. 10.29). Functional reconstruction is less critical here. Skin can be reconstructed with an inferiorly based nasolabial flap up to the philtral ridge, and by advancing the contralateral lip skin (Fig. 10.30). Forehead flap can provide a mustache even if the hair lays in the wrong direction. For larger defects, lip switch procedures or cheek advancement flaps are indicated. Balance in the lengths of upper and lower lips is important and tissue should be shared evenly if performing lip switch procedures.

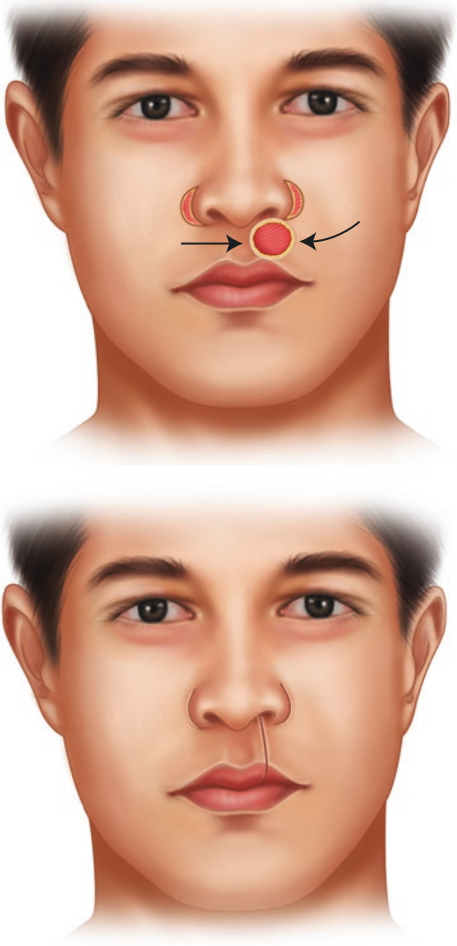

Fig. 10.29 Lateral lip advancement with perialar crescentic excision

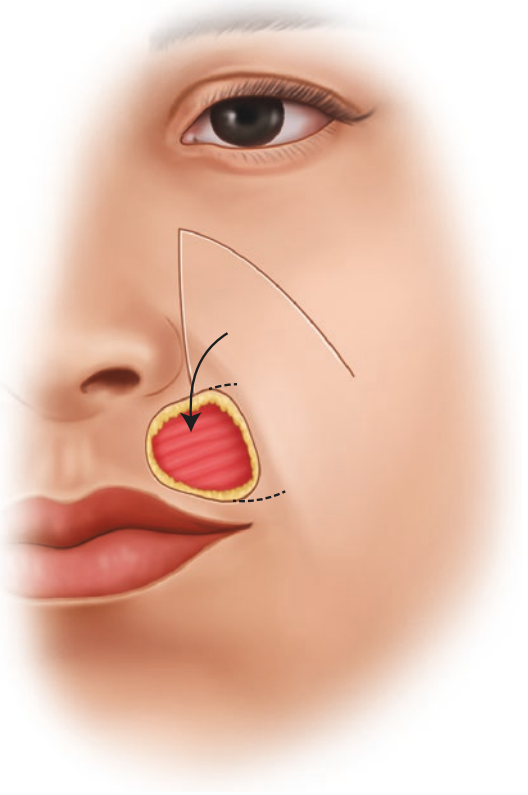

Fig. 10.30 Nasolabial flap for upper lip reconstruction

References

1. NCCN Clinical Practice Guidelines in Oncology, Basal Cell and Squamous Cell Skin Cancers, Version 2.2013, https://www.nccn.org.
2. Baker SR. Reconstruction of the nose. In: Baker SR, editor. Local flaps in facial reconstruction. 2nd ed. St. Louis: Mosby; 2007. p. 416–74. Chapter 18.
3. Thorne CH. Techniques and principles in plastic surgery. In: Charles H, editor. Grabb and Smith's plastic surgery. 6th ed. Philadelphia: Thorne. Lippincott Williams and Wilkins; 2007. p. 3–14. Chapter 1.
4. Leedy JE, Janis JE, Rohrich RJ. Reconstruction of acquired scalp defects: an algorithmic approach. Plast Reconstr Surg. 2005;116(4):54e–72.
5. Orticochea M. New three-flap reconstruction technique. Br J Plast Surg. 1971;24(2):184–8.
6. Yap LH, Langstein HN. Reconstruction of the scalp, calvarium and forehead. In: Thorne CH, editor. Grabb and Smith's plastic surgery. 6th ed. Philadelphia: Lippincott Williams and Wilkins; 2007. p. 358–66. Chapter 35.
7. Dobratz EJ, Hilger PA. Cheek defects. Facial Plast Surg Clin North Am. 2009;17(3):455–67.
8. Mustardé JC. The use of flaps in the orbital region. Plast Reconstr Surg. 1970;45(2):146–50.
9. Jowett N, Mlynarek AM. Reconstruction of cheek defects: a review of current techniques. Curr Opin Otolaryngol Head Neck Surg. 2010;18(4):244–54.

10. Menick FJ. Nasal reconstruction. Plast Reconstr Surg. 2010;125(4):138e–50.
11. Yellin SA, Nugent A. Melolabial flaps for nasal reconstruction. Facial Plast Surg Clin North Am. 2011;19(1):123–39.
12. Patel KG, Sykes JM. Concepts in local flap design and classification. Oper Tech Otolaryngol Head Neck Surg. 2011;22(1):13–23.
13. Man LX, Chang B. A simple method of designing a bilobed flap using a triangle template. Dermatol Surg. 2004;30(10):1345–8.
14. Menick FJ. Nasal reconstruction: forehead flap. Plast Reconstr Surg. 2004;113(6):100e–11.
15. Boyd CM, Baker SR, Fader DJ, Wang TS, Johnson TM. The forehead flap for nasal reconstruction. Arch Dermatol. 2000;136(11):1365–70.
16. Langstein HN, Robb GL. Lip and perioral reconstruction. Clin Plast Surg. 2005;32(3):431–45. viii.
17. Godek CP, Weinzweig J, Bartlett SP. Lip reconstruction following Mohs' surgery: the role for composite reswwwection and primary closure. Plast Reconstr Surg. 2000;106(4):798–804.

Local/Regional Flaps in Oral/Head and Neck Reconstruction

11

Rui P. Fernandes and Phillip Pirgousis

11.1 Introduction

The contemporary dictum in head and neck reconstruction is to utilize microvascular transfer techniques. More and more, the use of local or regional flaps has been relegated to the use in the salvage setting of failed microvascular flaps or in patients deemed too sick to undergo long anesthetics as is required for free flap transfers.

The author's belief is that in many scenarios, the use of local or regional flaps is often better indicated and would likely offer a superior final reconstruction than the alternative of free tissue transfer.

Clearly, the use of local or regional flaps is most commonly employed in those cases where the need for bone is not mandatory or the lack of use would not negatively impact the final outcome.

The benefits of local and regional flaps are many; the most apparent ones are similarity in tissue texture, color match, and the diminished operative time. When properly selected, patients who undergo reconstruction with local or regional flaps will often have an overall shorter hospital course when compared to those patients treated with free tissue transfer. The exception to this is when local and regional flaps are used in the salvage setting or when they are used to reconstruct the medically compromised patients. In these cases, the reason for the longer hospital stay is

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not a directly related to the reconstructive option but rather the medical comorbidities which mandate the longer, more complex medical management.

This chapter will present a selected number of flaps commonly used in head and neck reconstruction. The flaps selected are the ones that the author deems to be absolutely necessary in the reconstructive armamentarium of today's head and neck reconstructive surgeon.

The "workhorse" flap in the salvage setting, i.e., the pectoralis major myocutaneous flap, will be presented with details on how to elevate the flap. Three additional flaps will be presented, the submental island flap, the supraclavicular flap, and the internal mammary perforator flap. These flaps may be considered "newer" in the head and neck arena but in fact have been present in some form for many decades.

11.2 Flap Options in the Head and Neck

As with any surgical endeavor, the selection of a flap to reconstruct a defect in the head and neck region should take into account several factors. The most obvious one is the overall health of the patient and his or her ability to withstand the operation.

Once that is deemed appropriate, other factors that need to be assessed by the surgeon are previous surgical interventions in the head and neck, history of radiation therapy to the head and neck, and body habitus of the patient.

11.3 Regional Flaps

11.3.1 Submental Island Flap

Martin and colleagues first described the submental island flap in 1993 [1]. This publication introduced this new donor site and highlighted its anatomy and use as both as a free tissue flap and most importantly as a pedicled flap. The authors described the use of the submental flap illustrating its use in eight clinical cases ranging from cheek defects to forehead and auricular defects. Numerous other publications quickly followed Martin's publication. These contributions helped to further refine the use of the flap including among them the reverse flow flap [2].

11.3.1.1 Indications

The submental island flap can be used to repair numerous defects in the head and neck. It has been described for use in the oral cavity [3], for palatal reconstruction [4], for pharyngeal defects [5], and even for the reconstruction of prevertebral defects [6]. As with any other pedicled flap, the main limitation of this flap is the arc of rotation and therefore the reach of the flap.

The use of the reversed flow flap allows for an extended reach, and thus the flap can be used in defects as far away as the forehead.

11.3.1.2 Anatomy

The basis for the submental flap lies in its namesake vessel, the submental artery and vein. The facial artery gives off the submental artery branch, which travels along the inferior border of the mandible and medial to the submandibular gland to gain access to the submental region. Along its path, the submental branch gives off perforators to the skin.

Magden and colleagues found that the submental artery and its accompanying vein travel deep to the anterior belly of the digastric muscle in 81 % of time, and in the remaining 19 %, its path is superficial to the anterior belly of the digastric muscle [7].

11.3.1.3 Flap Harvest

With the patient in a supine position, the head is extended. A pinch test is done to determine the amount of skin that may be taken while allowing for primary closure of the donor site.

Once the width is determined, a fusiform shape is designed in the submental region with the distal end of the drawing extended to incorporate it into the apron flap design.

A subplatysmal flap is then elevated to up to the inferior border of the mandible and along the fusiform design of the flap.

Flap elevation commences from the contralateral side (distal end of the skin paddle).

The incision is deepened to the anterior belly of the digastric, and dissection is extended along this plane toward the midline. Once the attachment of the digastric is encountered, the ipsilateral digastric is disinserted from the mandible in order to allow for flap elevation deep to the ipsilateral digastric.

The inferior dissection is continued along this plane until the digastric tendon is encountered. The tendon is divided, and the dissection is carried out to identify the pedicle of the flap and remove the submandibular gland in order to better delineate the pedicle while improving the arc of rotation.

In cases where the pedicle is found to travel through the submandibular gland, the intraglandular/periglandular dissection should be done in a meticulous manner with the aid of the bipolar electrocautery in order to minimize injury to the pedicle.

Once the pedicle dissection is completed, the arc of rotation is checked to confirm reach without tension.

When the flap is to be used to reconstruct defects in the oral cavity, a wide mylohyoid tunnel is made so as to allow easy transfer of the flap.

Once the flap is transferred, the geometry and lay of the pedicle need to be assessed and confirmed not to have any twists or kinks along its path. A kink or twist could severely hinder the arterial inflow or venous outflow to the flap and therefore jeopardize the flap success.

The flap is then inserted and the donor site is closed primarily.

11.3.1.4 Flap Variation

The reverse flow flap is a variation of the submental island flap, whereby the facial artery is ligated and divided below the takeoff of the submental artery. The venous main technical detail of this variation is the inclusion of the larger superficial vein that feeds the skin flap. According to the study performed by Kim et al., the facial vein running 1 cm lateral to the artery has sufficient connections to the neighboring veins by large channel that it can overcome the reversed venous flow against the valves [2].

The main advantage of the reverse flow is the ability to reconstruct defects in the head and neck that would be out of reach from the conventional submental island flap.

Case #1

This patient was referred for resection of a long-standing basal cell carcinoma of the left cheek region which had extended toward the upper lip. Significant submucosal extension was palpated (Fig. 11.1).

The plan for reconstruction with the submental island flap was discussed with the patient and the desired flap was marked (Fig. 11.2).

The resection was performed, and it rendered a wide and deep defect mostly on the left cheek region but with extension medial to the nasolabial fold onto the upper lip (Fig. 11.3).

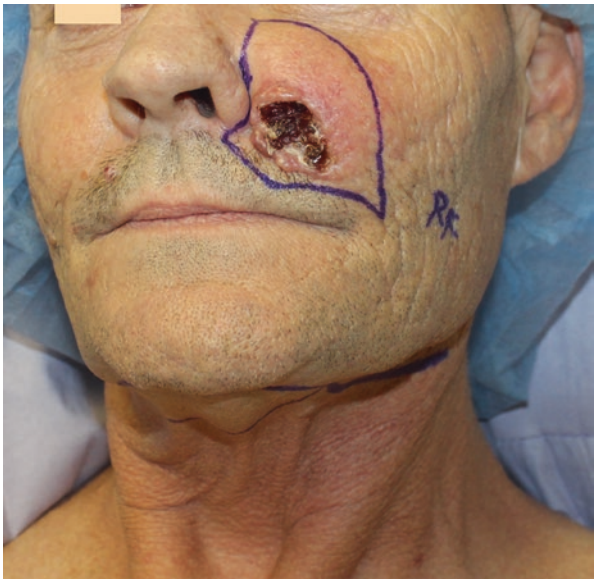


Fig. 11.1 Patient marking for planned resection of skin malignancy

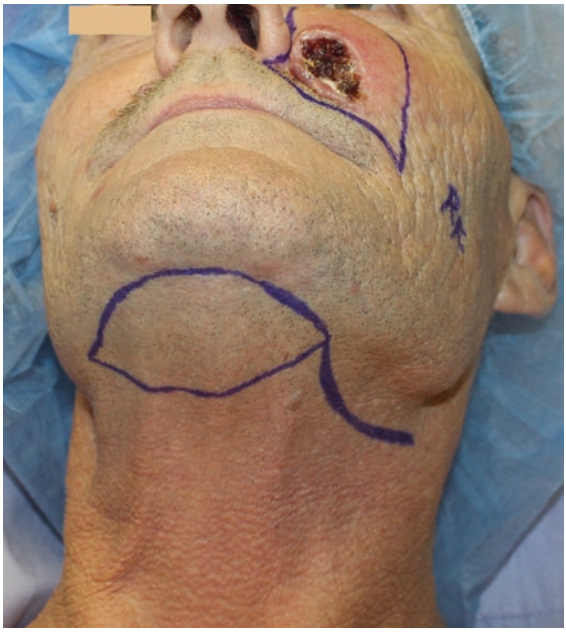


Fig. 11.2

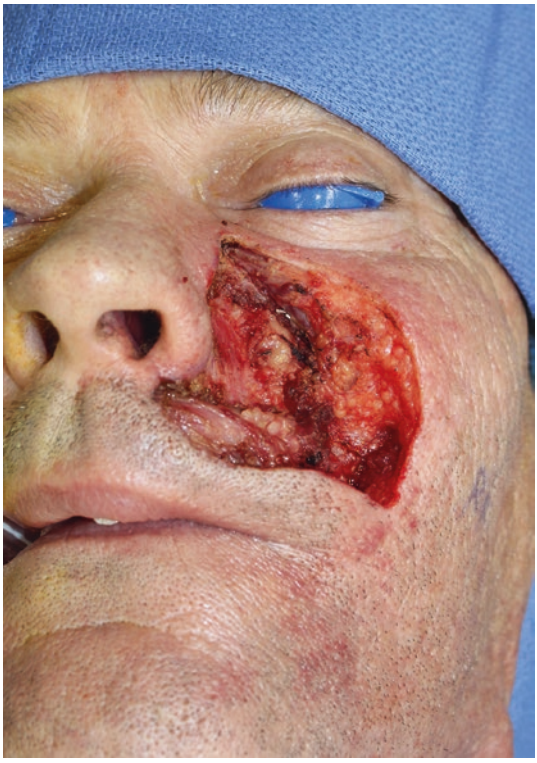


Fig. 11.3

The submental island flap was elevated, and the arc of rotation was confirmed to assure adequate reach without undue tension (Figs. 11.4 and 11.5).

A subcutaneous tunnel was developed and the flap was transferred to the defect site and inset (Fig. 11.6).

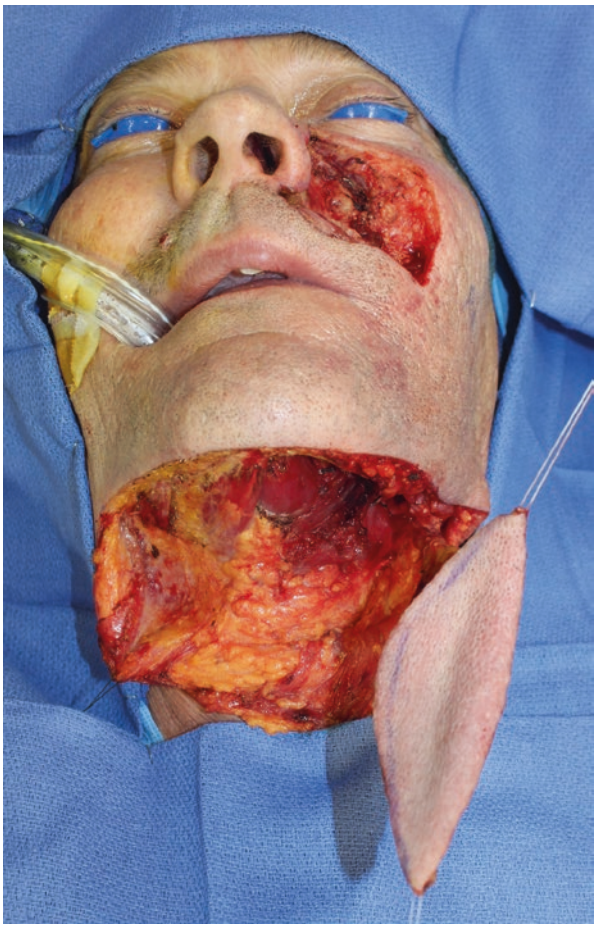


Fig. 11.4

Early postoperative result showed a significant redundant tissue along the nasolabial fold (Fig. 11.7).

After discussion with the patient, a revision was performed whereby the flap was debulked and the redundant skin was excised and the scar placed along the nasolabial groove (Fig. 11.8).

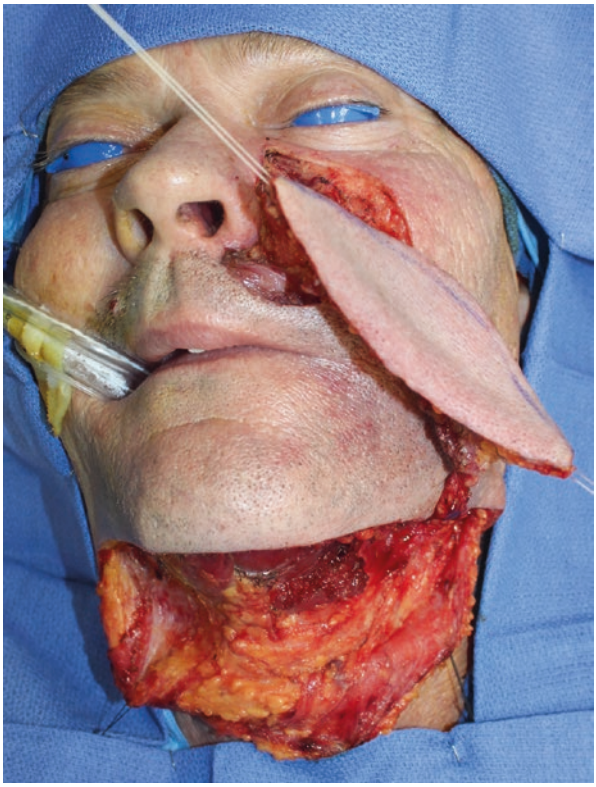


Fig. 11.5

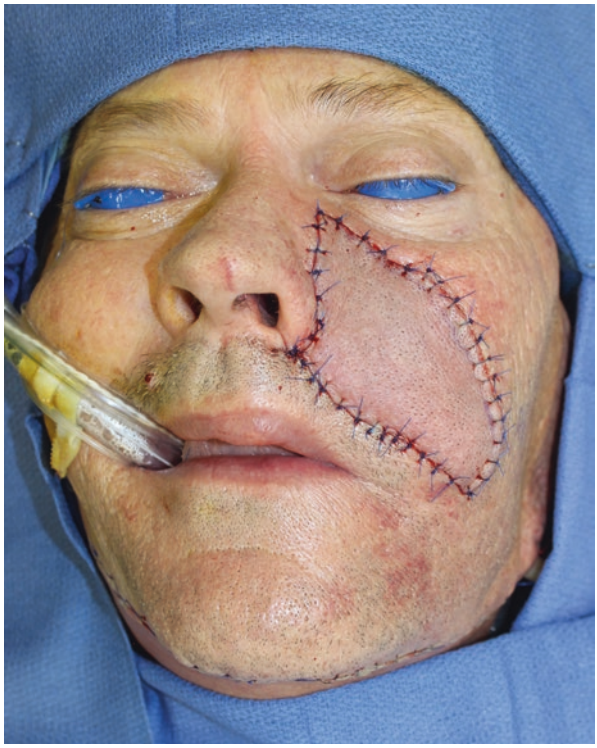


Fig. 11.6

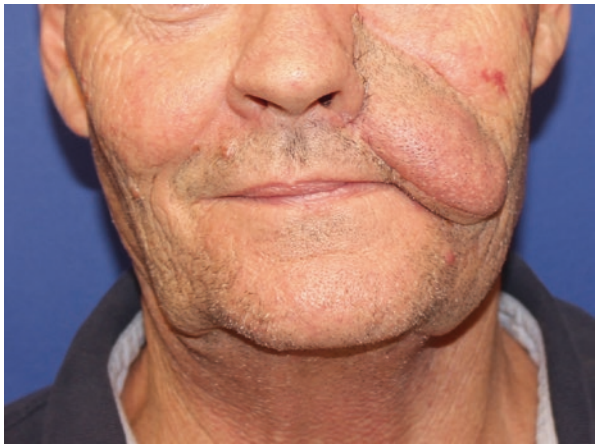
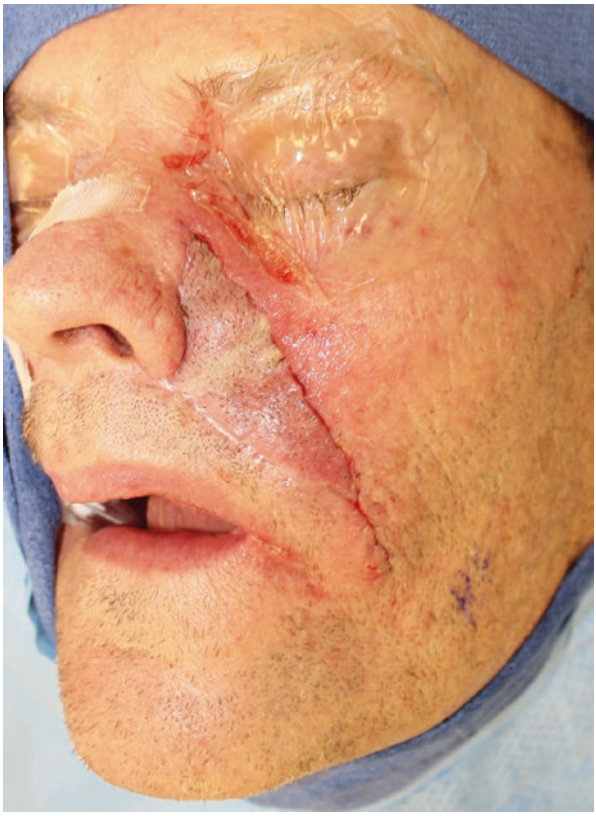


Fig. 11.7

Fig. 11.8



Case #2

A patient with a T2 lateral tongue squamous cell carcinoma presented for surgical treatment. After the reconstructive options were discussed with the patient, he opted for the submental flap reconstruction of his eventual hemiglossectomy defect. The planned flap was marked along with the incision for the neck dissection (Fig. 11.9).

A simultaneous neck dissection and elevation of the flap were performed after the glossectomy (Fig. 11.10).

With the elevation of the flap completed, the arc of rotation was assured. Note the meticulous dissection of the pedicle with removal of all of the lymphofatty tissue (Figs. 11.11 and 11.12).

A tunnel was then created along the mylohyoid muscle and into the floor of the mouth, and the flap was transferred while ensuring that the pedicle was not kinked nor compressed (Fig. 11.13).

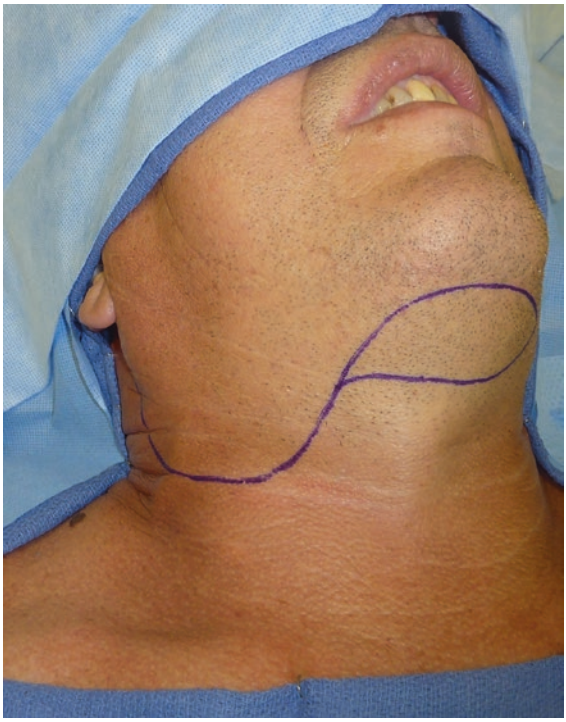


Fig. 11.9

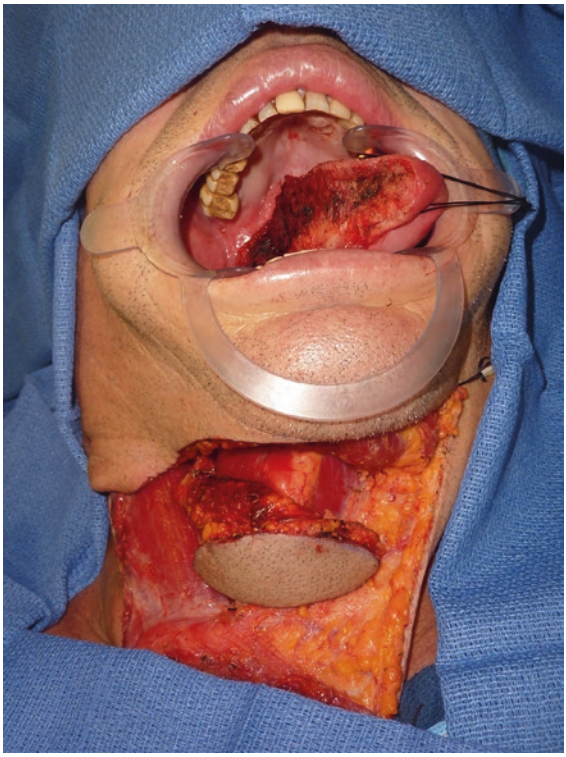
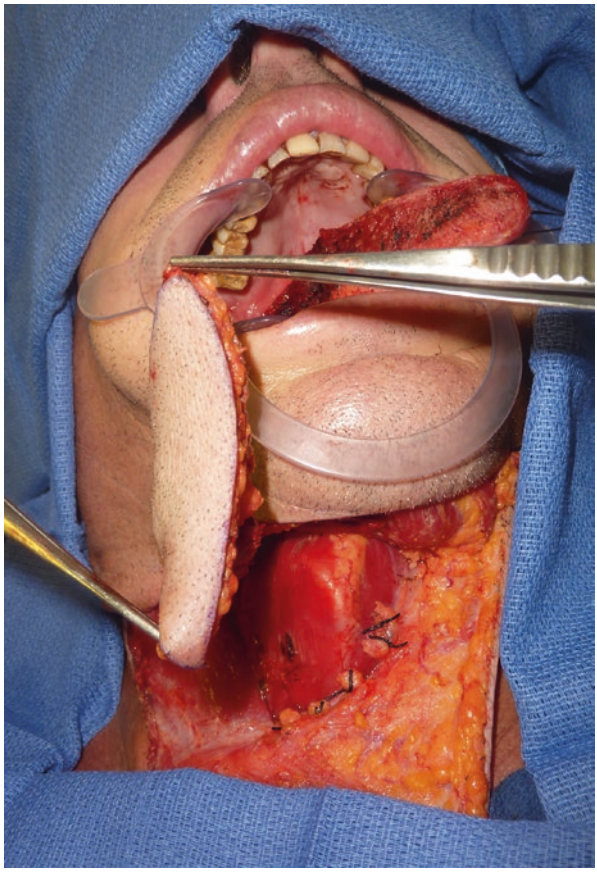


Fig. 11.10

Fig. 11.11



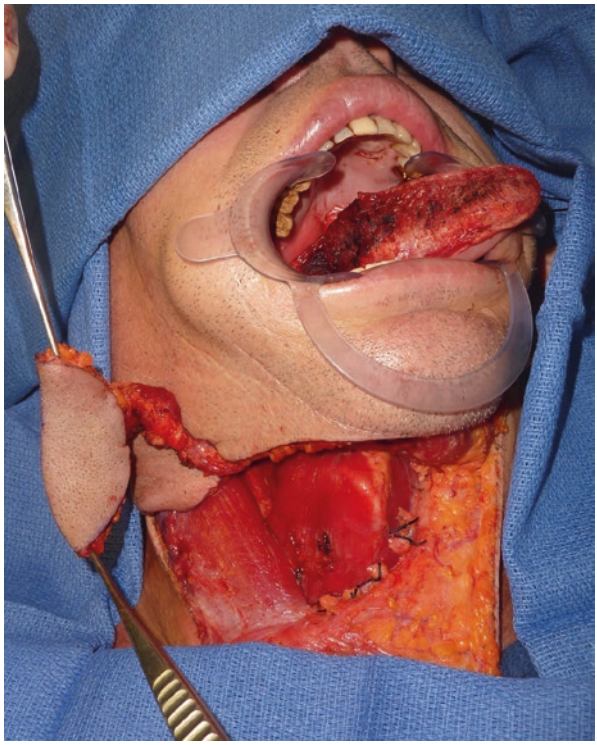


Fig. 11.12

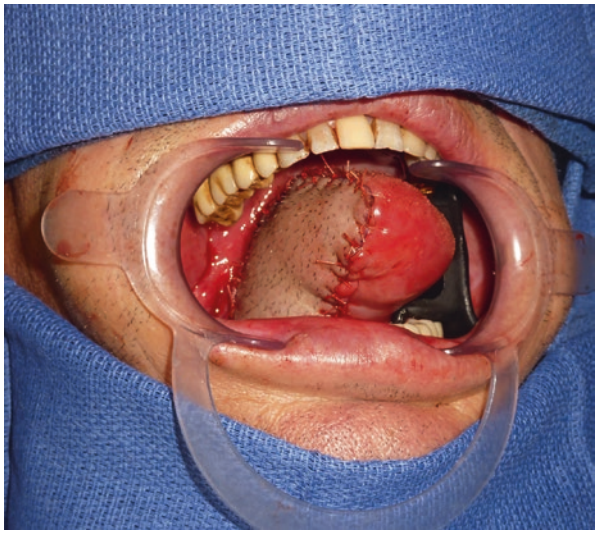


Fig. 11.13

11.3.1.5 Advantages/Disadvantages

There are several advantages of the submental island flap over free tissue transfer. The first and most commonly referred to is superior color and texture match of the submental island flap over free tissue transfer. Another significant advantage is the shorter operating time and the fact that there is no need for microsurgical technique when using this flap in its pedicled form [8]. Paydarfar and Patel found in their comparative study of the submental island flap vs. the radial forearm free flap that not only was the operative time shorter but also there was a shorter hospital stay without any compromise on the functional outcomes [9].

One of the main disadvantages of the submental island flap is the transfer of hair-bearing tissue to the oral cavity. This problem is obviously encountered in males and can be addressed by excising the skin at a later date and placing a skin graft [10].

Critics of the submental island flap have often expressed their distrust of its use in patients with head and neck malignancies, the fear being that there is a chance of transferring cancer-containing nodes within the reconstruction. In a recent publication, Howard and his colleagues reported their experience with the use of the submental island flap in the oncologic setting where they reported that with appropriate management of the level I nodal compartment, oncologic outcomes are not compromised [11].

11.3.2 Supraclavicular Flaps

It is often said that old things become new things. This saying can certainly be applied to the supraclavicular flap. In 1842, Mutter initially described the use of this flap as a randomly based flap [12]. Confusion exists in the reported literature as to elaboration of the anatomical details of the flap, Di Benedetto credits Kazanjian and Converse with the description of the "in charretera" flap [13]. Kokot and colleagues attribute the "in charretera" description to Kirschbaum [14]. Mizerny and colleagues performed dye cast studies and described the role of the transverse cervical artery to the fasciocutaneous flap [15]. Although many other surgeons described their experience with this flap, it was not until the early 2000s when surgeons like Pallua and Hartmann began to popularize the use of the pedicled supraclavicular flap that it began to harness widespread attention from reconstructive surgeons across several specialties [16–18].

Today, this "newcomer" has found a solid footing in the reconstructive armamentarium of most reconstructive surgeons.

11.3.2.1 Indications

The supraclavicular flap can be used in a variety of situations. The flap finds its greatest use in reconstructing defects in the neck and lower facial region [19, 20]. Oral and oropharyngeal defects can be routinely reconstructed with the supraclavicular flap [21].

Defects located higher in the head and neck region such as the parotid bed, scalp, and skull base are adequately reconstructed with the supraclavicular flap without the need for pre-expansion [22–24].

Additionally, the flap can be reliably used to reconstruct the above stated defects even in patients in whom the neck have been dissected and or radiated [12].

11.3.2.2 Anatomy

The anatomy of the supraclavicular region has been well studied in recent years. The thyrocervical trunk gives rise to the transverse cervical artery, which in turn gives rise to the perforators to the fasciocutaneous area of the shoulder. Cordova and her colleagues showed that on average there are four perforators for the skin area of the shoulder. These perforators come from the superficial branch of the transverse cervical artery in 75 % of the time and from the artery itself in 25 % [25]. The venous drainage to the flap is by the vena comitans as well as the superficial external jugular vein.

11.3.2.3 Flap Harvest

The patient is placed in a supine position with the neck slightly rotated to the contralateral side. A shoulder roll is placed on the side of the flap so as to elevate the donor shoulder.

The vascular supply to the flap is confirmed with the aid of a Doppler. The main trunk of the artery can be found in the area superior to the clavicle and lateral to the posterior border of the sternocleidomastoid muscle. Once the artery is confirmed, it is traced laterally toward the shoulder.

The skin paddle is then marked out by doing a pinch test to determine the maximum width of the flap. The length of the flap should not extend beyond the insertion of the deltoid muscle.

Elevation of the flap is performed with a needle electrocautery. The skin is incised, and a subfascial elevation is carried out beginning laterally and moving medially toward the root of the neck.

Once dissection reaches the fatty area medial to the trapezius, the bipolar electrocautery is used to meticulously dissect the vascular pedicle. The pedicle is dissected circumferentially without sacrificing the external jugular vein. The arc of rotation and reach of the flap is confirmed. Once adequate reach without tension is achieved, the flap is inset.

Closure of the defect is done by generally undermining the lateral edges. Typically, the area over the shoulder is closed first followed by the rest.

Case 1

The patient has a history of previous head and neck malignancy, which was treated with resection, neck dissection, and reconstruction with a free fibula flap. He received postoperative adjuvant radiation and later developed dehiscence and exposure of the reconstruction plate (Fig. 11.14).

A supraclavicular flap was planned after Doppler confirmation of the presence of the artery.

Fig. 11.14

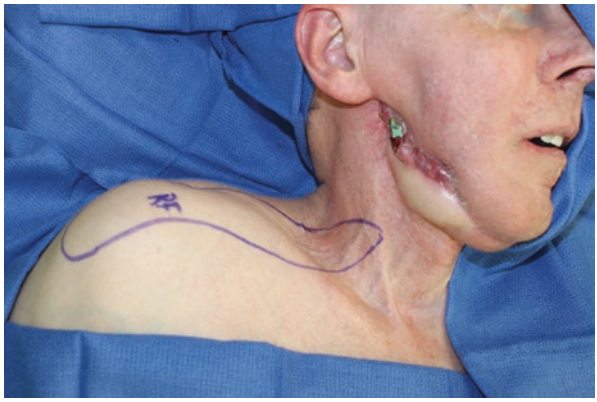
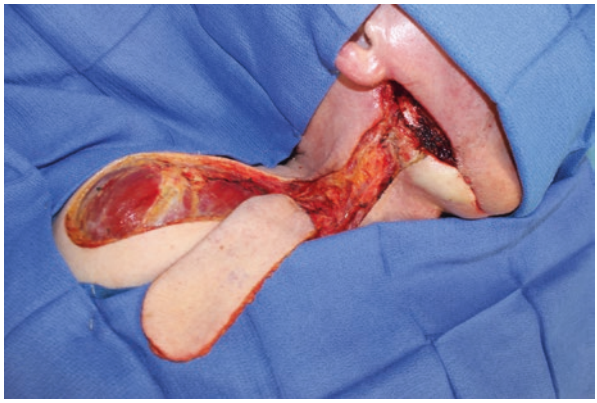


Fig. 11.15



The flap was elevated after removal of the exposed plate and debridement of the necrotic tissues (Fig. 11.15).

Once the arc of rotation and reach of the flap was confirmed to be satisfactory, the flap was then inset to the defect (Fig. 11.16).

Early postoperative evaluation revealed an acceptable reconstruction with good soft tissue quality and color match (Fig. 11.17).

Case 2

This middle-aged man with history of mandibular squamous cell carcinoma status post mandibular resection, neck dissection, and radiation therapy followed by post-operative radiation therapy presented for management of new lesion on the lower lip.

Given his previous surgical history and radiation, the plan was made for wide local excision and immediate reconstruction of the defect with a supraclavicular flap (Fig. 11.18).

The flap was elevated in a subfascial plane as previously described (Fig. 11.19).

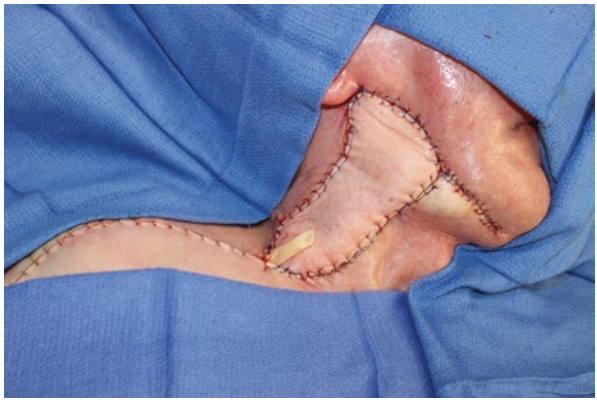


Fig. 11.16

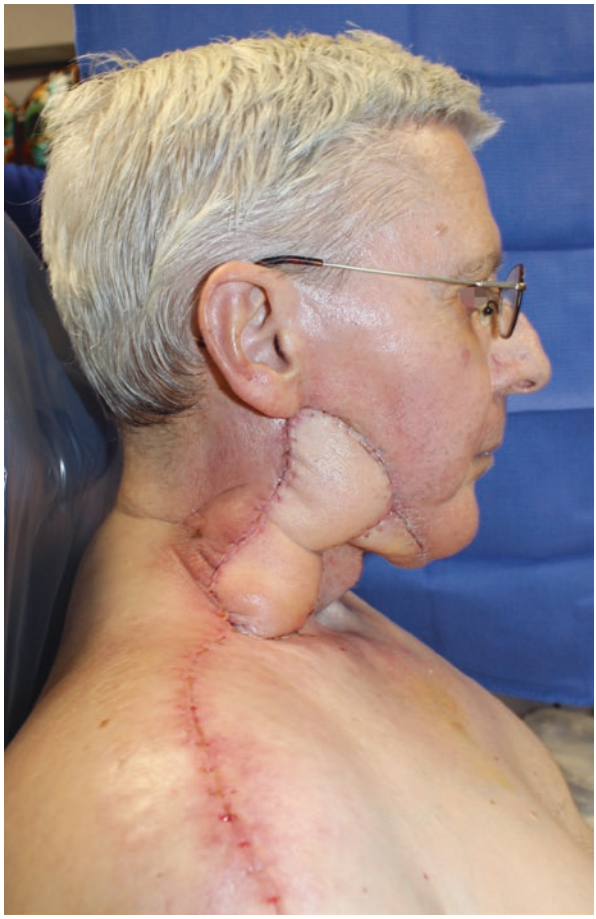
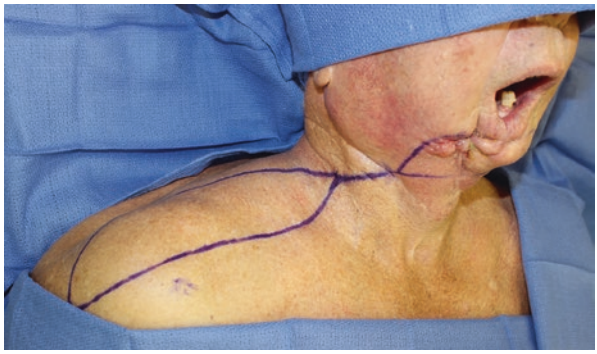


Fig. 11.17

Fig. 11.18



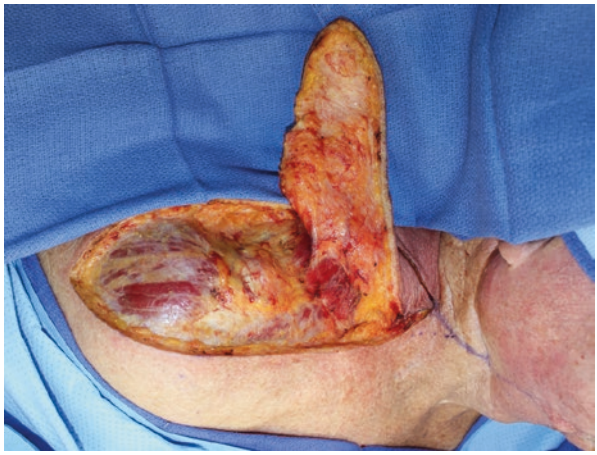


Fig. 11.19

With the elevation completed, the reach of the flap was confirmed to assure that the reconstruction would be done without tension (Fig. 11.20).

The flap was then inset in a standard fashion (Fig. 11.21).

11.3.2.4 Advantages and Disadvantages

The advantage of the supraclavicular flap lies in its reliability even in those patients with history of previous neck dissections and radiation [12]. Additionally, the wide range of defects that may be reconstructed with the supraclavicular flap can span pharyngeal defects, oral defects, skin defects, and up to skull base defects.

Although there are few disadvantages to this flap, nonetheless, they do exist. The commonly encountered is the widened scar at the donor site, which may be of concern to some patients, particularly female patients.

When the supraclavicular flap is used to reconstruct patients with history of radiation therapy to the head and neck, the donor site may have a prolonged period of erythema, and dehiscence may also occur.

Fig. 11.20

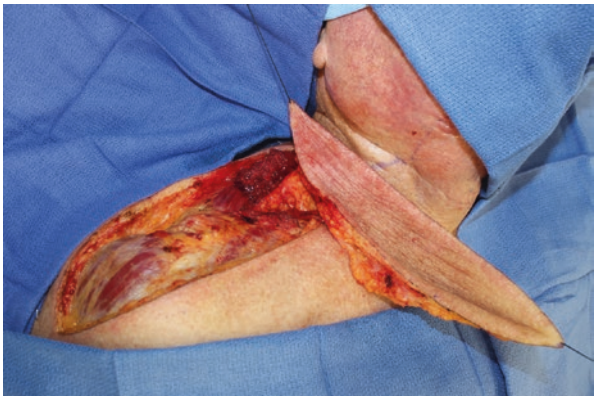
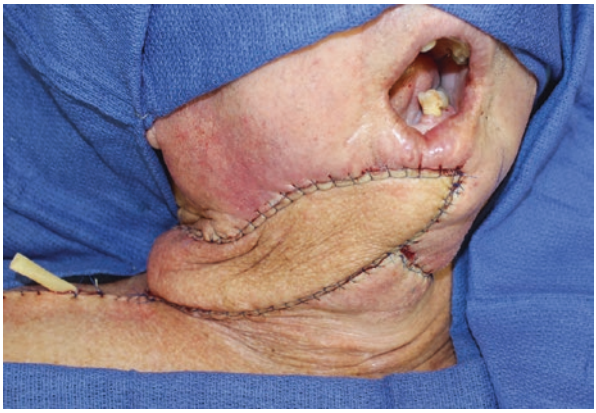


Fig. 11.21



11.3.3 Pectoralis Major Flaps

Every so often, a development occurs in the surgical world that leads to a dramatic change in practice, a true paradigm shift. This can be said about the pectoralis major myocutaneous flap. In 1978, during a surgical conference, Ayrian presented his experience with the use of the pectoralis major muscle flap to reconstruct various head and neck defects. One year later, he published this report in the journal of Plastic and Reconstructive Surgery. Since this description, the pectoralis major myocutaneous flap has remained an integral flap in the reconstructive armamentarium of head and neck reconstructive surgeons. Although its popularity has declined since microsurgical techniques became a commonplace, it is still one of the most commonly utilized flaps in the salvage setting of failed free tissue transfer as well as a primary option in reconstructing patients with multiple comorbidities who are not deemed to be good candidates for the longer microvascular options.

11.3.3.1 Indication

The pectoralis major can be used to repair a wide range of defects in the head and neck. The flap is routinely used to cover the pharyngeal suture lines in patients undergoing salvage laryngectomy after failed chemoradiation therapy. The pectoralis flap may be used to reconstruct tongue, floor of the mouth, and retromolar defects as well as pharyngeal defects without much difficulty. The use of the pectoralis to reconstruct defects as high as the maxilla is well reported, but it comes with it a higher rate of dehiscence along the highest points and therefore renders its use in that setting less ideal.

11.3.3.2 Anatomy

The vascular anatomy to the pectoralis major comes from several sources. The internal mammary artery perforators supply the medial portion of the muscle and its overlying skin. The main pedicle to the muscle comes from the thoracoacromial artery. The lateral thoracic artery supplies the lateral aspect of the muscle.

The pectoralis muscle is a large muscle that covers the anterior chest. The pectoralis muscle originates from the clavicle, the sternum, and the ribs and inserts on the greater tubercle of the humerus.

11.3.3.3 Flap Harvest

The flap is harvested with the patient in a supine position and with the defect well delineated. With either a suture string or with the string from a surgical lap, a pivot point is placed somewhere lateral from the midpoint of the clavicle, and the string is allowed to passively rest on the neck, and the outermost portion of the defect is marked. With the pivot point still remaining, the string is rotated to the chest and the mark of the defect is marked on the chest. This mark will represent the portion of the cutaneous part of the flap that needs to reach the part of the defect most distal to the pivot of the flap.

The desired skin paddle is then marked along the chest wall. The author will usually harvest a fusiform shape in order to aid in closure of the donor site.

The marking is then extended in a superior lateral direction in a curvilinear fashion.

Incision is typically begun on the medial aspect of the skin paddle to confirm that the majority of the skin paddle is located over the muscle; typically the skin paddle should not extend more than a few centimeters beyond the muscle.

The dissection is extended in an oblique manner so that the base of the skin paddle is wider than the surface. Once the skin paddle is exposed circumferentially, the skin may be sutured to the fascia of the muscle in order to minimize the potential of sheering.

The lateral chest skin is elevated off the muscle fascia toward the lateral edge of the muscle. Once this is identified, the plane between the pectoralis major and minor is entered, and a combination of blunt and sharp dissection is performed in a caudal direction to the desired length beyond the skin paddle.

The medial dissection is performed by incising the muscle with caution to identify the internal mammary perforators that may be encountered as the dissection is extended toward the clavicle.

With the muscle elevated, the thoracoacromial pedicle is easily identified, and care should be taken to protect it for the remainder of the operation.

The lateral insertion of the pectoralis muscle to the humerus is divided with electrocautery. Care should be taken to identify the cephalic vein as it runs along the deltopectoral groove.

With the flap harvest completed, attention should be directed to the development of the skin flap to transfer the flap to the neck and eventually to the defect site.

The superior skin above the curvilinear incision is elevated up to the clavicle and made to communicate with a previously developed skin flap from the neck. When a tunnel is created, one should ensure that it is adequate in size to accommodate the flap transfer and not compress the pedicle once it is transferred.

The donor site is closed with minimal undermining and over a suction drain.

Case #1

A middle age male was referred for the management of persistent neck disease after primary chemotherapy for a tonsil malignancy. The patient was positioned and prepped for the neck dissection and flap harvest (Fig. 11.22).

The neck dissection was completed and a muscle-only flap was elevated and checked for reach prior to transfer (Fig. 11.23).

A tunnel was created and the flap was transferred to the neck (Fig. 11.24).

The exposed vessels were covered with the flap (Fig. 11.25). The donor site was closed over suction drain (Fig. 11.26).

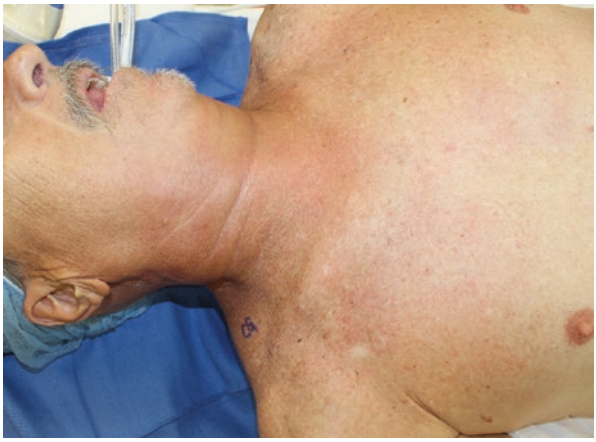


Fig. 11.22

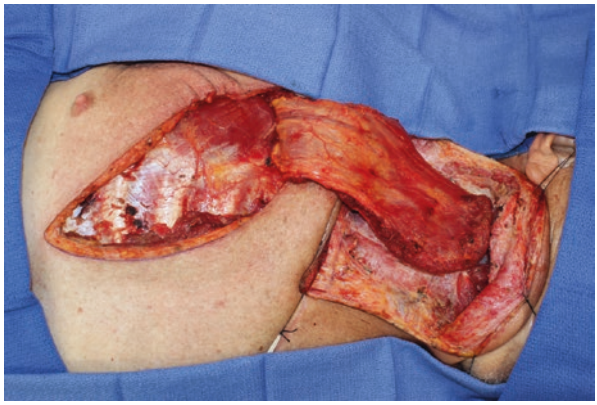


Fig. 11.23

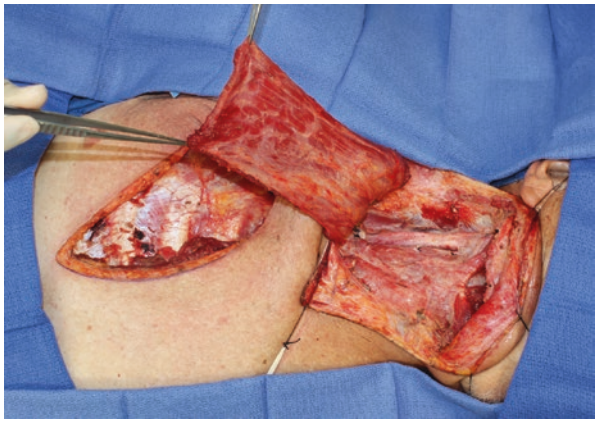


Fig. 11.24

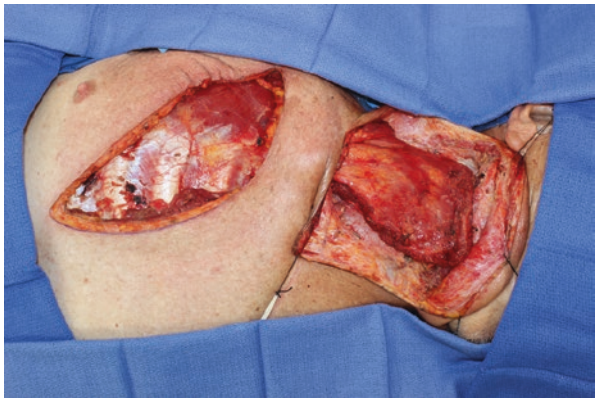


Fig. 11.25

Fig. 11.26

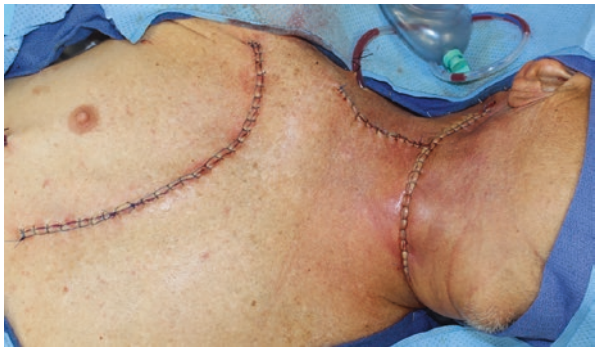
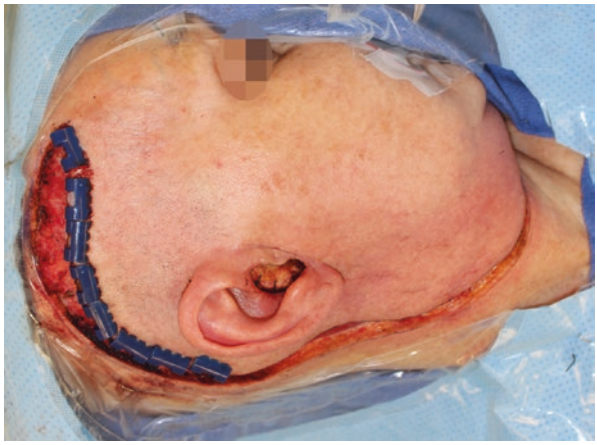


Fig. 11.27



Case 2

A young lady was referred to the department of salvage surgery after recurrence of a squamous cell carcinoma of the parotid with invasion to the temporal bone. A large skin flap was elevated (Fig. 11.27).

A total parotidectomy, mandibular resection, and a temporal bone resection were performed (Fig. 11.28).

A pectoralis flap was elevated and transferred into the neck (Fig. 11.29). The flap was advanced and inset to obliterate the temporal and parotid defect as well as for coverage of the great vessels (Fig. 11.30).

The recipient site was closed without significant depression in the operative site (Fig. 11.31).

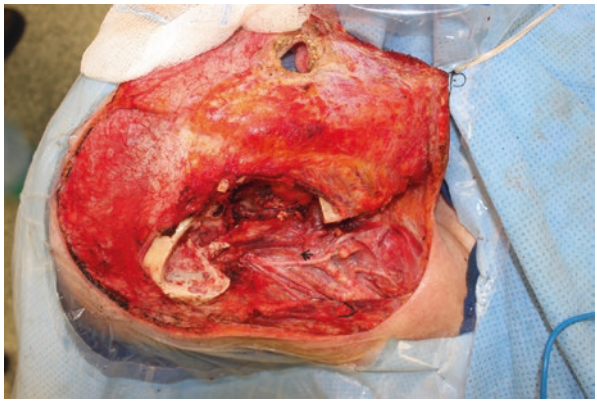


Fig. 11.28

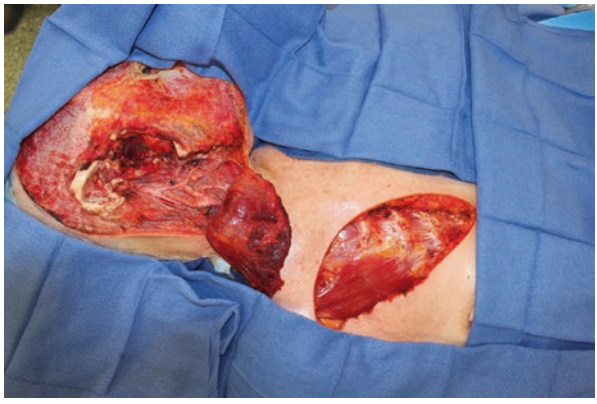


Fig. 11.29

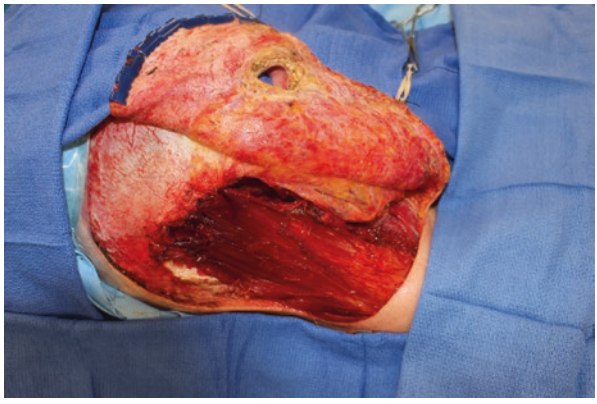


Fig. 11.30

Fig. 11.31

11.3.3.4 Advantages and Disadvantages

The pectoralis major myocutaneous flap has several advantages. The flap may be elevated very quickly due to the ease of harvest. Albeit tight, it also allows for a two-team approach for ablation and flap harvest. The flap is very reliable and can be used for coverage of large defects as a muscle-only flap with skin grafting or a large myocutaneous flap may be elevated and the donor site skin grafted.

The main disadvantage of this pedicle flap as compared to the other two described in this chapter is the color match. The pectoralis skin will be considerably lighter and with a different texture than the skin in the head and neck. The use of the pectoralis flap in female patients may be problematic as it often results in the distortion of the breast. Additionally, the limitations of reach can at times limit the flap.

References

1. Martin D, Pascal JF, Baudet J, et al. The submental island flap: a new donor site. Anatomy and clinical applications as a free or pedicled flap. Plast Reconstr Surg. 1993;92(5):867–73.
2. Kim JT, Kim SK, Koshima I, Moriguchi T. An anatomic study and clinical applications of the reversed submental perforator-based island flap. Plast Reconstr Surg. 2002;109(7):2204–10.
3. Rahpeyma A, Khajehahmadi S. Submental artery island flap in intraoral reconstruction: a review. J Craniomaxillofac Surg Off Publ Eur Assoc Craniomaxillofac Surg. 2014;42(6):983–9.
4. Genden EM, Buchbinder D, Urken ML. The submental island flap for palatal reconstruction: a novel technique. J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg. 2004;62(3):387–90.
5. Wang WH, Hwang TZ, Chang CH, Lin YC. Reconstruction of pharyngeal defects with a submental island flap after hypopharyngeal carcinoma ablation. ORL J Otorhinolaryngol Relat Spec. 2012;74(6):304–9.
6. Abboud O, Shedid D, Ayad T. Reconstruction of the prevertebral space with a submental flap: a novel application. J Plast Reconstr Aesthet Surg JPRAS. 2013;66(12):1763–5.

7. Magden O, Edizer M, Tayfur V, Atabey A. Anatomic study of the vasculature of the submental artery flap. Plast Reconstr Surg. 2004;114(7):1719–23.
8. Abouchadi A, Capon-Degardin N, Patenotre P, Martinot-Duquennoy V, Pellerin P. The submental flap in facial reconstruction: advantages and limitations. J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg. 2007;65(5):863–9.
9. Paydarfar JA, Patel UA. Submental island pedicled flap vs radial forearm free flap for oral reconstruction: comparison of outcomes. Arch Otolaryngol Head Neck Surg. 2011; 137(1):82–7.
10. Vural E, Suen JY. The submental island flap in head and neck reconstruction. Head Neck. 2000;22(6):572–8.
11. Howard BE, Nagel TH, Donald CB, Hinni ML, Hayden RE. Oncologic safety of the submental flap for reconstruction in oral cavity malignancies. Otolaryngol Head Neck Surg Off J Am Acad Otolaryngol Head Neck Surg. 2014;150(4):558–62.
12. Su T, Pirgousis P, Fernandes R. Versatility of supraclavicular artery island flap in head and neck reconstruction of vessel-depleted and difficult necks. J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg. 2013;71(3):622–7.
13. Di Benedetto G, Aquinati A, Pierangeli M, Scalise A, Bertani A. From the "charretera" to the supraclavicular fascial island flap: revisitation and further evolution of a controversial flap. Plast Reconstr Surg. 2005;115(1):70–6.
14. Kokot N, Mazhar K, Reder LS, Peng GL, Sinha UK. The supraclavicular artery island flap in head and neck reconstruction: applications and limitations. JAMA Otolaryngol Head Neck Surg. 2013;139(11):1247–55.
15. Mizerny BR, Lessard ML, Black MJ. Transverse cervical artery fasciocutaneous free flap for head and neck reconstruction: initial anatomic and dye studies. Otolaryngol Head Neck Surg Off J Am Acad Otolaryngol Head Neck Surg. 1995;113(5):564–8.
16. Heitland AS, Pallua N. The single and double-folded supraclavicular island flap as a new therapy option in the treatment of large facial defects in noma patients. Plast Reconstr Surg. 2005;115(6):1591–6.
17. Pallua N, von Heimburg D. Pre-expanded ultra-thin supraclavicular flaps for (full-) face reconstruction with reduced donor-site morbidity and without the need for microsurgery. Plast Reconstr Surg. 2005;115(7):1837–44. discussion 45–7.
18. Hartman EH, Van Damme PA, Sauter H, Suominen SH. The use of the pedicled supraclavicular flap in noma reconstructive surgery. J Plast Reconstr Aesthet Surg JPRAS. 2006;59(4):337–42.
19. Chu MW, Levy JM, Friedlander PL, Chiu ES. Tracheostoma reconstruction with the supraclavicular artery island flap. Ann Plast Surg. 2015;74(6):677–9.
20. Emerick KS, Herr MA, Deschler DG. Supraclavicular flap reconstruction following total laryngectomy. Laryngoscope. 2014;124(8):1777–82.
21. Chen WL, Zhang DM, Yang ZH, et al. Extended supraclavicular fasciocutaneous island flap based on the transverse cervical artery for head and neck reconstruction after cancer ablation. J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg. 2010;68(10):2422–30.
22. Emerick KS, Herr MW, Lin DT, Santos F, Deschler DG. Supraclavicular artery island flap for reconstruction of complex parotidectomy, lateral skull base, and total auriculectomy defects. JAMA Otolaryngol Head Neck Surg. 2014;140(9):861–6.
23. Epps MT, Cannon CL, Wright MJ, et al. Aesthetic restoration of parotidectomy contour deformity using the supraclavicular artery island flap. Plast Reconstr Surg. 2011;127(5):1925–31.
24. Hunt JP, Buchmann LO. The supraclavicular artery flap for lateral skull and scalp defects: effective and efficient alternative to free tissue transfer. J Neurol Surg Rep. 2014; 75(1):e5–10.
25. Cordova A, Pirrello R, D'Arpa S, Jeschke J, Brenner E, Moschella F. Vascular anatomy of the supraclavicular area revisited: feasibility of the free supraclavicular perforator flap. Plast Reconstr Surg. 2008;122(5):1399–409.

Multiunit Defects

12

Jacob G. Yetzer and Rui P. Fernandes

A discussion of multiunit defect reconstruction of the maxillofacial complex requires an appropriate definition of the term. While there are a number of classification systems which define subdivisions of individuals units such as the lower face or orbitomaxillary complex [1–5], yet detailed classification of multiunit defects of the face as a whole has not been described. Gonzalez-Ulloa originally provided a system of classifying the esthetic subunits of the face, and Zan et al. provide a more modern classification of cutaneous facial defects based upon the extent of reconstruction [6, 7]. These classifications, while including consideration of subunits of the face, are particularly applicable to surface anatomy. They do not necessarily account for the important three-dimensional and functional aspects that have considerable impact on outcomes in complex post-ablative defects. While the average head and neck surgeon would likely "know it when they see it," to paraphrase Supreme Court Justice Stewart, a broad definition should include defects that involve more than one anatomic or functional component of the maxillofacial complex. Examples would be a defect involving the skin, mucosa, and bone or mandible plus the maxilla or tongue plus the pharynx. The list of possible combinations is long.

Other chapters in this text include in-depth discussions of the reconstructive techniques employed for individually defined facial subunits. Therefore, it is not the purpose of this section to rehash those methods. Rather, this section is intended to provide unique considerations and representative cases which call for integrating the tools and techniques emphasized throughout this volume.

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DOI 10.1007/978-3-319-43854-2_12

12.1 General Considerations

The goals in multiunit facial reconstruction are vastly similar to the sum of the goals sought in the reconstruction of the constituent defects. Such objectives include coverage and obliteration of the defect using vascularized tissue. Sterile and non-sterile compartments should be separated from one another. Last, but important, every effort should be made to restore the patient functionally and esthetically in order to preserve quality of life from a psychological and social standpoint.

When approaching the reconstruction of a multiunit defect, goal-directed planning taken prior to the resection is critical. Because of the additional complexity as compared to the single-unit defect, the additional planning of the ideal reconstruction as well as several potential alternatives will greatly ease the situation once the operation has begun. Reconstruction will be affected, at least in part, by the etiology of the defect, which may include trauma, infection, neoplasm, osteoradionecrosis, or prior reconstructive failure.

Understandably, a large majority of multiunit defects will be related to pathology, most commonly malignant. A good starting point in treatment planning is the extent and completeness of the oncologic resection that is to be expected. Clearly, a tumor resection that is expected to result in these types of defects will usually be for a high-volume tumor that has an increased likelihood of involving critical structures. The surgeon must therefore be certain that structures of critical significance be addressed prior focusing on other aspects. For instance, the case of the extensive skull base resection for nasal carcinoma (Fig. 12.1a–g) would require skull base coverage in the region of dural resection as leaving this area unreconstructed for any reason may result in catastrophic consequences. Likewise, ablative procedures resulting in exposure of the great vessels of the neck should merit a high position on the reconstructive surgeon's priority list. On the other hand, these are the very cases when conservative reconstruction may be wise in the primary setting. When the margin status or patient prognosis depends upon dissection of difficult anatomy or critical structures of the head and neck, then delayed reconstruction can provide an opportunity to confirm definitive histopathologic results. Good judgment and patience in such situations may mean the difference between a sound oncologic and reconstructive outcome for the patient and disaster.

Assuming all critical structures are adequately protected, consideration ought to be given to staged or secondary reconstruction. Leaving a defect unreconstructed for the sake of clinical surveillance is not shown to improve outcomes [8]; however in cases involving questionable margin status and where further resection would lead to significant morbidity, a delay in reconstruction can prove most well advised. Tumors involving the carotid, skull base, or prevertebral area may be considered a part of this category.

As an example, *Case 1* is a young man with extensive nasal squamous cell carcinoma with dural involvement. He presented originally to the radiation oncology unit and preferred to undergo radiotherapy rather than surgery. The tumor

Case 1

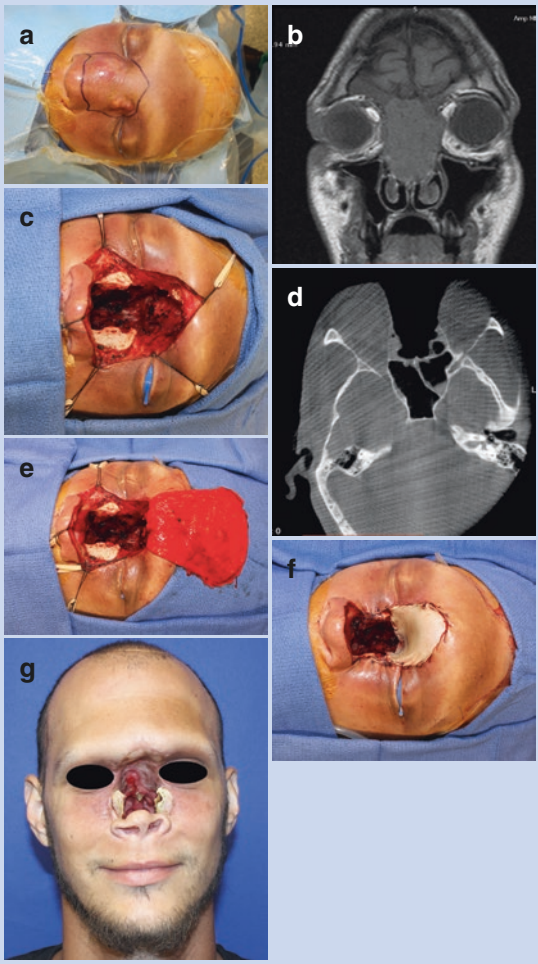

Fig. 12.1 (**a**) Case 1 is a 28-year-old male with a large nasal squamous cell carcinoma demonstrating skin involvement. The patient recently completed radiotherapy with poor response. (**b**) Coronal MRI image showing the large nasal tumor with orbital and anterior skull base involvement. (**c**) Completion of resection shown for Case 1 including subtotal rhinectomy, ethmoidectomy, sphenoidectomy, and transfacial anterior skull base resection. (**d**) Intraoperative CT showing completed resection. (**e**) Elevation of pericranial flap for repair of dural resection. While this patient will undergo a staged reconstruction, it is crucial to achieve dural repair in order to prevent CSF leak or CNS infection. (**f**) Pericranial flap inset with split-thickness skin graft. (**g**) Case 1 patient after removal of dressing. Skull base repair is well healed and all final margins are clear. This patient will now undergo nasal reconstruction. An interim prosthesis has been fabricated

demonstrated only partial response to radiation, and he was then treated with salvage surgery for a high-volume tumor of the nasal cavity with involvement of the skin, medial orbit, and anterior skull base. He underwent subtotal rhinectomy, ethmoidectomy, and sphenoidectomy with transfacial anterior skull base resection with intraoperative navigation. In this case primary reconstruction of the dura was performed using a pericranial flap and skin graft in order to prevent CSF leak or potentially catastrophic infection. The remainder of the reconstruction was delayed for a later date in order to allow time to confirm final margins and disease control. Depending on the duration of the delay, a temporary prosthesis can be fabricated, and autogenous reconstruction planned as per patient desires.

A further consideration in cases of high-volume tumors involving multiple units is patient prognosis. In many ways this is no different from any reconstruction performed for oncologic resection – the patient must be thought of as a whole. However, as the magnitude of the reconstructive procedure to be performed increases, the attention to the relative merits of the surgery should be weighed more heavily. Often, a multiunit defect will require flaps involving greater complexity or multiple flaps. These methods have the attendant downsides of additional operative time and greater donor-site morbidity as well as a higher likelihood of slower recovery. By their very nature, large tumors will have a higher likelihood of recurrence with its accompanying implications for patient survival [9]. For these reasons a careful analysis of the risks and benefits of the reconstruction should be performed with careful weighing of the patient's desires and goals.

Last to be discussed, but potentially the first line of thought in cases of multiunit reconstruction, should be a careful discussion with the ablative surgeon. With precise planning, defects and therefore the necessary reconstruction can be greatly simplified if a careful and oncologically sound resection can be done in a manner that results only in a single-unit defect rather than multiple. This obviates the need for additional complexity. The example, *Case 2* shows a 43-year-old female who presented with biopsy-proven maxillary adenoid cystic carcinoma. Biopsy was done in her home country where she presented with midfacial pain, ipsilateral orbital swelling, and epiphora. Both clinically and radiographically, she appeared to have gross orbital involvement on initial evaluation. Oncologic principles would indicate the correct operation is orbital exenteration with maxillectomy. However, by allowing for a degree of adaptability during the course of the operation, the ablative surgeon identified a defined surgical plane of dissection allowing for clear margins with preservation of the eye. Such a defect as shown in the case images is much easier to reconstruct with the eye left intact (Fig. 12.2a–f). Of course contingencies need to be discussed prior to the case beginning, but the merit of careful coordination of the oncologic and reconstructive portions of the surgery should be clear.

Case 2

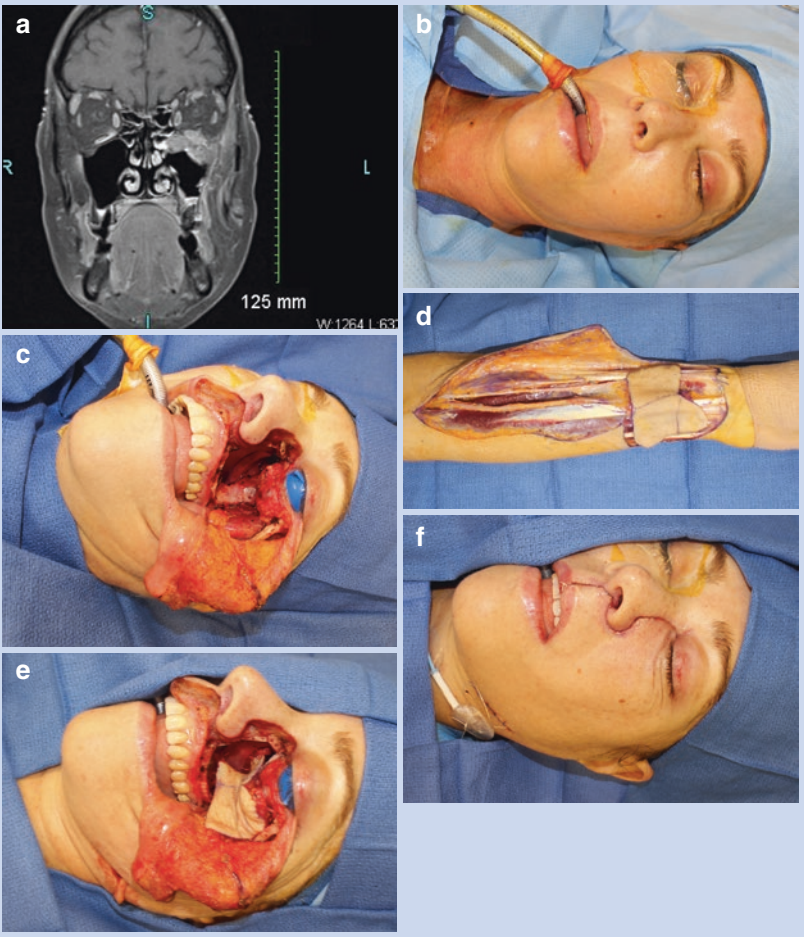

Fig. 12.2 (**a**) Coronal image of a 43-year-old female with maxillary adenoid cystic carcinoma with orbital involvement who presented with left facial swelling, pain, orbital swelling, and epiphora. (**b**) Intraoperative image of the patient prior to surgical start. Left midface fullness and eyelid edema can be noted here. (**c**) Case 2 showing post-resection state. Great care was taken to preserve the eye despite orbital floor involvement. Clear frozen margins were achieved which allowed reconstruction with radial forearm flap alone. (**d**) The radial forearm flap is elevated based on a paper template contoured to the defect. (**e**) Forearm flap insetting into the maxillary defect. An orbital floor implant has been placed and is re-lined by the flap in order to prevent extrusion. (**f**) Image showing final closure after flap insetting and anastomosis

12.2 Multiple Flaps

Often, a single flap will not provide the quantity, tissue types, or geometry required to reconstruct a multiunit defect. Using multiple flaps either simultaneously or in a staged manner allows the reconstructive surgeon to rehabilitate more complex, high-volume tumor resections and has been demonstrated to be an effective method of doing so [10, 11]. Indications include large defects of soft tissue and/or bone, complex geometry required for insetting, and complex skull base defects [11, 12]. Commonly reported combinations include fibula osteocutaneous plus a fasciocutaneous flap such as a radial forearm or ALT, but any composition may be utilized depending on the specific tissues required and surgeon preference [10, 13]. For instance, the gentleman highlighted in *Case 3* underwent reconstruction using fibula osteocutaneous flap along with anterolateral thigh fasciocutaneous flap (Fig. 12.3a–f). He initially had been diagnosed with osteoradionecrosis of the anterior mandible after radiation for a prior squamous cell carcinoma. However, after failure to improve, a repeat biopsy revealed recurrent SCC involving the entire floor of the mouth and mandible. The tumor included extensive skin involvement of the entire lower face as well as bilateral oral commissures. He was reconstructed using the fibula cutaneous paddle for repair of the floor of the mouth. An ALT was then designed to cover the lower facial skin defect in addition to the bilateral cheeks and upper lip. Bilateral anastomoses were used with end-to-end anastomosis to branches of the external carotid arteries. For large oromandibular defects such as this, the large and entirely independent skin paddle allows for reconstruction of the cutaneous portion while the fibula skin paddle can be utilized for the mucosal layer.

There are clear benefits to using multiple free flaps as opposed to chimeric flaps, for instance. First, each missing tissue component of the defect can be reconstructed with the ideal tissue for that particular subunit. Soft tissue, for example, must be ample enough to separate components and provide appropriate pliability without being overly bulky. By allowing the surgeon to choose specific tissue characteristics, these goals can be more easily achieved. In addition, the geometric arrangement of each flap can be planned entirely separately from the others. This can help decrease the likelihood of acute bends or folding that could result in untoward complications.

Reported outcomes of double free flap reconstruction of the head and neck are varied but on balance provide support for the method. Reported survival rates for double flap reconstructions are very similar to single-flap reconstructions with reported success rates from 95 to 100% [10, 12, 18, 19]. From a functional standpoint, a range of outcomes have been reported as well. The series of patients described by Guillemaud and Bianchi had good speech intelligibility in the majority of patients. These reports in addition to Wei et al. support oral intake in patients in

Case 3

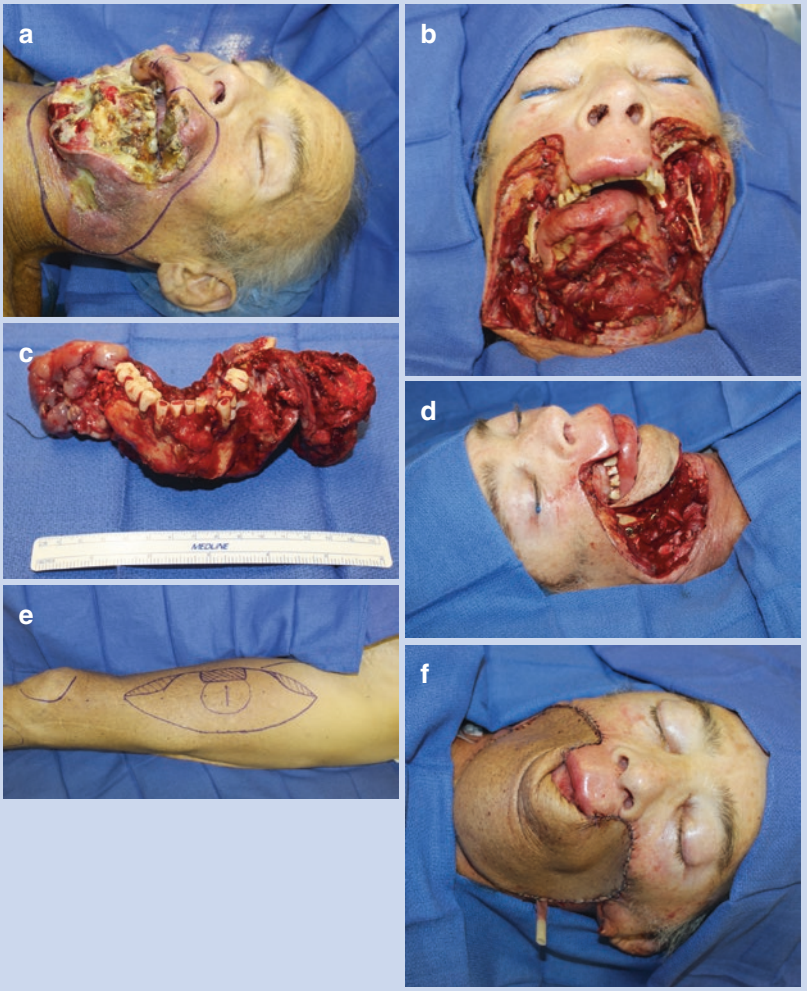

Fig. 12.3 (**a**) Case 3 showing recurrent squamous cell carcinoma involving the entire anterior mandible, skin of both upper and lower lips and chin, as well as the floor of the mouth. (**b**) Patient after an extensive resection resulting in a large multiunit defect. (**c**) Specimen from Case 3 is shown here. (**d**) This image demonstrates the patient after insetting of the first flap – a fibula osteocutaneous flap with the skin paddle used to restore the floor of the mouth. (**e**) Anterolateral thigh marked for reconstruction of the chin, lower lip, bilateral cheeks, and portion of the upper lip. (**f**) Patient shown after insetting of the second flap – an anterolateral thigh flap – overlying the fibula flap

the 94–100% range following multiple free flap reconstruction [18, 19]. Balasubramanian also reported positive functional outcomes in a series of 21 patients with double-flap reconstruction. While others have reported less favorable speech and swallow outcomes [12, 20], it is difficult to pinpoint with precision the expected outcome as the location of certain defects, such as glossectomy or anterior mandibular resection, would pose significantly more difficult rehabilitation situations than others such as a purely lateral defect, for instance.

Extra effort is demanded of the surgeon in these cases. Measures must be taken to optimize the patient preoperatively as the case length will increase with each additional flap. Also, the surgeon must consider vessel availability carefully, and preservation of vessels during dissection is of paramount importance. This can be particularly challenging in patients who have had multiple operations or have undergone radiotherapy [17]. While direct end-to-end anastomosis to ipsilateral vessels would be preferable to most surgeons, multiple flaps often require one to look further for adequate recipient vessels. The transverse cervical vessels are often available even in an otherwise vessel-depleted neck [21]. Cephalic vein transposition and the internal mammary vessels may also be considered depending on the length of the vascular pedicle [22]. Of course, vein grafting is also available as a means to achieve greater vessel length but has the attendant risk of thrombosis as well as increased operative time.

In the absence of sufficient available vessels for two sets of anastomoses, serial flaps with end-to-end anastomosis can be performed. The principles of such flow-through techniques were originally described by Soutar et al. [14], and his method has been modified with success in reperfusion of extremities as well as for serial flaps [15, 16]. This option does have the drawback, however, of the possibility for total loss of the entire reconstructive complex [17].

Another alternative is to make use of one or two pedicled flaps in place of either free flap, thus obviating the need for a second anastomosis [29]. For instance, in *Case 4* this patient had a recurrent basal cell carcinoma which required resection of the anterior maxilla, upper lip, and nose (Fig. 12.4a–f). The defect was reconstructed using a combination of radial forearm free flap plus a paramedian forehead flap. The forearm restored the anterior maxilla and upper lip while the paramedian forehead flap went to reconstruct the external nose.

The benefit of utilizing a pedicled flap as opposed to a second free flap is not limited only to the decreased complexity. Color match tends to be better when using local or adjacent tissue, a characteristic of local flaps that lends itself to better esthetic outcomes [19]. Useful applications include, but are not limited to, cervicofacial or cervicopectoral flaps as well as cheek advancement flaps and paramedian forehead flap. Of course, there are also limitations to these methods. While a single free flap has relative freedom of geometry for insetting, the accompanying locoregional flap will not have the same flexibility. Inappropriate application of a pedicled

Case 4

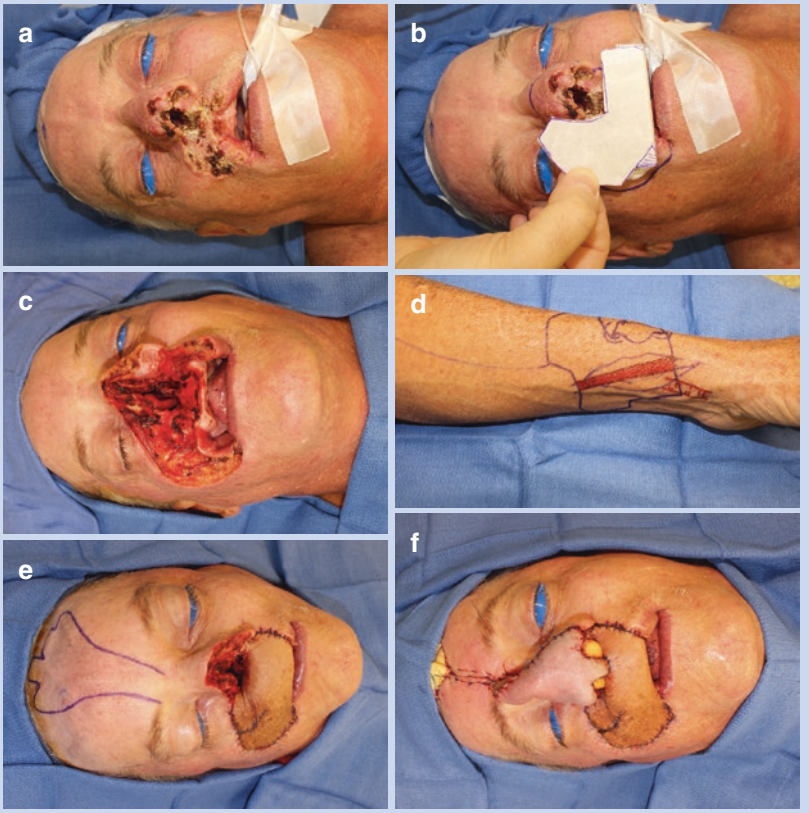

Fig. 12.4 (**a**) Case 4 demonstrates a long neglected basal cell carcinoma of the upper lip, maxilla, and nose. (**b**) This image demonstrates use of a paper template for planning of the anticipated forearm flap. The template is bent in order to accommodate both the skin and mucosal layers. (**c**) Patient shown after completion of a large, multiunit resection including subtotal rhinectomy and upper lip and anterior maxillectomy. (**d**) Drawing of template transfer to the left forearm with recipient site anatomy drawn for reference. (**e**) Patient shown after insetting and anastomosis of the forearm flap. The nasal floor, upper lip, and anterior maxilla have been reconstructed. Now paramedian forehead flap is marked out for reconstruction of the external nose. (**f**) Case 4 shown after insetting of the paramedian forehead flap. This case demonstrates the use of a free flap plus pedicled flap

flap in the presence of a free flap has the risk of placing too much tension or bulk on the reconstruction just as one would expect it would for a single-unit reconstruction. These risks should be met with added attention in multiunit situations, however, as breakdown in one flap can lead to failure of the other.

Case 5 demonstrates the use of two regional flaps for repair of a full-thickness defect of the cheek secondary to resection of a squamous cell carcinoma (Fig. 12.5a–e). This is an 86-year-old female with numerous medical comorbidities who had a buccal squamous cell carcinoma with invasion of the right mandibular body. This case demonstrates that by making use of regional alternatives rather than free tissue transfer, a shorter operating time and length of hospital stay can be achieved without compromising the esthetic outcomes. In her case, an ipsilateral myocutaneous pectoralis major flap was used for the mucosal layer, and a cervicofacial flap was used to reconstruct the skin. The mandible was reconstructed with a simple reconstruction plate rather than osseous reconstruction. In considering tailored treatment options for each patient's needs, it is important that the reconstructive surgeon remembers traditional techniques such as these.

12.3 Chimeric Flaps

Putting aside the use of multiple flaps to reconstruct multiunit defects of the head and neck, chimeric flaps are a good source of alternative methods to accomplish the same goals. Hallock defined chimeric flaps in 1991 as a type of compound flap in which several separate tissue paddles, whether of a single or multiple tissue types, are able to be moved and rotated independently of each other and are together nourished by a single parent vessel [23]. This is in contradistinction to composite flaps, another type of compound flap, which transfers multiple tissue types on the same flap that is interdependent and thus cannot be freely oriented in an independent manner [24]. The original name for the chimeric flap was borrowed from the Greek mythological monster "chimera" which had the head of a lion, the body of a goat, and the tail of a serpent.

The angiosome concept as described by Taylor and Palmer provide the basis for chimeric flaps [25, 26]. This concept states that the body is divided into individual territories known as angiosomes which share a common blood supply. In concept, at least, one would be able to create a chimeric flap based upon the branches and perforator vessels to any tissue type within any of the 40 described angiosomes. Thus the variety of flaps that can be created are limited only by the surgeon's creativity and morbidity of a given donor site.

Because of this, a great many chimeric flaps have been described for reconstruction of the head and neck region as well as other parts of the body. Huang et al. provide a relatively simple classification which breaks down chimeric flaps into

Case 5

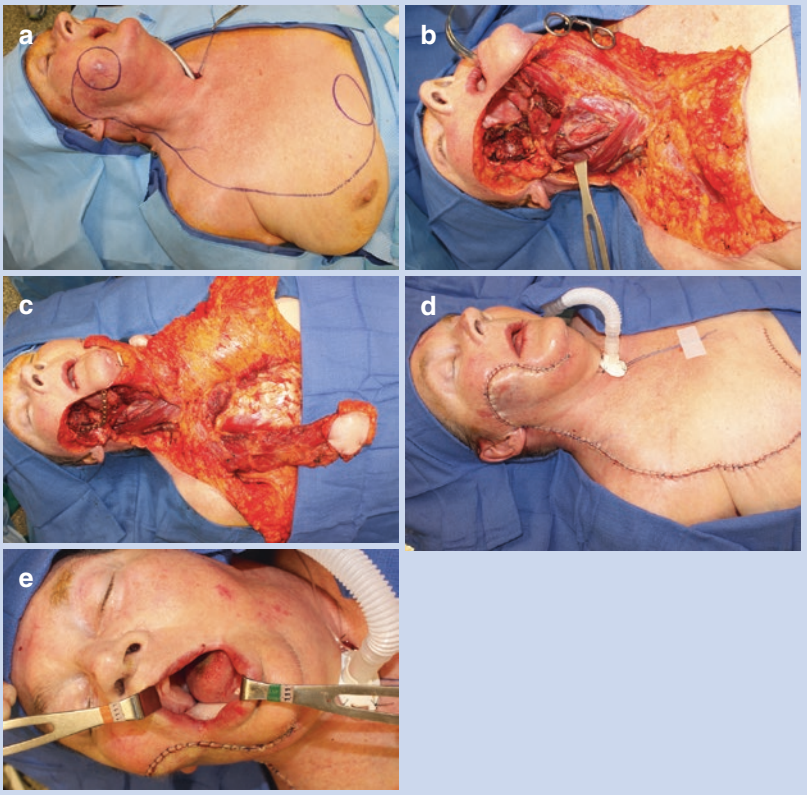

Fig. 12.5 (**a**) Case 5 is an 86-year-old female with a buccal mucosal squamous cell carcinoma with cutaneous involvement. Shown here with resection marked as well as the anticipated cervicofacial and pectoralis major myocutaneous flap. (**b**) Patient shown after resection including segmental mandibulectomy and ipsilateral neck dissection. The cervicofacial flap has been elevated in continuity with the neck dissection. (**c**) Image showing elevation of the pectoralis myocutaneous flap. A heavy titanium plate has been used for the mandibular continuity defect given the patient's compromised medical status. (**d**) Closure showing advancement of the cutaneous flap into the defect. Good color match is an advantage of this technique. (**e**) Intraoral image of Case 5 with insetting of the pectoralis flap

three basic types: branch based, perforator based, and microsurgically prefabricated [27]. The branch-based variety has large, direct branches off the vascular pedicle to each component part of the flap. These include some of the most common sources of microvascular free flaps for use in the head and neck such as the subscapular system and lateral femoral circumflex system. The perforator-based chimeric flaps are based off of separate cutaneous perforator vessels. These are smaller and more variable than the flaps seen in the branch-based category. Examples would include anterolateral thigh chimeric flap based off multiple perforators or those based upon lateral leg perforators or even those arising from the thoracodorsal artery. Finally, the Huang classification includes prefabricated chimeric flaps which are comprised of two separate free flaps with an additional microvascular anastomosis from one to another using either a side chain or end branch in flow-through fashion. While this does technically create a type of compound flap, it is often considered in the same category as a two-flap reconstruction since it requires an additional anastomosis and second donor site. Thus many of the advantages inherent in the chimeric flaps are given up.

The advantages of chimeric flap reconstruction are multiple especially for the types of complex defects present in the multiunit situation. Foremost is the availability of multiple tissue components that can be inset independently into a site of difficult three-dimensional geometry. Much like using multiple flaps, this is enormously beneficial when multiple layers or tissue types need reconstruction. Two independent skin paddles, for example, could more easily be used to reconstitute both the skin and mucosal lining in a full-thickness type of defect than simply folding a traditional fasciocutaneous flap [28]. Moreover, the surgeon can achieve these benefits without the need for a second anastomosis as all of the individual components share a common vascular supply. This can be a major advantage in the vessel-depleted neck. A chimeric flap also limits the number of donor sites to one as opposed to a multi-flap reconstruction, which should reduce morbidity, assuming all else is equal.

On the other hand, there are downsides to the use of the chimeric flap. First is the fact that with increasing complexity of the flap due to numerous pedicles, the number of angles and turns of vessels increases. Because each individual component is inset with its own orientation, the risk of twisting or kinking one of them is meaningful and requires precise planning and careful attention. Also, in a multiunit reconstruction such as may involve sites separated in space, the individual branches must accommodate not only the reach of the individual tissue component to its planned inset location but also maintain enough of the main vascular pedicle to reach the recipient vessels. Depending on the patient, this can be a more complex situation than using multiple flaps each with their own pedicle and anastomosis. Also, because the chimeric flaps in the multiunit reconstruction will usually be of considerable size, a second venous anastomosis may be indicated which partially offsets some of the benefit of a single vascular pedicle [30]. Anatomic variability is a concern for certain of the flaps, particularly those that rely upon well-spaced perforator vessels as these types of flaps are known to have greater variability. Finally, though one donor site would generally be considered to have lower morbidity than

multiple – it is possible that those single donor flaps that demand too much volume could leave a patient with greater morbidity than might be accomplished with two smaller flaps from separate sites.

As mentioned previously, the options available within the realm of chimeric flaps are many. For the head and neck reconstruction, there are several more commonly used options that are worth mentioning. First, the subscapular system is a robust source for a number of flap designs. Flaps that can be harvested from the region include the scapula, parascapular, serratus, and latissimus dorsi with all of their variations. This system is unique in that it allows one or two bone flaps, if the angular artery is used for scapular angle, plus multiple soft tissue paddles comprised of muscle and/or skin by making use of the thoracodorsal and circumflex scapular vessels and their branches. The anatomy of the region was first described by Saijo in 1978 [31] who suggested it may be a potential donor site. With the circumflex scapular and thoracodorsal arteries each contributing multiple branches to the bone, muscle, and skin distributions that can be individually raised, it was a likely source for chimeric transfers. Gilbert performed the first free flap of the scapula [32]. Since then, a significant number of modifications and uses have been described for both oromandibular and maxillofacial defects [33–35]. The sheer variety of flap compositions as well as the unimpeded ability to ambulate even in patients with poor baseline function make this a valuable piece of the surgeon's armamentarium. Specifics of harvest technique of the scapular flap are discussed in depth in other portions of this text.

Other common donor sites for chimeric flaps of the head and neck include the anterolateral thigh from the lateral femoral circumflex vessels and variations of the fibula flap using branches of the peroneal vessels. The anterolateral thigh flap was described originally by Song et al. [36]. Further refinements of the anatomy have revealed that suitable perforators are available to elevate multiple skin paddles in at least 84 % of flaps as dictated by their takeoff from the main vessel. This is based upon the work of Kimata et al. [37]. This flap can also be raised with muscular cuff of vastus lateralis or rectus femoris by maintaining muscular perforators as well as the potential to include vastus lateralis [38]. As such this flap can be used for a wide range of reconstructions including large scalp and facial defects and full-thickness oromandibular, glossectomy, and combined orbitomaxillary and skull base defects. Despite the benefits of ample size and low donor-site morbidity, the surgeon must be prepared with alternative plans for reconstruction given the low, but not insignificant, chance that the perforator pattern is not consistent with the needs of the reconstruction.

Likewise, the peroneal system, also a very common part of the reconstructive repertoire in the head and neck, provides options for chimeric design. Since Hidalgo originally described the fibula flap for mandibular reconstruction, our understanding of the associated perforasome anatomy has advanced significantly [39]. Work by Wei et al. confirmed the predictable presence of multiple cutaneous perforators which are the basis for multi-skin paddle fibula flaps [40, 41]. In addition, Wong described the presence of constant muscular perforators proximally which allow for hemisoleus inclusion as an additional soft tissue component [42].

As fibula flap harvest is a familiar technique to most microvascular surgeons who manage head and neck defects, the option to include multiple skin and muscle in a chimeric arrangement is valuable for complex defects. Donor-site morbidity is low, the quality and quantity of bone are good, and the vascular pedicle is usually long. One potential difficulty with fibula flap chimeric flaps is the fact that each perforator is short and they are linearly arranged off the peroneal artery, characteristics that limit the freedom of geometry that may be desired in a multiunit scenario.

12.4 Virtual Surgical Planning

Any reconstructive procedure requires detailed planning in order to provide precise and predictable outcomes, and this is even more critical in large or multiple unit defects. Advanced imaging and the increasingly available three-dimensional surgical planning software are very useful adjuncts that can be used to translate a surgical plan into the actual execution in the operating room. Not only does the virtual surgical planning aid in visualization, surgical cutting guides for donor and recipient sites as well as prefabricated reconstruction plates can aid in predictability [43, 44]. The use of this technology results in high accuracy. Roser and Ramachandra showed accuracy of the fibular and mandibular osteotomies to be within 1.3 and 2 mm of the planned sites with volumetric predictability of the fibular segments of approximately 90% [45]. Additionally, work by Hanasono suggests that significant time benefit can be achieved in terms of overall operating time while confirming a high degree of accuracy [46].

The benefits ascribed to virtual planning are particularly salient when it comes to multiunit reconstruction. When large defects are present, the surgeon is challenged with loss of reference points upon which to base the reconstruction. Orienting the bone flap and appropriately contouring the reconstruction plate in the absence of a reliable reference frame can be frustrating even for the most experienced reconstructive surgeon. An illustrative case is *Case 6*. This is a 76-year-old female with a history of oropharyngeal carcinoma treated with external beam radiation over 10 years prior. She presented with stage three osteoradionecrosis of the mandible with involvement from ramus to ramus seeking surgical management. She had previously been treated for ORN of the right mandibular body with resection and placement of reconstruction plate without osseous reconstruction. Virtual surgical planning was used to design osteotomies extending from the left subcondylar region with disarticulation on the right side. Patient-specific fibula based on her CTA was used to plan bilateral fibula flaps as she had inadequate bone length for single-flap reconstruction. A flow-through flap design was used with anastomosis to the left facial artery and common facial vein. In order to aid with the reconstruction, cutting guides were planned along with a prebent reconstruction plate. The virtual planning images of these are shown below (Fig. 12.6a–e).

Case 6

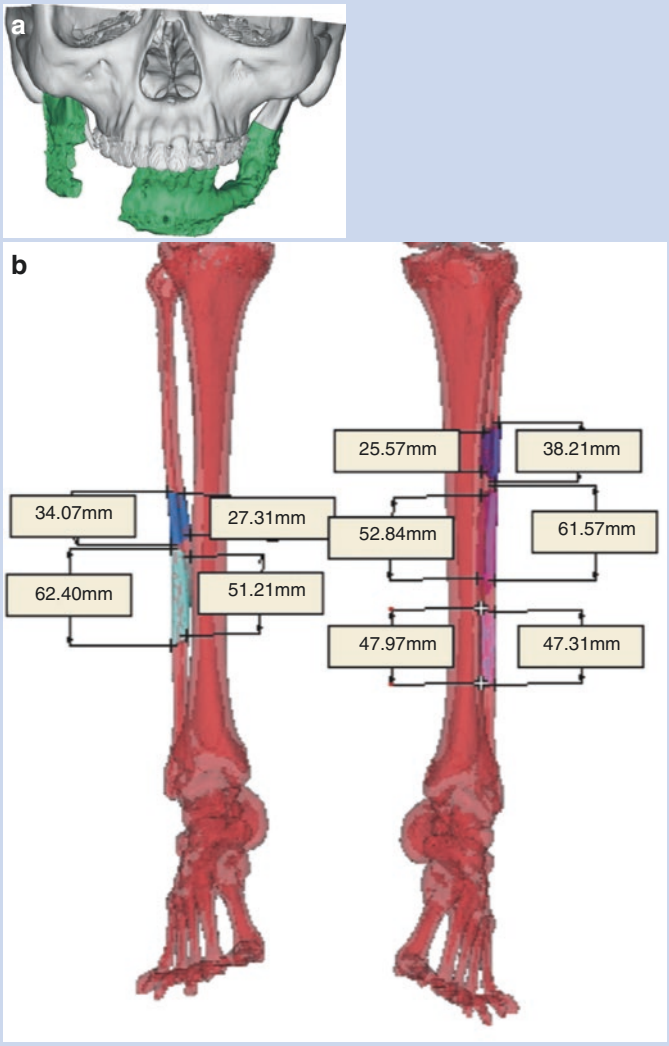

Fig. 12.6 (**a**) Case 6 is a 76-year-old female with recurrent ORN of the entire mandible. Image (**a**) shows anticipated resection based on the virtual surgical planning. (**b**) Patient-specific fibula imaging showing length and location of osteotomy sites. She required two fibula flaps as she did not have adequate length with only one. (**c**) Example of the planned fibula cutting guides which would be used on the left fibula with anticipation to bring this flap to the right mandible. The cutting guides help to ensure that the virtual plan is carried out precisely in the operating room. (**d**) Anticipated fibula reconstruction of the mandible. The *pink/purple* segments represent the left fibula and the *green/blue* the right. The two flaps were connected with a flow-through style design. (**e**) A prebend reconstruction plate is designed and shown here

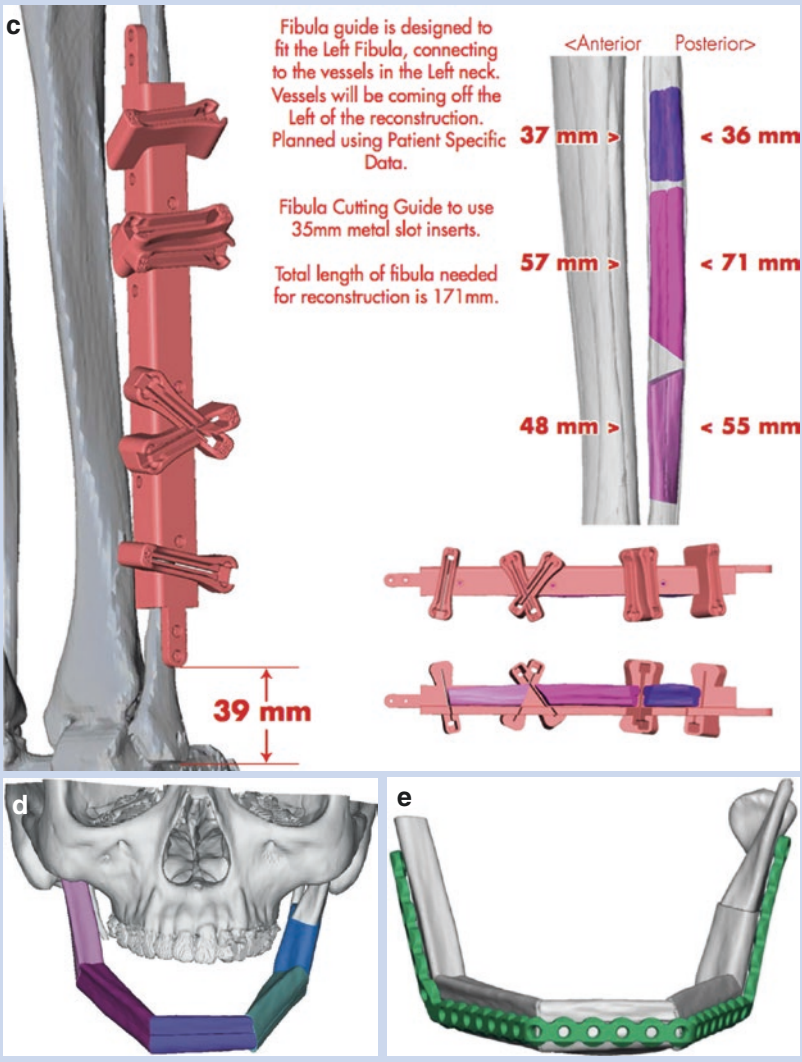

Fig. 12.6 (continued)

References

1. Jewer DD, Boyd JB. Orofacial and mandibular reconstruction with iliac crest free flap: a review of 60 cases and a new method of classification. Plast Reconstr Surg. 1989;84:391–405.
2. Boyd JB, Gullane PJ, Brown DH. Classification of mandibular defects. Plast Reconcstr Surg. 1993;92(7):1266–75.
3. Urken ML, Weinberg H, Vickery C, et al. Oromandibular reconstruction using microvascular composite free flaps. Report of 71 cases and a new classification scheme for bony, soft-tissue, and neurologic defects. Arch Otolaryngol Head Neck Surg. 1991;117:733–44.
4. Cordeiro PG, Santamaria E. A classification system and algorithm for reconstruction of maxillectomy and midfacial defects. Plast Reconstr Surg. 2000;105:2331.
5. Brown JS, Shaw RJ. Reconstruction of the maxilla and midface: introducing a new classification. Lancet Oncol. 2010;11:1001.
6. Gonzalez-Ulloa M. Restoration of the face covering by means of selected skin in regional aesthetic units. Br J Plast Surg. 1956;9:212–21.
7. Zan T, Li H, Gu B, Liu K, Xie F. Surgical treatment of facial soft-tissue deformities in postburn patients: a proposed classification based on a retrospective study. Plast Reconstr Surg. 2013;132:1001e.
8. Moreno MA, Skoracki RJ, Hanna EY, et al. Microvascular free flap reconstruction versus palatal obturation for maxillectomy defects. Head Neck. 2010;32:860.
9. Wallace CG, Tsao C, Wei FC. Role of multiple free flaps in head and neck reconstruction. Curr Opin Otolaryngol Head Neck Surg. 2014;22:140–6.
10. Wei FC, Yazar S, Lin CH, et al. Double free flaps in head and neck reconstruction. Clin Plast Surg. 2005;32:303–8.
11. Balasubramanian D, Thankappan K, Kuriakose MA, et al. Reconstructive indications of simultaneous double free flaps in the head and neck: a case series and literature review. Microsurgery. 2012;32:423–30.
12. Hanasono MM, Weinstock YE, Yu P. Reconstruction of extensive head and neck defects with multiple simultaneous free flaps. Plast Reconstr Surg. 2008;122:1739–46.
13. Posch NA, Mureau MA, Dumans AG, Hofer SO. Functional and aesthetic outcome and survival after double free flap reconstruction in advanced head and neck cancer patients. Plast Reconstr Surg. 2007;120:124–9.
14. Soutar D, Scheker L, Tanner N, McGregor I. The radial forearm flap: a versatile method for intraoral reconstruction. Br J Plast Surg. 1983;36:1–8.
15. Ceulemans P, Hofer SOP. Flow-through anterolateral thigh flap for a free osteocutaneous fibula flap in secondary composite mandible reconstruction. Br J Plast Surg. 2004;57:358–61.
16. Wells MD, Luce EA, Edwards AL, et al. Sequentially linked free flaps in head and neck reconstruction. Clin Plast Surg. 1994;21:59.
17. Yazar S, Wei FC, Chen H, et al. Selection of recipient vessels in double free-flap reconstruction of composite head and neck defects. Plast Reconstr Surg. 2005;115:1553.
18. Guillemaud JP, Seikaly H, Cote DW, et al. Double free-flap reconstruction: & indications, challenges, and prospective functional outcomes. Arch Otolaryngol Head Neck Surg. 2009;135:406–10.
19. Bianchi B, Ferrari S, Poli T, et al. Oromandibular reconstruction with simultaneous free flaps: experience on 10 cases. Acta Otorhinolaryngol Ital. 2003;23:281–90.
20. Gabr E, Kobayashi MR, Salibian AH, et al. Mandibular reconstruction: are two flaps better than one? Ann Plast Surg. 2004;52:31–5.
21. Yu P. The transverse cervical vessels as recipient vessels for previously treated head and neck cancer patients. Plast Reconstr Surg. 2005;115:1253.
22. Urken ML, Higgins KM, Lee B, Vickery C. Internal mammary artery and vein recipient vessels for free tissue transfer to the head and neck in the vessel depleted neck. Head Neck. 2006;28:797.
23. Hallock GG. Simultaneous transposition of anterior thigh muscle and fascia flaps: an introduction to the chimera flap principle. Ann Plast Surg. 1991;27:126–31.

24. Hallock GG. Bipedicled fasciocutaneous flaps in the lower extremity. Ann Plast Surg. 1992;29:397–401.
25. Taylor GI, Palmer JH. The vascular territories (angiosomes) of the body: experimental study and clinical applications. Br J Plast Surg. 1987;40:113–41.
26. Taylor GI, Palmer JH, McManamny D. The vascular territories of the body (angiosomes) and their clinical applications. In: McCarthy JG, editor. Plastic surgery, vol. 1. Philadelphia: WB Saunders; 1990. p. 329–78.
27. Huang WC, Chen HC, Wei FC, Cheng MH, Schnur D. Chimeric flap in clinical use. Clin Plast Surg. 2003;30:457–67.
28. Koshima I, Yamamoto H, Hosoda M, Moriguchi T, Orita Y, Nagayama H. Free combined composite flaps using the lateral circumflex femoral system for repair of massive defects of the head and neck regions: an introduction to the chimeric flap principle. Plast Reconstr Surg. 1993;92:411–20.
29. Rigby MH, Hayden RE. Regional flaps: a move to simpler reconstructive options in the head and neck. Curr Opin Otolaryngol Head Neck Surg. 2014;22:401–6.
30. Chen WF, Kung YP, Kang YC, Lawrence WT, Tsao CK. An old controversy revisited-one versus two venous anastomoses in microvascular head and neck reconstruction using anterolateral thigh flap. Microsurgery. 2013;34:377–83.
31. Saijo M. The vascular territories of the dorsal trunk: a reappraisal for potential donor sites. Br J Plast Surg. 1978;31:200–4.
32. Gilbert A, Teot L. The free scapular flap. Plast Reconstr Surg. 1982;69:601–4.
33. Aviv JE, Urken ML, Vickery C, Weinberg H, Buchbinder D, Biller H. The combined latissimus dorsi-scapular free flap in head and neck reconstruction. Arch Otolaryngol Head Neck Surg. 1991;117:1242–50.
34. Coleman SC, Burkey BB, Day TA, Resser JR, Netterville JL, Dauer E, Sutinis E. Increasing use of the scapula osteocutaneous free flap. Laryngoscope. 2000;110:1419–24.
35. Valentini V, Gennaro P, Torroni A, Longo G, Aboh IV, Cassoni A, Battisti A, Anelli A. Scapula free flap for complex maxillofacial reconstruction. J Craniofac Surg. 2009;20:1125–31.
36. Song YG, Chen GZ, Song YL. The free thigh flap: a new free flap concept based on the septocutaneous artery. Br J Plast Surg. 1984;37:149–59.
37. Kimata Y, Uchiyama K, Ebihara S, et al. Anatomic variations and technical problems of the anterolateral thigh flap: a report of 74 cases. Plast Reconstr Surg. 1998;102:1517–23.
38. Koshima I, Fukuda H, Utunomiya R, et al. The anterolateral thigh flap; variations in its vascular pedicle. Br J Plast Surg. 1989;42:260–2.
39. Hidalgo DA. Fibula free flap: a new method of mandible reconstruction. Plast Reconstr Surg. 1989;84:71.
40. Wei F, Seah C, Tsai Y, Liu S, Tsai M. Fibula osteosepto-cutaneous flap for reconstruction of composite mandibular defects. Plast Reconstr Surg. 1994;93:294.
41. Wei FC, Chen HC, Chuang CC, Noordhoff MS. Fibular osteoseptocutaneous flap: anatomic study and clinical application. Plast Reconstr Surg. 1986;78:191–9.
42. Wong CH, Ong YS, Chew KY, Tan BK, Song C. The fibula osteoseptocutaneous flap incorporating the hemisoleus muscle for complex head and neck defects: anatomical study and clinical applications. Plast Reconstr Surg. 2009;124:1956–64.
43. Thankappan K, Trivedi NP, Subash P, Pullara SK, Peter S, Kuriakose MA, Iyer S. Three-dimensional computed tomography-based contouring of a free fibula bone graft for mandibular reconstruction. J Oral Maxillofac Surg. 2008;66:2185–92.
44. Eckardt A, Swennen GR. Virtual planning of composite mandibular reconstruction with free fibula bone graft. J Craniofac Surg. 2005;16:1137–40.
45. Roser SM, Ramachandra S, Blair H, Grist W, Carlson GW, Christensen AM, Weimer KA, Steed MB. The accuracy of virtual surgical planning in free fibula mandibular reconstruction: comparison of planned and final results. J Oral Maxillofac Surg. 2010;68:2824–32.
46. Hanasono MM, Skoracki RJ. Computer-assisted design and rapid prototype modeling in microvascular mandible reconstruction. Laryngoscope. 2013;123:597–604.

Computer-Assisted Head and Neck Oncologic Surgery

13

Majeed Rana and André M. Eckardt

13.1 Summary

Over the past years, computer-assisted surgery has gained more importance in craniomaxillofacial surgery, especially in primary and secondary reconstruction of head and neck ablative defects. The clinical application of 3D imaging for head and neck tumors has been facilitated through advances in image analysis and computer technology. Basic requirements for oncologic treatment in the head and neck region include detailed imaging studies using computed tomography (CT), cone beam computed tomography (CBCT) or magnetic resonance imaging (MRI), data transfer to specific 3D image analysis platforms, and the integrated use of specific computer-assisted infrared-based navigation systems. These techniques allow for a preplanned image-guided path to the particular tumor region for taking biopsies, resection, or reconstruction. This chapter will focus on four categories for oncologic surgical procedures in which computer-assisted surgery has been increasingly used in recent years:

1. Preplanned trajectorial-guided tumor biopsy
2. Intraoperative image-controlled tumor resection
3. Virtual 3D tumor mapping
4. Reconstruction after ablative tumor surgery (true to original)

Image-guided navigation technique for head and neck oncologic surgery provides a precise, safe surgical method with excellent real-time anatomic orientation.

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Regarding the advantages of computer-assisted surgery, this technique will play a major part in craniomaxillofacial reconstructive surgery and will address widespread general methodological solutions which are of great interest in multidisciplinary oncologic treatment of head and neck tumors.

13.2 Background

13.2.1 Historical Evolution

In 1908 Horsley and Clarke initially introduced intraoperative planning in neurosurgery based on X-ray pictures with the use of stereotactic systems [1]. These stereotactic systems used head frames rigidly fixed to the patient's skull and maintained in a constant position during image data acquisition and the whole surgical procedure. This method of frame-based stereotaxy is based on a stereotactic atlas used to assign coordinates of intracranial structures to external structures. With the introduction of modern imaging techniques, CT- or MRI-guided stereotactic surgery started with modified conventional stereotactic instruments [2, 3] and later evolved through the development of specialized instrumentation [4, 5]. These modern imaging techniques allowed for a more precise analysis of the individual patient's morphology. In consequence, stereotactic atlases became less important. Frame-based stereotaxy carries several disadvantages such as unreliable determination of the position of the surgical instrument, restriction of the operative field due to the complicated frame assembly, and the frame incompatibility with CT scanning due to artifacts [6, 7].

Watanabe et al. introduced computer-assisted surgery using frameless stereotaxy to neurosurgery in 1987 [8]. Such neuronavigation technique allowed for selective intraoperative localization of anatomical structures based on CT or MRI data sets acquired before surgery. The navigation system and instruments consisted of an articulated mechanical arm linked to a computer workstation. The first commercially available mechanical navigation system that was introduced in 1993 to routine clinical use was the Viewing Wand system (ISG Technologies, Toronto, Ontario, Canada) [9, 10]. Although widely used since 1993 in neurosurgery, head and neck surgery, and craniomaxillofacial surgery, the system had its limitations due to the mechanical coupling of an arm-guided navigation thereby restricting its use in difficult-to-reach areas of the skull base and other head and neck sites [11–13]. Consequently innovative systems using ultrasound-based and electromagnetic navigation systems were developed. A major drawback of electromagnetic systems was their variable stability of the magnetic field, distortion of the magnetic field through metallic objects, and their limited accuracy [14–16]. Mainly due to the lack of intraoperative accuracy, ultrasound-based navigation systems have hardly been used commercially at all [17].

Nowadays, because of their high technical precision and accuracy, optical instrument-based navigation systems are widely used. Heilbrunn et al. introduced the first optical instrument-based navigation system in 1992 [18], and other systems with some modifications followed. These navigation systems follow the principle of instrument tracking by detection of light-emitting diodes (LEDs) through infrared

cameras and offer the advantage of a high technical precision and accuracy in the range of 0.1–0.4 mm [19]. Infrared-based optical navigation systems are increasingly used and are becoming standard for intraoperative navigation in neurosurgery, head and neck surgery, and craniomaxillofacial surgery as well [20–24].

13.2.2 Current Clinical Use of Computer-Assisted Surgery and Future Perspectives

Oncologic head and neck treatment profits more and more from interdisciplinary exchange of information and conferences; however, if it comes to therapy, mainly mono-disciplinary views are applied to the given information: the surgeon is resecting the tumor and reconstructing the area after ablative surgery, the radiotherapist is planning and performing the radiotherapy, and if required, the oncologist is planning and controlling the effect of chemotherapy. Based on our knowledge, there is no software solution commercially available that allows to path all the needed voxel-based data set information through the specific therapeutic strategy. Our intention was to focus on a new software solution and platform generation, based on iPlan 3.0 (Brainlab®, Feldkirchen, Germany).

Advances in image analysis methods and computer-assisted surgery have increasingly facilitated the clinical application of three-dimensional (3D) imaging for head and neck tumors over the last decade [25, 26]. In order to optimize treatment, computer-assisted navigation technology might be a useful tool in tumor resection. For adequate treatment of craniomaxillofacial tumors, a computer-assisted analysis and planning of 3D image data like magnetic resonance imaging (MRI) and computed tomography (CT) are essential for tumor staging. Primary and secondary craniomaxillofacial reconstruction after ablative tumor surgery of the head and neck region, as well as reconstruction of the midface in all kinds of oral cancer, is a major challenge to the reconstructive surgeon [20, 21, 27]. Topographical considerations and the complex three-dimensional (3D) anatomy and geometry of the human skull and face make it difficult to reach pathological lesions localized close to anatomic sensitive structures. The outcome of the surgical intervention often depends on the surgeon's experience and calculations and requires much more extensive transfacial approaches.

An ideal image-analyzing platform is required to fuse multimodal image data (CT, MRI) to plan resection boundaries and required safety margins and to fuse further 3D data for restaging. Intraoperative navigation is also useful in monitoring for tumor recurrence in oncological follow-ups [25]. Furthermore, there is a demand for planning tools for reconstruction and manufacturing of patient-specific implants (PSI). However, different methods of computer-assisted navigation surgery for tumor resection or tumor biopsy have been specified like computer-assisted endoscopic approach [24, 28] or image-guided neurosurgical navigation [29, 30]. These techniques have shown variable accuracy and success and can be considered as partial solutions [24, 28–30]. Still, these techniques are difficult to perform in a daily routine, and additionally, there is a margin of diagnostic error due to scarcity

of harvested material. Some methods are described to use intraoperative CT, which are able to provide intraoperatively imaging [31, 32]. Unfortunately these systems are very expensive. Most of the application devices use virtual segmentation by thresholding to achieve a volumetric facial skeleton with an untextured 3D facial soft tissue surface. However, currently great efforts are required to virtually segment the tumor manually and thus to achieve individually adjustable tumor compounds. Only a few authors report that it was possible to outline safety margins preoperatively and to perform reconstructions exactly as virtually planned [28, 33, 34]. There is a tremendous demand for proper visualization of certain anatomical structures in soft and hard tissues. Therefore most systems are not proved to offer a more precise surgical resection of tumor boundaries. Meanwhile some of them enable also a combination of intraoperative MRI with integrated navigation system for planning tumor resection [35]. However, the clinical routine suffers from a poor handling and an insufficient workflow. The crucial disadvantage is the inaccurate visualization of the segmented tumor and a manual or three-point image fusion system to fuse MRI, CT, and PET-CT Digital Imaging and Communication in Medicine (DICOM) data. Since these systems do not represent a complete 3D planning and navigation software, they have to be supplemented by additional software tools and hardware devices. In consequence, the handling of these systems is of experimental nature, and the precise localization, segmentation, and image fusion of the 3D (voxel-based) tumor position and size are still a challenge. The most promising method of image-guided navigation system iPlan 3.0 (Brainlab®, Feldkirchen, Germany) allows for segmentation of the tumor area, virtual planning of the tumor resection, and biopsy for the diagnosis of lesions. This system may offer an alternative, less traumatic approach to these tumors, as well as to lesions invading the orbita. iPlan 3.0 (Brainlab®) provides a specific language-independent multidisciplinary tool to provide intraoperative collected data (tumor landmarks) to the surgeon, oncologist, radiation oncologist, pathologist, and radiologist.

The purpose of this work was to develop, establish, and clinically evaluate a novel, user-friendly, 3D planning, and navigation software solution for treatment of craniofacial tumors based on advanced autosegmentation and automatically image fusion algorithms and an excellent volume rendering.

13.3 Technical Procedures and Workflow

13.3.1 Preoperative Imaging and Planning

As a basis for tumor treatment planning, CT and MRI images of a patient were recorded, whereas the MRI data set was used to identify the tumor tissue and the CT data set to define and visualize the patient's bony anatomy. During the acquisition of the CT data, either four surgically inserted navigation landmarks (bony landmarks, 2.0 cross-drive titanium miniscrews, or an individual dental splint with additional titanium screws [25]) (Fig. 13.1a) were used for registration of the individual patient. These screws were used as registration points during planning and surgery.

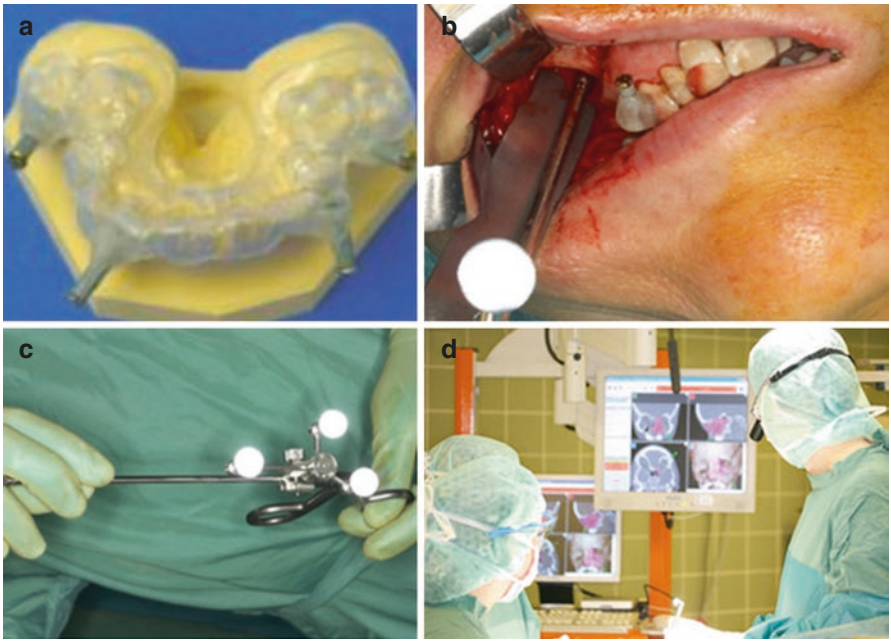

Fig. 13.1 (**a**) Individual dental splint with additional four titanium screws used as registration points during surgery. (**b**) Intraoral view of a biopsy with a forceps. (**c**) Forceps equipped with passive infrared markers, which could be captured by the camera. (**d**) Setup of a navigation-assisted operation

The resulting DICOM data of the patient's anatomy was imported into the planning application (iPlan 3.0, Brainlab®, Feldkirchen, Germany). To understand the clinical situation, a symmetric view of the data and its 3D reconstruction is necessary for further planning; therefore, CT slice is oriented according to the Frankfort horizontal and midsagittal (FHMS) planes in all dimensions (axial, coronal, and sagittal).

After that alignment, both image data sets (CT and MRI) were co-registered by a so-called image fusion, a surface and voxel-based matching method, to have the whole multimodal information available within the previously adjusted alignment. This method of multimodal rigid image registration is based on mutual information, using features like multi-resolution, intensity rebinning, and parameter space scaling.

Similar to this co-registration of data sets, a registration of the real patient with its virtual data set was required during surgery later on. For that registration, reference points like anatomical landmarks could be defined during the planning procedure, whereas the CT data is preferred to set such landmarks. Instead of using anatomical reference points, a dental splint with additional titanium screws was used, as previously described. A method like this provides unobtrusive, rigid, and

exact landmarks which are clearly visible on virtual data sets (CT images) as well as during a navigation procedure, as no surgical preparation is needed to reach those screws. Registration points are then planned virtually on the screw heads within the dental splint.

After all necessary preplanning steps have been finalized, the anatomical structures and the target tumor tissue were segmented out of the image sets. For particular anatomical structures, an automatic atlas-based algorithm was used. The central task of such an algorithm is to find the one-to-one correspondence between a patient's data set and an atlas data set that defines correct and verified anatomical templates. The structures are segmented automatically by an elastic deformation of the templates to match with the patient's anatomy. Given this algorithm, not only bone structures but anatomical regions like the orbit could be segmented and used for further surgical reconstruction planning. As a result of that procedure, we have received all necessary anatomical structures in the area of interest for the tumor resection or biopsy as 3D segmented objects. The tumor shape was outlined manually after using different software tools such as brushing, as a tumor is not automatically recognized and segmented within a patient's anatomy. According to this planning step, we have received clearly defined anatomical representations of the patient's anatomy together with a target region at the tumor position for resection or taking the biopsies. To ensure to reach the exact positions for the target, additional trajectories were planned starting at the exit point of anatomical landmarks or screws and defining a path along the midface or orbital roof directly to the tumor region. Those trajectories could be referenced and used for navigation during surgery as well. All preplanned virtual patient data, objects, and trajectories were transferred to an image-guided surgery system ("navigation system").

13.3.2 Intraoperative Infrared-Based Navigation

Before surgery, the patients were fixed in the "Mayfield Clamp" or a mini tripod "Skull Reference Base" with three trackable spheres, fixed with a single titanium miniscrew on the patient's skull, to identify the exact position and orientation of the patient. Intraoperative accuracy was checked using at least four precise "navigation landmarks." Infrared-based navigation system (Kolibri-Brainlab®) was used intraoperatively.

By using a stereoscopic infrared camera, such a system is able to reference a "real-world patient's" position with its planned virtual data and further to track and display instrument positions in real time. For that, the patient as well as any instrument needs to be equipped with passive infrared markers, which could be captured by the camera. This specific technique also enables the surgeon to guide the tip of any tracked surgical tool (forceps, drill, chisel, and endoscope) or to localize the focus of a surgical microscope (Fig. 13.1b, c). The patient position and anatomy were registered to the preplanned data by inserting the patient with navigational landmarks, like the abovementioned dental splint, and by pointing the screw heads within according to their preplanned positions. During surgery, the position of the

navigation tip was monitored in real time to ensure that the tumor resection or biopsy is exactly at the desired position according to the preoperative virtual planning. Additionally intraoperative landmarks were recorded (acquired) and a "screenshot" was done at every biopsy position or safety margins (Fig. 13.1d). These points (tumor cloud) were transferred to the virtual plan after surgery and helped to identify and define the exact positions of the tumor resection at any time later on.

13.3.3 Postprocessing of the Data Set

The acquired intraoperative landmarks were postoperatively added to the virtual plan. After final release of the histological findings, the individual points were color-coded according to their classification (benign/malignant). Visualization now allows for an optimized three-dimensional information about potential residual tumor.

13.3.4 Export of the Data Set

The DICOM format is a standard for transmitting information in medical imaging and was developed by the DICOM Standards Committee. With iPlan 4.0 beta (not released yet), the acquired point cloud could be written into the patient's DICOM data set. The authors selected only the points with tumor-positive histology. These points (voxel) were allocated with Hounsfield unit of 3500 H. This value is far out of the traditional highest range of around 3100 H and makes manipulation to the original DICOM data set obviously and fast segmentation of the point cloud by using threshold values possible.

13.3.5 Import into the Radiation Therapy Simulation Platform

The thus enhanced DICOM data set (enDICOM) could be imported in any radiation therapy planning platform. The described enDICOM was routinely imported with the Oncentra MasterPlan (Version 3.3, Nucletron, Netherlands/USA) and superimposed with the postoperative CT scan. The well-defined high Hounsfield unit of the selected points facilitates segmentation and visualization of the additional intraoperative information and could be used to plan the geometric and radiological aspects of the therapy.

13.3.6 Surgical Procedures Using Computer-Assisted Oncologic Surgery

13.3.6.1 Preplanned Trajectorial-Guided Tumor Biopsy

Intraorbital space-occupying lesions always pose a challenge both in terms of definite surgical removal and of preoperative tissue sampling for histopathological examination [36]. The following case illustrates the advantages of the preplanned trajectorial-guided

algorithm. A 59-year-old female with an unknown orbital tumor left, described in MRI, was presented in our department with proptosis, pain, and exophthalmos. To assure the diagnosis, trajectorial-guided biopsy was performed (Fig. 13.2a, c).

For the biopsy procedure, the preplanned trajectories defining the path to the tumor region were used (Fig. 13.2b, d). To ensure reaching the exact positions for the target, additional trajectories were planned starting at the exit point of the left infraorbital nerve. An "auto-pilot" feature was implemented to find the correct entry point as well as to adjust the correct direction of the forceps (Fig. 13.2d). This feature displays the deviation from a desired path in all spatial directions to ensure to follow a planned track as accurate as possible. The position of the forceps was monitored in real time in the meantime to ensure to take a biopsy at its exact anatomical position and depth within the orbit. These points were acquired intraoperatively and transferred to the virtual plan after surgery. The tumor region was approached and a representative biopsy was taken. The pathology report confirmed the diagnosis of a lymphoma.

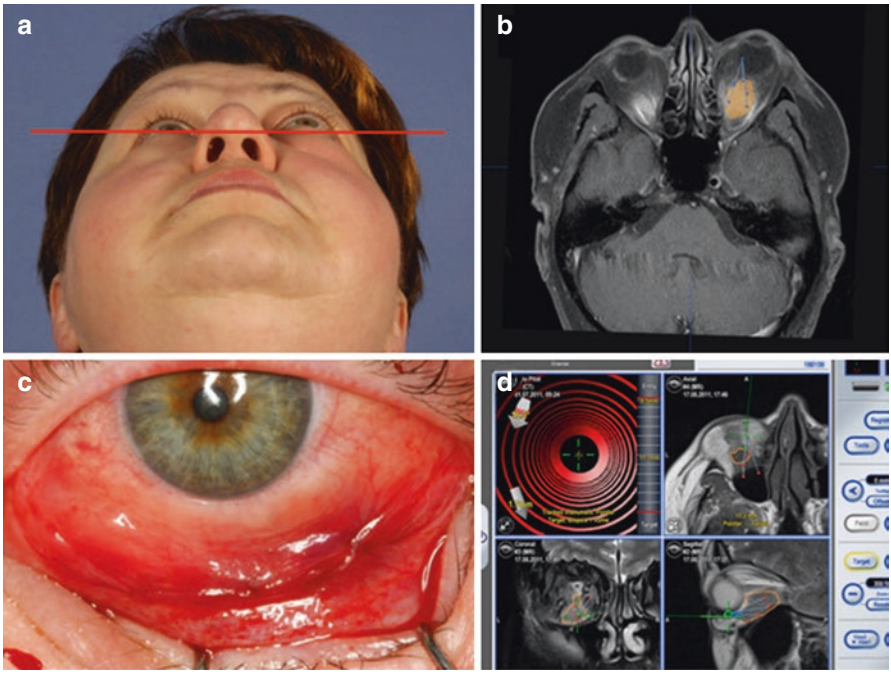

Fig. 13.2 (**a**) Fronto-caudal view of a 59-year-old female with an unknown orbital tumor and a severe exophthalmos left. (**b**) Display of the MRI data set in the axial view; the area to be biopsied was marked preoperatively (*brown*) and can be identified intraoperatively in the multiplanar display of the MRI data set; four preplanned trajectories are marked (*blue*). (**c**) Transconjunctival approach after incision. (**d**) Navigation-assisted exploration of the orbital cavity. The tip is pointing the tumor (*green*), which is displayed in the multiplanar mode (axial, sagittal, and coronal); an auto-pilot feature displays the deviation from a desired path in all spatial directions to ensure to follow a planned track

13.3.6.2 Intraoperative Image-Controlled Tumor Resection

In head and neck oncologic surgery, complete resection and analysis of resection margins are fundamental. Navigation techniques define resection margins more accurately and facilitate complete tumor removal by preserving vital structures [37]. Modern imaging systems fusing DICOM data (MRI/CT/PET-CT) are used in some clinical institutions and are able to demonstrate tumor volume end extension with higher precision than previously [38, 39]. However, even with this combined imaging modality, the intraoperative evaluation of the distance between the resection margins and the tumor margin remains a challenge in oncologic surgery [40].

An 81-year-old male with a residual T4a squamous cell carcinoma (SCC) of the upper lip was presented in our department after tumor resection and radiochemotherapy twice alio loco (Fig. 13.3a) Due to radiation, there was a lack of soft tissue coverage of the left cheek (Fig. 13.3b). After the preplanned image-guided tumor resection, the defect was navigated with the pointer, and the distance between resection margins and the 3D image of the tumor image on the CT was controlled in every direction (Fig. 13.4a). This "safety margin" was created automatically after the segmentation of tumor (Fig. 13.4a). By detection of inadequate distance, additional resection was performed and intraoperative landmarks were recorded (Fig. 13.4b). The resected tumor was presented to the pathologist, who confirmed tumor-free margins (Fig. 13.4c). Soft tissue reconstruction was achieved with a latissimus dorsi flap (Fig. 13.4d). 3D (voxel-based) data set allows to judge the

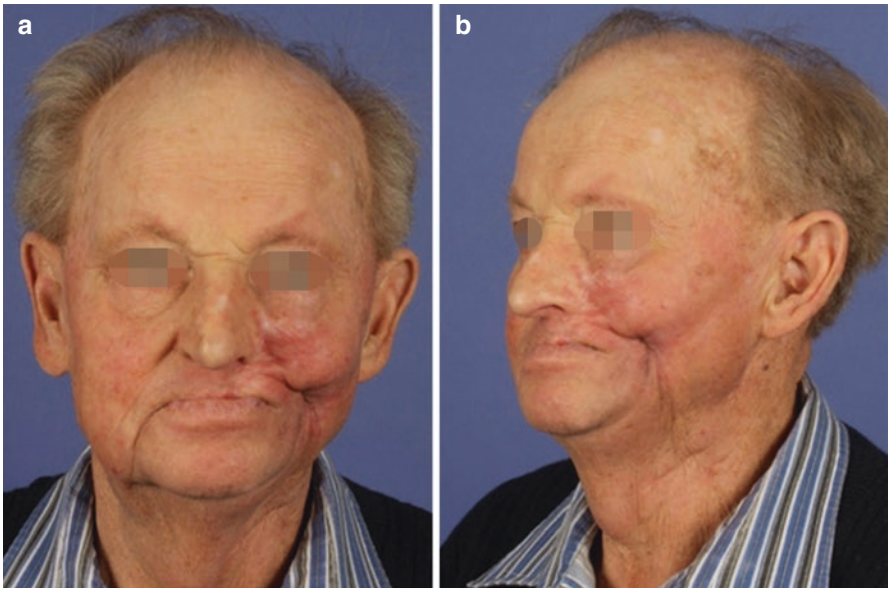

Fig. 13.3 (**a**) Frontal view of an 81-year-old male with a residual T4a squamous cell carcinoma (SCC) of the upper lip after tumor resection and radiochemotherapy alio loco. (**b**) Lateral view demonstrates the lack of soft tissue coverage

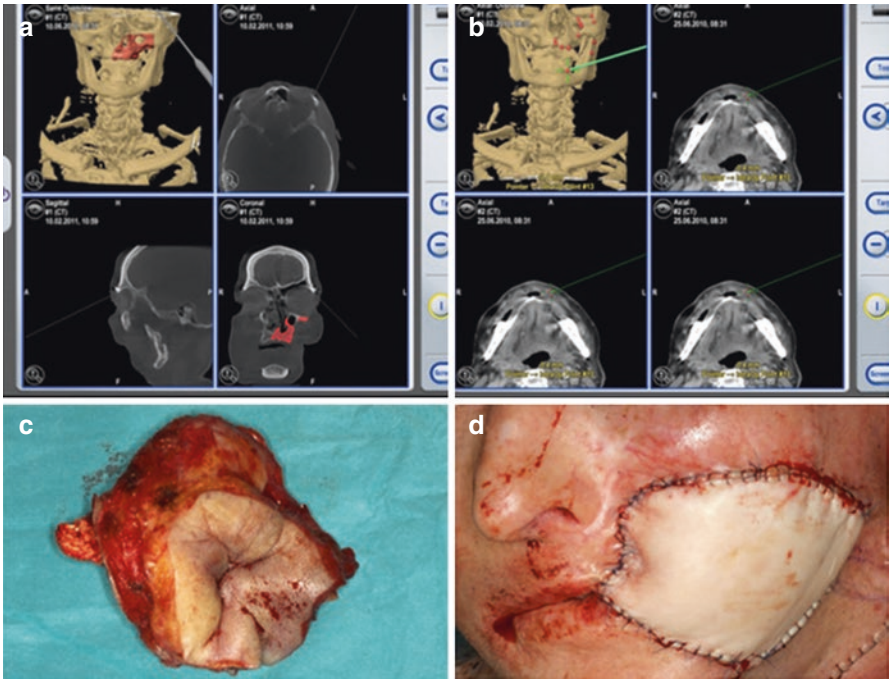

Fig. 13.4 (**a**) The area to be resected was marked preoperatively (*brown*) and can be identified intraoperatively in the multiplanar display of the CT data set planned track. (**b**) Navigation-assisted control of tumor margin. The tip is pointing the tumor (*green*), which is displayed in the multiplanar mode (axial, sagittal, and coronal), intraoperative landmarks acquired at every biopsy. (**c**) Resected tumor of the left cheek. (**d**) Fronto-lateral view after reconstruction with a latissimus dorsi flap

extension of head and neck tumor macroscopically. Preoperatively, the tumor shape and margins can be outlined manually after using different software tools, such as brushing. A major problem during tumor resection (without navigation) is to name and exactly allocate the anatomical 3D position of specimens. Advantage of intraoperative navigation is not only to plan tumor resection margin but also the definitive marking and mapping of frozen sections. These data could be stored and transferred in DICOM format to communicate patient's specific tumor information (invasion to vessels, nerves, skull base, non-resectable tumor) to the oncologist, radiation oncologist, and pathologist for further oncologic treatment.

13.3.7 Virtual 3D Tumor Marking: Exact Intraoperative Coordinate Mapping

Three of the most challenging interfaces in oncologic treatment in head and neck cancer exist between surgeon and pathologist just as between surgeon and radiotherapist and/or oncologist. The former interface is relevant to hopefully confirm the

achieved complete resection (R0 resection) which is especially difficult due to the complex anatomy of the head and neck region. The recording and naming of frozen sections or resection margins do often not allow for later well-defined three-dimensional (3D) orientation. Due to this 3D complexity in between written words and the real location of the malignant lesion, pathologists are not able to rule out residual tumor without consultation of the surgeon, who sometimes has to stitch more to his personal memory than to reliable recorded information.

If there is an indication for adjuvant radiation therapy, such as minimal tumor residuals (R1 resection), the same problem discounts for radiation therapy planning to be challenging: the radiotherapist could not gain access to reliable intraoperative information and uses mainly the results of the histological findings, the operation protocol, and the postoperative computed tomography (CT scan) for the simulation planning.

In summary, histopathological findings should be ideally three-dimensionally mapped, and information should be without loss and ideally language-independent digitally stored, to improve the interdisciplinary interface for the benefit of the patient.

Computer-assisted preoperative planning (CAPP) is commonly used in intraoperative visualization and reconstruction in ablative surgery of the head and neck. Therefore, multimodal three-dimensional imaging could be matched to outline tumor dimensions and demonstrate virtually augmented surgical margins. The minor additional expenses to enable intraoperative navigation ease anatomical orientation and true-to-original reconstruction after ablative surgery. These data could be saved in DICOM format (Digital Imaging and Communication in Medicine) and transferred to pathologists and radiotherapists.

The workflow of virtual 3D marking including preparation, intraoperative setting, and postoperative postprocessing is described and illustrated.

A 79-year-old male with a primary T4a adenoid cystic carcinoma (ACC) of the maxillary sinus and nasal cavity with extension to the infratemporal fossa was planned for ablative tumor surgery. After tumor resection, the position of the forceps was monitored to take specimens from the tumor margin. Additionally, intraoperative landmarks were acquired and a "screenshot" was done at every biopsy. These points (tumor cloud) were transferred to the virtual plan after surgery and helped to identify and define the exact positions of the resection. The specimen showed a margin between tumor and resection of less than 2 mm and positive nodes in the neck dissection were detected in the histopathological report. Unfortunately the specimen collected from the periosteum at the entry of the internal carotid artery in the skull base was positive for tumor infiltration; additional resection was not possible. The intraoperative collected data (tumor cloud) were then forwarded to the radiation oncologist to plan adjuvant radiotherapy. In this manner, the radiotherapy field can be monitored to the postoperative anatomic topography (Fig. 13.5). The novel method of intraoperative marking of specimen either frozen sections or surgical margins eases the storage and further use of intraoperative information. In the field of craniomaxillofacial surgery, indications for this technique are at the moment limited to tumor locations close to hard tissue. But this technique is well used by tumors close to the liver, pancreas,

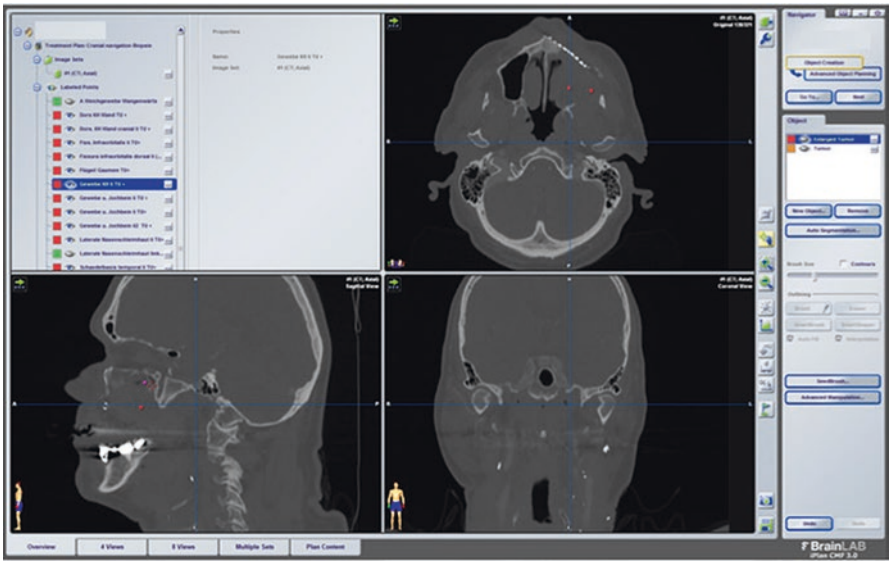

Fig. 13.5 Multiplanar mode (axial, sagittal, and coronal) with intraoperative landmarks acquired at every biopsy; these points (tumor cloud) were transferred to the virtual plan after surgery and helped to identify and define the exact positions of the resection; intraoperative landmark (*violet*) is marked as a minimal tumor residual (R1 resection). This virtually marked DICOM data was exported to the radio oncologist

and adrenal. The more frequently head and neck malignancies affect the mandible, floor of the mouth, and tongue. These locations do not allow for the described method. An adequate soft tissue navigation would be a necessary precondition. Currently, assessing resection margins intraoperatively is possible by means of frozen sections. If positive, they can be a guide to additional resection, but when negative, they add no information about the distance from the tumor of the margin.

13.3.8 Reconstruction After Ablative Tumor Surgery (True to Original)

Loss of hard and soft tissue structures of the midface due to tumor resection is associated with substantial, functional, and aesthetic deficits [41]. Computer-aided design/modeling (CAD/CAM) software that allows "mirroring" planning coupled to navigation systems has dramatically improved surgical strategies in reconstructive surgery of the craniomaxillofacial skeleton, particularly with respect to the prediction of suitable symmetric bone repositioning [22, 42, 43].

A well-established procedure of our institution is demonstrated in a 57-year-old female with a primary T2 squamous cell carcinoma (SCC) of the left maxillary sinus (Fig. 13.6a), in which titanium meshes are customized for individual defect situations using computer-assisted techniques in combination with primary soft tissue transfer. A

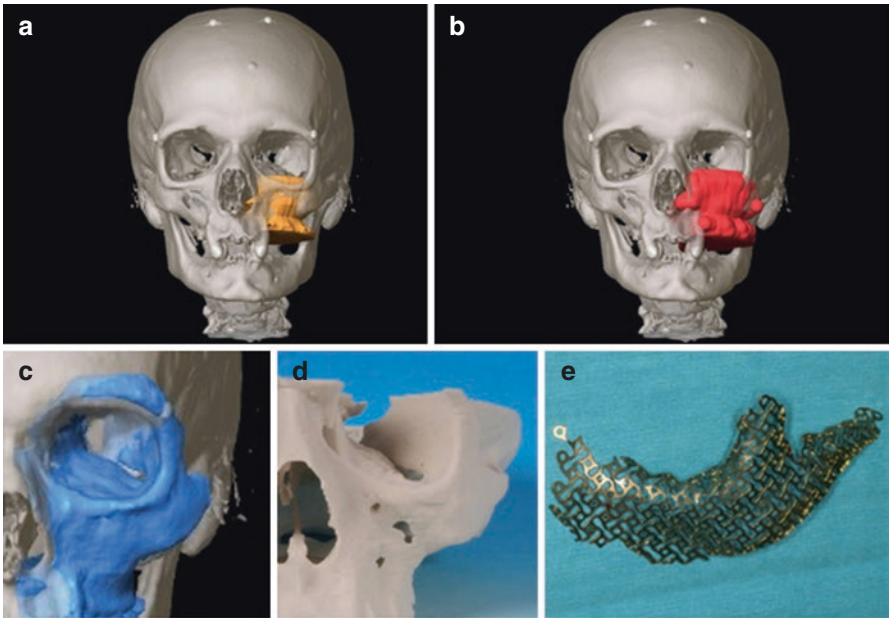

Fig. 13.6 (**a**) Frontal 3D view of a 57-year-old female with a primary T2 squamous cell carcinoma (SCC); the tumor is segmented (*brown*). (**b**) 3D view of the skull with a "safety margin" (*red*), which was created automatically after segmentation of tumor. (**c**) Virtual mirrored template (*blue*) created from the uninvolved right midface. (**d**) A stereolithographic (STL) midfacial skull model, produced via rapid prototype modeling. (**e**) A prebended titanium mesh for reconstruction of the zygoma and left midface

"safety margin" (red) was created automatically after segmentation of tumor (brown) (Fig. 13.6b). After all important preplanning steps for tumor resection have been finalized, the automatic atlas-based algorithm was used to virtually design anatomical region of zygoma and the orbital floor for surgical reconstruction (Fig. 13.6c). A stereolithographic (STL) midfacial skull was exported and produced via rapid prototype modeling (Fig. 13.6d, e). The reconstruction of the orbital floor and zygoma was done with a prebent titanium mesh, and the correct final position of the mesh was controlled with the navigation system. For quality control, the postoperative data set was superimposed with the virtual mirrored template (blue) of the uninvolved right midface and the postoperative result (Fig. 13.7a, b). The correct position of the 3D orbital mesh in the orbital cavity was controlled in the sagittal view (Fig. 13.7c). Soft tissue reconstruction was achieved with a vascularized latissimus dorsi flap (Fig. 13.7d).

13.4 Results

Based on our current experience with 82 patients, we could demonstrate that computer-assisted surgery is a feasible and precise method for the treatment of head and neck tumors. Image-guided tumor resection and reconstruction is a

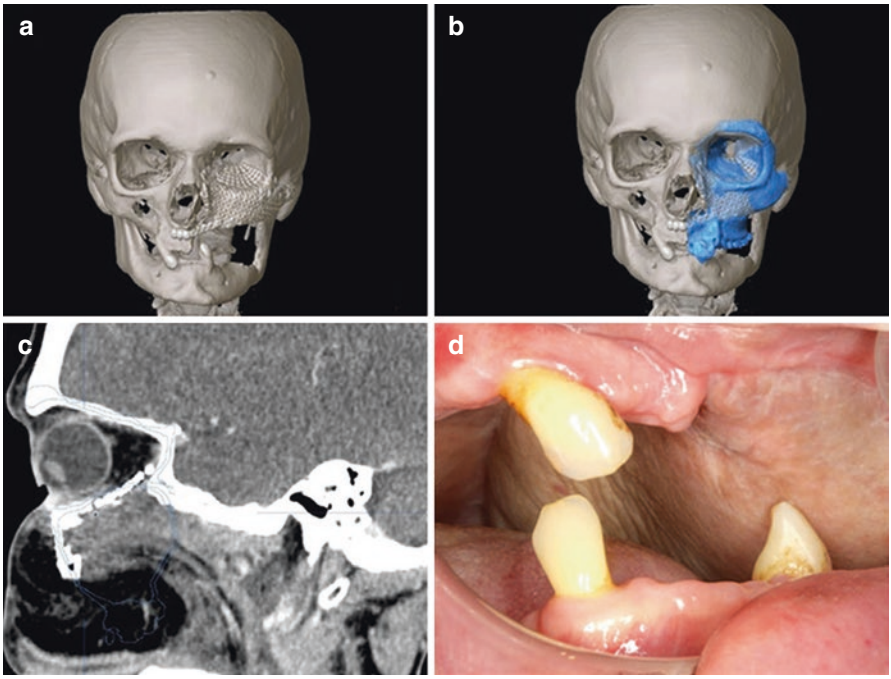

Fig. 13.7 (**a**) Frontal 3D view of a 57-year-old female with a primary T2 squamous cell carcinoma (SCC) after resection and reconstruction with the patient-specific implant. (**b**) Superimposition of the virtual mirrored template (*blue*) and the postoperative result (3D view). (**c**) Sagittal view demonstrating the correct position of the 3D orbital mesh in the orbital cavity. (**d**) Intraoral view after tumor resection and reconstruction with a latissimus dorsi flap 6 months postoperative

well-established procedure at our institution for complex craniomaxillofacial procedures.

For all cases, image data suitable for navigation was obtained and successfully processed. The time needed for preoperative planning including data transfer, data set alignment, automatic and manual object segmentation, trajectories, and additional safety checkups took about 20 min.

Before any surgical navigation can occur, the planned anatomical landmarks or registration markers (fiducial markers, screw heads) must be exposed, and a point-to-point matching registration process, including meticulous landmark checks, must be done. This procedure, which was performed by a resident, required about 2–5 min, depending on the type of landmark planned. The registration of patient data at the navigation system using screws as fiducial markers delivered a navigation accuracy with a mean deviation of 1.3 ± 0.6 mm in our cases. Additional landmark checks performed from time to time during the whole surgical procedure revealed exceptionally high accuracy without any measurable discrepancies. The navigational parts of the surgery took about 20 min altogether.

In cases where intraoperative scanning has been performed, the time-out for image acquisition took about 10–15 min. The data transfer to the navigation system

including image co-registration with the planned data was performed automatically at a time range of 2–5 min.

The surgical time saved could not be quantified objectively. But qualitatively improvements were achieved in terms of better orientation within a data set, easier selection of biopsy positions, and faster reconstructions with an instant quality feedback. If postoperative data was acquired following up to the surgery, it has been fused with the pre- and intraoperative data for quality control and evaluation directly on the navigation system within 5 min. High levels of consistency between the fused preoperative plan and intra- as well as postoperative CT data set were seen. In addition, all data and results were transferred back to the planning system for follow-up inspections of the biopsy positions marked during the surgery.

13.5 Discussion

Many studies in oral and maxillofacial surgery have addressed the benefit of computer-assisted surgery in treatment of head and neck tumors [20–22, 25, 44]. A number of different techniques have been used for computer-assisted tumor resection or biopsy [25, 26]. In this work, we could demonstrate a new and precise method of preplanned trajectorial-guided tumor biopsy.

Modern imaging techniques like CT and MRI have dramatically improved oncologic staging in the last 20 years in the head and neck region and are able to demonstrate with greater accuracy both the bulk and the extension of the tumor [45]. Still there is a demand of an ideal image-analyzing platform to fuse multimodal image data (CT, MRI, PET-CT) to plan oncologic treatment. Currently assessing resection margins intraoperatively is possible by means of frozen sections. If positive, they can be a guide to additional resection, but when negative, they add no information about the distance from the tumor of the margin [40]. Computer-assisted oncologic surgery increases reliability by facilitating correct safety margins and protecting vital structures. In addition, it increases the precision of radiotherapy planning and it facilitates the reconstruction process [25, 34]. For the postoperative follow-up, it is a useful tool to correlate and transfer the outlined tumor boundaries into various image data sets to capture tumor recurrences or the result of adjuvant chemo- and radiotherapy to improve treatment outcome and quality of life [45, 46]. Surgeons still have to know that the virtual segmented tumor is not a histopathological margin.

Reconstruction in the oral and maxillofacial region is a difficult task. Anatomical, functional, and aesthetic aspects have to be taken into account while performing reconstructive surgery [27]. Relating to our results, computer-assisted surgery using the automatic atlas-based algorithm is a feasible tool for surgical reconstruction. It segments a patient's anatomical structures automatically and delivers specific templates for rebuilding defective regions. The additional time invested in the planning process is saved during surgery by an easier interpretation of the clinical situation and the possibility of quality control performed on the fly by real-time instrument tracking.

Registration technique used in surgical treatment of head and neck tumor is a key element in the precision of surgical navigation [47]. So the authors recommend to use 2.0 cross-drive titanium miniscrews or a dental splint with additional titanium screws. Bony or anatomical landmarks should serve as a backup. Main aspect of pre-, intra-, and postoperative virtual planning is quality control of treatment strategy. Future research in this area should focus on soft tissue assessment with a skin surface prediction based on planning data and a visualization enhanced by superimposition of skin surface scan data (e.g., VRML data) and hard tissue (e.g., based on CT DICOM data). Further, an automated generation of computer-designed patient-specific implants (PSI) should be investigated together with a guided and navigated implant positioning during surgery.

Conclusions

In recent years, reports on the use of 3D preoperative planning tools together with intraoperative navigation in craniomaxillofacial oncologic and reconstructive surgery had been published in an increasing number. Such imaging-guided navigation technique for head and neck oncologic surgery provides a precise, controlled, safe, and minimal invasive surgical method with excellent real-time anatomic orientation, thereby improving the surgeon's ability to accurately diagnose, plan, and perform ablative surgery as well as complex reconstructive surgery of craniomaxillofacial defects. Regarding the advantages of computer-assisted surgery, this technique will continue to play a role in craniomaxillofacial reconstructive surgery. However, before such technique gains further widespread acceptance, outcome studies as well as cost/benefit analyses are definitively needed.

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References

1. Horsley V, Clarke RH. The structure and function of the cerebellum examined by a new method. Brain. 1908;31:45–124.
2. Leksell L, Jernberg B. Stereotaxis and tomography. Acta Neurochir. 1980;52:1–7.
3. Goerss S, Kelly PJ, Kall B, Alker GJ. A computed tomographic stereotactic adaptation systems. Neurosurgery. 1982;54:375–9.
4. Perry JH, Rosenbaum AE, Lunsford LD, Swinck CA, Zorub DS. Computed tomography-guided stereotactic surgery: conception and development of a new stereotactic methodology. Neurosurgery. 1980;7:376–81.
5. Apuzzo MLJ, Sabshin JK. Computed tomographic guidance stereotaxis in the management of intracranial mass lesions. Neurosurgery. 1983;12:277–84.
6. Anon JB, Klimek L, Mösges R, Zinreich SJ. Computer-assisted endoscopic sinus surgery. Adv Sinus Nasal Surg. 1997;30:389–401.

7. Bale RJ, Vogele M, Freysinger W, Gunkel AR, Martin A, Bumm K, Thumfahrt WF. Minimally invasive head holders to improve the performance of frameless stereotactic surgery. Laryngoscope. 1997;107:373–7.
8. Watanabe E, Watanabe T, Manaka S, Mayanagi Y, Takakura K. 3D digitizer (Neuronavigator): new equipment for computed tomography-guided stereotactic surgery. Surg Neurol. 1987;27:543–7.
9. Guthrie BL, Adler JR. Computer-assisted preoperative planning, interactive surgery and frameless stereotaxy. Clin Neurosurg. 1992;38:112–31.
10. Golfinos JG, Fitzpatrick BC, Smith LR, Spetzler RF. Clinical use of a frameless stereotactic arm: results of 325 cases. J Neurosurg. 1995;83:197–205.
11. Freysinger W, Gunkel AR, Martin A, Bale RJ, Vogele M, Thumfahrt WF. Advancing ear, nose and throat computer-assisted surgery with the arm-based ISG Viewing Wand: the stereotactic suction tube. Laryngoscope. 1997;67:690–3.
12. Barnett GH, Kormos DW, Steiner CP, Weisenberger J. Intraoperative localization using armless, frameless stereotactic wand. J Neurosurg. 1993;78:510–4.
13. McDermott MW, Gutin PH. Image-guided surgery for skull base neoplasms using the ISG viewing wand. Neurosurg Clin N Am. 1996;7:285–95.
14. Metson R, Glicklich RE, Cosenza M. A comparison of image guidance systems for sinus surgery. Laryngoscope. 1998;108:1164–70.
15. Kato A, Yoshimine T, Hayakawa T, Tomita Y, Ikeda T, Mitomo M, Harada K, Mogami H. A frameless, armless navigational system for computer-assisted neurosurgery. J Neurosurg. 1991;74:845–9.
16. Fried MP, Kleefield J, Gopal H, Reardon E, Ho BT, Kuhn FA. Image-guided endoscopic surgery: results of accuracy and performance in a multicenter clinical study using an electromagnetic tracking system. Laryngoscope. 1997;43:594–601.
17. Mösges R. Computer-assistierte Chirurgie im Kopf- und Halsbereich. Forum der Medizin-Informatik. 1998;4:4–9.
18. Heilbrunn MP, McDonald P, Wiker C, Köhler S, Peters W. Stereotactic localization and guidance using a machine vision technique. Stereotact Funct Neurosurg. 1992;58:94–8.
19. Khadem R, Yeh CC, Sadeghi-Tehrani M, et al. Comparative tracking error analysis of five different optical tracking systems. Comput Aided Surg. 2000;5:98–107.
20. Markiewicz MR, Bell RB. Modern concepts in computer-assisted craniomaxillofacial reconstruction. Curr Opin Otolaryngol Head Neck Surg. 2009;19:295–301.
21. Katikaneni R, Hirsch D, Markiewicz MR, et al. Computer-assisted virtual planning in maxillofacial reconstruction using microvascular free fibula flaps. J Oral Maxillofac Surg. 2010;68 Suppl 9:e26–7.
22. Hanasono MM, Jacob RF, Bidaut L, et al. Midfacial reconstruction using virtual planning, rapid prototype modelling, and stereotactic navigation. Plast Reconstr Surg. 2010;126:2002–6.
23. Vougioukas VI, Hubbe U, van Velthofen V, et al. Neuronavigation-assisted cranial reconstruction. Neurosurgery. 2007;55:162–7.
24. Koele W, Stammberger H, Lackner A, Reittner P. Image guided surgery of paranasal sinuses and anterior skull base – five years experience with the InstaTrak-System. Rhinology. 2002;40:1–9.
25. Schramm A, et al. Computer-assisted navigation in craniomaxillofacial tumors. J Craniofac Surg. 2008;19(4):1067–74.
26. Bell RB. Computer planning and intraoperative navigation in cranio-maxillofacial surgery. Oral Maxillofac Surg Clin North Am. 2010;22(1):135–56.
27. Rana M, Warraich R, Kokemüller H, Lemound J, Essig H, Tavassol F, Eckardt A, Gellrich NC. Reconstruction of mandibular defects – clinical retrospective research over a 10-year period. Head Neck Oncol. 2011;3:23.
28. Kingdom TT, Delgaudio JM. Endoscopic approach to lesions of the sphenoid sinus, orbital apex, and clivus. Am J Otolaryngol. 2003;24:317–22.

29. Hejazi N. Frameless image-guided neuro-navigation in orbital surgery: practical applications. Neurosurg Rev. 2006;29:118–22.
30. Vougioukas VI, Hubbe U, Hochmuth A, Gellrich NC, van Velthoven V. Perspectives and limitations of image-guided neurosurgery in pediatric patients. Childs Nerv Syst. 2003;19(12):783–91.
31. Uhl E, Zausinger S, Morhard D, et al. Intraoperative computer tomography with integrated navigation system in a multidisciplinary operating suite. Neurosurgery. 2009;64:231–9.
32. Heiland M, Habermann CR, Schmelzle R. Indications and limitations of intraoperative navigation in maxillofacial surgery. J Oral Maxillofac Surg. 2004;62(9):1059–63.
33. Hohlweg-Majert B, Schoen R, Schmelzeisen R, et al. Navigational maxillofacial surgery using virtual models. World J Surg. 2005;29:1530–8.
34. Schramm A, Gellrich NC, Schoen R, et al. Advantages of computer assisted surgery in the treatment of cranio-maxillo-facial tumors. In: Lemke HU, Inamura K, Vannier MW, Farman AG(H), editors. Computer assisted radiology and surgery: proceedings of the 13th international congress and exhibition, Paris, 23-26 June 1999. New York: Elsevier; 1999. p. 903–7.
35. Moche M, Busse H, Dannenberg C, Schulz T, Schmitgen A, Trantakis C, Winkler D, Schmidt F, Kahn T. Fusion of MRI, fMRI and intraoperative MRI data. Methods and clinical significance exemplified by neurosurgical interventions. Radiologe. 2001;41(11):993–1000.
36. Eckardt A, Rana M, Essig H, Gellrich NC. Orbital metastases as first sign of metastatic spread in breast cancer: Case report and review of the literature. Head Neck Oncol. 2011;3:37.
37. Schramm A, Gellrich NC, Schoen R, et al. Non invasive referencing in computer assisted surgery. Med Biol Eng Comput. 1999;37:644–5.
38. Beyer T, Townsend DW, Brun T, Kinahan PE, Charron M, Roddy R, Jerin J, Young J, Byars L, Nutt R. A combined PET/CT scanner for clinical oncology. J Nucl Med. 2000;41:1369–79.
39. Cohade C, Wahl RL. Applications of positron emission tomography/computed tomography image fusion in clinical positron emission tomography clinical use, interpretation methods, diagnostic improvements. Semin Nucl Med. 2003;33:228–37.
40. Feichtinger M, Pau M, Zemann W, Aigner RM, Kärcher H. Intraoperative control of resection margins in advanced head and neck cancer using a 3D-navigation system based on PET/CT image fusion. J Craniomaxillofac Surg. 2010;38(8):589–94.
41. Kokemueller H, et al. Complex midfacial reconstruction: a combined technique of computer-assisted surgery and microvascular tissue transfer. J Oral Maxillofac Surg. 2008;66(11): 2398–406.
42. Terzic A, Scolozzi P. Image guided surgical navigation integrating “mirroring” computational planning based on intra-operative cone-beam CT imaging: a promising new approach for management of primary bilateral midfacial fractures. Comput Aided Surg. 2011;16(4):170–80.
43. Schramm A, Wilde F. Computer-assisted reconstruction of the facial skeleton. HNO. 2011;59:800–6.
44. Eckardt A, Swennen GR. Virtual planning of composite mandibular reconstruction with free fibula bone graft. J Craniofac Surg. 2005;16:1137–40.
45. Stoeckli SJ, Steinert H, Pfaltz M, Schmid S. Is there a role for positron emission tomography with 18F-Fluorodeoxyglucose in the initial staging of nodal negative oral and oropharyngeal squamous cell carcinoma. Head Neck. 2002;24:345–9.
46. Gellrich NC, et al. Follow-up in patients with oral cancer. J Oral Maxillofac Surg. 2002;60(4):380–7.
47. Eggers G, Mühling J, Marmulla R. Image-to-patient registration techniques in head surgery. Int J Oral Maxillofac Surg. 2006;35:1081.
48. Rana M, Essig H, Eckardt AM, Tavassol F, Ruecker M, Schramm A, Gellrich NC. Advances and innovations in computer-assisted head and neck oncologic surgery. J Craniofac Surg. 2012;23(1):272–8. https://doi.org/10.1097/SCS.0b013e318241bac7.
49. Essig H, Rana M, Meyer A, Eckardt AM, Kokemueller H, von See C, Lindhorst D, Tavassol F, Ruecker M, Gellrich NC. Virtual 3D tumor marking-exact intraoperative coordinate mapping improve post-operative radiotherapy. Radiat Oncol. 2011;6:159. https://doi.org/10.1186/1748-717X-6-159.

14 Minimally Invasive Techniques: Transoral Robotic Surgery and Photodynamic Therapy

Hassan Arshad

Chemoradiation is the standard at many cancer centers for the treatment of oropharyngeal cancers. Transoral robotic surgery (TORS) has reintroduced surgery as a viable option for patients with cancers of the tonsil and tongue base. Some cancers that were previously resected with midline mandibulotomies are now taken out completely from a less invasive transoral route. TORS can be used to resect tumors of the tonsil, tongue base, supraglottic structures, parapharyngeal space, nasopharynx, and some glottic tumors [1, 4, 9, 10, 12]. Its use in the oral cavity is limited, but it can be used to remove retromolar trigone tumors [5].

The robot is controlled by the surgeon sitting at a console. The console and the robotic camera give the surgeon a clear 3D view of the operative field. The robot has four working arms, three of which are typically used in head and neck surgery (two operative arms and one camera arm). The working arms can be mounted with cautery, graspers, dissectors, or needle drivers. TORS is essentially a four-handed surgery because a first assistant is required at the head of the bed (Fig. 14.1).

Advantages of TORS are many. Patients have a shorter hospital recovery time compared to standard open surgical techniques. Some patients may avoid the need for postoperative radiation and/or chemotherapy. In addition, mounting evidence points to better swallowing outcomes when compared to chemoradiation [6, 8]. Disadvantages include the cost of the robot and the learning curve involved in becoming proficient with TORS.

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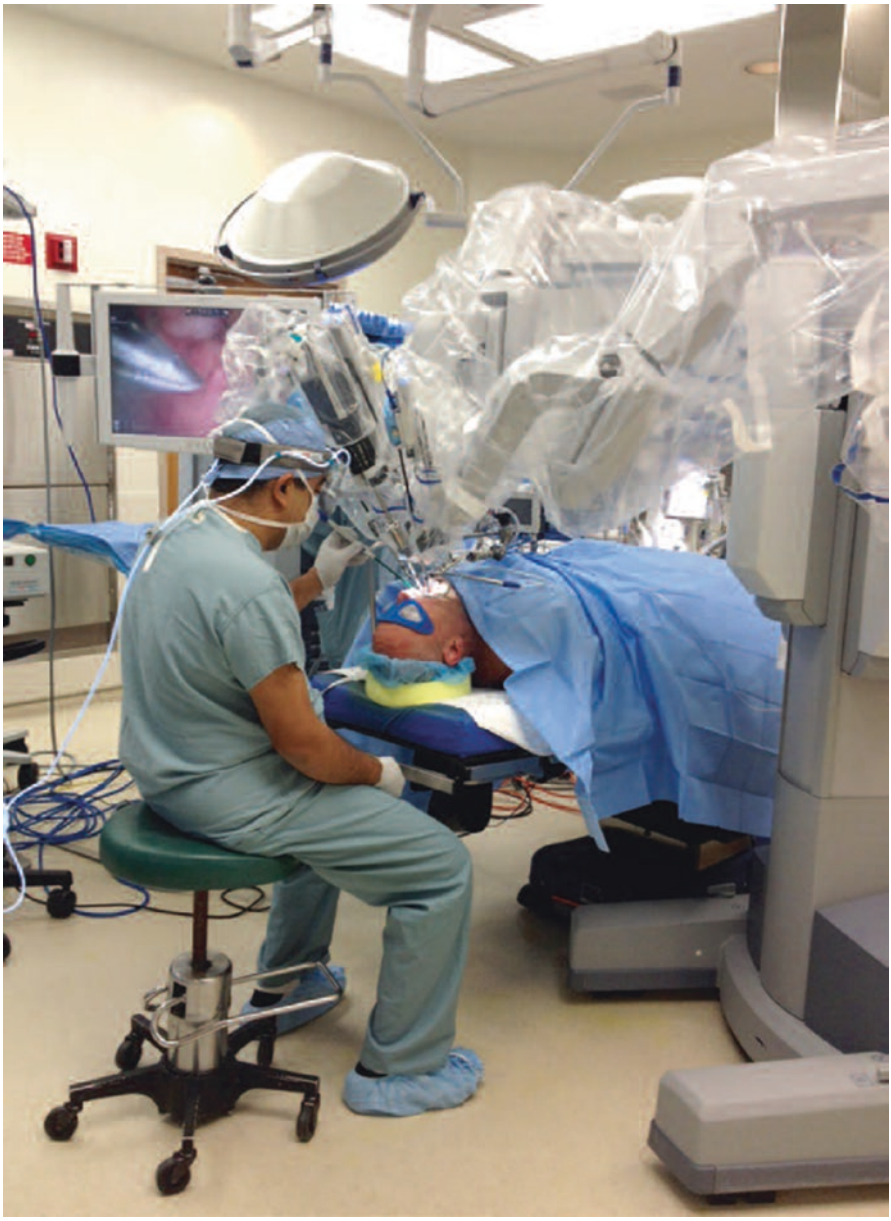

Fig. 14.1 Assistant sitting at the head of bed with robot docked at bedside

When deciding to perform TORS, there are several considerations. Favorable patient anatomy is key. One must be able to visualize the tumor and margins adequately. Patients with trismus or a large body habitus may not be candidates. If it is likely that the patient will require chemoradiation postoperatively, adding TORS

may also not be beneficial (i.e., the patient may not get an additional survival benefit from trimodality treatment). Also, if the resection will require free flap reconstruction, an open surgery may be more straightforward, although some groups have reported robotic insetting of flaps [7].

14.1 Photodynamic Therapy

Photodynamic therapy (PDT) has been used for head and neck cancers since the 1980s but has not gained widespread use despite its effectiveness. PDT is used for cancers of the skin, GI tract, lung/bronchus, and GU tract. The process is relatively straightforward and minimally invasive. The patient is exposed to a photosensitizing agent (by intravenous injection, topical application, or intralesional injection). The drug is then selectively taken up by cancer cells, with less absorption into normal

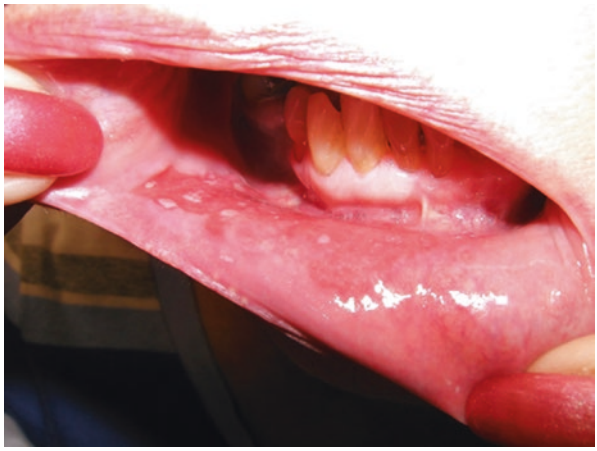

Fig. 14.2 Preoperative view of patient with oral squamous cell carcinoma, before photodynamic therapy

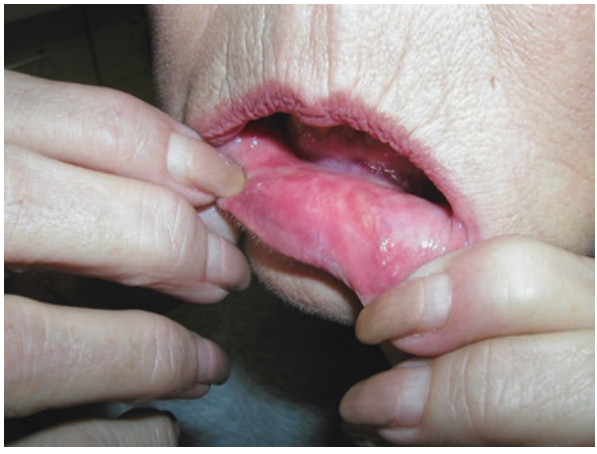

Fig. 14.3 Patient in Fig. 14.2, 2 months after PDT treatment

tissues. A non-cutting laser light of a specific wavelength is then used to activate the drug. Cell death occurs by the formation of radical oxygen species and vascular shutdown to the tumor. Because there is minimal absorption in the surrounding tissues and the light is focused on the tumor and margins, there is little collateral damage. The main side effects for the patient are pain at the treatment site and photosensitivity. The treated site heals with minimal scarring (Figs. 14.2 and 14.3). For head and neck cancers, PDT has an established track record in the treatment of early carcinomas of the oral cavity and larynx. Authors report outcomes comparable to conventional methods of treatment with surgery and radiation [2, 3, 11].

References

1. Arshad H, Durmus K, Ozer E. Transoral robotic resection of selected parapharyngeal space tumors. Eur Arch Otorhinolaryngol. 2013;270(5):1737–40. doi:10.1007/s00405-012-2217-y.
2. Biel MA. Photodynamic therapy treatment of early oral and laryngeal cancers. Photochem Photobiol. 2007;83(5):1063–8.
3. Biel MA. Photodynamic therapy of head and neck cancers. Methods Mol Biol. 2010;635:281–93.
4. Carrau RL, Prevedello DM, de Lara D, Durmus K, Ozer E. Combined transoral robotic surgery and endoscopic endonasal approach for the resection of extensive malignancies of the skull base. Head Neck. 2013;35(11):E351–8. doi:10.1002/hed.23238.
5. Durmus K, Apuhan T, Ozer E. Transoral robotic surgery for retromolar trigone tumours. Acta Otorhinolaryngol Ital. 2013;33(6):425–7.
6. Dziegielewski PT, Teknos TN, Durmus K, Old M, Agrawal A, Kakarala K, Marcinow A, Ozer E. Transoral robotic surgery for oropharyngeal cancer: long-term quality of life and functional outcomes. JAMA Otolaryngol Head Neck Surg. 2013;139(11):1099–108. doi:10.1001/jamaoto.2013.2747.
7. Ghanem TA. Transoral robotic-assisted microvascular reconstruction of the oropharynx. Laryngoscope. 2011;121(3):580–2. doi:10.1002/lary.21428.
8. Hurtuk AM, Marcinow A, Agrawal A, Old M, Teknos TN, Ozer E. Quality-of-life outcomes in transoral robotic surgery. Otolaryngol Head Neck Surg. 2012;146(1):68–73. doi:10.1177/0194599811421298.
9. O'Malley Jr BW, Weinstein GS, Snyder W, Hockstein NG. Transoral robotic surgery (TORS) for base of tongue neoplasms. Laryngoscope. 2006;116(8):1465–72. doi:10.1097/01.mlg.0000227184.90514.1a.
10. Ozer E, Alvarez B, Kakarala K, Durmus K, Teknos TN, Carrau RL. Clinical outcomes of transoral robotic supraglottic laryngectomy. Head Neck. 2013;35(8):1158–61. doi:10.1002/hed.23101.
11. Shafirstein G, Rigual NR, Arshad H, Cooper MT, Bellnier DA, Wilding G, Tan W, Merzianu M, Henderson BW. Photodynamic therapy with 3-(1′-hexyloxyethyl) pyropheophorbide a (HPPH) for early stage cancer of the larynx- phase Ib study. Head Neck. 2015. doi:10.1002/hed.24003.
12. Weinstein GS, O'Malley Jr BW, Snyder W, Sherman E, Quon H. Transoral robotic surgery: radical tonsillectomy. Arch Otolaryngol Head Neck Surg. 2007;133(12):1220–6.

Prosthetic Reconstruction of the Orofacial Region

15

G. Gehl

15.1 Introduction

The term "epithesis" refers to aesthetic coverage of defects using alloplastic material. An epithesis serves as an aesthetic cover, which is designed to restore a defect to a natural contour and complexion (*epi thema*, Greek: an object that is placed on something = lid). Epitheses already showed their worth in the sixteenth century with the designs of the French military surgeon Ambroise Paré, who treated various facial injuries caused by cutting and stabbing weapons with defect coverage. "Epithesis" eventually became established as a technical term in Central European languages. Midface defects were also caused by syphilis and lupus vulgaris until the mid-twentieth century. These facial defects were functionally and aesthetically corrected with concealers and epitheses [50]. Epitheses became particularly important after the First World War, when countless wounded soldiers survived thanks to advances in surgery, and epitheses served as replacements for injured facial contours.

However, after the Second World War, advances in microsurgery, pharmacology, and anesthesia gradually reduced the use of facial epitheses, and the vast improvements in trauma surgery and diagnosis often ensure the maintenance or restoration of natural tissues and organ structures [18, 34, 57].

However, the epithesis is gaining new and global significance in relation to tumor surgery; innovations in aesthetic design of epitheses are provided by practitioners of the fine arts or medical artists and dental technicians during tumor surgery [3, 9, 52,

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54]. However, most native English speakers are not familiar with the term "epithesis" and refer to "facial prostheses" and "somato prostheses," terms that are quite appropriate for the current trend, since the options for fixation with osseointegrated titanium implants mean that the substitute serves not just as a passive aesthetic object for covering defects but that implant retention construction now has a functional prosthetic significance and the anchorage has a biomechanical or bioactive interrelationship with adjacent and impacting tissue structures [6, 53]. Since epitheses play an important functional role, we will refer to them in the following as facial prostheses and prosthetic rehabilitation, according to common usage in the Anglo-American literature.

15.2 Indications for Facial Prostheses

Tumors are often detected early by routine checks and modern imaging techniques. With tumor resections, the wound cavity can often be covered and restored in a single session. However, recurrence is not uncommon. After several follow-up resections, the end result is an extensive defect, which cannot always be covered satisfactorily and aesthetically with plastic surgery. In these cases, a facial prosthesis serves as a removable long-term temporary measure, usually made of flexible silicone. This enables observation of the defect region with direct visualization as well as imaging procedures over a monitoring period of 3–5 years (Fig. 15.1a, b). Such a monitoring period seems to be advisable so that restoration with plastic surgery after a possible recurrence is viable for longer. The recommendation of Olbrisch [46] to minimize surgical trauma in order to protect both the patient and

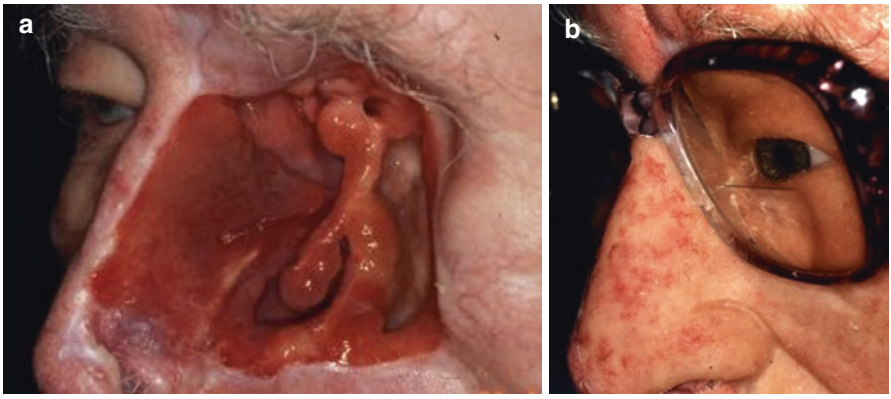

Fig. 15.1 (**a**) Extensive midface defect after recurrent basal cell carcinoma in a 67-year-old patient. Direct visual monitoring of the defect cavity. (**b**) Defect coverage with spectacle-retained silicone facial prosthesis

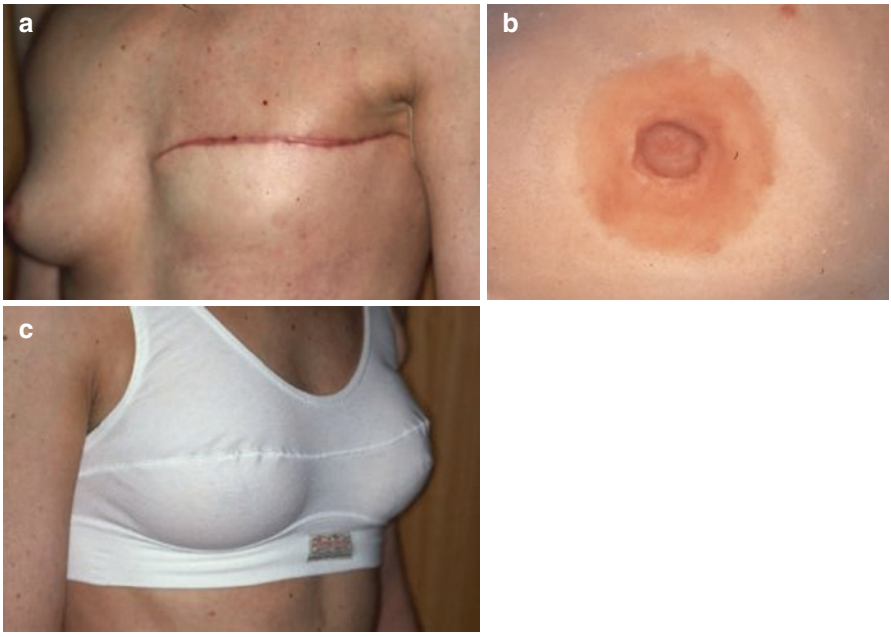

Fig. 15.2 (**a**) Status postmastectomy (*left*) of a 41-year-old patient. (**b**) The custom-made foam-filled silicone prosthesis. (**c**) Volume compensation with custom-made silicone foam prosthesis. The prosthesis is held in place by an aerobic bra. It is therefore very suitable for sportswomen

his tissue is certainly appropriate in this context. Prostheses are therefore used primarily after tumor resection in the craniofacial region as well as in rehabilitation after partial or total mastectomy [25, 27, 30, 31] (Fig. 15.2a–c).

Facial prostheses may also be used for accident patients if part of the face (e.g., with traumatic ablation of the external ear) requires temporary or definitive replacement with a facial prosthesis. Finger replacements after traumatic loss were made out of dental PMMA prosthesis plastic [41] and are still (with modified processing technology) an option today [7]. Silicone prostheses are also used to correct traumatic defects of the hand and calf (Fig. 15.3a–e).

Finally, new options for surgical treatment are starting to benefit patients with congenital craniofacial malformations. In the surgical correction of facial malformations, callus distraction of the mandible with intraoral access is increasingly used in childhood for early improvement of speech, swallowing, and masticatory function (Fig. 15.4) [51]. Simultaneous treatment with bone-anchored hearing aids (BAHAs) significantly improves the communication and learning ability of these patients. From an aesthetic viewpoint, unilateral or

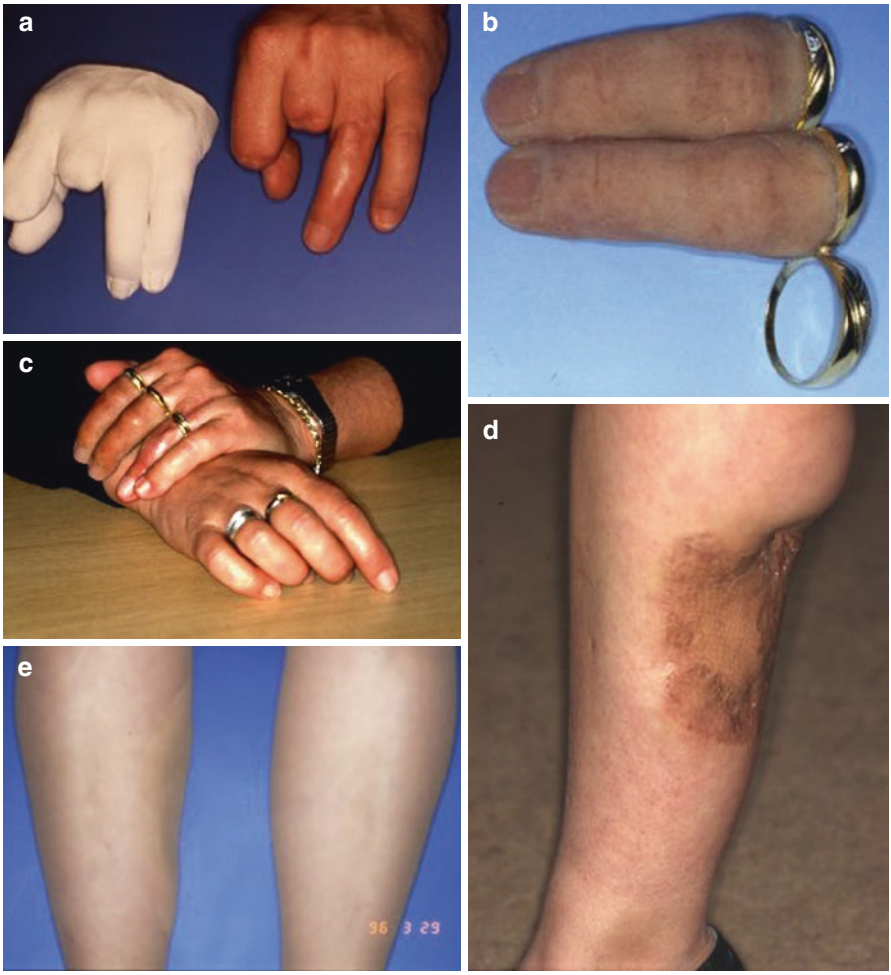

Fig. 15.3 (**a**) Status post lawnmower injury in a 42-year-old patient, impression for working model. (**b**) The prosthesis is retained on the remaining fingers with a ring anchor on the ring finger on one side and positioning on the stump of the index finger on the other side. The middle finger stump provides no support. The middle finger is therefore incorporated into the prosthesis as a tangential member. (**c**) Silicone prosthesis in situ, functionally splinted with gold framework. Splinting improves grasping function as well as retention on the remaining fingers. (**d**) Calf defect in a 34-year-old patient after walking into a glass door. (**e**) Volume compensation with a foam-filled silicone prosthesis. This is held in place by the tights that the patient is wearing

bilateral incorporation of implant-retained auricular epitheses is a significant therapeutic improvement [26]. Functional and aesthetic correction with surgical prostheses should therefore be discussed (and perhaps undertaken) before young patients start school.

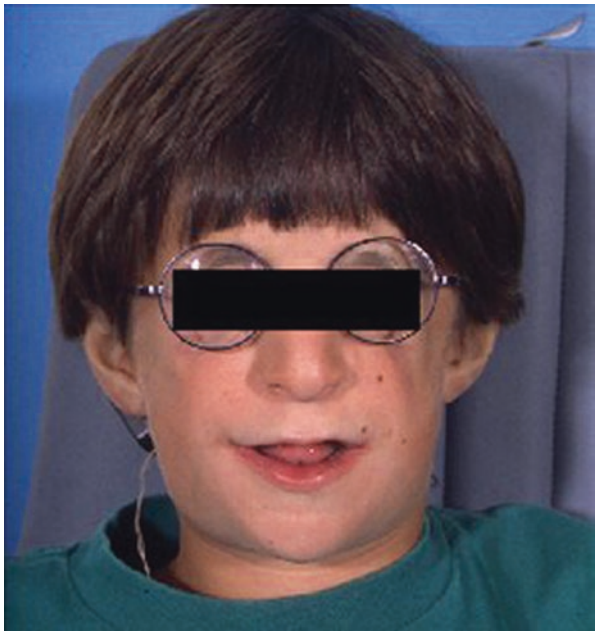

Fig. 15.4 Eight-year-old patient after bilateral distraction osteogenesis of the mandible. Implant-retained auricular prosthesis (*right* and *left*), as well as BAHA on *right*

15.3 Impression Making for Facial Prosthesis Production

The doctor or orthodontist is responsible for planning the production and placement of facial prostheses. This also applies to making impressions for the production and integration of prostheses, particularly where open defect cavities are involved and if respiratory functions may be impaired [48]. Lehmann and Schwenzer [42] pointed out that an accurate model of the face with a clear representation of the defect's borders is normally an essential prerequisite for the creation of a facial prosthesis and that the related process of making the impression may still present some problems. It should be noted that the physician is responsible for any complications with preparation of the prosthesis, such as aspiration of impression material. Previously alginate and plaster were used to make an impression of the whole face, and this was used to create a working model for the technician. With the new planning principles, many patients only require a partial mold. Silicone in twin mixing cartridges simplifies the process of making the impression since the ratio of the components is fixed by the cartridges, and the time taken for preparation and polymerization as well as the final Shore A hardness is set by the manufacturer in the ready-to-use cartridges (Fig. 15.5). Silicone is available in consistencies of fluid to firm for impressions as well as lining material. The mixing nozzle ensures optimal mixing of the components for the impression process and also minimizes usage of the material, since mixing errors (and therefore repeated preparation) can be avoided. However, making the impressions can still be difficult for the uninitiated. In order to avoid

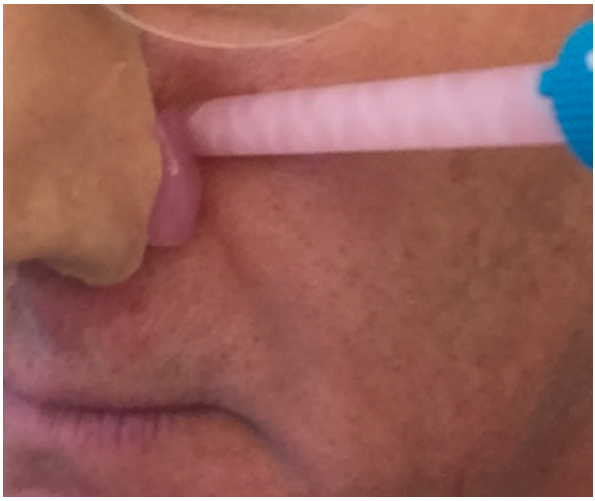

Fig. 15.5 Preparation of the impression or lining is made easier by using silicone (Available in twin cartridges with a mixing nozzle, Mucopren®, Kettenbach Dental)

problems of displacement, deformation of soft tissue and even the risk of aspiration of the impression material, we developed model prototypes that could be adapted to the defect for orbital prostheses (Fig. 15.12a) as well as for nasal and auricular prostheses [17, 19]. This makes preparation of an impression unnecessary, but the prosthesis must still be adapted. Corrective impressions and possibly direct lining and integration must still be performed by the doctor or orthodontist, as pointed out by Reitemeier [48].

15.4 Dermatological Testing of Facial Prosthesis Material

Various materials have been used for the preparation of facial prostheses. Tissue compatibility, aesthetics, and durability of the material are all important characteristics. In the 1960s, the material most frequently used for prostheses was poly(methyl methacrylate) (PMMA) since it was found to be particularly durable, but in the 1970s, softer and more flexible materials such as latex as well as polyurethane and silicone elastomers were found to be suitable alternatives [36]. Silicone has been used increasingly for the last 40 years as facial prosthesis material as well as lining and impression material. However, it should be noted that "silicone" is a collective term for a material of variable quality and quite diverse physical properties, in polymerization systems or hardness grades from fluid through supple and elastic to rigid. This material is therefore continually being

developed and modified for an increasing variety of medical applications, and its biocompatibility is assessed repeatedly depending on the particular application [17, 47]. However, the user of facial prosthesis materials will find little information on the skin compatibility of silicone products. Although most patients have no allergic reactions to silicone prosthesis material, severe skin redness may develop in some cases. Factors such as the "moist chamber" have been discussed as possible causes. However, there is still some uncertainty about the actual causes. Lanman et al. [40] therefore carried out a cumulative irritation test in which 12 prosthesis and lining materials were tested on 20 healthy subjects over a period of 21 days. During these 3 weeks of testing, the subjects' skin was in permanent contact with the test materials for five consecutive days per week. The tested prosthesis and lining materials were generally well tolerated [58]. No significant differences between the various materials were detected, either between condensation cross-linked, addition cross-linked, and platinum-catalyzed A-silicones or between heat-polymerized silicones and silicones vulcanized at room temperature. The materials were tested on the patient's back (not on the face), which seems unrealistic even on purely technical grounds. However, the range of prostheses that are currently produced includes not only facial prostheses but also finger, calf, and breast prostheses, which all lie flat on various areas of the skin. All the materials in this test had equally low irritant properties. In the future, when selecting a suitable material for facial prostheses, we will therefore be able to pay greater attention to economic, technical, and other aspects of the material, such as dye affinity, color retention, and durability as well as ease of correction and repair [28].

15.5 Prostheses After Partial or Total Mastectomy

Resection of extensive breast cancer often results in conspicuous asymmetry. The most elegant form of aesthetic rehabilitation is undoubtedly primary restoration of the breast with plastic surgery [15]. Restoration with a silicone prosthesis is also a proven technique, in which provision of the prosthesis involves the use of tissue expanders or a Silastic® prosthesis [4]. However, surgical repair is not always indicated and is subject to critical evaluation [39, 45]. Industrially manufactured exoprostheses are therefore also used for temporary volume compensation. Industrially prefabricated breast exoprostheses usually consist of a lightweight cotton-filled cushion to fill the bra or a soft exoprosthesis filled with silicone gel. This is carried in a special reinforced bra, but is not always tolerated due to its weight (500–800 g).

A custom-made, soft, foam-filled silicon prosthesis (weighing about 250 g) is a recent design that fills a therapeutic gap between the options of restoration with plastic surgery and augmentation with an industrial product (Fig. 15.6a, b). If the patient does not wish to have an immediate restoration with plastic surgery, an individually fitted medical prosthesis should be considered as a viable alternative. This makes a medical approach to restoration and rehabilitation a more appropriate

method of treatment [30]. In fact an individual, provisional long-term prosthesis should be fitted as soon as possible after a mastectomy: this should take the aesthetic needs of the patient and the topography of the scar tissue into account, be light in weight and should not obstruct the lymphatic vessels (Fig. 15.6c, d). The option of a surgical restoration is maintained. A particular advantage of the light and aesthetic prosthesis is that it can be worn in the usual underclothing without special fixation, since the silicone base has good anti-slip properties (Fig. 15.6e, f). This prosthesis sits firmly in place even in a strapless bra (Fig. 15.6d).

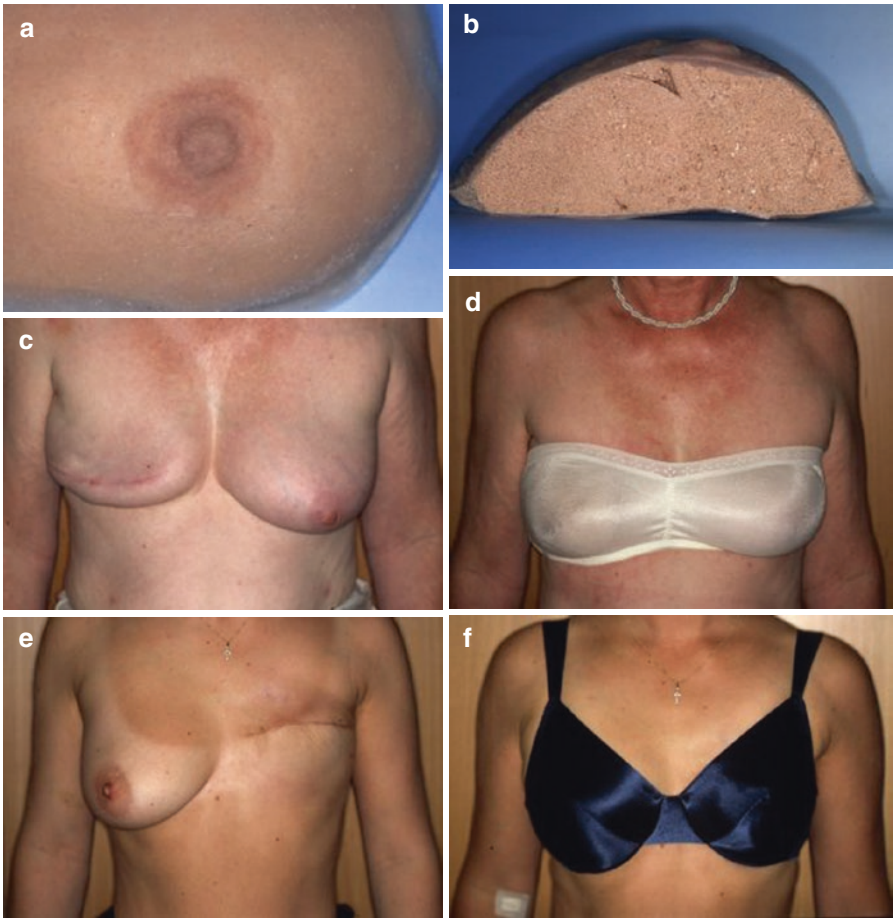

Fig. 15.6 (**a**) The appearance of the soft custom-made silicone prosthesis is quite acceptable. (**b**) The breast prosthesis is filled with silicone foam and covered with a thin silicone skin; it is therefore light in weight (cross section of a demonstration model). (**c**) Status post partial mastectomy (*right*) in a 61-year-old patient. (**d**) The light silicone prosthesis can be worn without additional fixation in a strapless bra. (**e**) Status post mastectomy on left of a 36-year-old patient. (**f**) For volume compensation the silicone foam prosthesis can be worn in a fashionable bra, since the silicone base has good nonslip properties against the skin

The aesthetics and lightweight of these new breast prostheses are certainly advantageous, but the Shore A hardness is still a problem, since the silicone foam does not have the supple softness of natural breast tissue.

15.6 Craniofacial Surgery with Epitheses

Experience with facial prosthesis surgery has shown that gradual rehabilitation of the patient gives the best results, because willingness to cooperate, personal acceptance, and the patient's trust in a new part of the face made of a foreign material only develop during the fitting and adaptation of a prosthesis. After completion of a spectacle-retained prosthesis as a provisional long-term measure, patients may find that the spectacle-retained prosthesis can slip and is still noticeable as a foreign body, in which case they might prefer an implant-retained prosthesis. In any case, a spectacle-retained prosthesis should be fitted as early as possible (depending on the indication) because covering the defect results in rapid psychosocial integration. While the long-term provisional prosthesis is being fitted and adjusted, implant placement should be discussed and possibly undertaken, since with early implant placement, the temporary facial prosthesis will cover the defect during the implant's healing time of about 3 months. Later the model of the temporary prosthesis can be used as a master mold for preparation of the final implant-retained prosthesis. It is advisable to undertake rehabilitation gradually in the following stages:

1. Prosthesis retained with adhesive or spectacles
2. Final implant-retained prosthesis

If the general condition of the patient makes it possible (underlying disease, age, healing ability, freedom from cancer), each stage of this treatment plan provides an interdisciplinary surgical and prosthetic improvement until the final surgical aesthetic restoration.

15.7 Adhesive Retention of Epitheses

A facial prosthesis can be matched in shape and color to the patient and retained with adhesive. It is applied immediately postoperatively (Fig. 15.7a, b). Such a temporary prosthesis avoids the use of a conspicuous gauze dressing, makes it easier to change the dressing, and also constitutes a model for the definitive facial prosthesis [22, 23]. Another indication for an adhesive-retained prosthesis is ear replacement, although adhesives and cleansing agents soon impair its appearance and mechanical durability (Fig. 15.8a, b). This may require preparation of a new prosthesis after a relatively short period. An alternative to a soft silicone prosthesis is one made of poly(methyl methacrylate), which is much more resistant to mechanical damage and has obvious functional advantages [7].

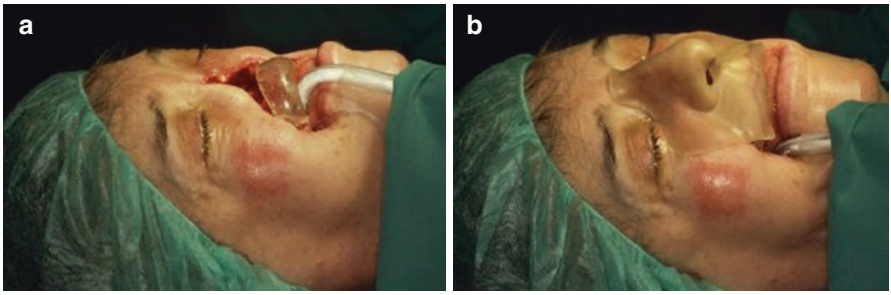

Fig. 15.7 (**a**) Extensive midface defect with fixed maxillary plate in a 48-year-old patient. (**b**) Immediate prosthesis in the form of a dressing plate (cf. Fig. 15.12a)

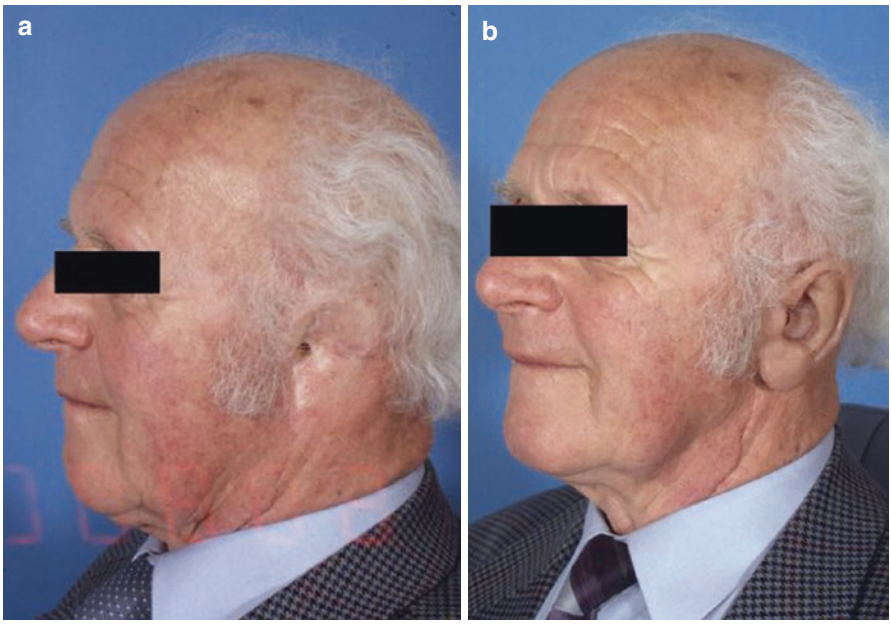

Fig. 15.8 (**a**) Status post loss of external ear in an 87-year-old patient. (**b**) Ear replacement with adhesive-retained silicone prosthesis

15.8 The Spectacle-Retained Facial Prosthesis

A spectacle-retained facial prosthesis made of soft silicone is very comfortable to wear and is very durable, since its margins are not damaged by adhesives or detergents. These epitheses should last for up to about 5 years with proper cleaning and monitoring, a factor worth noting in the context of cost containment. The

spectacle-retained prosthesis is preferable for midface defects as a long-term provisional measure, since it can already be fitted shortly after the operation and before wound healing is complete. However, the margins of the prosthesis must form a circular lid over the wound cavity and protect the defect without any mechanical interference with the wound-healing process. Most patients prefer this type of initial treatment, because rehabilitation with this type of prosthesis can start quickly without additional surgical intervention (Fig. 15.9a, b). The prosthesis is made of silicone with a Shore A hardness of 20; has thin, soft, extended margins; and is anchored to the spectacle frames with 0.9 mm remanium® spring wire (Fig. 15.10a, b). This elastic retention reduces the risk of breakage if there is a blow to the spectacles, while the soft margins of the prosthesis and the sprung attachment reduce the risk of injury to the patient [17, 25, 27].

Disadvantages of spectacle retention are firstly that the prosthesis can slip with the spectacles and secondly that the spectacles need to be removed in order to be cleaned. This would reveal the defect, which could be embarrassing for the patient. Another disadvantage is that the patient is dependent on this single pair of glasses in combination with the prosthesis.

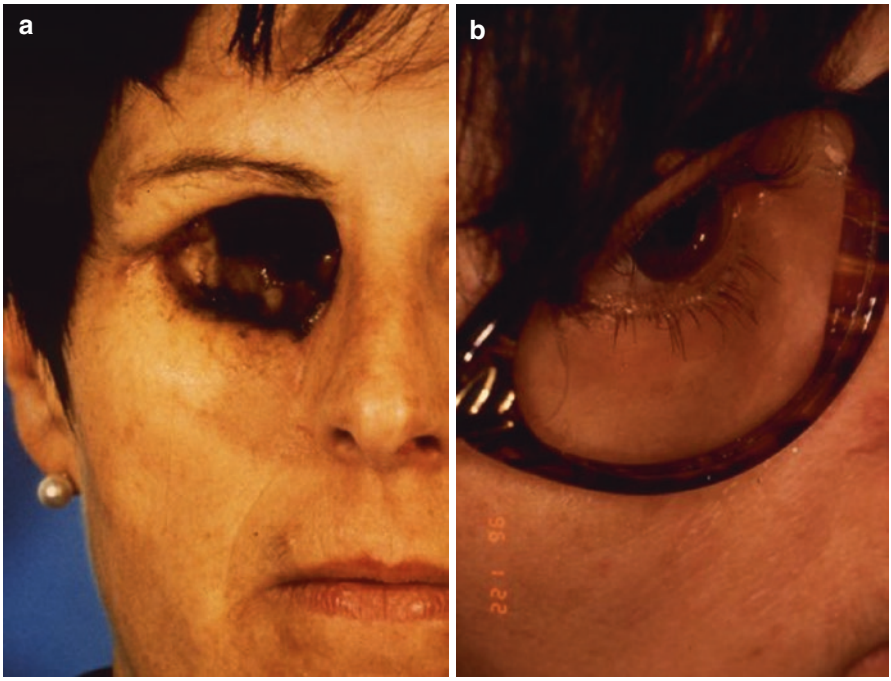

Fig. 15.9 (**a**) Status postorbital evisceration on right in a 45-year-old patient. (**b**) Initial treatment with a spectacle-retained facial prosthesis can already be carried out shortly after surgery

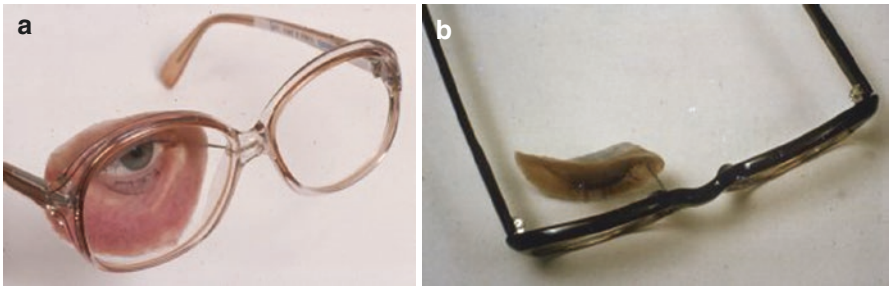

Fig. 15.10 (**a**) The spectacle-retained silicone prosthesis only contacts the skin gently with its margins and protects the wound cavity like a lid. (**b**) Retention with remanium® spring wire and soft silicone margins makes this prosthesis more comfortable to wear than a rigidly fixed PMMA structure

15.9 The Implant-Retained Facial Prosthesis

The implant-retained prosthesis, i.e., one retained in a defined position independent of spectacles or adhesive, is currently regarded as the definitive type of facial prosthesis. It is incorporated very well, since it is hardly perceived as a foreign body and is easy for the patient to maintain. It is removable and held in place with mini-magnets, bar constructions, or comparable fixation elements on osseointegrated titanium implants. For extraoral prostheses, modifications of proven dental implants made of titanium are available that are osseointegrated as individual posts [5, 38]. The numerous publications on this topic show that the various craniofacial titanium implant systems have comparable long-term durability. They are therefore regarded as equally useful in rehabilitation with epitheses.

15.10 Planning for Pre-prosthetic Surgery

A surgical and prosthetic substructure and superstructure adapted to one another will enable optimal long-term osseointegration of implants [2], since in dental and surgical prosthetics, planning the location of an implant, hygiene in the region of the implant, as well as physiological and mechanical adaption of the overall structure is a prerequisite for long-term success. Comparable design principles in dental prosthetics and materials science are the basis of both intraoral and extraoral implantology (Fig. 15.11a–c).

15.11 Planning for Orbital Epitheses

After surgical removal of a tumor, for example, with orbital evisceration, the extent of surgical lining of the defect cavity should be limited so that sufficient room is available for a prosthesis structure. The defect cavity must have enough room to

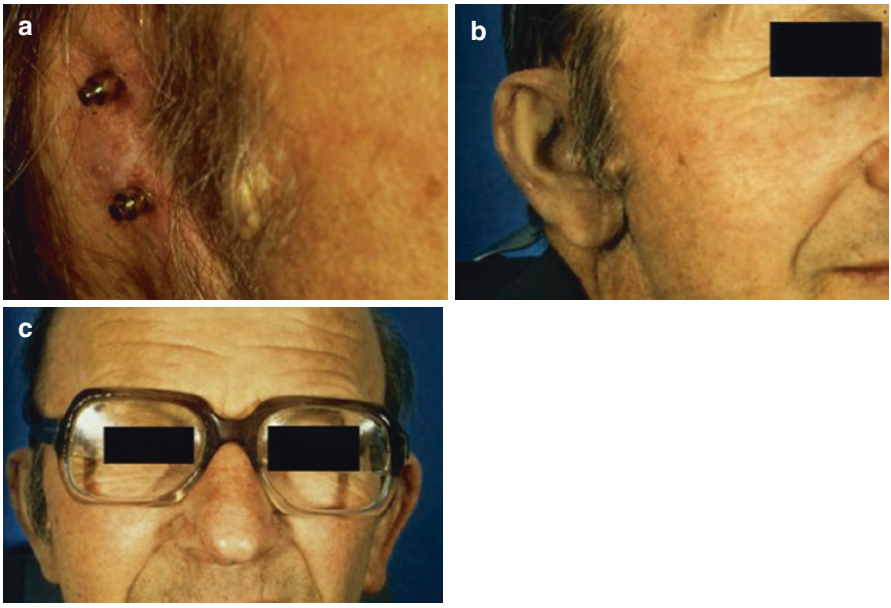

Fig. 15.11 (**a**) Two cylindrical telescoping magnetic posts as retention elements for an auricular prosthesis after cancer-related loss of the auricle in a 67-year-old patient. (**b**) Silicone ear in situ, mounted on two magnetic telescoping posts. This design principle prevents side shift and rotational moments and therefore allows support for spectacles. (**c**) The implant-retained prosthesis is presently regarded as the definitive technique, especially for a restoration with support for a pair of glasses

house the fixation elements and the body of the prosthesis in both sagittal and transverse planes so that the prosthesis is not asymmetrically displaced. This also applies to spectacle-retained and implant-retained epitheses. A preoperative case conference is therefore recommended in order to determine the most favorable position for osseointegration of the implants in relation to the prosthesis, so that permanent osseointegration of the implants as well as correct integration of counter elements in the body of the prosthesis can be achieved. Planning templates have been developed for this purpose [17, 19]. For example, during an orbital evisceration, the optimal location and angle of inclination of the implants are determined with the aid of a transparent prosthesis template, and these can be put in place in the same operation (Fig. 15.12a–c). The transparent template makes it possible to visualize the probable prosthesis volume within which the fixation elements are to be positioned. The position and angle of inclination of the implants should provide a minimum height of 12 mm from the bone surface in the axial direction for the fixation elements. To ensure proper hygienic conditions in the area of the implants, the distance and axial inclination of the implants should be such that the mounting posts are at least 15 mm apart from each other at the points where they penetrate the skin (Fig. 15.12d–f).

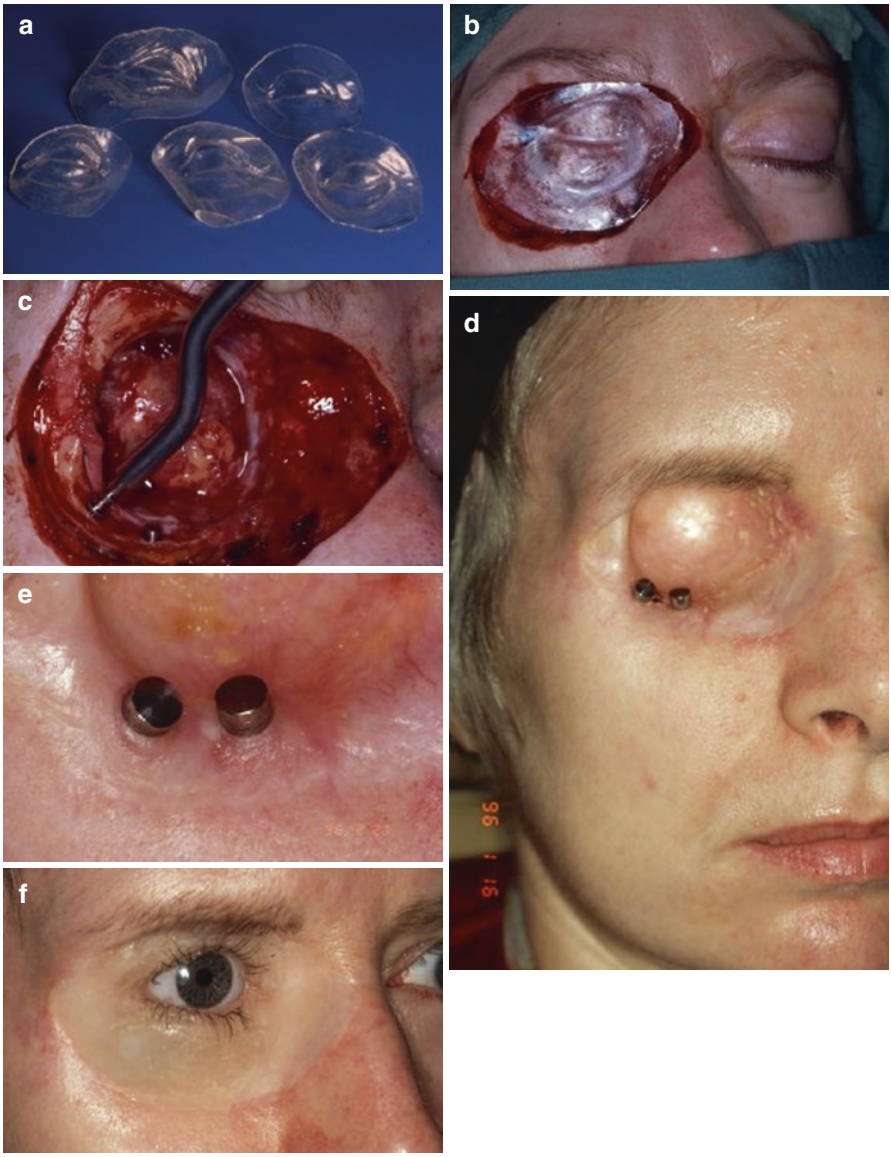

Fig. 15.12 (**a**) Partly prefabricated prosthesis models as planning templates. The templates can also be used as dressing plates or temporary prostheses. (**b**) After orbital evisceration, the gas-sterilized transparent template shows the boundaries of the volume required by the prosthesis. (**c**) Position, angle of inclination, and height of the planned retention anchor should be within the boundaries of the planning template. (**d**) Status post 3 months healing of the implants (Friadent®) and insertion of the magnetic anchors (steco®). (**e**) Peri-implant overview showing that the free-standing pillars allow optimal hygiene. (**f**) Magnet-retained orbital prosthesis in situ in a 42-year-old patient

15.12 Planning for Nose Replacements

For partial or total nose replacement, implants can be inserted at the border of the piriform aperture after the bone margin has been prepared by grinding down to a plateau width of about 6 mm for reception of the implants. The axis of the implant should point in the direction of the bridge of the nose, so that the retention elements can be placed inside the body of the prosthesis with sufficient height. Sufficient bone for insertion of an implant is also available beneath the glabella (Fig. 15.13a–c). For fixation of epitheses with only a small amount of bone, a titanium mesh implant (3-D carrier plate, Epitec®) with associated fixation elements has been developed for the retention of fully flexible silicone epitheses with elimination of the usual hard PMMA base [10, 20].

15.13 Planning for Ear Replacements

For ear replacements, a sketch on a flat transparent plastic foil is sufficient for the planning of implant positions (> Chap. IV-9.2, Fig. 15.2a). Planning is best carried out with the patient sitting upright, since one needs to see the ear in profile view and also assess symmetry in a frontal view (> Chap. IV-9, IV-9.2, IV-9.3). The planning sketch is necessary to ensure that the fixation elements do not protrude from the concha of the prosthesis body and that the implant anchors are positioned so that the superstructure can be fully integrated into the helix of the auricle. According to the literature, the ideal position for the implants is about 20 mm posterior to the external auditory meatus. The implants are positioned at specific time points on an imaginary clockface, with the external auditory meatus as its center [42, 55, 56]. However, it is sometimes difficult to determine the positions of the time points if the patient is draped. We therefore developed a horizontal reference plane whose endpoints are palpable in a draped patient. This plane is comparable with the Frankfurt horizontal, although the palpable prosthesis horizontal is located slightly superior to the Frankfurt horizontal. The external auditory meatus and the lateral margin of the orbit are the cardinal points. The external auditory meatus is designated as the center of the clock dial, and the shortest line connecting it to the lateral margin of the orbit is the horizontal line from 3:00 to 9:00 on the clockface that serves as the reference for implant insertions (Fig. 15.14a, b).

Since treatment with implant-retained auricular epitheses is a proven method with good long-term results, we are seeing an increasing number of patients with congenital craniofacial malformations. If a patient with microtia has no external auditory canal, the auricular rudiments can be used as landmarks for the planning sketch. A mirror image of a sketch of the position and contour of the healthy ear on firm transparent film can be used on the malformed side. The theoretical location of the external auditory meatus can then be used to reconstruct the prosthetic horizontal. Auricular rudiments should therefore be spared from surgery for various reasons, so that they can be retained initially for further planning and orientation. It may be possible to position a gas-sterilized, milled planning template in the draped

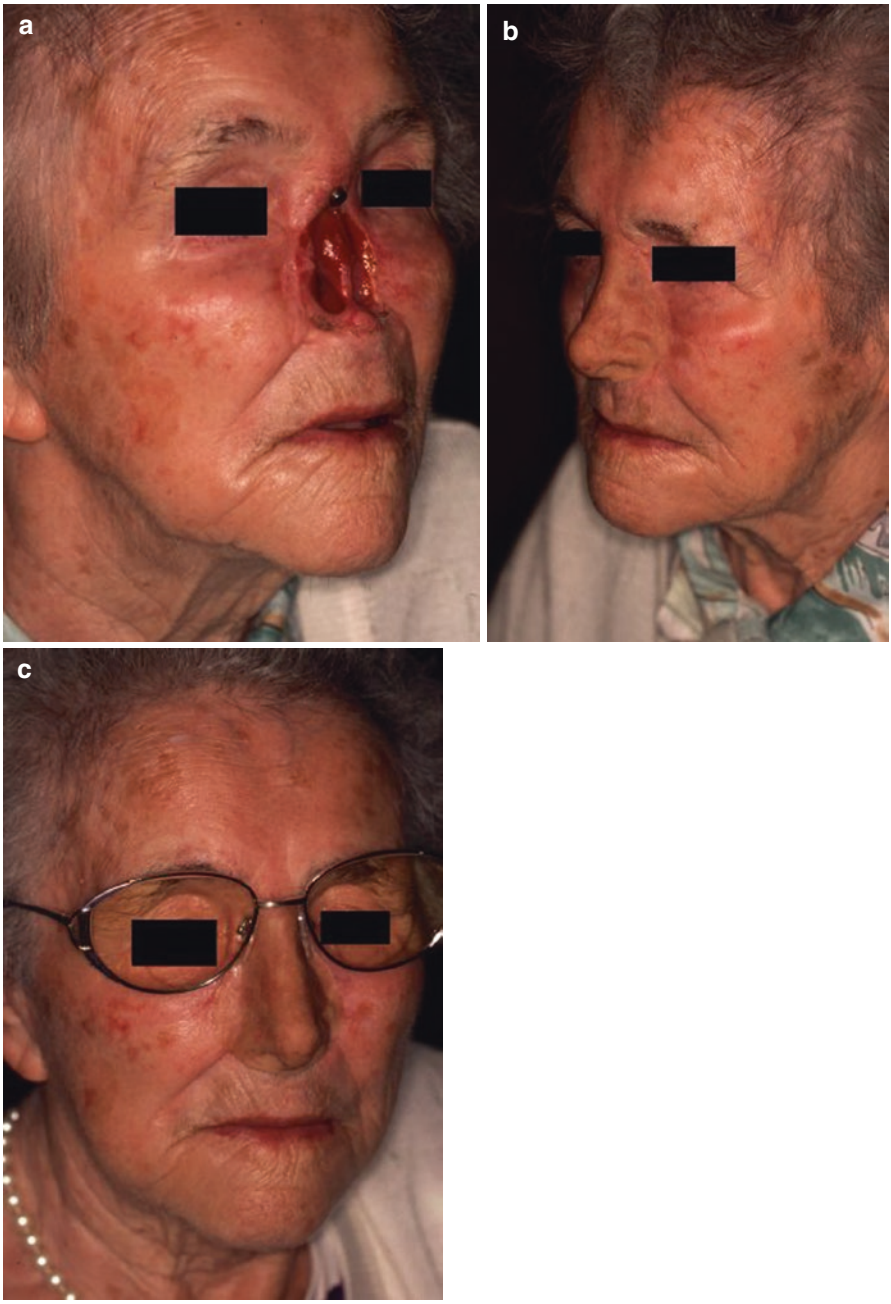

Fig. 15.13 (**a**) 84-year-old patient after nasal ablation for recurrent basal cell carcinoma. Implant retention below the glabella. (**b**) Defect coverage with magnet-retained silicone prosthesis on a single pillar. (**c**) The implant-retained nasal prosthesis provides an aesthetic restoration of the nasal contour. Support for spectacles is also restored

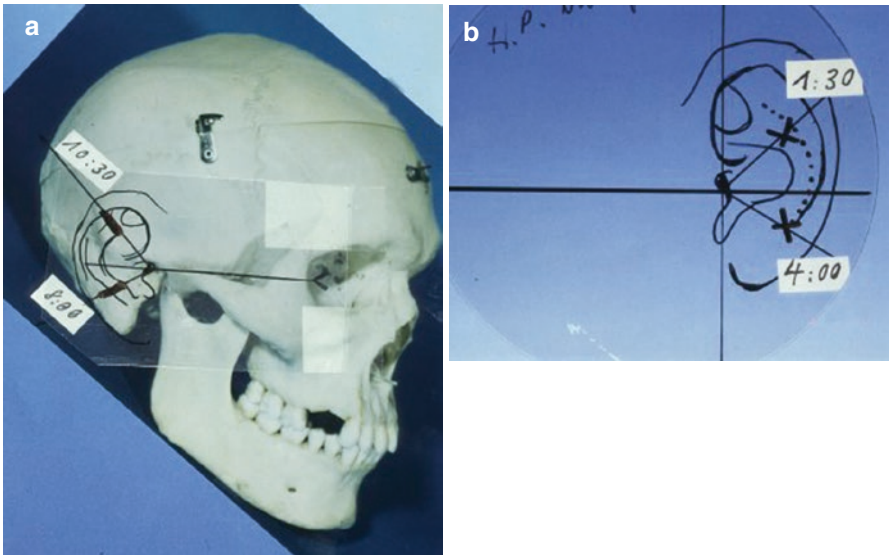

Fig. 15.14 (**a**) This reference horizontal for the positioning of implants is palpable in draped patients. On the right side, implants should be placed 20 mm posterior to the external auditory meatus at 8.00 and 10.30 o'clock. (**b**) A preoperative planning sketch on a transparent foil can be used for orientation during surgery in the form of a sketch on a transparent template. On the left, the implant positions should be at 1.30 and 4.00 o'clock

patient (Fig. 15.15). When planning the positioning of an ear prosthesis in a patient with microtia, one should remember that the rudiments follow the growth trend of the soft tissues of the splanchnocranium and are often displaced anteriorly, so that they are not a reliable guide for placement of the auricle. A posterior adjustment during planning may therefore be advisable when matching the position of the prosthesis with the normal side.

In addition to the first-line option of plastic surgery for auricular restoration in patients with microtia or aplasia [59, 60], a temporary or definitive prosthesis is also worth considering since the patient may not be satisfied with the outcome of surgical restoration, particularly if there have been repeated attempts at surgical correction. Insertion of two implant anchors followed by surgical smoothing of the region in a second step and fitting of an auricular prosthesis may result in an outcome that the patient finds more acceptable. For the same reason, it is worth considering whether an auricular prosthesis is indicated for otomandibular dysostosis (Fig. 15.16).

15.14 Benefits of Stereolithography for Planning a Facial Prosthesis

Planning is much more difficult in patients with Treacher Collins syndrome (Franceschetti-Klein syndrome). With regard to craniofacial surgery, callus distraction of the mandible and correction of the zygomatic bone are the most

Fig. 15.15 The contour of the normal ear is superimposed on the malformed side with the aid of a sketch in black ink on transparent foil. The outlines of the rudiments and the positions of the implants are then drawn in red. A milled template can also be prepared

common approaches (> Chap. IV-12). The basis for planning in such cases is a stereolithography model [51]. This model is also used for planning the location of the implants for bilateral auricular replacement and for BAHAs (bone-anchored hearing aids [26]). Stereolithography provides a very clear model for planning facial prostheses in this area. One issue is that bone in the region of the mastoid is irregular and may therefore be unsuitable for implant placement (Fig. 15.17a); another problem is that maintained growth of the mandible and the zygomatic bone causes an unattractive inferior displacement of the mastoid region. This means that the mastoid process has moved inferiorly with respect to the splanchnocranium. If the mastoid is now recommended for implant insertion (as is often the case), the retention elements would be too far inferior and the ears (and the BAHAs) would be placed in the nape of the neck. The aesthetic results would not be optimal. For

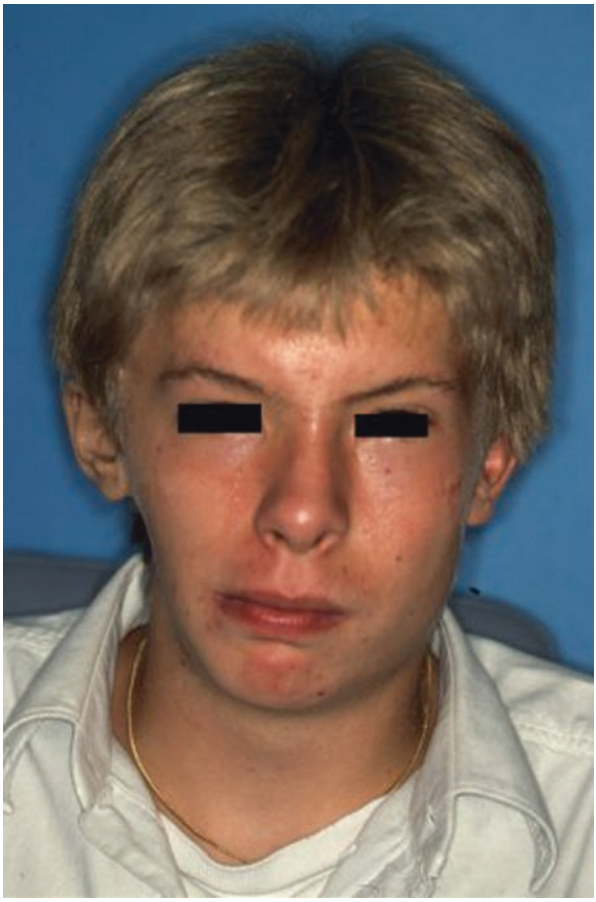

Fig. 15.16 Implant-retained auricular prosthesis for a 17-year-old patient with otomandibular dysostosis on the right, after several plastic surgery operations for auricular restoration did not produce the desired result. Surgical lengthening of the right mandible is still pending

external orientation, the ear should therefore be situated between the alae of the nose as the inferior limit (both in profile and en face) and the eyebrows as the superior limit. These positions can be marked on the planning sketch, so that the rudiments can be used as external contours for orientation during surgery. In applying this external assessment based on the stereolithography model from an aesthetic viewpoint, one can see that the implant positions must be moved very far distocranial from the mastoid region in order to obtain an optimal aesthetic result (Fig. 15.17b–d). After insertion of the implants, a decision as to how the ear rudiments should be incorporated into the overall design should only be made after osseointegration while placing the prosthetic pillars in a second step. In the case presented here, a cartilage rudiment was surgically formed into the tragus, the soft tissue was drawn posteriorly, and these steps were integrated into the design of the prosthesis (Figs. 15.4 and 15.17d).

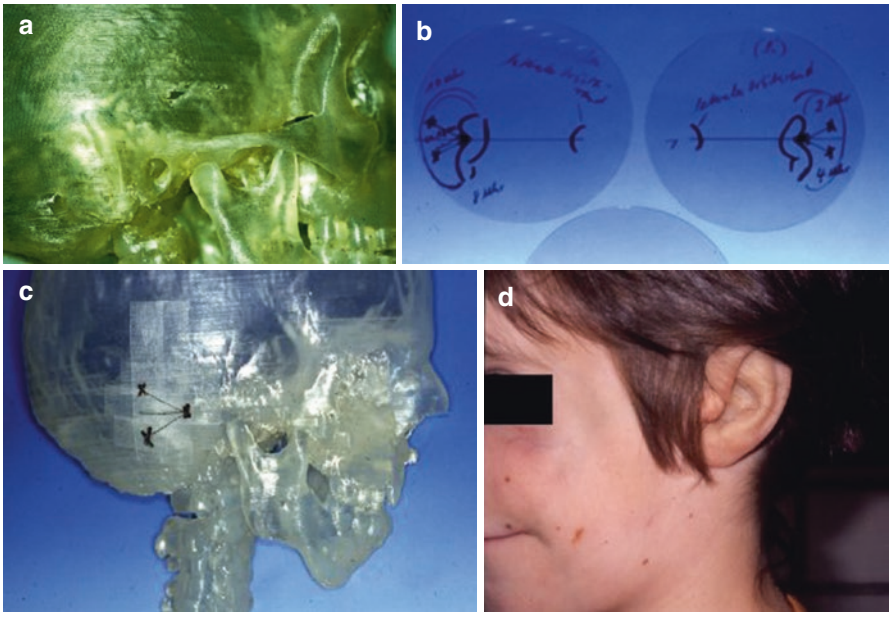

Fig. 15.17 (**a**) The stereolithography model shows that the bone is irregular in the mastoid region. (**b**) Determining the external contours of the auricles based on aesthetic criteria. (**c**) Transfer of the external aesthetic assessment onto the stereolithography model shows that the ideal position of the two implants is far distocranial from the mastoid process (the anterior point is the virtual external auditory meatus). (**d**) 8-year-old patient (Franceschetti syndrome) with magnet-retained prosthesis in situ: according to the plan for pre-prosthetic surgery, the cartilage component of the auricle rudiment was converted into a tragus and integrated as an autologous component into the alloplastic prosthesis

15.15 Fixation Elements for Implant-Retained Craniofacial Epitheses

The preparation of fixation elements for facial epitheses is usually similar to the production of superstructures for dental implants. For extraoral prostheses, bars were initially the primary conventional method of fixation to osseointegrated pillars. There are also anchoring methods that use a snap-fastener system. Both methods, bar and bar attachments and snap-fastener fixation, have the disadvantage that the force required to detach the prosthesis is variable and indefinite. In this context, there are valid concerns that excessive detachment forces and bending moments may place too much stress on the osseointegration of the implants and lead to loss of the implant. In addition, bar construction prevents good hygiene and an optimal overview of the implant area. However, in the course of development of mini-magnets as fixation elements on individual intraoral posts, mini-magnets with defined detachment forces have also become available as retention elements for extraoral defect prosthetics. These magnet inserts are corrosion resistant [61] and

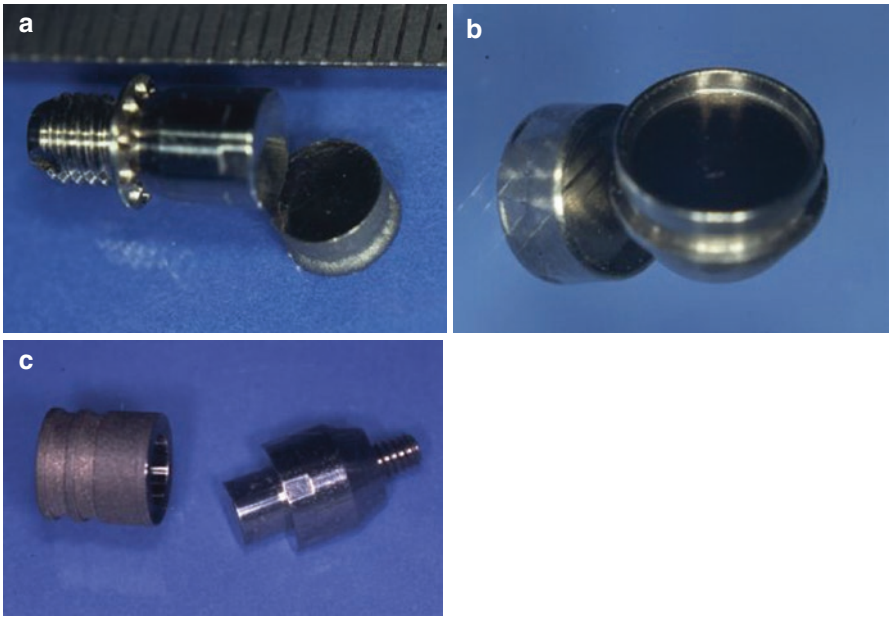

Fig. 15.18 (**a**) Abutment with integrated spherical magnet on a Brånemark implant (Nobel Biocare®) and prosthesis mini-magnet as counter magnet. (**b**) Lipped magnet (Technovent®) with circular lip to protect against lateral displacement. (**c**) Telescoping inserts and cylindrical telescoping magnets provide various prosthetic functions (steco®)

have a defined detachment force of 1.5–3 N as stated by the manufacturer. Various designs with specific functional benefits are available, depending on the application: the simple prosthesis mini-magnet in spherical form, functioning purely for retention, as well as a lip magnet and a long-lip magnet, whose circular metal lips provide protection against transverse forces. There is also a cylindrical telescoping magnet with retaining, supporting, and tilt prevention functions that protects against transverse forces and provides resilience (Fig. 15.18a–c).

15.16 Magnet Retention for Orbital Epitheses

The basic design for fixation of orbital epitheses with mini-magnets usually incorporates spherical prosthesis magnets (steco®, Hamburg) as implant inserts, with counter magnets in the body of the prosthesis. Fixation on two or more posts gives the prosthesis a stable support and a defined seating. Although the prosthesis can be moved laterally on the surface of the magnets, its position in the orbital cavity gives it substantial stability. This means that fixation in the orbital cavity with simple prosthetic magnets is usually satisfactory (Fig. 15.12d–f). However, additional protection against lateral displacement is provided by lipped magnets (Technovent®, Leeds) (Fig. 15.18b).

15.17 Magnet Retention of Auricular Epitheses

Fixation elements for auricle replacement must meet a number of functional requirements to ensure that the prosthesis is correctly seated and its lateral displacement or rotation is prevented. Magnet systems are therefore suitable as retention anchors if they have sufficient retention force (about 1.5 N) and protection against transverse forces in the form of a long metal lip (Technovent®) or a cylindrical telescope (steco®). Designs that incorporate positioning of the auricular prosthesis on two magnetic telescoping posts have proven their worth in practice [24]. This design stabilizes the prosthesis against rotational and shear forces and results in a stable three-point support (ear-nose-ear) for spectacles (Figs. 15.10a–c and 15.13a–c). Furthermore, this prosthetic design also prevents tilting and allows a telescoping movement in case an earpiece of the patient's spectacles gets wedged behind his ear as he removes them. It used to be necessary to ensure that the telescopic posts were parallel, but the development of fully flexible silicone epitheses without a PMMA base [20, 24, 25, 27] simplifies the production and handling of implant-retained epitheses and allows fixation onto diverging or converging telescopic posts, since the body of the prosthesis can be attached to the posts by its base (Fig. 15.19a–c). The fully elastic silicone prosthesis protects the osseointegrated implant against nonphysiological tilting moments, since it acts as a stress breaker due to its full flexibility. Compressive forces on the auricle as well as leverage forces (which may be exerted, e.g., by a spectacle earpiece on the auricular prosthesis) are largely neutralized by torsion of the prosthesis body. This protects the osseointegration of the implants from overload and reduces the danger of thread breakage for the inserts, which has often been observed in structures with acrylate bases. Integral abutments (pillars) with integrated magnets are recommended as retention elements, since they are less susceptible to loosening than multiple components screwed together. Cone magnets have recently become available, and these have a much greater tolerance with respect to the direction of insertion [37]. Since cone and counter magnets provide stabilization against shear forces, rigid prosthesis bases on two or more diverging or converging implant posts are usually stable when positioned in both intraoral and extraoral applications.

Fixation designs for auricular epitheses should always be consistent with the following functions and design principles (cf. Figs. 15.11a–c, 15.18c and 15.19a–c):

- Sufficient retaining force
- Defined location
- Defined detachment forces
- Protection against rotation of the prosthesis
- Protection against shear forces
- Support function
- Protection against tilting
- Resilience (telescopic mobility)
- Stress-breaking function
- Overview of implant site
- Access for hygienic purposes

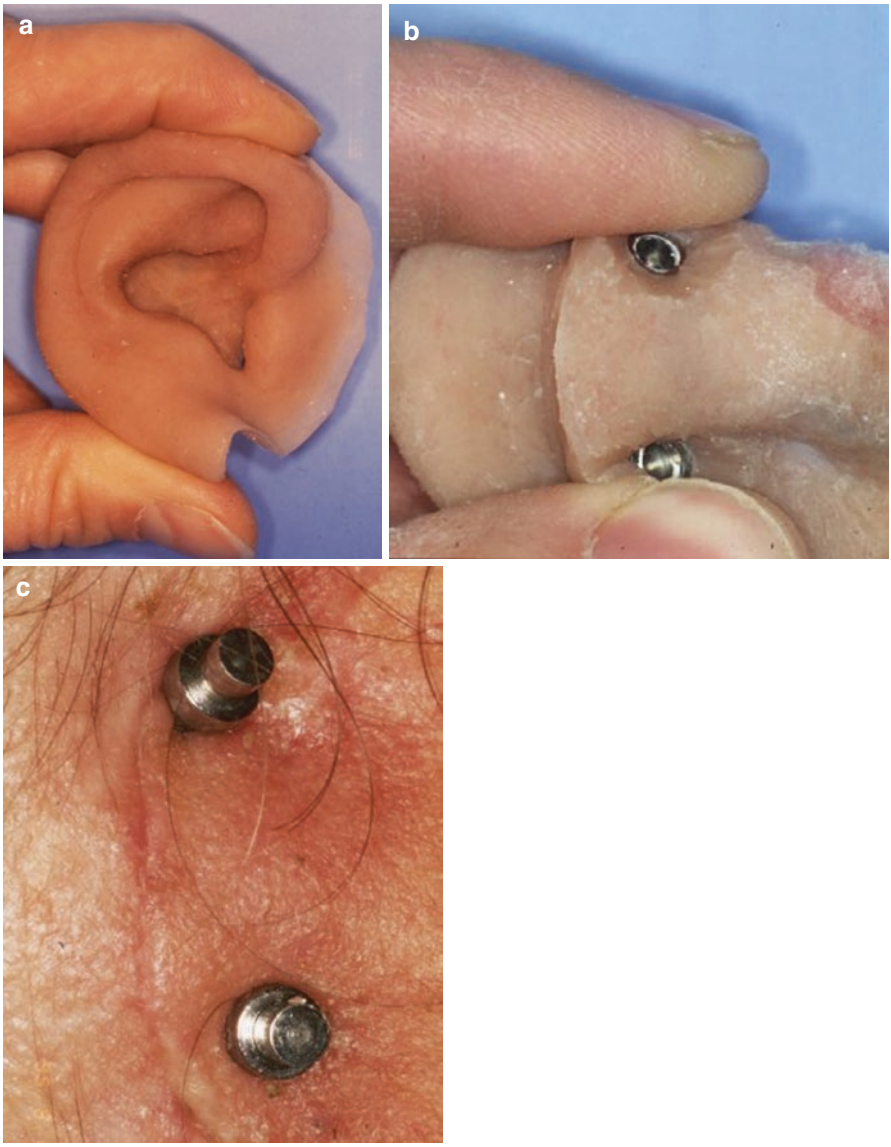

Fig. 15.19 (**a**) Fully flexible silicone auricular prosthesis. (**b**) Telescoping magnet in flexible prosthesis body (base). (**c**) Divergent or convergent telescopic posts as an anchor for a fully flexible prosthesis provide defined fixation and an optimal overview for hygienic purposes

15.18 Magnet Retention for Nasal Epitheses

Nasal epitheses can be anchored by a single pillar with magnetic retention (Fig. 15.13a–c). Combined support with different retention elements may be necessary for the fixation of extensive midface epitheses with problematic bone quality.

In this context, the use of a 3D carrier plate provides a supplement or alternative to individual posts [10, 21–23].

15.19 Immediate Surgical Treatment with Facial Prostheses

Titanium implants are frequently placed after removal of a tumor in the midface region. They are used to anchor a facial prosthesis after osseointegration of the implants. With extraoral prostheses the healing period for single posts is usually 3 months. In a subsequent operation, the implants are exposed, the skin is thinned, and the abutments and retaining elements are screwed in. An alternative method of prosthesis retention is provided by the Epitec System®, with which we anchor the facial prosthesis immediately. Although it has already been noted that the Epitec plate can be loaded 3 weeks after insertion, a two-stage procedure is preferable with loading applied no sooner than 3–6 months after insertion [10, 11]. As a rule a prosthesis is usually only fitted 6 months postoperatively, although in some cases the delay may be a year or more. This procedure means that patients have a long wait until surgical restoration of aesthetic facial contours starts. For psychosocial reasons it is of course best for patients to have a definitive prosthesis as soon as possible. During the last 30 years, there have been innovative changes in cranio-maxillofacial prosthetics, such that debate about new implant designs has resulted in the abandonment of certain surgical dogmas and rules of prosthetic practice. Those who have introduced innovations and modifications based on extensive clinical experience, the utility of which was originally doubted on scientific grounds, are now considered to have made significant contributions in intraoral and extraoral implantology to what is now generally regarded as the "state of the art." It was previously customary to wait for 3–6 months after removal of a tumor in the midface region until osseointegration of the implant anchors, and the posts were then placed in a second operation. However, we have now developed successful methods for extraoral implant prosthetics that reduce this waiting period to a few days.

This involves a one-step method with which we reconstruct the facial contours immediately. For early restoration of facial contours, a 3D grid plate (Epitec, Stryker Leibinger) is fitted as an anchoring element and screwed stress-free to the bone on one side next to the resection cavity. The grid plate is fixed with at least two self-tapping bone screws, which provide its primary stability. The Epitec System® has proven itself with the design of a titanium mesh for stress-free adaptation to the bone. In order to avoid tensile forces on the bone screws where the bone structure is delicate (e.g., in the region of the piriform aperture), stress-free fitting of the plate appears to be necessary. The soft tissue is blunt dissected from the screws in the bone to the exit point. Tunneling is used to accommodate the grid plate. The free side of the grid plate perforates the skin (Fig. 15.20a–c). This grid plate is a modified osteosynthesis plate. The Epitec plate has an internal thread in each grid aperture. Mini-magnets are screwed in here as fixation elements to anchor the facial prosthesis. The soft tissue is not thinned at the point of penetration through the skin, as was usually the case with the use of retention posts. Following this procedure

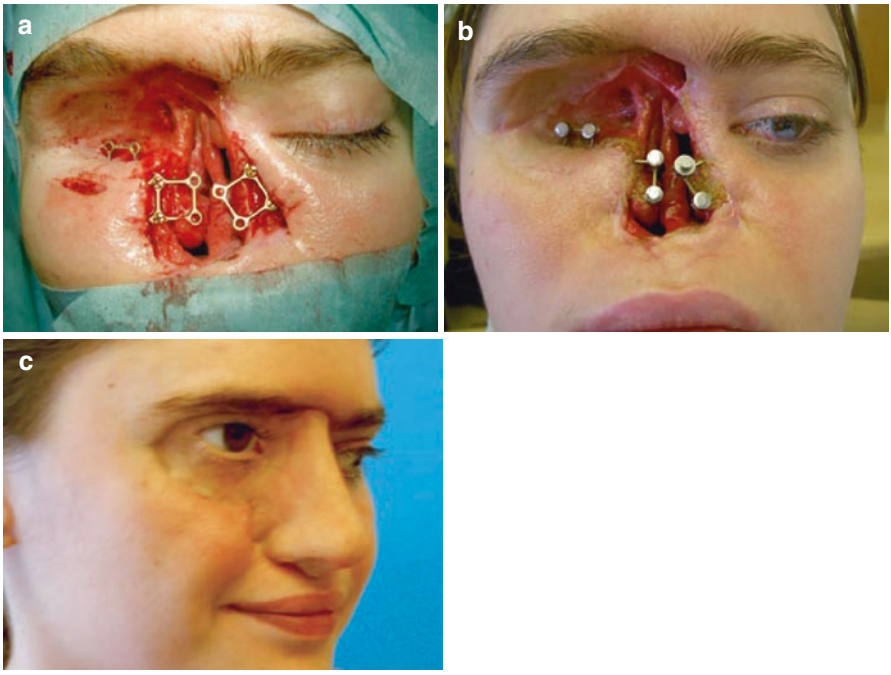

Fig. 15.20 (**a**) Status post loss of one eye and the nose. Tunneling of the soft tissue from the fixture of the Epitec plate on the infraorbital rim to the exit point of the plate in the orbit. (**b**) Three plates with mini-magnets for retention of the orbitonasal prosthesis in situ. (**c**) Prosthesis in situ four days postoperatively; reconstructed facial contour

reduces soft tissue trauma and consequent postoperative swelling. This concept has since been improved further due to modification of Mucopren (Kettenbach Dental: silicone for maxillofacial prosthetics). The prosthesis is made of Mucopren E (for epithetics) and lined directly with Mucopren Soft in situ on counter magnets (see Fig. 15.5). This silicone is characterized by short polymerization times and ease of repair and is therefore ideally suited for extensions, linings, and modifications in the field of silicone prosthetics. Full silicone technology without the use of an acrylate base has proven its value [24], because the Mucopren silicon layers bind well with each other and there is no mixing or abutting edge with other plastics.

With this concept, the patient can even be provided with a magnet-retained facial prosthesis immediately after removal of the tumor and while still under general anesthesia (Fig. 15.21a–f). A prefabricated silicone prosthesis can be fitted to the defect as an interim measure. The previously prepared full silicone prosthesis is cut with scissors to fit the defect cavity. The technology for preparing prosthesis templates and their early adaptation as an immediate measure has been described repeatedly in the literature [17, 19, 22, 23]. Further adjustments may be necessary after 2–3 months; these are made with Mucopren; a similar medical silicone for facial prostheses is the slow-curing Bioplast® (Detax, Germany). This method of

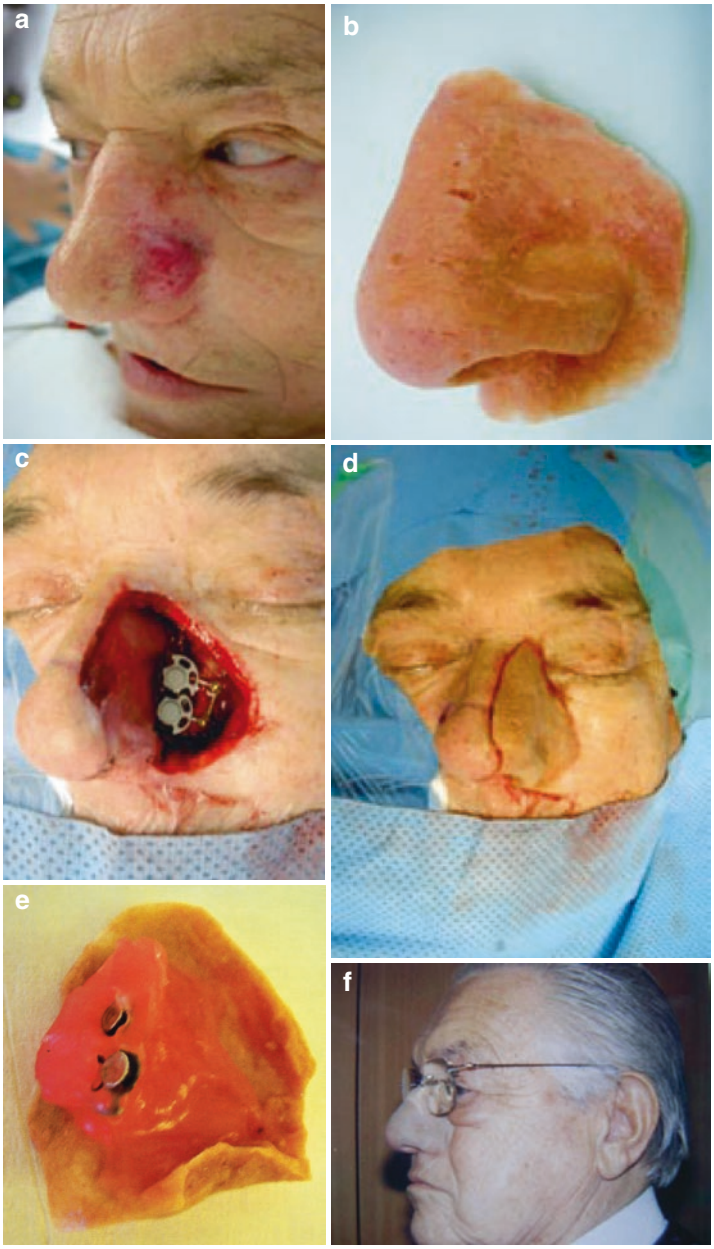

Fig. 15.21 (**a**) Tumor in situ. (**b**) Individually prepared model of the nose. (**c**) Epitec plate with mini-magnets and counter magnets for retention of the prosthesis. (**d**) The prosthesis is lined with Mucopren during surgery as a "dressing plate" on counter magnets. (**e**) Rear view of the prosthesis with counter magnets embedded in the polymer. (**f**) The prosthesis 3 weeks postoperatively, modified and with readapted margins

immediate prosthetic restoration has a particular advantage in that the facial prosthesis can easily be modified and renewed, even if the defect site is altered by wound healing. This means that further surgical corrections are usually unnecessary, which significantly reduces costs as well as mental and physical stress for the patient. After surgery, the prosthesis is initially used as a dressing plate. This greatly simplifies nursing care of the defect, since the prosthesis only needs to be removed from the magnets in order to change the dressing, and no other bandage is needed after the defect has been cleaned. During this wound-healing phase, only slight swelling of the soft tissue can be seen in the region of the implants, and the region around the implant heals rapidly and uneventfully. Wound healing was found to be benefited by firm attachment of the soft tissue to all rough areas of the grid bars. This adhesion improved sealing of the skin cuff while the polished retaining elements projected from the soft tissue structures. In the last 25 years, a large number of plates were inserted and hundreds of magnetic posts were used as superstructure. Very few implants were lost. However, in two patients the titanium plates were explanted because they caused dysesthesia in the region of the facial muscles. Impaired wound healing was observed with the use of absorbable suture material. It is known from intraoral prosthetics that only atraumatic nonabsorbable suture material should be used. This is even more important where skin-perforating implants are used, since full absorption does not take place in this region and mechanical removal of the suture material remains incomplete. If the Epitec System is not available, an alternative is the Titanium Plate System Epiplating®, available from Medicon eG, Germany [12–14]. The superstructure is available from Cosmesil.de (Germany).

15.20 Significance of Immediate Aesthetic Restoration

After 25 years of experience with the early application technique in craniofacial prosthetics, it can be stated that no problematic cases of inflammation occurred in the region of the grid implant with this one-step method. The one-step method helps to protect the tissues and results in less stress for patients than in the past.

Our approach reduces the waiting time for fitting and adjustment of a facial prosthesis from 6 months to a few days; modification of Mucopren for prosthetics was a major contribution in this regard. No correctable silicone was available previously for craniofacial prosthetics. Clinical developments and experimental studies have shown that Mucopren is particularly suitable for the creation of prostheses as well as for their correction and lining [49]. The early aesthetic and functional restoration of lost facial contours with implant prostheses is a satisfactory and cost-effective method.

Providing primary stability of the grid plate by anchoring it with self-tapping bone screws is particularly advantageous. With immediate provision of implants, the prosthetic concept of splinting is also achieved by the square structure of the grid plate. The grid elements should therefore remain as closed squares if possible, since the square structure would lose its stability if one of the rungs of the square was severed. A rough surface of the implant plate facilitates firm attachment of the

skin, which helps to prevent invasion of bacteria through the skin penetration site. However, the polished surface of the thick post would prevent attachment of the skin and allow entry of bacteria, which might cause inflammation and potential loss of the implant. Stable attachment of the soft tissue to the titanium texture improves wound healing and sealing of the skin cuff, especially in extraoral prosthetics. Our concept of immediate restoration of facial contours has also proven to be beneficial for psychological patient management, since patients and their families find the loss of a facial area less confronting with immediate prosthetic replacement, both preoperatively and postoperatively, than if a cavity or flap were to alter the midface profile for a long period (Figs. 15.9a and 15.20). This is almost perceived as "contour loss," but immediate replacement of the facial contour can improve the patient's self-confidence since the loss of facial contour and disfigurement are aesthetically concealed. Return to work is also facilitated by our concept of immediate restoration of facial contours with a magnet-retained facial prosthesis. In some cases, preoperative clarification of the immediate treatment resulted in better maintenance of the patient's pre- and postoperative self-confidence and psychological stability, as well as a more rapid return to their accustomed lifestyle and work environment.

This is a factor that is particularly important for the financial security of employees with leadership roles and self-employed individuals. Another advantage is that an implant-retained prosthesis on mini-magnets is permanently incorporated and comfortable to wear, as is the case with incorporation of implant-supported removable dentures. The option of a spectacle-retained facial prosthesis is not recommended, since this means that the patient is dependent on his spectacles. However, patients who work must use different spectacles for different purposes, which is why a magnet-retained prosthesis is the best choice for everyday use. Finally, early provision of customized implant-retained facial prostheses has functional as well as aesthetic advantages for the spectacle wearer, since the implant-retained nose or ear prosthesis provides exactly the right support for the spectacles immediately postoperatively. Without replacement of the ear or nose, the spectacles would not be properly supported. Proper fitting of spectacles is not only necessary for the use of communication tools such as computers, phone, or correspondence but is also very important for orientation and meal preparation by pensioners living alone. Properly fitting spectacles therefore assist patients to reintegrate rapidly into social and professional life.

15.21 Causes and Prevention of Errors

Prevention and correction of failures is facilitated by the awareness and constant improvement of basic knowledge [44]. This is a prerequisite for routine patient care, and the relevant basic criteria are described above.

Surgical prosthetics and epithetics is a marginal area of dentistry [8] that presents many difficulties. It requires a basic knowledge of medical and material sciences, advanced and practical skills in these areas, and significant clinical experience in order to recognize in advance possible sources of error that could result in failure.

Insufficient planning for pre-prosthetic surgery can result in an unfavorable topographical result, with no room for a prosthesis or options for retaining one (Fig. 15.22). An interdisciplinary approach to pre-prosthetic surgery should therefore be developed in order to avoid a complete failure. After the patient has received an explanation of the current plan and agreed to it, the plan should be carried out gradually and consistently until an acceptable result is achieved (Figs. 15.9a, 15.10b, and 15.12a–f).

Insufficient support and stability of the prosthesis results in dislocation. The patient therefore always regards a prosthesis as an unincorporated foreign body, resulting in disorders and/or reduced self-confidence, particularly in young people [59]. If no defined site for the surgical provision of a bed for a prosthesis can be found and no retaining elements can be integrated into the body of a prosthesis for secure anchorage with the aid of dental prosthetics and materials technology, provision of a prosthesis should be postponed until the required conditions can be made available.

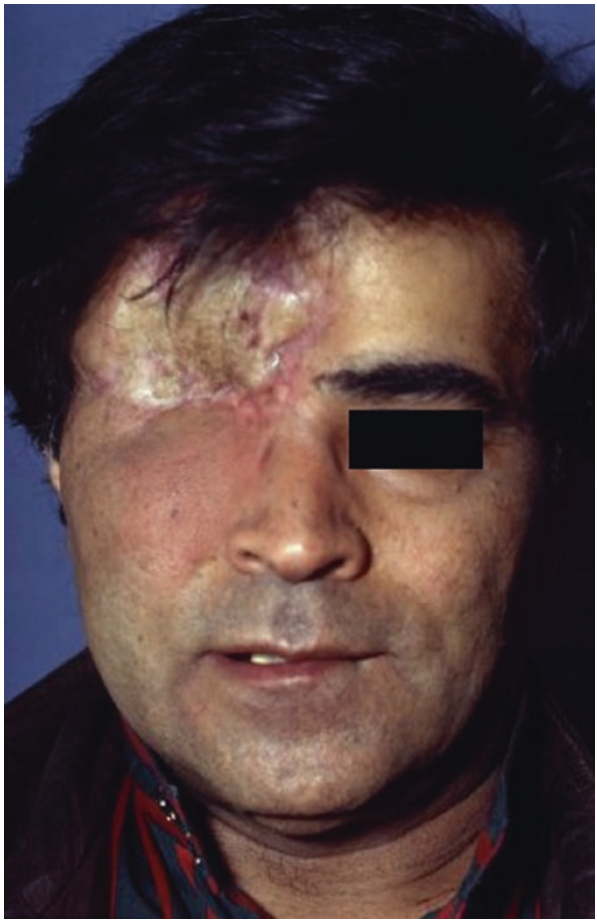

Fig. 15.22 Result after extensive tumor resection in a 43-year-old patient. Inadequate room and topography without options for retention are unfavorable conditions for rehabilitation with a facial prosthesis

Insufficient overview and hygiene in the region of implants with pillars that are too close together or short bar constructions can result in the deposition of exudates and dirt, particularly with extraoral structures (Fig. 15.23a–c), since no natural cleansing takes place such as intraoral cleansing of the pillars by rinsing with saliva. Although crusts can be cleaned off extraorally with interdental brushes, hygienic measures are much simpler if the pillar separation is at least 15 mm and circumferential cleaning is carried out daily for each pillar with water and a damp cotton swab. In addition, the surrounding epithelium should be cleaned regularly every 6 months with professional monitoring and the use of 3 % hydrogen peroxide. With inadequate hygiene, inflammation of the implant region can enlarge the cutaneous gateway for bacteria. In this case, application of Bepanthen® often succeeds in eliminating the inflammation. For more persistent infections, application of an

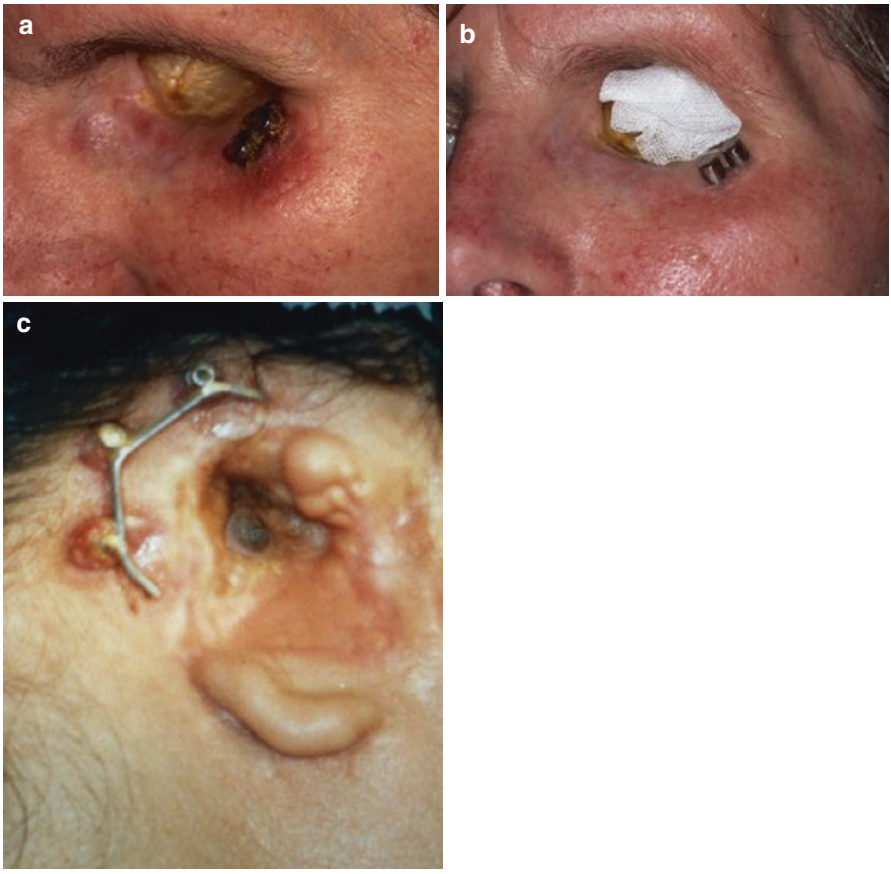

Fig. 15.23 (**a**) Crowding of the pillars prevents an overview of the implant site and hygienic measures and provokes inflammation. (**b**) Absence of inflammation after treatment with a local antibiotic ointment (e.g., Terra-Cortril®). (**c**) Bar construction hinders hygienic measures, particularly with low structural heights. Inflammation may result in the implant area

antibiotic ointment can heal and tighten the skin cuff around the pillar that has been softened and distended by inflammation. This allows the skin cuff to recover its ability to seal the junction (Fig. 15.23b). Daily cleaning of the skin penetration site with moistened cotton swabs moving clockwise around the pillar is recommended in order to avoid complications. This is part of the patient's hygiene instructions, since a minimal clockwise impulse will tend to tighten the insert into the implant, while counterclockwise cleaning will tend to loosen it.

Loosening of the retention elements can cause inflammation if a subcutaneous gap opens between the implant and the insert in which necrotic material can accumulate. Clinical evaluation reveals exudate (or pus if inflammation is advanced) seeping out of the implant pocket. This can result in a rocking movement of the insert in the threaded portion, which can ultimately lead to thread breakage. The basic rule is: the fewer the screw connections in the superstructure, the lower the risk of loosening. The patient should check the tightness of the insert by rotating it clockwise between his thumb and fingertip.

This means that the insert is continually tightened to the limit of the thread. A health professional should check that the inserts are seated firmly with an applicator and 3 % hydrogen peroxide. This should be done every 6 months during a routine inspection.

Deposits from detergents cause skin irritation, and this can result in skin redness at the base of the prosthesis if it is not removed before the hair is washed, the detergents are not rinsed completely away, and soap as well as moisture remains in the bed of the prosthesis (Fig. 15.24a). Patient instructions should include advice to

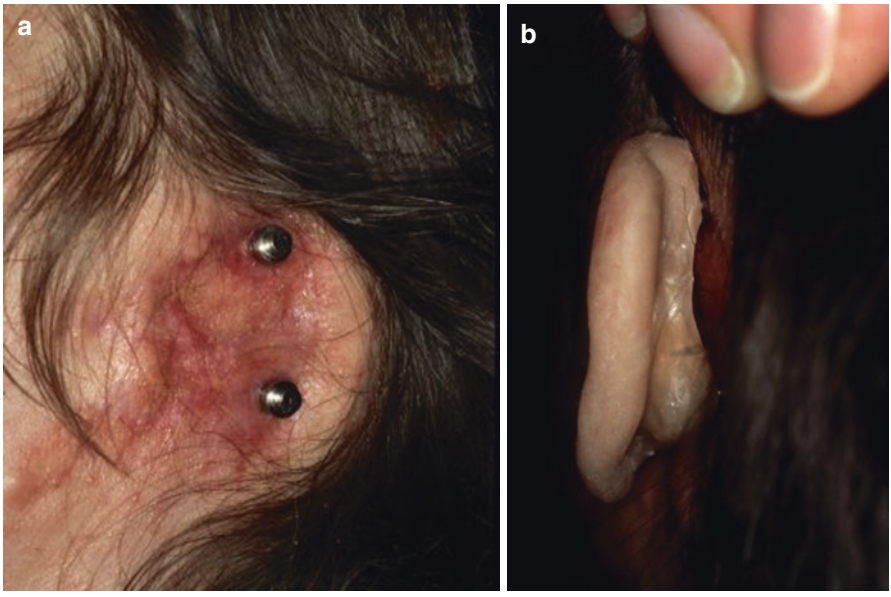

Fig. 15.24 (**a**) Cutaneous inflammation of the base of the prosthesis can be caused by detergent deposits. (**b**) The base of the prosthesis should be "hollowed out" for ventilation

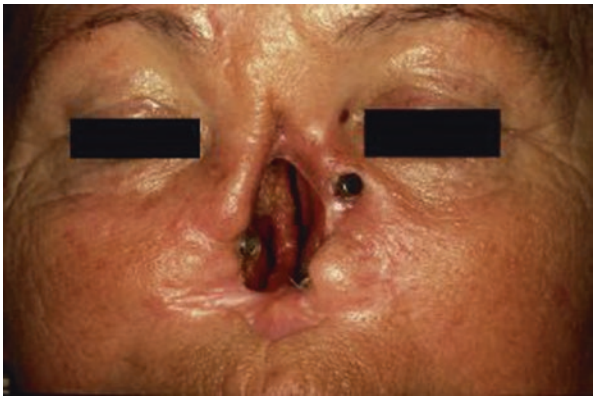

Fig. 15.25 The position and axial inclination of the superior pillar are situated unfavorably and outside the volume and contour of a prosthetic reconstruction of the nose. However, the lower right pillar is ideally positioned in the piriform aperture. A superstructure of normal height can therefore be integrated well into the body of the prosthesis

remove the prosthesis before washing the hair, to rinse the defect region with water and then to dry it. The base of the prosthesis should be hollowed out for ventilation to prevent formation of a "moist chamber" (Fig. 15.24b).

Unsuitable positioning of the implants and too little room for the superstructure may entail overextension of the body of the prosthesis, resulting in impaired aesthetic quality (Fig. 15.25). This problem can be solved with angled components (console abutments), but this results in multiple screw connections in the superstructure and thus involves the problems mentioned above regarding loosening of multi-screw retention elements. The aim is therefore to achieve axial screw connection of the insert with an integrated magnet as well as ideal positioning and axial inclination of the osseointegrated implant. This aim and prevention of failures are both achieved by planning the pre-prosthetic surgery together with colleagues [2, 21, 29].

15.22 Prospects

Restoration of the orbit with a hydroxyapatite (HA) eyeball (Bio-Eye®) as a functional prosthesis anchor covered with mucosa is still a special case in surgical prosthetics: after enucleation as a result of an accident or cancer, an open-pore HA eyeball is inserted into the cavity and sutured in place with functional integration of the extraocular muscles but without tension. During the healing process, a conformer is inserted into the palpebral fissure; this forms the bed for the future prosthetic eyecup with room in the superior and inferior conjunctival fornices as well as the medial and lateral angles of the eye for the definitive eyecup. After a healing period of 3 months, the porous bioconductive hydroxyapatite implant is invaded by soft tissue. In a second operation, an anchorage is created in the implant with a

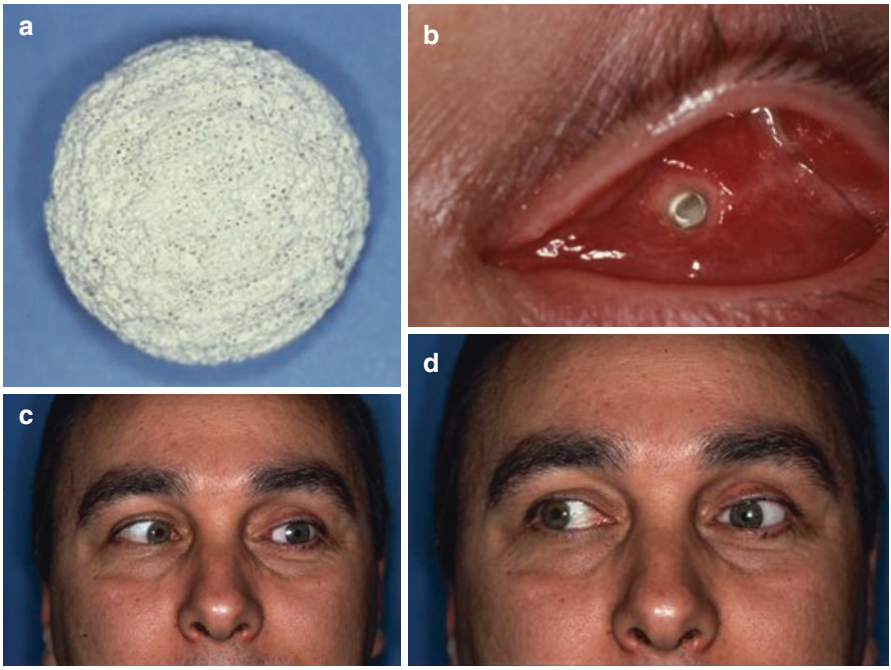

Fig. 15.26 (**a**) Open-pore, bioconductive hydroxyapatite implant as a nonabsorbable eyeball replacement. (**b**) Hydroxyapatite eyeball with covering mucosa and coupling socket in situ. (**c**, **d**) The functionally retained epiprosthesis (left orbit) is moved by the coupling pin in the coupling socket via the hydroxyapatite eyeball and the extraocular muscles

permucosal coupling pin for a custom-made removable PMMA eyecup, so that the prosthetic reconstruction has the same motility as the contralateral eye (Fig. 15.26a–d). The hydroxyapatite endoprosthesis thus serves as a functional retention anchor for the aesthetic exoprosthesis. The whole prosthetic structure is therefore biomechanically interconnected with the adjacent tissue structures and their specific physiological capabilities. This challenging prosthetic application requires stepwise progress and collaboration between prosthetic and surgical colleagues all the way from planning pre-prosthetic surgery to completion.

Surgical prosthetics offers further examples of new opportunities in defect rehabilitation that are provided by bioconductive implants and biodegradable materials [1, 35, 43]. These developments suggest that enormous resources in materials technology are available for the reconstruction of lost tissue contours with alloplastic bioactive materials, which open the way to new techniques for prosthetic surgery in clinical practice in terms of the tissue remodeling of extensive defects.

During the last 20 years, we have been able to develop a biocompatible granular material and a mineral paste that induce soft tissue growth in situ and enable alloplastic regeneration of granulation tissue and rehabilitation without a scaffold (Fig. 15.27). In pilot cases of chronic wounds, soft tissue was regenerated in the

Fig. 15.27 Various HA granulate formulations for a number of indications and a paste for skin regenerations

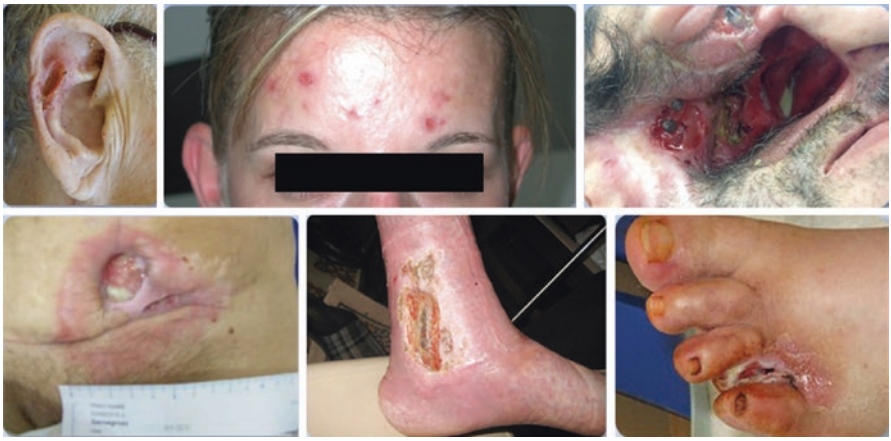

Fig. 15.28 Various chronic insufficiencies and defects

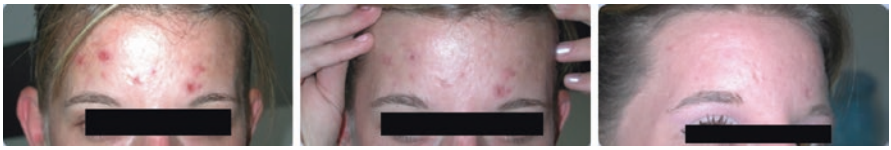

Fig. 15.29 27-year-old woman, status post several years of acne. Treatment with paste every three days. Completion of treatment after 18 days

shape and volume of the original tissue and we also obtained regeneration of mucosal tissue [32, 33]. This medical device appears to enable the restoration of extensive soft tissue defects with very little scarring (Figs. 15.28, 15.29, 15.30, 15.31, and 15.32).

After our initial experience with Epimineral® (Medical Minerals AG, Switzerland) and a number of successful treatments of pilot cases, a systematic study (with a clinical partner) of about 40 patients would now be worthwhile. A

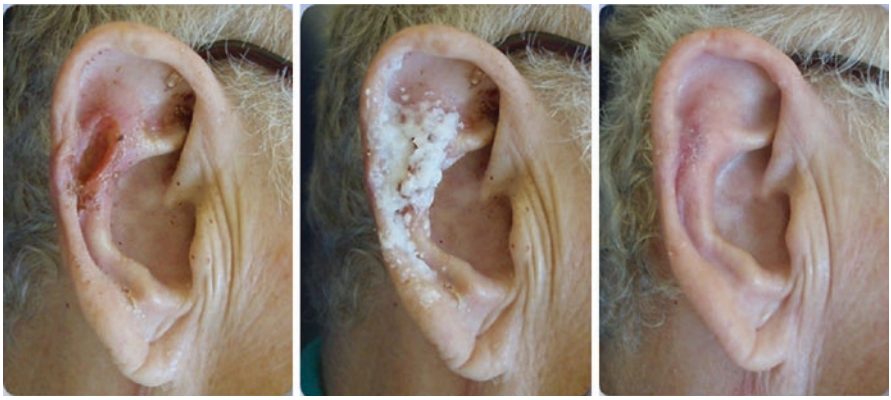

Fig. 15.30 Chondrodermatitis nodularis helicis (CNH). Status post 12 weeks of treatment. Secondary finding: anterior wrinkle reduction

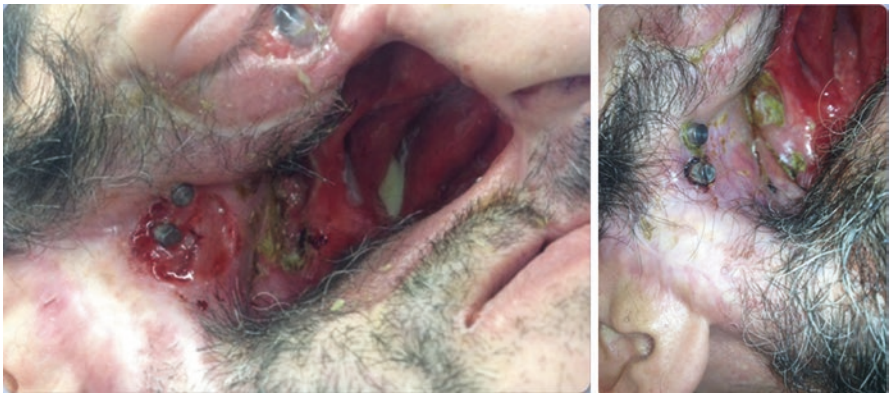

Fig. 15.31 46-year-old patient, irradiation 5 years before placement of implants, dehiscence of the skin. Treatment with mineral paste, healing after 4 weeks

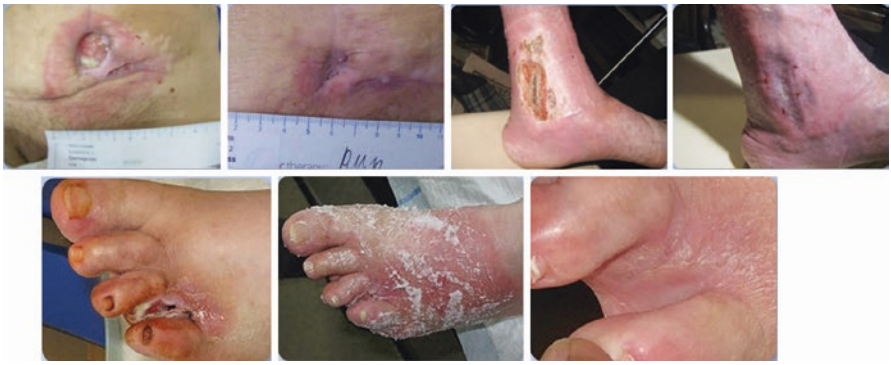

Fig. 15.32 Infected abdominal wound, treatment with mineral granules. Condition after 8 weeks

study of the skin as well as a study of the mucosa would be relevant for various indications. This product makes it possible to restore tissue defects at low cost.

15.23 Summary and Conclusion

The facial prosthesis is a suitable means of concealing a superficial tissue defect aesthetically. It satisfies the need to minimize surgical trauma in order to protect the patient and reduce tissue injury. The goal of surgical prosthetics and epithetics is to create an optimal bed for fixation of the prosthesis in a defined position with minimally invasive surgery and to prevent dislocation of the prosthesis so that the patient experiences no additional psychosocial trauma. The therapeutic concept therefore includes preoperative patient counseling and consultation among colleagues regarding pre-prosthetic surgery. The patient needs to understand the final result that he can expect, the opportunities provided by biocompatible materials, and their biomechanical limitations with regard to uneventful and satisfactory function in the long term.

The aim of maxillofacial prosthetics was primarily artistic and aesthetic [16, 17], and excellent results are currently obtained, with outstanding individual surgical and epiprosthetic achievements being particularly noteworthy. However, given the innovations in prosthetics and in view of the high number of cancer cases, new rehabilitation concepts with a broad range of clinical applications in facial and somatic prosthetics are clearly desirable [30]. There is a tendency to involve facial prosthesis design as a porous scaffold for restoration. Incorporation of tissue-integrated prosthetics will increasingly become an interdisciplinary challenge involving surgery, prosthetics, and materials science, which is why this area of rehabilitation is referred to collectively as surgical prosthetics and rehabilitation [48]. Meanwhile, we have shown that extensive chronic soft tissue defects and wounds with MRSA can be restored with this mineral medical device [32, 33].

Ulcer of the lower leg, condition after 4 weeks of treatment. Diabetic foot syndrome: amputation of the fourth toe and then relapse. Diagnosis: amputation of the foot. The foot nine days after first treatment. Healing with minimal scarring after 15 weeks.

References

1. Beleites E, Neupert C, Augsten G, Vogel W, Schubert H. Rasterelektronenmikroskopische Untersuchung des Zellwachstums auf maschinell bearbeiteter Biovitrokeramik und Glaskohlenstoff in vitro und in vivo. Laryngol Rhinol Otol. 1985;64:217–20.
2. Besimo CE, Gräber G, Lambrecht JT. Bildgebende Verfahren zur prächirurgisch-prothetischen Planung implantatgetragener Suprastrukturen. Implantologie. 1995;3:193–207.
3. Biet-Weber M, Farmand M. Färb- und Formgestaltung bei Silikonepithesen: Eine künstlerische Herausforderung. In: Kongreßband zum XI. Internationalen Symposium für Chirurgische Prothetik und Epithetik; 1998. pp. 105–12. +41 44.
4. Bohmert H. Der prothetische Wiederaufbau der Mamma. In: Krupp S (Hrsg). Plastische Chirurgie, Klinik und Praxis, ecomed Verlagsgesellschaft AG & Co. KG, Landsberg, V1-4.1; 1995. pp. 1–14.

5. Brånemark PI, Hansson BO, Adell R, Breine U, Lindström J, Hallen O, Öhman A. Osseointegrated implants in the treatment of the edentulous jaw. Scand J Plast Reconstr Surg. 1977;111 Suppl 16:1–132.
6. Brånemark P-I, Albrektsson T. Titanium implants permanently penetrating human skin. Scand J Plast Reconstr Surg. 1982;16:17–21.
7. Bucher P, Lüscher NJ, Troeger H, Prein J. Die Materialfrage in der Epithetik – Haben die harten Kunststoffe eine Existenzberechtigung? In: Schwipper R, Tilkorn H, editors. Fortschritte in der kraniofazialen chirurgischen Prothetik und Epithetik. Reinbek: Einhorn-Presse Verlag; 1997. p. 199–206.
8. Diedrichs U. Interdisziplinäre Zusammenarbeit in der Kiefer-Gesichts-Prothetik. dental-labor, XL11. Heft. 1994;6:819–22.
9. Duncan GF. Entwicklung zur Vollkommenheit: Die Rolle der amerikanischen Gesellschaft für Anaplastologie in Nordamerika. In: Schwipper R, Tilkorn H, editors. Fortschritte in der kraniofaszialen chirurgischen Epithetik und Prothetik. Reinbek: Einhorn-Presse Verlag; 1997. p. 239–44.
10. Farmand M. Ein neues Implantat-System für die Befestigung von Epithesen (Epitec-System). Dtsch Z Mund Kiefer Gesichtschir. 1991;15:421–7.
11. Farmand M. Die epithetische Rehabilitation von Patienten mit Gesichtsdefekten mit dem Epitec-System – Grundlagen, Prinzipien, Resultate. In: Schwipper R, Tilkorn H, editors. Fortschritte in der kraniofaszialen chirurgischen Prothetik und Epithetik. Reinbek: Einhorn Presse Verlag GmbH; 1997. p. 78–88.
12. Federspil PA. Ear epitheses as an alternative to autogenous reconstruction. Facial Plast Surg. 2009;25:190–203.
13. Federspil PA. Auricular prostheses. Adv Otorhinolaryngol. 2010;68:65–80.
14. Federspil PA. Implant-retained craniofacial prostheses for facial defects. In: Pau HW, ed. Technology for quality of life – implants and biomaterials in otorhinolaryngology. Mönchengladbach: Rheinware Verlag; 2011. (Current topics in otolaryngology – head and neck surgery; vol. 8). pp. 259–85.
15. Frey M. Die Primärrekonstruktion der Brust – Eine anspruchsvolle interdisziplinäre Aufgabe. In: Waclawiczek HW, Menzel CH, Hausmaninger H, Kogelnik HD, Wolf G (Hrsg). Die interdisziplinäre kurative Behandlung des Mammakarzinoms. Heidelberg: Johann Ambrosius Barth Verlag 1998; 86–92.
16. Gehl G. Über die Ausbildung eines Epithetikers. Oesterreichische Zahnprothetik. Heft. 1982;4:14–7.
17. Gehl C. Ein neues Verfahren bei der Versorgung von Gesichtsdefekten. In: Ehring F, editor. Die Epithese zur Rehabilitation des Gesichtsversehrten. Berlin/Chicago/London/Sao Paulo/Tokio: Quintessenz Verlags-GmbH; 1985. p. 77–82.
18. Gehl G. Verletzungsmuster bei Mehrfachverletzten mit einem Bauchtrauma. Inaugural-Dissertation der Medizinischen Fakultät der Friedrich-Alexander-Universität Erlangen-Nürnberg (27.11.1989).
19. Gehl G. Epithesenmodell ohne Abformung? In: Kongreßband des II. Internationalen Symposiums für Chirurgische Prothetik und Epithetik, Linz; 1990. pp. 29–34.
20. Gehl G. Eine neuartige Fixierung bei Silikonepithesen. In: Kongreßhand zum IV. Internationalen Symposium für Chirurgische Prothetik und Epithetik, Linz; 1992. pp. 39–44.
21. Gehl G, Lechner KH, Farmand M. Die interdisziplinäre Zusammenarbeit bei ausgedehntem Kiefer- und Gesichtsdefekt. In: Kongreßband zum V. Internationalen Symposium für Chirurgische Prothetik und Epithetik, Linz; 1993. pp. 24–31.
22. Gehl G. Erhöhung der Lagestabilität von Resektionsprothesen durch Verschlüsselung mit einer implantatgestützten Epithese. In: Kongreßband zum VI. Internationalen Symposium für Chirurgische Prothetik und Epithetik, Linz; 1994. pp. 39–43.
23. Gehl G. Die Immediatepithese. Dtsch Zahnärztl Z. 1994;138–41.
24. Gehl G. Die implantatfixierte Vollsilikonepithese ohne PMMA-Basis. In: Kongreßband zum Vll. internationalen Symposium für Chirurgische Prothetik und Epithetik, Linz; 1995. pp. 35–40.

25. Gehl G. Optimization of fixation methods for epitheses. J Craniofac Surg. 1996;24 Suppl 1:135.
26. Gehl G, Sailer HF, Zollikofer CE, Stucki P. Epithetic treatment principles and the use of stereolithography. J Craniofac Surg. 1996;24 Suppl 1:46.
27. Gehl G. Epithetische Versorgungsmöglichkeiten im Gesichtsbereich. In: Dummer R, Panizzon R, Burg G, editors. Operative und konservative Dermatoonkologie im interdisziplinären Grenzbereich, Band 11. Berlin/Wien: Blackwell Wissenschafts-Verlag; 1996. p. 16–21.
28. Gehl G. Die Korrekturfähigkeit bei Vollsilikonepithesen. In: Kongreßband zum VIII. Internationalen Symposium für Chirurgische Prothetik und Epithetik, Linz; 1997. pp. 83–91.
29. Gehl G, Sailer HF, Simmen D, Frey M, Meyer VE. Von der Immediatepithese zur definitiven implantatfixierten Gesichtsepithese: Das Zürcher Versorgungskonzept. In: Schwipper V, Tilkorn H (Hrsg). Fortschritte in der kraniofazialen chirurgischen Prothetik und Epithetik. Reinbek: Einhorn-Presse Verlag; 1997. pp. 222–5.
30. Gehl G. Die Brustepithese als Langzeitprovisorium. Tumordiagn u Therapie. 1999;20:67–9.
31. Gehl G. Titanimplantate in der kraniofazialen Rehabilitation: Eine Vielzahl funktioneller Vorteile? In: Kongreßband zum X. Internationalen Symposium für Chirurgische Prothetik und Epithetik. Linz. 1999. pp. 89–92.
32. Gehl G. Gesteuerte Regeneration mittels bioaktiver Paste ohne vorgefertigtes Scaffold? BioNanoMaterials. 2013;14:139.
33. Gehl G. Tissue Engineering in situ bei ausgedehnten Weichgewebsdefekten. BioNanoMaterials. 2013;14:216.
34. Grätz KW, Sailer HF, Oechslin C, Haers PE. Die Unterkieferrekonstruktion mit Schädelkalottenknochen und Temporalismuskellappen. Fortschr Kiefer-Gesichtschir. 1995;39:84–7.
35. Groten M, Hoffmann J, Cornelius CP, Pröbster L, Pfannenberg C, Geis-Gerstorfer J. Herstellung individueller Keramikimplantate für Orbitarekonstruktionen. Dtsch Zahnarztl Z. 1997;52(4):268–71.
36. Hulterström M. Moderne Epithesenwerkstoffe. Quintessenz. 1981;3:539–43.
37. Jäger K, Wirz J, Baumann F. Konus-Titanmagnetics (Komafix) – ein neues Verankerungselement für die Hybridprothetik. Quintessenz. 1998;49(1):75–80.
38. Kirsch A, Ackermann KL. Das IMZ-system, methode – klinik – ergebnisse. Zahnarztl Welt. 1986;95:1134–44.
39. Kubik-Huch RA, Garzoli EE, Marincek B. Bildgebende Verfahren nach Mammarekonstruktion. Tumordiagn u Therapie. 1999;20:63–6.
40. Lanman BM, Elvers WB, Howard CS. The role of human patch testing in a product development program. In: Proceedings of the Joint Conference on Cosmetic Sciences. Washington, DC: The Toilet Association; 1968. pp. 135–45.
41. Lehmann KM. Ersatz eines Fingergliedes mit den Methoden der Epithetik. Quintessenz Zahnärztl Lit. 1973;24:845.
42. Lehmann KM, Schwenzer N. Maxillofaziale Prothetik. In: Schwenzer N. Zahn-Mund-Kieferheilk. Band 3, Prothetik u. Werkstoffkunde. Stuttgart: Thieme 1994. pp. 425–95.
43. Le Huec JC, Schaeverbeke T, Clement D, Faber J, Le Rebeller A. Influence of porosity on the mechanical resistance of hydroxylapatite ceramics under compressive stress. Biomaterials. 1995;16(2):113.
44. Marxkors R. Ursachen, Auswirkungen und Behebungen von Misserfolgen. Dtsch Zahnarztl Z. 1999;54(10):600–10.
45. Meuli-Simmen C, Meyer VE. Mammarekonstruktion ohne Lappenplastik. Tumordiagn u Therapie. 1999;20:60–2.
46. Olbrisch RR. Der Zweiteingriff. In: Krupp S (Hrsg). Plastische Chirurgie, Klinik und Praxis, ecomed verlagsgesellschaft AG & Co. KG, Landsberg II-9; 1994. pp. 1–3.
47. Reitemeier B, Schmidt A, Gebelein S, Richter G. Experimentelle Untersuchungen des eichbleibenden Werkstoffes Elastosil-M-3500 unter dem Aspekt des Einsatzes als Epithesenwerkstoff.

In: Kongressband zum IX. Internationalen Symposium für Chirurgische Prothetik und Epithetik. Linz; 1998. pp. 99–104.
48. Reitemeier B. Weiterbildungsempfehlungen der Internationalen Gesellschaft für Chirurgische Prothetik und Epithetik, Linz; 1996.
49. Reitemeier B, FriedrichsenI, Gehl G, Richter G. Experimentelle Untersuchungen zum Verbund von Epithesensilikonen. Jahresjournal für Chirurgische Prothetik und Epithetik, Linz; 2003. pp. 73–5.
50. Renk A. Die Geschichte der Epithetik unter besonderer Berücksichtigung der klinisch-praktischen Anwendung sowie der Problematik von Gesichtsprothesen. In: Habilitationsschriften der Zahn-, Mund- und Kieferheilkünde. Berlin: Quintessenz Verlags-GmbH; 1992.
51. Sailer HF, Haers PE, Locher M, Warnke T, Zollikofer CPE, Stucki P. The value of stereolithographic models for preoperative diagnosis of craniofacial deformities and planning of surgical corrections. Int J Oral Maxillofac Surg. 1998;27:327–33.
52. Schilling N. Möglichkeiten in der Epithetik. In: Kongreßband zum V. Internationalen Symposium für Chirurgische Prothetik und Epithetik. Linz; 1994. pp. 93–6.
53. Spilker G, Stark GB. Der alloplastische Gewebeersatz. In: Krupp S (Hrsg). Plastische Chirurgie, Klinik und Praxis, ecomed verlagsgesellschaft AG &. Co. KG, Landsberg II-6; 1994. pp. 1–18.
54. Stoiber E. Neuere Arbeitserfahrungen mit Palamed und Mollomed. In: Ehring F, editor. Die Epithese zur Rehabilitation des Gesichtsversehrten. Berlin/Chicago/London/Sao Paulo/Tokio: Quintessenz Verlags-GmbH; 1985. p. 69–76.
55. Tjellström A, Lindström J, Nylén O, Albrektsson T, Brånemark P-I. The bone-anchored auricular epithesis. Laryngoscope. 1981;91:811.
56. Tjellström A. Osseointegrated implants for replacement of absent or defective ears. Clin Plast Surg. 1990;17:355–66.
57. Trentz O, Ertel W. Neue diagnostische Strategien beim Polytrauma. Chirurg. 1997;68:1071–5.
58. Wah J. Epithesenwerkstoffe im kumulativen Irritationstest. Inaugural-Dissertation der Medizinischen Fakultät der Universität Zürich. Genehmigt im Auftrag von Prof. Dr. C. Burg und Prof. Dr. V.E. Meyer; 1999.
59. Weerda H, Siegert R. Zugangswege zur plastischen Ohrmuschelkorrektur im Kindesalter. In: Schmelzle R, Bschorer R, editors. Plastische und Wiederherstellungschirurgie. Hamburg: Unimed Verlag; 1994.
60. Weerda H. Das frische Ohrmuscheltrauma. HNO. 1996;44:701–9.
61. Wirz J, Schmidli F. Magnetanker im Korrosionstest. Quintessenz. 1990;41:879–86.

Tissue-Engineered Maxillofacial Reconstruction: Focus on Bone

16

Riitta Seppänen-Kaijansinkko and Risto Kontio

16.1 Introduction

There are two main principles for maxillofacial reconstruction. The reconstructive surgery should provide form and enable function of oromaxillofacial (OMF) region. The facial skeleton has an extreme complex structure, and reconstruction should restore volume, shape, bone continuity and symmetry of bone skeleton. On the other hand, OMF soft and hard tissues enable several functions like mimics, mastication, swallowing and articulation. The reconstruction should be considered as marriage of both aesthetic and reconstructive objectives.

Depending on the severity of deformity or defect, there are several surgical options to overtake the goals of these principles [1]. In simple defects, a direct closure or skin/bone graft is often sufficient. In more complex situations, distant flap or microvascular free flap is essential to reach the best possible result.

At present, free flap reconstruction is the golden standard for OMF in complex deformity or defect repair. However, there are several drawbacks in free flap reconstruction of OMF region. The volume and the shape of facial skeleton are difficult to obtain with composite free flap options available, such as deep circumflex iliac artery (DCIA), fibula or scapular flap due to their original anatomy. The supply of suitable bone is limited especially in osteoporotic, paediatric and oncological patients. The operation is also time consuming due to fact that bone flaps are

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relatively difficult to raise and require shaping to achieve proper form. Especially complex maxillary defects are extremely difficult to reconstruct satisfactorily. Finally, the donor site complication rate is significant.

Both computer-aided design (CAD) technology for surgery and tissue engineering and regenerative medicine (TERM) have evolved considerably during the last 5–10 years [2, 3, p. 17, 4–6]. The combination of these two may in the near future give novel tools for OMF reconstructive surgery. It is quite natural that these two separate technologies support each other and will enable complex reconstructions in the future [7]. TERM will provide proliferating cells with vital environment, and CAD technology enables anatomically precise scaffold and matrix manufacturing to guide proliferating cells to right form and to allow regeneration and maturation of tissue, replacing accurately the OMF defect [8].

There are several translational and clinical research projects regarding CAD and TERM at the present [7–10]. A growing number of translational and clinical research reports are available related to stem cell bone reconstruction in OMF region [11–14]. Also, there are clinical reports of successfully performed reconstructions using CAD–CAM (computer-aided manufacturing) technique in OMF region. A few reports of OMF reconstruction using the combination of these two above-mentioned techniques have appeared to literature during recent years [15].

16.2 Computer-Aided Simulation, Planning and Manufacturing

The focus of CAD–CAM technology in medicine is to enable detailed planning and simulation of surgery [4, 16]. Furthermore, it should support implant design [17]. As a consequence, it should shorten operation time, improve recovery of the patient and lower morbidity. The definitive objectives are to improve the form and function of OMF skeleton and provide better quality of life compared to traditional surgical reconstructive techniques (Fig. 16.1).

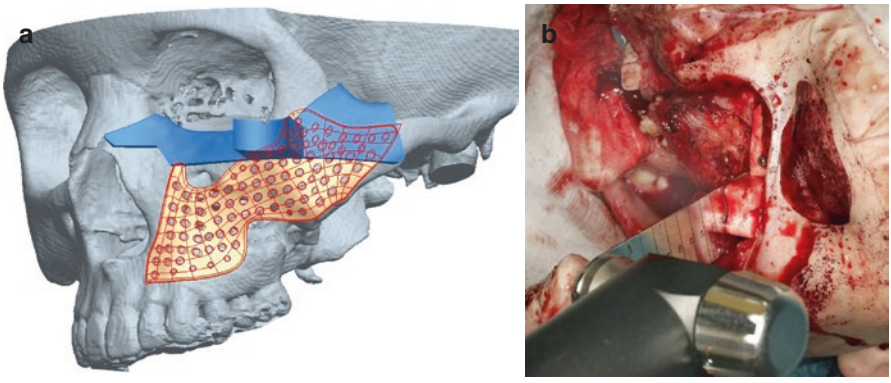

Fig. 16.1 (**a**) Virtual planning of maxillectomy of a 12-year-old male with SCC. (**b**) The jig to guide the surgery was rapid manufactured (RP) based on virtual 3D model

Traditionally, the CAD–CAM in medicine is considered as a path of four consecutive phases: (1) CT 3D imaging data; (2) data conversion, CAD; (3) planning of surgery/manufacturing of implant; and (4) actual surgery accordingly.

At the present, when an increasing number of CAD–CAM in medicine studies are available, the process of computer-aided simulation (CAS), planning and manufacturing has proven to be much more complicated [4, 16, 18]. It seems that there are at minimum seven critical stages, which may interfere with the process. Firstly, the CT imaging process has an utmost importance. The relevant factors like gantry, tilt, slice thickness and distortion should be adjusted properly in order to avoid incorrect database. Secondly, the preset CT algorithms have a great influence on data. Algorithms are to modify the accentuation of shades of grey colour. The human eye recognizes less than thirty grey shades, but the CT may produce up to 1000 shades. Algorithm computation emphasizes the essential shades to achieve best possible resolution for tissue in question. This means that original range of the grey shades is distorted and CAD virtual image is therefore not accurate compared to original anatomy. Thirdly, data formats of CT and formats of CAD are not compatible, and conversion from surface geometry format to volumetric format is mandatory. Although this process is semiautomatic, even automatic in some cases, it includes risks for errors. After these phases, the virtual 3D image is available for surgeon and engineer for planning and simulation of surgery and design of possible implant. Virtual implant can be manufactured directly to solid model using 3D printers or laser rapid prototyping techniques.

The implementation of virtual planning and simulation into clinical operation needs consideration [19]. There are a few options to carry out operation according to the virtual planning. One is to use navigation to ‘bridge’ virtual and real. Another choice is to use ‘jigs’ or guide blocks to execute the virtual plan. However, risks for errors in this phase of surgery are significant. The same risk exists with implant. Regarding implants, in Europe, the devices implanted to human being (like surgical implants) need to meet several specifications and directives such as Directive 93/42/EEC/Article 1, Directive 2007/47/EU and ASTM F136 – standard among others. This is significant when considering implant printing processes and materials.

16.3 Tissue Engineering and Regenerative Medicine (TERM)

The gold standard for reconstructive bone surgery is autologous bone, either free graft or free vascularized flap. Autologous bone defines criteria for ideal implant: histocompatible, non-immunogenic, osteogenetic, osteoinductive and osteoconductive. But there are several drawbacks of autologous bone, both at the donor and at the recipient site. It would therefore be ideal to build up the bone at the reconstruction site, at the distant site or outside of the patient and transfer it into defect area.

Tissue engineering and bone regeneration process requires several components that should support the growth and maturation of the bone. At the present, certain components are considered to have prominent role in the process. An

osteoconductive matrix is essential to support the ingrowth of cells and to enhance new bone growth. Osteoinductive proteins are required to start and maintain the mitogenesis of undifferentiated cells. Osteogenic cells are necessary to generate new bone. In the bioreactor or human tissue environment, the above-mentioned components refer to matrix = biomaterial, to cells = stem cells/osteoblast precursors, to osteoinductive proteins = cytokines and morphogenetic proteins and to angioinductive factors = cytokines/growth factors.

The matrix should provide tissue-specific environment, architecture and scaffold to enable bone formation. It should be osteoinductive/osteoconductive, give mechanical support, facilitate cell attachment and support cellular communication by allowing diffusion of nutrients and by allowing signalling of cytokines and growth factors. There are several bone substitutes, both alloplastic and allografts, that are candidates for ideal matrix. The most studied and clinically used materials are beta-tricalcium phosphate (β-TCP) and biphasic calcium phosphate (BCP) [9, 10, 15, 20–22]. There are also several published reports on ceramics and bioactive glasses used for bone substitute [23, 24]. Allografts have been shown to be effective to support bone growth and regeneration. Most known materials are anorganic bovine-derived hydroxyapatites and cancellous bone allografts.

It remains unclear what are the most suitable cells for tissue engineering and bone regeneration. There are several options available such as mesenchymal stem cells, bone marrow stromal cells, osteoblast precursors and periosteal cells [2, 25, 26]. In human environment, if periosteum is left unchanged, external cells might be superfluous due to migration of remaining periosteal cells. However, it is difficult to assess the efficacy of matrix and cell combinations.

Osteoinductive proteins are capable to modulate proliferation and differentiation of precursor cells to osteoblastic course. The most studied proteins are BMPs (BMP-2, BMP-7) and TGF-β. The focus of the research has been to optimize pharmacokinetics and to immobilize the proteins within the matrix. Angioinductive growth factors (e.g. VEGF and β-FGF) have several potential mechanisms through endothelial cells and local tissue matrix to enhance capillary ingrowth. Their clinical importance is unclear although wide translational research is ongoing [27, 28]. Nevertheless, the rationale of enhancing angioinduction potential is to enable adequate vascularization for cell survival and bone formation.

16.4 TERM, Clinical Fundamentals

The fundamentals of bone regeneration are growth, maturation and bone maintenance. Bone growth is related to cells, scaffolds and matrix. Maturation requires successful graft incorporation. Continual maintenance is mandatory for engineered bone survival and permanence. The maintenance refers to mobility, load-bearing capacity, haematopoiesis and continuous resorption–renewal–remodelling processes. CAD–CAM technique enables design and manufacturing of both micro- and macrostructure of matrix resulting in directing the shape of the forming bone to desired goal.

Bone grafts, including bone marrow, have been in clinical use for reconstruction for many years. A few reports on the use of stem cells or progenitor cells have been published, most of them in vitro or experimental in vivo work.

Autologous mesenchymal cells are an attractive alternative for bony reconstruction, as there is no rejection and they do not carry any infectious agents. They can often be obtained in large quantities. They are multipotent cells and can undergo osteogenic, chondrogenic, adipogenic, neurogenic and myogenic differentiation in vitro [29, 30]. When autologous cells are handled and prepared without animal-derived material in good manufacturing practice (GMP) standard clean rooms, the cells can be considered safe for clinical cell therapy applications and are called as advanced therapy medicinal products (ATMPs).

Growth factors are also key factors in regenerative medicine. The bone morphogenic proteins (BMPs) are part of the transforming growth factor beta (TGF-beta) superfamily and have been shown to take part in bone and cartilage formation, fracture healing and repair of other musculoskeletal tissues [31]. Of this superfamily, osteoinductive growth factors rhBMP-2 and rhBMP-7 have been accepted for clinical use. They induce ossification by recruiting mesenchymal cells from surrounding tissues and enabling their differentiation towards osteoblasts [32].

16.5 Recent Clinical Developments

16.5.1 Cells

There are not very many clinical trials on stem cells used in tissue engineering for major maxillofacial reconstruction. With search words ‘stem cells’, ‘bone regeneration’ and ‘maxillofacial’, only two trials were found registered in clinicaltrials.gov on March 15, 2015. If search word ‘maxillofacial’ was left out, it resulted in a list of 85 registered clinical trials, but they all were not related to bone regeneration.

In the English literature, only some case report-type studies in humans have been published [9, 10, 15, 33]. The cells used have been MSCs derived from bone marrow or adipose tissue. They have been used with different types of carriers and containments (scaffolds) and sometimes with added growth factors.

The limiting factor at the moment is the high cost of producing stem cells for tissue engineering purposes in special GMP – class clean rooms. However, as technology advances, we most likely will be able to manufacture cells on site, or the cells are available as off-the-shelf products.

16.5.2 CAD/CAM

The computer-aided reconstruction can be performed either using direct or indirect technique. Indirect technique refers to process where CT data is simply converted to STL format and manufactured into solid model; in other words, virtual anatomy is

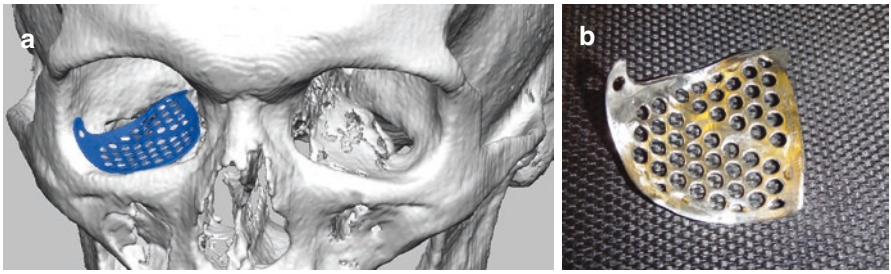

Fig. 16.2 (**a**) Virtual 3D image of orbital floor reconstruction mesh plate to repair orbital wall fracture. A lateral ledge was designed to guide the plate into right anatomic position during the surgery. (**b**) The solid titanium plate manufactured using direct metal laser sintering technique; note the lateral guiding ledge

converted into an exact 3D solid replica. The simulation, planning and implant design is carried out on solid 3D replica. The implants are manually prepared on the 3D replica, too. Direct technique refers to process where all phases are carried out fully digitally including the jigs (guide devices) and implants. These virtual objects are then manufactured by direct 3D printing or laser rapid prototyping technique if required [34] (Fig. 16.2).

16.5.3 Clinical Reports

There are only few reports where OMF defect reconstruction has been performed using computer-aided technology and stem cells or bone marrow cells.

One of the first reports came from Kiel, Germany. Warnke with his group repaired mandible continuity defect using vascularized custom-made bone flap with indirect technique [35]. The CT data of the patient was uploaded to CAD software, and the defect reconstruction of the mandible was virtually simulated and planned, and virtual implant was designed to repair the defect. The virtual implant was then converted into solid 3D Teflon replica. Teflon replica was used as a model to shape titanium mesh accordingly. This was done manually. Titanium mesh scaffold was filled with bovine bone mineral blocks combined with recombinant human BMP-7, bovine collagen type 1 and autologous iliac crest bone marrow. The scaffold was then implanted into the patient's latissimus dorsi muscle. Seven weeks later, the flap including the newly formed heterotopic bone and the titanium scaffold was raised as microvascular flap to reconstruct the patient's mandible continuity defect. After the follow-up of 4 weeks, the patient was able to use her mandible and was satisfied with the aesthetic outcome. The authors conclude that heterotopic bone induction to form a mandible replacement in a human being is possible. Furthermore, this technique allows for a lower operative burden compared with conventional techniques by avoiding creation of secondary bone defect.

A few years later, on 2011, Zétola and his coworkers published a report of mandible defect repair using recombinant human bone morphogenetic protein-2

associated with collagen sponge, autogenous bone chips and synthetic hydroxyapatite and β-TCP blocks. The mandible continuity defect was due to ameloblastoma resection, and an indirect technique was executed. The titanium reconstruction plate and titanium scaffold filled with the above-mentioned combination were implanted into the defect area. The collagen with rhBMP-2 was superposed above the open titanium mesh to allow muscle cells and periosteum to migrate to the defect area. After the follow-up of 7 months, the patient had stable occlusion and mandible. The control CT showed good bone formation directed to the centre of the defect. The authors concluded that the reported reconstruction technique gave a satisfactory result with less invasive surgery and with minimum morbidity. However, studies with larger number of patients are required to indicate the treatment modality as a routine in cases of bone continuity defects.

The largest experience of the use of autologous stem cells with 13 consecutive cases of craniomaxillofacial hard tissue reconstruction has been published by Sándor et al. [10]. The group reported on reconstruction of defects at four anatomically different sites, namely, frontal sinus (three cases), cranial bone (five cases), mandible (three cases) and nasal septum (two cases). Expanded (according to ATMP principles) autologous adipose-derived stem cells (ASCs) were used with biodegradable material (beta-TCP or bioactive glass). In some cases, recombinant human bone morphogenetic protein-2 was also used.

In the mandible, continuity defect repair was carried out using computer-aided surgical planning and ASCs. After resection of ameloblastomas, in all three cases, the defect was repaired with ASCs, β-TCP granules, rhBMP-2 and indirect custom-made titanium scaffold. The patients were followed between 27 and 51 months. In all three patients, the healing was uneventful. Two patients received a total number of seven dental implants later, which are being loaded in masticatory function. The authors concluded that although results are promising, further research is needed with animal studies and long-term human series. This view is supported by other research groups, too.

Matsuo et al. [36] used indirect technique in mandible defect repair. After surgical simulation, a PLLA patient-specific mesh tray was manually prepared and filled with hydroxyapatite. Intraoperatively, particulate cancellous bone marrow was harvested and with platelet-rich plasma placed into the tray. Two patients with mandible defect were included to the study. The follow-up was 28 and 33 months. One of the patients received dental implants after 10 months of the initial surgery. The heterotopic bone was macroscopically well formed. The CT evaluation showed good bone quality. However, the authors concluded that there are several limitations to the trial.

Mesimäki and coworkers reported a successful maxillary defect reconstruction using microvascular flap with heterotopic bone in the year 2009 [15]. The male patient had a hemimaxillary defect due to resection of a keratocyst. The patient did not tolerate removable obturator prosthesis. The repair was decided to execute using heterotopic bone flap. A combination of ASCs, β-TCP granules and rhBMP-2 with indirectly manufactured titanium scaffold was implanted into the rectus abdominis muscle. After 8 months, the rectus muscle with maturated heterotopic bone was

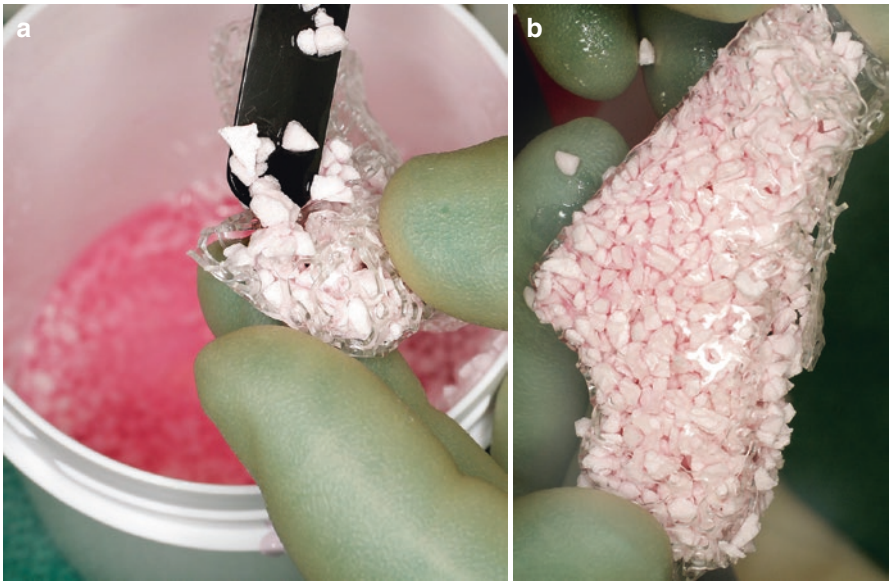

Fig. 16.3 (**a**) β-TCP seeded with autologous ASCs and rhBMP-2 is transferred into PLA scaffold. (**b**) The PLA zygomatico-maxillary scaffold is designed and manufactured using 3D computer modelling technology

raised and transferred into maxillary defect area. The anastomosis of flap recipient vessels was performed to neck vessels and flap was fixated with titanium plates. After uneventful healing of 1 year, dental implants were inserted to heterotopic 'neobone' and subsequently loaded in masticatory function. The histology confirmed normal bone tissue in heterotopic bone area. The same group performed similar reconstruction to a male patient after total maxillary defect. The combination of ASCs, β-TCP granules and rhBMP-2 in polylactide scaffold was implanted into the anterolateral thigh (ALT) flap. Computer-aided design with indirect technique was used to shape polylactide scaffold (Fig. 16.3). At the same time, the titanium patient-specific (PS) reconstruction plate to fixate the future 'neomaxilla' was designed and manufactured using direct computer technique and laser rapid prototyping. After a maturation of 7 months, the microvascular ALT flap with heterotopic bone was raised and placed into the area of resected maxilla. The orientation and fixation of the flap were secured with PS reconstruction plate. After eventful healing of 5 months, the dental implants were placed and occlusion was established with removable prosthesis (not yet published) (Fig. 16.4).

Same research group used similar direct CAD–CAM technique and tissue engineering to repair mandible defects. Fourteen patients were included into the study. Most of the patients had squamous cell carcinoma followed by ameloblastoma. The surgery was simulated and patient-specific implant (PSI) designed on virtual model by ProEngineer software. The PSI was a combination of scaffold and reconstruction plate with screw holes (Fig. 16.5). The virtual PSI was manufactured using Arcam

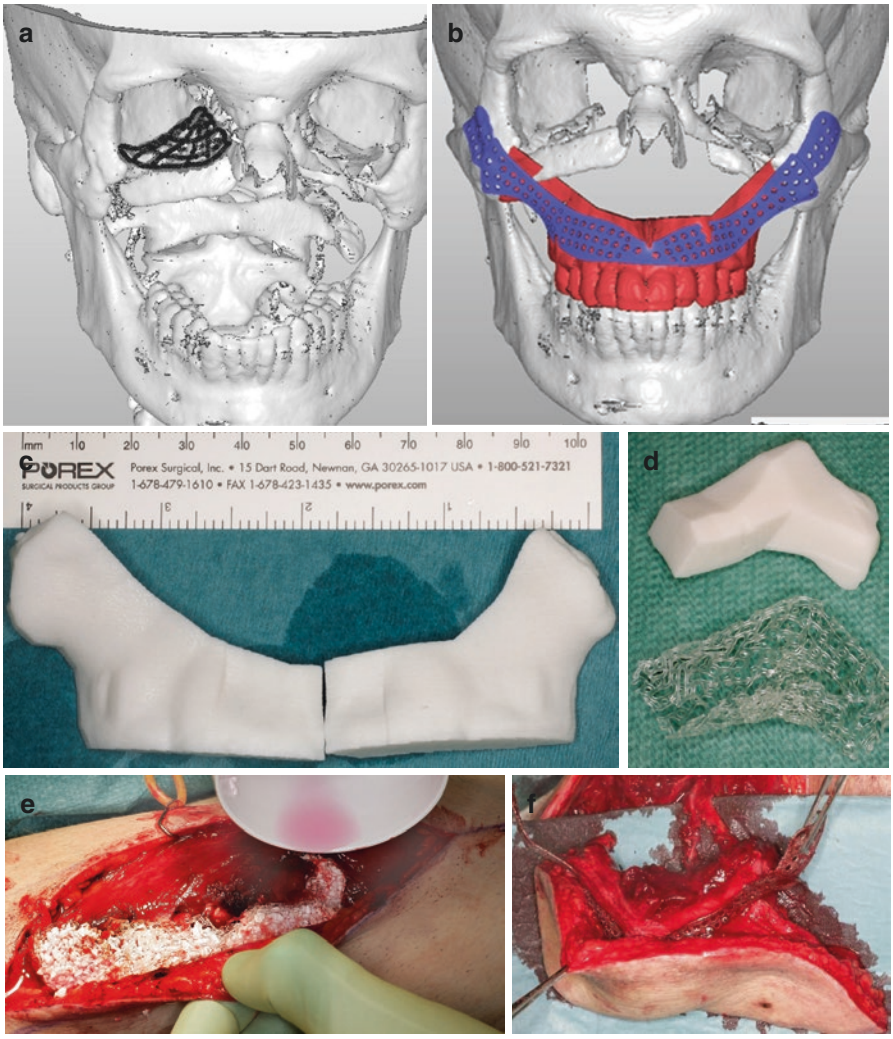

Fig. 16.4 (**a**) Same patient case as in Fig. 16.3; 3D image shows total maxillary defect. (**b**) Fusion 3D image, 3D image superimposed with pre-resection 3D (maxilla in red), post-resection skull (in grey), and PSI virtual reconstruction plate (in blue). (**c**) Maxilla replicas 3D printed to be used to shape the PLA scaffolds. (**d**) Right maxilla replica and PLA scaffold. (**e**) Both scaffolds filled with ASC, β-TCP and rhBMP-2 implanted into left ALT region. (**f**) The flap with the neomaxilla is raised after 8 months of implantation. (**g**) The maxillary defect reconstructed with the combination of ALT and neomaxilla, fixed with PSI titanium rapid prototyped reconstruction plate, lateral view. (**h**) PTG showing neomaxilla in place with dental implants. (**i**) Clinical intraoral image showing dental implants in place. (**j**) Prosthesis fixed with implants

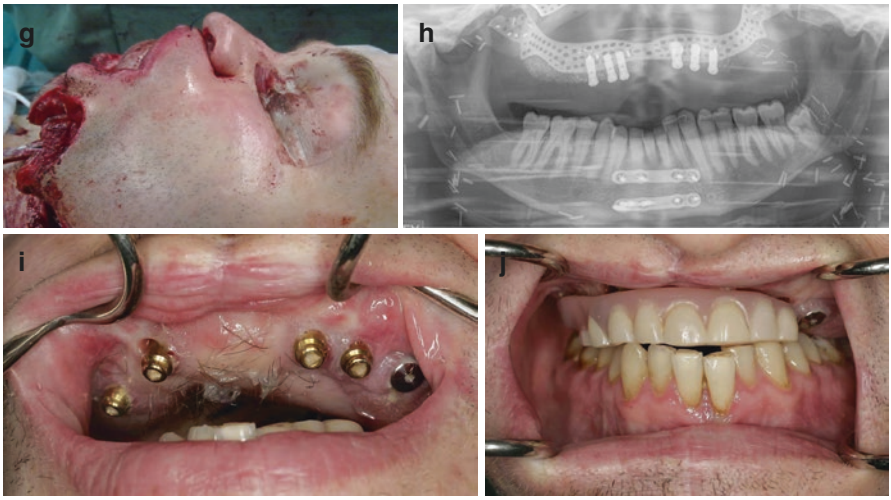

Fig. 16.4 (continued)

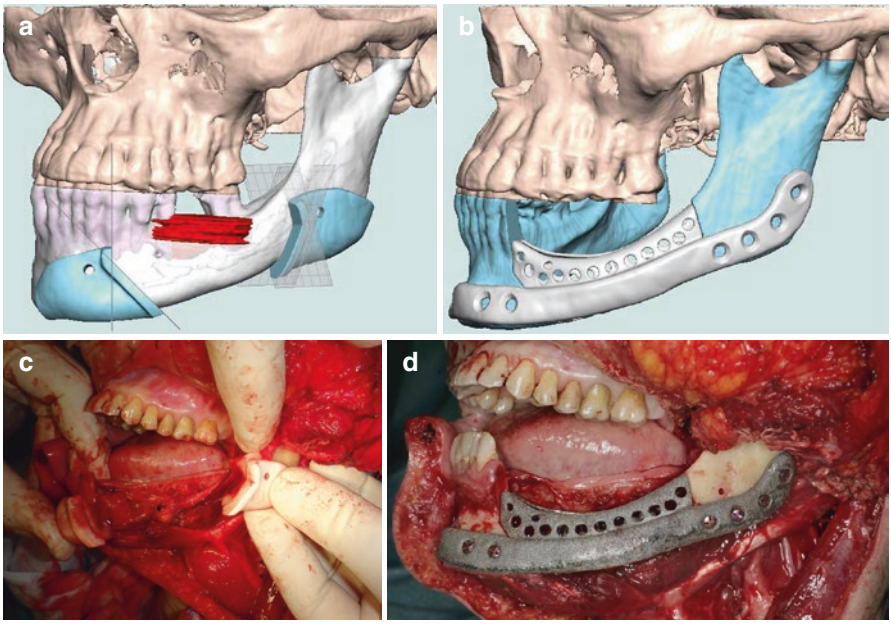

Fig. 16.5 (**a**) 3D planning of resection of mandible due to gingival SCC; note the two jigs to guide the surgery. (**b**) Virtual plate with inbuilt scaffold, designed to reconstruct the mandible defect. (**c**) Jigs in place and the resection of mandible performed accordingly. (**d**) Solid titanium reconstruction plate manufactured using direct metal laser sintering technique

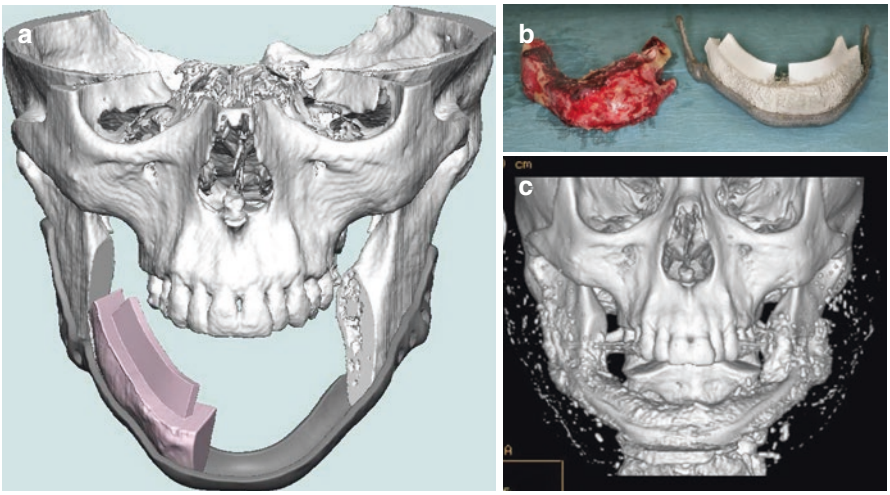

Fig. 16.6 (**a**) Virtual 3D of patient with stage 3 ONJ in the mandible; note virtual subtotal mandible resection and part of neomandible and PSI reconstruction plate. (**b**) Intraoperative image showing mandible resection and 3D printed mandible with PLA scaffold and PSI rapid prototyped reconstruction plate. (**c**) 6-month postoperative 3D CT image showing maturation of β-TCP and maybe new bone formation. Patient was symptomless, without any fistulas or pain

electron beam melting technology to solid titanium PSI. During the surgery, PSIs were filled with β-TCP granules (ChronOS granules 1.4–2.8 mm, Synthes, Oberdorf, Switzerland) and with autologous cancellous bone chips harvested from iliac crest. With ameloblastoma and drug-induced osteonecrosis cases, BMP-2 (Inductos®) soaked in a sponge was placed to cover the cage to improve the bone formation. Finally, PSI was covered with collagen membrane and either radial for arm or ALT microvascular flap. The follow-up was between 9 and 24 months. The overall recovery of the patients was favourable. The facial appearance with respect to symmetry and continuity of the mandible was obtained (Fig. 16.6). Three patients had a major complication. Major dehiscence through the mucosa and/or microvascular flap leads to infection, and the PSI is needed to be removed. In these patients, the mandible was re-reconstructed with a deep circumflex iliac artery (DCIA) composite microvascular flap. The authors concluded that PSI combined with tissue engineering seems to be a promising solution for treatment of patients demanding large reconstruction of the mandible. Extreme caution should be exercised to avoid soft tissue injury or dehiscence during the surgery and follow-up (not yet published).

The neovascularization with prompt recovery of nutrition is considered to be a key issue of bone regeneration. Kokemueller et al. [37] reported a clinical case of craniomaxillary defect that was reconstructed with the combination of autologous iliac crest bone marrow, β-TCP and rhBMP-2 in titanium scaffold. They designed and produced β-TCP cylinder that had central passage with a diameter of 7 mm. The cylinder was implanted into the latissimus dorsi muscle. Perforator vessels were placed into central passage to enhance capillary growth. After 6 months, the flap

with heterotopic bone was raised and transferred to OMF defect. There were no complications during the follow-up of 1 year. The authors conclude that the use of autologous bone marrow and β-TCP block with central vessels to repair OMF bone defects is reliable and well tolerated. Furthermore, most of the donor site morbidity can be avoided with this technique. The research group did also experimental studies with same protocol, and the results confirmed the clinical achievements.

Conclusions

There is no doubt that in the future patients are able to benefit from developments both of regenerative medicine and of computer-aided design and manufacturing. The scientists and clinicians are continuously challenging the limits of biotechnology and tissue engineering. There are multiple open questions. One of the most essential issues is the ideal combination of biomaterials, growth factors and stem cells. It is also unclear whether angiogenic factors are required to develop heterotopic bone to enhance the nutrition for cells. Although functionally and anatomically proper OMF bone cannot be produced at the present, there is good evidence that the methods will develop and reliable computer-designed and tissue-engineered bone identical to the missing bone part will be available in the near future.

Literature

1. Wexler A. Posttraumatic facial restoration: a philosophy of care. J Craniofac Surg. 2009;20:12–4.
2. D'Aquino R, De Rosa A, Lanza V, et al. Human mandible bone defect repair by the grafting of dental pulp stem/progenitor cells and collagen sponge biocomplexes. Eur Cell Mater. 2009;18:75–83.
3. Lee J, Sung HM, Jang JD, et al. Successful reconstruction of 15-cm segmental defects by bone marrow stem cells and resected autogenous bone graft in central hemangioma. J Oral Maxillofac Surg. 2010;68:188–94.
4. Stoor P, Suomalainen A, Lindqvist C, Mesimäki K, Danielsson D, Westermark A, Kontio RK. Rapid prototyped patient specific implants for reconstruction of orbital wall defects. J Craniomaxillofac Surg. 2014;42(8):1644–9.
5. Fiegel HC, Lange C, Kneser U, et al. Fetal and adult liver stem cells for liver regeneration and tissue engineering. J Cell Mol Med. 2006;10:577–87.
6. Chenard KE, Teven CM, He TC, Reid RR. Bone morphogenetic proteins in craniofacial surgery: current techniques, clinical experiences, and the future of personalized stem cell therapy. J Biomed Biotechnol. 2012;2012:1–14.
7. Abukawa H, Zhang W, Young CS, et al. Reconstructing mandibular defects using autologous tissue-engineered tooth and bone constructs. J Oral Maxillofac Surg. 2009;67:335–47.
8. Grayson WL, Fröhlich M, Yeager K, et al. Engineering anatomically shaped human bone grafts. Proc Natl Acad Sci U S A. 2010;107:3299–304.
9. Sándor GK, Tuovinen VJ, Wolff J, et al. Adipose stem cell tissue-engineered construct used to treat large anterior mandibular defect: a case report and review of the clinical application of good manufacturing practice-level adipose stem cells for bone regeneration. J Oral Maxillofac Surg. 2013;71:938–50.
10. Sándor GK, Numminen J, Wolff J, Thesleff T, Miettinen A, Tuovinen VJ, Mannerström B, Patrikoski M, Seppänen R, Miettinen S, Rautiainen M, Öhman J. Adipose stem cells used to

reconstruct 13 cases with cranio-maxillofacial hard-tissue defects. Stem Cells Transl Med. 2014;3(4):530–40. doi: 10.5966/sctm.2013–0173.
11. Zétola A, Ferreira FM, Larson R, Shibli JA. Recombinant human bone morphogenetic protein-2 (rhBMP-2) in the treatment of mandibular sequelae after tumor resection. Oral Maxillofac Surg. 2011;15:169–74.
12. Desai SC, Sclaroff A, Nussenbaum B. Use of recombinant human bone morphogenetic protein 2 for mandible reconstruction. JAMA Facial Plast Surg. 2013;15:204–9.
13. Herford AS, Boyne PJ. Reconstruction of mandibular continuity defects with bone morphogenetic protein-2 (rhBMP-2). J Oral Maxillofac Surg. 2008;66:616–24.
14. Hart KL, Bowles D. Reconstruction of alveolar defects using titanium-reinforced porous polyethylene as a containment device for recombinant human bone morphogenetic protein 2. J Oral Maxillofac Surg. 2012;70:811–20.
15. Mesimäki K, Lindroos B, Törnwall J, et al. Novel maxillary reconstruction with ectopic bone formation by GMP adipose stem cells. Int J Oral Maxillofac Surg. 2009;38:201–9.
16. Ciocca L, Mazzoni S, Fantini M, et al. CAD/CAM guided secondary mandibular reconstruction of a discontinuity defect after ablative cancer surgery. J Craniomaxillofac Surg. 2012;40:e511–5.
17. Logan H, Wolfaardt J, Boulanger P, et al. Exploratory benchtop study evaluating the use of surgical design and simulation in fibula free flap mandibular reconstruction. J Otolaryngol Head Neck Surg. 2013;42:2–9.
18. Ciocca L, Donati D, Fantini M, et al. CAD–CAM-generated hydroxyapatite scaffold to replace the mandibular condyle in sheep: preliminary results. J Biomater Appl. 2013;28:207–18.
19. Levine JP, Bae JS, Soares M, et al. Jaw in a day: total maxillofacial reconstruction using digital technology. Plast Reconstr Surg. 2013;131:1386–91.
20. Cha JK, Park JC, Jung UW, Kim CS, Cho KS, Choi SH. Case series of maxillary sinus augmentation with biphasic calcium phosphate: a clinical and radiographic study. J Periodontal Implant Sci. 2011;41(2):98–104.
21. Lindgren C, Mordenfeld A, Hallman M. A prospective 1-year clinical and radiographic study of implants placed after maxillary sinus floor augmentation with synthetic biphasic calcium phosphate or deproteinized bovine bone. Clin Implant Dent Relat Res. 2012;14(1):41–50.
22. Pandit N, Gupta R, Gupta S. A comparative evaluation of biphasic calcium phosphate material and bioglass in the treatment of periodontal osseous defects: a clinical and radiological study. J Contemp Dent Pract. 2010;11(2):025–32.
23. Piitulainen JM, Kauko T, Aitasalo KM, Vuorinen V, Vallittu PK, Posti JP. Outcomes of cranioplasty with synthetic materials and autologous bone grafts. World Neurosurg. 2015;83:708. pii: S1878-8750(15)00036-4.
24. Ioannou AL, Kotsakis GA, Kumar T, Hinrichs JE, Romanos G. Evaluation of the bone regeneration potential of bioactive glass in implant site development surgeries: a systematic review of the literature. Clin Oral Investig. 2015;19(2):181–91.
25. Yamada Y, Ito K, Nakamura S, et al. Promising cell-based therapy for bone regeneration using stem cells from deciduous teeth, dental pulp, and bone marrow. Cell Transplant. 2011;20:1003–13.
26. Xu H, Han D, Dong JS, et al. Rapid prototyped PGA/PLA scaffolds in the reconstruction of mandibular condyle bone defects. Int J Med Robot. 2010;6:66–72.
27. Amirian J, Linh NT, Min YK, Lee BT. Bone formation of a porous Gelatin-Pectin-biphasic calcium phosphate composite in presence of BMP-2 and VEGF. Int J Biol Macromol. 2015;76:10–24. doi:10.1016/j.ijbiomac.2015.02.021. [Epub ahead of print].
28. Gothard D, Smith EL, Kanczler JM, Rashidi H, Qutachi O, Henstock J, Rotherham M, El Haj A, Shakesheff KM, Oreffo RO. Tissue engineered bone using select growth factors: a comprehensive review of animal studies and clinical translation studies in man. Eur Cell Mater. 2014;28:166–207; discussion 207–8.
29. Gimble J, Guilak F. Adipose-derived adult stem cells: isolation, characterization, and differentiation potential. Cytotherapy. 2003;5:362–9.
30. Huang JI, Zuk PA, Jones NF, Zhu M, Lorenz HP, Hedrick MH, Benhaim P. Chondrogenic potential of multipotential cells from human adipose tissue. Plast Reconstr Surg. 2004;113:585–94.

31. Matthews SJ. Biological activity of bone morphogenetic proteins (BMP's). Injury. 2005;36 Suppl 3:S34–7.
32. Samartzis D, Khanna N, Shen FH, An HS. Update on bone morphogenetic proteins and their application in spine surgery. J Am Coll Surg. 2005;200:236–48.
33. Mendonca JJ, Juiz-Lopez P. Regenerative facial reconstruction of terminal stage osteoradionecrosis and other advanced craniofacial diseases with adult cultured stem and progenitor cells. Plast Reconstr Surg. 2010;126:1699–709.
34. Tuomi J, Paloheimo KS, Vehviläinen J, et al. A novel classification and online platform for planning and documentation of medical applications of additive manufacturing. Surg Innov. 2014;9:45–8.
35. Warnke PH, Springer IN, Wiltfang J, et al. Growth and transplantation of a custom vascularised bone graft in a man. Lancet. 2004;364:766–70.
36. Matsuo A, Chiba H, Takahashi H, et al. Clinical application of a custom-made bioresorbable raw particulate hydroxyapatite/poly-L-lactide mesh tray for mandibular reconstruction. Odontology. 2010;98:85–8.
37. Kokemueller H, Spalthoff S, Nolff M, et al. Prefabrication of vascularized bioartificial bone grafts in vivo for segmental mandibular reconstruction: experimental pilot study in sheep and first clinical application. Int J Oral Maxillofac Surg. 2010;39:379–87.

Face Transplantation

17

R.F. Lohman, C. Ozturk, and A.H. Dorafshar

17.1 History and Ethical Aspects of Face Transplantation

Penetrating trauma, burns, congenital disorders, and tumor excision can cause complex wounds involving several different types of tissue, leading to severe facial disfigurement. Patients may lose the ability to eat, smell, breathe, speak, and see normally. Often these patients require a permanent feeding tube and tracheotomy. Equally important, patients also lose the ability to communicate their emotions to others by way of their facial expressions. These circumstances lead to diminished feelings of self-worth and social isolation. Prior to the era of facial transplantation, reconstruction of major facial defects involved a prolonged series of challenging operations that typically combined various types of flaps, grafts, and prosthetic material. Patients were commonly subjected to dozens of operations. Aside from the need for multiple operations, other major drawbacks to this approach include expense, frequent complications, and the need for multiple flap and graft donor sites. Furthermore, the results of staged reconstruction, especially for central facial defects, are often so poor that patients frequently withdraw from routine social interactions. Writing in 2002 on the pages of *The Lancet*, Peter Butler called attention to this problem and wondered if transplantation was "fantasy or the future" for facial reconstruction [1].

Butler pointed out that face transplantation was feasible based on state-of-the-art surgical technique and the contemporary knowledge of immunology. His article sparked a discussion about whether or not face transplantation was a worthwhile goal for organized medicine to undertake [1]. Several ethical questions had to be considered and resolved before moving ahead. Given that facial disfigurement is not

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usually considered a life-threatening condition, was it appropriate to offer these patients an untested and potentially very risky operation? Moreover, current immunosuppression therapy is associated with approximately 10-year reduction in life expectancy, and some questioned if this was a reasonable trade-off. Some authors worried that by taking the face of another person, the recipient's sense of identity would be profoundly altered. Still others were concerned that facial transplantation would become an elective procedure available to people who simply wanted to change their facial appearance. The discussion was not restricted to the medical literature and it became a topic in the popular media as well; for the most part, public acceptance of face transplantation seemed to lead that of medical professionals.

By 2004, Maria Siemionow's group in Cleveland had the first Institutional Review Board (IRB)-approved protocol in place and started to evaluate patients. In 2005, Bernard Devauchelle and Jean-Michel Dubernard from Amiens, France, carried out the first partial face transplant; Joan Pere Barret et al. from Barcelona, Spain, carried out the first full-face transplant in 2010. Few months later Laurent Lantieri et al. from Lyon, France, performed the full-face transplant including lacrimal glands and lacrimal ducts [2]. To date (March 2015) 30 facial transplants have been performed at various locations around the world [2, 3]. Although four patients died after surgery, the other patients have fared well; both objective functional outcomes and esthetic appearance have steadily improved [2, 3]. At present, facial transplantation is certainly not considered mainstream therapy, but there has been steady growth in the number of academic centers interested in offering the procedure.

17.2 Current Indications

Patients most likely to benefit from facial transplantation are those with congenital deficiency/malformation or injury of the central face. Surgical restoration of severely disfigured lips, nose, eyelids, jaws, etc. is very difficult. Results that are both functional and cosmetically acceptable are rare, especially when the defect involves multiple facial units. Penetrating trauma, ballistic injuries, and major burns account for most of the injuries that have been treated by facial transplantation [2]. Other indications have included collagen vascular disorders and advanced neurofibromatosis type I. A defect resulting from a locally aggressive benign tumor might be a reasonable indication for facial transplantation, but only several years after curative excision. However, a defect resulting from excision of an advanced malignant tumor is an absolute contraindication to facial transplantation according to most surgeons, because of the high risk of recurrence (or a second primary lesion) associated with immunosuppressive therapy. Despite these concerns, some authors believe transplantation may become a useful technique for delayed reconstruction in patients who have undergone excision of malignant tumors. Pedro Cavadas from Valencia, Spain, performed a partial facial transplantation, including the lower third of the face with the tongue, for a patient with a defect resulting from resection of malignant tumor and radiation therapy. The patient, who was also infected with human immunodeficiency virus (HIV), died 5 years after the transplantation [4]. Initially, facial transplantation was only considered for patients who did not have a satisfactory result after conventional

reconstruction. However, as results improve, facial transplantation may become the preferred method of primary reconstruction of some defects. It seems unlikely that facial transplantation will be used for acute reconstruction, but this idea has also been challenged. In 2013, in Gliwice, Poland, surgeons performed urgent facial transplantation for a 33-year-old male patient with severe midface injury caused by an industrial accident involving stone-cutting machinery. The surgery was described as world's first life-saving face transplant and was performed 3 weeks after the injury.

To be considered for facial transplantation, patients must be fit enough to withstand a long operation, able to understand and participate in therapy after surgery, and to comply with immunosuppressive protocols. Patients must also clearly understand the risks and benefits of facial transplantation. The risks associated with facial transplantation include, but not limited to, allograft failure, rejection, immunosuppression toxicity, increased risk of malignancy, psychosocial issues, the risk of diminished life expectancy, and potential long-term financial burdens [5]. Patients who are unable to consent are not candidates, and for the time being, this includes children. Patients with HIV and active bacterial or fungal infections are also usually excluded. A prior suicide attempt is generally not considered a contraindication, but all patients must first undergo a rigorous psychiatric evaluation. There are two important aims of this evaluation: to determine how the patient will tolerate the multiple sources of psychosocial stress expected to occur after surgery and to asses their understanding of the consent process. Some groups have excluded blind patients from consideration because they believe these patients would have difficulty recognizing skin changes associated with early rejection, thus increasing the risk of graft loss. Blind patients may also have difficulty with facial reanimation therapy after surgery, which depends on visual feedback for best results. Other groups believe exclusion of blind patients amounts to unethical discrimination [6]. They also point out that blind patients have been able to feel inflammatory changes occurring in their skin during rejection and have recovered motor function in the transplanted tissue despite their lack of sight. Facial transplantation for burn patients has also been problematic. It has been difficult to find potential donors for patients who previously required extensive care in a burn unit because they often have high levels of reactive antibodies. Some authors have hypothesized these antibodies are related to the use of cadaver skin grafts and blood products during early burn management [5]. In the near future, the indications for facial transplantation are likely to remain individualized and dictated by local research protocols. But as clinical experience expands, the indications for facial transplantation are also likely to increase in parallel.

17.3 Organizing a Multidisciplinary Team

Only a few centers are currently performing facial transplantation. The teams at these centers often required years to assemble and are made up of people from several different backgrounds. Few team members have sufficient breadth of knowledge to be familiar with all aspects of the procedure. Instead, most team members have a deep understanding of few particular areas. For this reason, there should be redundancy at each position, so that there are no gaps in the team's expertise when one person is

traveling or busy with other responsibilities. It is especially important for the team to have a strong leader, but also a leader who is comfortable delegating some tasks and decisions to others. Over time, team members may come and go, so organizational learning is critical: the team must understand how to acquire and retain the knowledge it gains with experience and how to pass that knowledge to new team members, or even to outside organizations. Most importantly, the team members must work well with each other and be devoted to success of the project.

The team leader is usually a surgeon with a strong research background and knowledge of facial injury and reconstruction. The team leader usually develops the initial protocol and then works to coordinate activities between the operative group, other medical specialists, the IRB, organ procurement groups, hospital executives, outside funding agencies, and any other stakeholders. The team leader is usually supported by a project manager, who monitors day-to-day details to make sure the protocol is followed correctly, guides patients through the process from initial evaluation to aftercare, and may oversee related financial issues.

The operative group is made up of a lead surgeon, who has substantial experience with craniofacial operations and especially skilled at managing these problems. The lead surgeon may, or may not, be the same person who serves as team leader. At least four or five other experienced surgeons should also be included in the team. This facilitates simultaneous recovery of the allograft and preparation of the recipient by two surgeons at each location, and also means an adequate number of personnel are always available even some are away from the institution. The team should also include a transplant surgeon and an otolaryngologist experienced with sinus surgery and endoscopy. Other than surgeons, the operative group must include transplant anesthesiologists who are also experienced with challenging craniofacial cases. The anesthesiologists are full-fledged members of the team; they should participate in advanced planning and be familiar with all appropriate clinical details before surgery. To the extent possible, during facial transplantation the operating rooms should be staffed by nurses and technicians who choose to participate in the program, have been briefed ahead of time, and are familiar with the techniques and equipment used for craniofacial reconstruction. If everyone participating in the procedure knows what to expect, the operation is more likely to go smoothly.

Help from many medical disciplines is critical for the success of the transplant program. Thus the team also includes dedicated psychiatrists, transplant immunologists, pathologists, radiologists, infectious disease experts, and critical care specialists. Nutritionists, dentists, and orthodontists should also be available. Social workers play an essential role by helping the patient learn about the innumerable details related to matters such as immunosuppression, medications, and re-engaging with society. Therapists specialized in facial reanimation, speech, and swallowing are required to help maximize the potential for functional recovery. An advocate, who can be someone from the hospital's patient advocacy office, an outside medical or legal professional, or even a friend or family member, represents the patient; this person is a necessary part of the informed consent process and provides an extra layer of protection for the patient's interests. An ethicist is also required, primarily to ensure that recipient's interests are served, but also to ensure that the team makes decisions according to current ethical standards.

17.4 Preoperative Planning

17.4.1 Developing a Protocol

Facial transplantation is not a universally accepted reconstructive technique. The operation is complex and potentially risky; any group wishing to start a program will require substantial organizational support. Because the methodology for facial transplantation has not yet been standardized, a detailed protocol and IRB approval are also required. The protocol is important to specify the indications and contraindications for both the recipient and donor, as well as to delineate duties and expectations for the various personnel involved. The protocol also specifies the steps necessary before, during, and after the procedure; this helps minimize the risks that may occur if unexpected circumstances arise. A thoroughly engaged IRB is also important to ensure all decisions that may impact patient safety are carefully considered. The combination of a well-functioning team, a robust protocol, and a supportive IRB is essential for a program to operate with minimal morbidity. Several of the pioneering teams have published their protocols, and these documents can serve as useful templates for start-up groups. While each new program will probably need to develop a unique protocol, they have many core elements in common. This style of cooperation facilitates the growth of shared knowledge and cuts down on development time for new programs.

17.4.2 Patient Selection and Surgical Planning

Before any potential patient is listed as a potential recipient for a facial allograft, a through psychiatric evaluation is performed; social workers assess their out of hospital support system, and bioethicists evaluate their ability to fully understand the risks and benefits of the transplant. For patients who are more than 50 years old, a complete medical evaluation is also indicated to ensure the candidate is fit to withstand a long operation and will tolerate immunosuppression. This workup generally includes a CT scan of the chest, abdomen and pelvis, and upper and lower GI endoscopy and mammography as indicated to search for subclinical evidence of malignancy. A complete dental evaluation is required to ensure any potential source of infection in the oral cavity is prophylactically treated. The remainder of the pre-op testing is summarized in Fig. 17.1.

In the next stage, the defect itself is evaluated in order to formulate a detailed plan for the operation. The plan will be customized to meet the needs of each particular patient. Imaging studies include arterial- and venous-phase CT angiography to determine which vessels are available. Supplemental ultrasound and standard angiography are usually needed to better define the location and quality of vessels, which may have been disturbed during previous operations or trauma. MR studies of the head and neck may be needed to further delineate the extent and nature of the soft tissue defect. CT scans with bone windows are used to assess the underlying bony architecture; 3-D image reconstruction is especially helpful and can be used to create models, which are also useful in planning aids. Sensory testing and nerve

Typical Pre-Transplant Evaluation

Blood Tests

CBC, Metabolic Panel, PT/PTT, Hemoglobin A1-C, Liver Function Tests, Lipid Profile, HCG Pregnancy Test

Urine Tests

Urine Analysis including Toxicology Screening

Immunologic Tests

ABO Blood Typing and HLA Tissue Typing

Serology Tests

PPD or Interferon-Gamma Release Assay for TB, VDRL, Vericella Zoster IgG and IgM, Toxoplasmosis IgG, HSV IgG, HIV, CMV IgG, EBV IgG, Hepatitis B Core AB, Hepatitis B Surface Ag, Hepatitis C Ab

Cardiopulmonary Studies

EKG, Echocardiogram, PFT, other testing as indicated

Endoscopic Studies

EGD, Colonoscopy

Imaging Studies

Video and still Photography, Chest X-ray, Plain films of the hips, knees, head, neck and face, Panorex of the jaw, CT and MR of the head and neck with 3-D reconstruction, CT angiography of the head and neck, Venous ultrasound of the head and neck, CT or MRI of the chest, abdomen and pelvis

Functional & QOL Measures

ADL Questionnaires, Pain Inventory, Satisfaction with Life Scale, Musculoskeletal Function Assessment, Patient Health Questionnaire, Facial Disability Index

Psychosocial Measures

Mini-Mental State Exam, Reading and Verbal Learning Assessment, Recognition Memory Test, Brief Visuospatial Memory Test, Trails A & B, Brief Symptom Inventory, Affect Balance Scale, Rosenberg Self-Esteem Scores

Occupational Therapy Studies

Speech and Swallow Evaluation, Oral Competence, Facial Muscle Assessment, Sensory Testing with monofilament and 2 Point Discrimination, Smile Excursion, Facial Nerve Scoring, Video Analysis, Taste and Olfactory Assessment

Specialty Consultations

Cardiology, Infectious Diseases, Ophthalmology, Ob-Gyn, Dentistry, Otolaryngology, Psychiatry, Speech and Language Pathology, Occupational Therapy, Social Work

Fig. 17.1 Typical pre-transplant evaluation

conduction studies are used to document pre-existing trigeminal nerve function; motor testing and EMG studies are used to evaluate facial nerve function.

After the preoperative evaluation, the surgical team will be able to form a catalog listing precisely what tissue will be needed to adequately reconstruct the recipient's defect. It is helpful to think of defect as involving the upper, middle, or lower third of the face, or any combination of multiple thirds. The tissue types needed may include skin, muscle, nerve, bone, cartilage, teeth, and mucosa. Using this catalog, and the preoperative images, the surgeons can plan what must be excised from the recipient (scar and nonfunctional soft tissue, previously placed bone grafts, etc.) to recreate the initial defect. The surgeon should be prepared to excise normal areas of the recipient's face to facilitate exposure or to place suture lines at the borders of facial esthetic units. Takamatsu et al. originally suggested that the superficial temporal vessels should be the preferred recipient vessels for cases involving the upper third of the face, that both the superficial temporal and facial vessels should be used for middle third transplants, and that the great vessels of the neck should be utilized for lower third transplants [7]. However, clinical experience has shown that the entire face can be sufficiently perfused by a single facial artery.

Because of trauma or previous reconstructive operations, some recipient vessels may not be available. As the preoperative angiograms are reviewed, potential alternative vessels should be systematically considered, so the surgeon has two or three choices in mind before the operation starts. Typically these options include: local small vessels near the preferred vessels, regional large branches from the carotid and jugular system, and remote vessels near the base of the neck. Since the adjacent local vessels may be difficult to locate and may not have adequate flow, they are considered to be the option of last resort. Potential neurorrhaphy sites are also selected according to the results of preoperative EMG testing. If one or both jaws are to be included in the allograft, orthognathic modeling or CT-guided computerized modeling techniques are helpful to plan the orientation of the expected bone cuts and to determine how the various bone segments will fit together and which fixation techniques will work best. Here the goal is to minimize bony gaps that can delay union and to ensure appropriate occlusion after surgery. When the planning stage is complete, the team should have a clear mental picture of how the recipient defect will be prepared, what will be recovered from the donor, and what will be necessary to fit the allograft to the recipient. During the planning stage, it is also reasonable for the team to consider a backup plan for managing the recipient's defect in case there is catastrophic failure of the allograft.

17.4.3 Cadaver Practice

After developing an operative plan, practicing the procedure with fresh cadavers is vital. Cadaver practice and mock surgery can help identify potential problems with the operative plan, or areas that may pose particular technical challenges. It may be possible to modify the operative plan to mitigate these problems. Cadaver practice also allows the group to rehearse the operation, so each team member clearly understands their role and how the sequential steps of the operation will proceed. If the

preoperative planning and practice sessions have been sufficient, the actual operation will be reasonably expedient, with few surprises. As a group gains experience with facial transplantation, the need for cadaver practice may diminish.

17.4.4 Planning for Recovery of the Donor Allograft

Planning for the recovery of the donor allograft must start well before a patient is listed for transplant. The local organ procurement organization should be contacted as soon as the team begins to form; their buy-in is an essential component for success. Organ procurement organizations may initially be reluctant to participate in recovery of a facial allograft because of concerns that potential donors may be put off by the idea, and therefore refuse to donate both standard solid organs and facial tissue. Until facial transplantation becomes more common, it may be best to use an entirely separate consent process, including distinct forms and personnel, when discussing the recovery of the facial allograft with potential donors or families. Ideally, as many organs as possible are recovered with the facial allograft, and it may take several hours to procure the tissue needed for facial transplantation. Therefore, brain-dead donors who are otherwise stable are preferred, and donors without a beating heart are avoided. The donor should also be of the same general age and size as the recipient. However, it is not essential to match the donor and recipient for sex and race. Facial hair growth will depend on levels of circulating hormones in the recipient rather than the sex of the donor. But a qualitative match for the skin and hair tone is important, and it is useful to keep in mind that there may be more variation in the skin and hair tone between individuals of the same race than there is between individuals of different races. Details of how donor and recipient are to be matched are set out in the IRB-approved protocol and may vary from one institution to the next. Finally, it is essential to respect the appearance of the donor. A molded mask, composed of silicone or acrylic resin, must be made so that the donor's facial can be restored immediately after procurement.

17.5 Sequence of the Operation

17.5.1 Surgery for the Donor

Once a suitable donor is identified, and there is consent to recover the facial allograft, immunologic matching is performed. At this point, transferring the donor to the same (or a nearby) hospital as the recipient has a number of advantages. Before recovery of the facial allograft starts, the entire operative team, including the anesthesiologists and all necessary medical and nursing personnel, are called to the hospital. If the donor and recipient are prepared simultaneously in adjacent operating rooms, members of the two teams can easily move between rooms to communicate with each other. Should discrepancies arise between the intraoperative findings and the previously determined plan, they can be resolved more effectively with everyone in the same location. An initial elective tracheostomy may also facilitate recovery of the facial allograft. This improves exposure and allows dissection around the upper airway to

proceed more quickly and with less concern for dislodging or cutting the endotracheal tube. If the donor becomes unstable and cardiac death appears eminent, it may be necessary for the facial transplantation team to abandon their operation so that recovery of other potentially life-saving organs can go ahead. Very little is known about how facial tissue will tolerate ischemia time and different strategies are available to coordinate recovery of the other organs. The facial allograft can be removed entirely before surgeons start to recover the other organs, or the facial allograft can be partially dissected, but allowed to perfuse in situ while the other organs are removed. After the aorta is clamped, the final cuts are made to liberate the allograft. Regardless of the sequence of events, they should be discussed in detail with the other solid organ transplant surgeons so that everyone is aware of, and agrees to, the plan.

The nature of the soft tissue dissection, and the specific tissues recovered, depends on the nature of the recipient defect and the preoperative plan. The vessel and nerve stumps dissected as far proximally as possible, which usually requires removal of portions of the parotid gland. The stumps should be marked so that they can easily be identified when the time comes to connect them to the recipient. It is also important to maintain the soft tissue attachments between the bones and overlying skin and muscles. Portions of the maxilla included with the allograft will be nourished exclusively by the periosteum; if there is extensive subperiosteal dissection, segments of the bone may be rendered avascular. Furthermore, if retaining ligaments that secure the skin are divided, there may be an excessive degree of ptosis. Although individual branches of the external carotid artery (namely, the facial, internal maxillary and/or superficial temporal) should adequately supply the allograft, it is more practical to include both external carotid arteries. This ensures the allograft will be adequately nourished by a large caliber vessel of sufficient length. The surgeon should visualize the entire course of the facial artery to be doubly sure that it is intact and does in fact supply the allograft. Bone cuts, particularly around the maxilla, can result in significant bleeding and should be one of the last steps undertaken. Prior to the maxillary osteotomies, the orbital contents are removed or retracted (to preserve the corneas for transplantation elsewhere) in order to facilitate exposure, and then the internal maxillary artery is divided. Great care is required when making bone cuts around the posterior wall of the maxilla because the pterygopalatine plexus is in this area and may lead to excessive bleeding if disrupted. Once the allograft has been separated from the donor, the ischemia time is recorded. The facial allograft is then perfused with heparinized saline and University of Wisconsin (or similar) solution, cooled as needed, and transported to the recipient.

17.5.2 Surgery for the Recipient

While the donor tissue is procured, the recipient is also prepared. Injured tissue, scar, previous grafts, flaps, etc. are removed. As with the donor, the plane of dissection is usually anterior to the posterior wall of the maxilla and the skull base. After adequate debridement and dissection, the necessary target vessels are identified, controlled with vessel loops, divided, and flushed with heparinized solution. If teeth are present, the best possible occlusion is set, followed by osteosynthesis of the jaws

and facial bones as needed. In order to ensure adequate bony alignment, it may be necessary to remodel some of the bones with a few strategic cortical osteotomies. Definitive hardware is usually applied at this time. However, if for some reason the fixation is especially complex or there has already been a long ischemia time, it may be necessary to expedite the operation by initially applying provisional fixation and moving on the vascular work as quickly as possible. Alignment of the sinus ducts can be difficult, and various steps including DCR, mucosal excision, and/or ethmoidectomy may be required to ensure proper drainage. After the bone hardware has been applied, the vascular anastomoses are completed. The arterial anastomoses are performed first. Connection of a single artery is sufficient to perfuse the entire allograft, but at least two vessels are recommended: one on the right and one on the left. This provides a margin of safety if one artery clots or is accidently injured during a later revision operation. Although there has been considerable speculation about which vessels should be used in different circumstances, a handy approach is to simply make use of the largest healthy vessels available in the operative field. End-to-end anastomoses between external carotid arteries or between external carotid and facial arteries work well. Next, at least two large caliber venous anastomoses (one right and one left) are carried out to ensure adequate drainage.

Since the nerve connections are fragile and easily disrupted, they are delayed until after the bony fixation and vascular anastomosis are complete. Any functioning branches of the facial nerve should be preserved. Existing motor deficits are reconstructed by preserving appropriate facial nerve stumps in the donor tissue and then coapting them to the recipient facial nerve. The coaptation of nerve ends is performed using standard epineural suture repair and/or connectors with fibrin glue according to the surgeon's preference. In order to facilitate coaption of the facial nerve branches, a mastoidectomy or superficial parotidectomy may be needed. Similarly, foramen around branches of the trigeminal nerve can be enlarged to facilitate exposure. Liberal use of available graft from the donor (great auricular nerve usually available in the adjacent wound) ensures the connections are tension free. Next, the skin and mucosal suture lines are completed. Excess donor skin can be left along one of the incisions and then biopsied after surgery to monitor for histologic evidence of rejection. Alternatively, a sentinel skin flap (e.g., radial forearm) from the donor can be used for the same purpose and then excised at a later date.

17.6 Management After Surgery

17.6.1 Post-op Care

After surgery, the recipient will stay in the ICU for routine post-op care and monitoring. Given the complexity and risks of the operation, in-patient care may be needed for several weeks. During this time, the surgical team assesses wound healing and monitors for problems such as infection and hematoma. The team also watches for signs of rejection, such as skin erythema, edema, and blistering. Input

from participating psychiatrists, transplant immunologists, and infectious disease specialists is especially critical in the first few weeks after surgery. As the patient stabilizes and prepares to transition out of the hospital, the focus shifts from acute care to rehabilitation. During this period, physical and occupational therapists, speech and swallow specialists, nutritionists, dentists, and social workers play a more active role. The patient will probably need to follow up in all of these clinics after discharge. Endoscopy, biopsies, and CT and MR scans are frequently used after surgery to evaluate healing and to check for signs of rejection. Blood tests are also required to guide immunosuppressive therapy and screen for potential complications.

17.6.2 Secondary Operations

Facial transplantation has proven uniquely successful for replacing the intricate functional units of the face. However, much like conventional methods of facial reconstruction, transplantation should probably not be thought of as a single stage operation. For many reasons, including skeletal discrepancies, early swelling, healing complications, and so on, most patients will likely benefit from operations to revise their facial allograft after transplantation. Generally, indications for revision are related to skeletal and dental occlusion issues, soft tissue factors, and miscellaneous problems. For planning purposes, it can be helpful to consider each of them independently, but there may be considerable overlap between these areas. For example, repositioning the maxilla or mandible to improve occlusion will also change the position of the overlying soft tissues.

There can be several different types of skeletal problems. Even with careful attention to pairing the donor and recipient, the two skeletons will not precisely match and some gaps are expected where the two are fit together. If delayed union or asymptomatic nonunion occurs, in some cases no treatment may be required. However, if there is nonunion and eventually the hardware loosens or breaks, a segment of the facial skeleton will be unstable. This situation may lead to changes in occlusion, or asymmetry, and is likely to progressively worsen. When portions of the jaws and teeth are transplanted, it can be very difficult to achieve Class I occlusion at the initial operation. Furthermore, as the patient starts to eat, the forces of mastication may begin to alter the occlusal relations that were set during surgery [8]. Lastly, the contour of the donor skeleton may not match that of the recipient, resulting in surface abnormalities, particularly around the nose, cheeks, and jaw. All of these problems may benefit from late corrective osteotomies and revision of the existing fixation, with or without bone grafting. Three-dimensional imaging, model surgery, prefabricated cutting guides, and computer-assisted positioning systems can all improve the precision of secondary osteotomies. When performing secondary osteotomies, considerable care is needed in order to avoid accidently transecting the graft's blood supply, which could cause bone and soft tissue necrosis. Preoperative angiography may help the surgeon plan an operative approach that minimizes this risk.

Even when both upper and lower teeth are transferred from the donor to the recipient, it is difficult to achieve proper occlusion. If the discrepancy is minor, and not associated with bony malunion, treatment by orthodontic methods may be helpful and is probably worth trying before considering maxillary or mandibular surgery. However, there is not enough data to comment on the expected duration or durability of orthodontic treatment after face transplantation. When the maxilla and mandible are intact, but the alveolus and some or all teeth are missing, dentures are usually the most practical way to restore function. However, if sufficient bone stock is present, osseointegrated implants could also be considered for oral rehabilitation.

Several factors can cause soft tissue problems that may eventually require revision including transfer of excess tissue from the donor; ptosis; malposition of incisions around the eyelids, nose, or mouth; healing complications; and scarring. Initially, there may be a need for excess tissue at the recipient because of swelling (in either the donor or recipient), to facilitate exposure necessary to complete the vascular and nerve connections or to close the incisions without undue tension. In the postoperative period, the recipient may be left with a surprising amount of the redundant skin and soft tissue. Ptosis exacerbates the problem of excess skin and occurs if there is insufficient motor nerve recovery to animate the face or if the donor retaining ligaments were divided during recovery and transfer of the graft. Essentially all patients will benefit from skin tightening operations and scar refinement several months after transplant. Wound complications in transplant patients occur for all the same reasons as in other patients, but can be potentiated by immunosuppression. While healing problems with the skin have been uncommon, mucosal cutaneous and palatal fistulae have occurred and may require operative closure.

Miscellaneous procedures, such as endoscopic sinus surgery, may be performed at the same time as those designed to address skeletal and soft tissue discrepancies. Allograft tissue may obstruct the sinuses, interfering with drainage and causing mucous to accumulate. Prophylactic drainage procedures are indicated to reduce the risk of sinus infections. Reversal of pre-existing feeding tubes can be undertaken, but tracheostomy reversal (or cannula removal) should not be performed in the early post-op period, and if it is to be performed, only after very careful consideration in the late post-op period. Although upper airway volume and function seems to improve after face transplant, breathing difficulties, particularly at night, may persist [9]. Patients are probably always at risk for airway complications after a face transplant, and attempting to urgently secure an airway in these patients would likely be challenging.

There is insufficient clinical experience to make authoritative recommendations about the timing of revision operations. Prior to any elective procedure, the patient should be clinically stable and free of any ongoing complications related to immunosuppression, infection, or rejection. Prior to excision of the redundant skin, or correction of ptosis with facelift and/or brow repositioning techniques, tissues should be soft and pliable, with minimal swelling. Also, it may be wise to address any skeletal problems before making changes in the soft tissues. Contour adjustments by liposuction or fat grafting, scar revision, and other enhancements like blepharoplasty are usually the last steps to enhance the patient's appearance.

Because of infection risk, alloplastic implants have not been used to camouflage facial contour irregularities. Theoretically, autologous bone grafting would be less risky, but no data is available to support this idea.

17.7 Immunologic Issues

17.7.1 Rejection

As Whitaker et al. once pointed out, there is no way to definitively assess a patient's immunosuppressive level. Instead clinicians look for evidence of over- or under-immunosuppression [10]. An inadequate level of immunosuppression manifests as acute rejection. Despite careful monitoring, all patients have had at least single episode of acute rejection after facial transplantation. In the setting of facial transplantation, acute rejection is usually associated with an inflammatory reaction in the skin that can be diagnosed by physical exam and confirmed by skin biopsy. For these reasons, acute rejection is usually identified and immediately treated in its early stages. Repeated episodes of acute rejection contribute to the risk of chronic rejection and graft loss after solid organ transplantation. But this has not yet been observed after facial transplantation, perhaps because of the earlier diagnosis and more effective management of acute rejection, or perhaps this is an anomalous finding resulting from the analysis of a small sample of patients. This picture is further confounded by the fact that immunosuppressant drugs are toxic to many solid organs and they are not toxic to the tissue in facial allografts. Also the mechanism of chronic rejection for facial allografts may be different than it is for solid organs. According to Petruzzo et al., (i) the absence of chronic rejection of the skin might be related to the ability of the skin to recover without fibrosis following prompt diagnosis and treatment of acute rejection, (ii) the absence of circulating anti-HLA antibodies may limit the typical vasculopathy associated with chronic rejection, and (iii) the persistence of donor derived immunocompetent cells (Langerhans cells) in the skin may mitigate the risk of graft rejection [11]. Events associated with immunosuppression include infection, most commonly a systemic viral infection, or a superficial fungal infection; bacterial infections have been less common. And finally, drug toxicity leads to a number of problems, including cardiac disease, hypertension, elevated levels of cholesterol and other lipids, diabetes, and diminished renal function. In the long run, there will probably be an increased risk of cancer in facial transplant recipients, similar to that of other immunosuppressed patients. Of note, the world's first facial transplantation patient was diagnosed with cervical cancer 5 years after surgery.

17.7.2 Immunosuppressive Regimens

Unlike solid organ transplants, facial allografts consist of several different tissue components including the muscle, bone, nerve, skin, oral mucosa, etc. The skin

and mucosa are highly antigenic, and this causes a more robust immunogenic reaction than is seen with other organs [12]. Despite this fact, the immunosuppressive protocols used for facial transplantation are derived from the regimens used for solid organ transplantation. Prednisolone is the most common steroid used; it binds DNA to prevent cytokine expression. MMF selectively inhibits inosine monophosphate dehydrogenase, which is necessary for synthesis of guanosine, and guanosine is necessary for T- and B-cell division. Tacrolimus is a fungal-derived antibiotic that has replaced cyclosporine as a mainstay of immunosuppressive treatment. Tacrolimus binds to FKBP12, which results in calcineurin inhibition; this blocks IL-2 secretion and therefore limits B-cell activation and prevents T-cell activation. Some groups have also used sirolimus, which was initially developed as an antifungal drug, but was found to cause immunosuppression. It also binds FKBP12. The sirolimus-FKBP12 complex then binds to a serine/threonine kinase known as mTOR that normally regulates a variety of cell functions including transcription and protein synthesis. The sirolimus-FKBP12-mTOR complex interferes with IL-2 signal transduction and thus prevents T- and B-cell activation.

Various combinations of immunosuppressive agents are used at different times after transplant. Induction therapy refers to the combination of drugs, usually monoclonal and polyclonal antibodies, which are administered to induce a profound state of immunosuppression for about 2 weeks after surgery. Induction therapy reduces the risk of early rejection; it also postpones the onset and diminishes the severity of the first episode of acute rejection. Induction therapy also provides time to optimize the drug regime for maintenance therapy. Drawbacks associated with induction therapy include the high cost of the drugs and an increased risk of infection. Agents used for induction therapy include antithymocyte globin (ATG) which is a polyclonal antibody that is used to deplete the level of circulating T cells. Monoclonal antibody agents include alemtuzumab, which binds CD54 on the surface of mature lymphocytes, and OKT3, which binds CD3 receptors to inactivate T cells. Daclizumab and basiliximab are examples of anti-IL-2 receptor antibodies. IL-2 mediates proliferation of NK cells and macrophages and differentiation of CD4 cells.

Maintenance therapy is used to limit the risk of rejection over the long run. Usually a mixture of steroids, tacrolimus, and MMF is used for maintenance therapy. This combination is referred to as “triple therapy.” Tacrolimus appears to be especially effective in preventing rejection of allografts that include the skin. Interestingly, both tacrolimus and cyclosporin are effective when used topically, delivering what has been called “site-specific” immunosuppression. An added benefit of tacrolimus is that it may enhance nerve recovery through its action on calcineurin. Over time the risk of rejection lessens. As this occurs, the number of drugs used, or their dosage, can be reduced. In order to limit long-term toxicity, steroid- and tacrolimus-minimizing protocols are attractive.

Rescue therapy refers to treatment of acute rejection. When episodes of acute rejection occur, the drug regimes used for treatment are referred to as “rescue

therapy." Steroids are the mainstay of rescue therapy. However, acute rejection has also been successfully managed using topical tacrolimus and sirolimus at some centers. If these agents are not effective, antibody therapy is indicated. Another strategy for rescue therapy is extracorporeal photopheresis. It is not clear exactly how photopheresis blunts acute rejection, but it has been used successfully in the setting of solid organ transplantation. Hivelin and Lantieri successfully treated acute rejection in several patients after facial transplantation with this technique.

17.7.3 Tolerance

MHC Class I and II antigens are expressed on tissue surfaces, including vascular endothelium. Rejection occurs when the recipient's immune system recognizes the foreign MHC Class I and II antigens in the donor tissue. Non-MHC antigens are also present, but play a less pronounced role in mediating rejection. On the other hand, tolerance occurs when the recipient's immune system does not react to the presence of donor tissue; this is beneficial because it protects the allograft from rejection and eliminates the risk of toxicity associated with immunosuppression for the recipient. Tolerance can be induced when the donor and recipient are closely matched for MHC antigens, and a short course of immunosuppressive therapy is used after the transplant. However, given the combination of logistical barriers and the rarity of face transplantation, close MHC haplotype matching is not always possible, so this type of tolerance will probably always be rare.

Tolerance can also occur as a result of chimerism, which refers to a situation where cells from two organisms coexist together. After transplantation, microchimerism occurs when a small number of passenger leukocytes from the donor can be present circulating in the recipient's blood. It is not clear if microchimerism is a cause or effect of tolerance, and its occurrence does not seem to affect allograft survival. Macrochimerism occurs when donor hematopoietic stem cells are present in the recipient's marrow. To achieve this, the recipient is first conditioned, by depleting mature T cells that would recognize the donor tissue as foreign and then engrafting donor hematopoietic into the recipient's marrow. Some immature donor cells will migrate to the recipient's thymus, and become thymic dendritic cells. As the new population of T cells matures, all clones that react with either donor or recipient will be eliminated. Devauchelle and Dubernard sought to induce tolerance by administering donor bone marrow to the first patient who underwent facial transplantation [11]. Despite this, there was no clinical evidence of tolerance, nor was it possible to reduce the level of immunosuppression. Furthermore, it is likely that tolerance that results from chimerism will eventually be complicated by graft versus host disease. In the future, tolerance and chimerism may be useful to supplement, or even replace, current techniques for immunosuppression, but at present they are not considered standard therapy.

17.7.4 Monitoring for Rejection and Opportunistic Infections

Episodes of acute rejection require adjustments in the immunosuppressive drug regime. Acute rejection presents with inflammatory changes in the skin, including warmth, edema, blistering, and scaling. Screening biopsies are performed to identify subclinical evidence of acute rejection so that early treatment can begin. Both skin and mucosal biopsies may be performed. Samples are collected from areas of redundant tissue or from the monitoring flap if one was included with the facial allograft. The schedule for monitoring biopsies varies from one center to the next. Initially, biopsies are performed every few days, then less often as the clinical situation stabilizes. Screening biopsies are usually not needed after a year.

All immunosuppressed transplant patients are at risk to develop opportunistic infections, and the most common pathogen is cytomegalovirus (CMV). CMV infection within 100 days of transplant, which is often asymptomatic, is an independent predictor of mortality. With solid organ transplantation, the risk of CMV infection reaches about 50 % when a seronegative patient receives a graft from a seropositive donor. This situation requires strict universal precautions to reduce the risk of infecting the recipient, as well as prophylactic treatment with gancyclovir. Patients who previously required extensive medical care for burns or trauma may be colonized with antimicrobial resistant hospital-acquired bacteria. These patients are at risk to develop invasive soft tissue infections when they are immunosuppressed after trasplantation. Furthermore, their infections may be difficult to treat without reversal of the immunosuppressive drugs, which subiquently increases the risk acute rejectioin and graft loss [13].

17.8 Expected Outcomes and Future Aspects

Currently, the mortality risk after facial transplantation is about 13 %. Among the patients who have died after transplantation are one from China who was not compliant with immunosuppressive therapy; one from France who developed multiple complications after concurrent face and bilateral upper extremity transplantation, including a necrotizing pseudomonas aeruginosa soft tissue infection around the airway; one from Spain who died from complications related to recurrent cancer; and one from Turkey who developed related to rejection 10 months after surgery. While common, episodes of acute rejection have not proven to be especially difficult to manage. Hyperacute rejection, chronic rejection, and graft versus host have not been described. Induction therapy with ATG followed by triple-drug immunosuppressive regimen has proven to be reliable. Improved speech, improved upper airway function, feeding tube removal, and tracheotomy decannulation are typically expected. Early sensory recovery, including sense of smell, has been reported at 3–8 months; motor recovery has proceeded more slowly, occurring at 6–18 months. The recipient's facial appearance has been generally improved. For some patients, the improvement has been dramatic; for others, the result has been compromised by skin color and tone mismatch, discoloration of the allograft, or scaring that crosses

facial esthetic units. For most patients, multiple revision operations were required to achieve a refined, natural appearing result.

Writing in 1993, Langer and Vacanti suggested that over 7 million people per year sustain some sort of injury that results in a tissue deficit. This number is likely to vastly overestimate the number of patients who would ever be candidates for facial transplantation. While it is difficult to know precisely how many patients will want facial transplantation, there may be surprisingly large population of patients who could benefit from it. The need for lifelong immunosuppression and the cost and complexity of the operation are substantial barriers. Even with improved results and growing experience, facial transplantation is not likely to become the method of choice for reconstruction of any defect that can be satisfactorily managed using conventional techniques. However, the indications for facial transplantation will probably expand in the future. Facial transplantation is now legitimately considered to be first-line treatment for patients with extensive central facial deficits. As facial transplantation becomes more common, surgeons will have to grapple with new questions. For example, should children with severe facial deformities be offered reconstructive transplantation? Is concurrent facial and extremity transplantation presently safe enough to perform? Should burn surgeons consider techniques to minimize the use of cadaver allograft skin in patients with disabling facial burns? Will facial transplantation ever be indicated for deficits that occur after resection of malignant tumors? Fortunately, as we take up these new questions, it is possible to start putting others aside. Compared to the early stages of major organ transplantation, facial transplantation has so far proven to be relatively safe and durable. The patients involved have been pleased with the outcomes and have been able to reintegrate into society. The patients as well as society in general appear to believe the risks associated with facial transplantation are a reasonable trade-off for the benefits.

References

1. Butler P. Face transplantation—fantasy or the future? Lancet. 2002;360:5–6.
2. Siemionow M, Ozturk C. An update on facial transplantation cases performed between 2005 and 2010. Plast Reconstr Surg. 2011;128(6):707e–20.
3. Khalifian S, Brazio PS, Mohan R, et al. Facial transplantation: the first 9 years. Lancet. 2014;384(9960):2153–63.
4. Cavadas PC, Ibanez J, Thione A. Surgical aspects of a lower face, mandible and tongue allotransplantation. J Reconstr Microsurg. 2012;28(1):43–7.
5. Pomahac B, Nowinski D, Diaz-Siso JR, et al. Face transplantation. Curr Probl Surg. 2011;48(5):293–357.
6. Pomahac B, Diaz-Siso JR, Bueno EM. Evolution of indications for facial transplantation. J Plast Reconstr Aesthet Surg. 2011;64(11):1410–6.
7. Takamatsu A, Harashina T, Inoue T. Selection of appropriate recipient vessels in difficult, microsurgical head and neck reconstruction. J Reconstr Microsurg. 1996;12:499–507.
8. Mohan R, Fischer M, Dorafshar A, et al. Principles of face transplant revision: beyond primary repair. Plast Reconstr Surg. 2014;134(6):1295–304.

9. Fischer S, Wallins JS, Bueno E, et al. Airway recovery after face transplantation. Plast Reconstr Surg. 2014;134(6):1305.
10. Whitaker IS, Duggan EM, Alloway RR, et al. Composite tissue allotransplantation: a review of relevant immunological issues for plastic surgeons. J Plast Reconstr Aesthet Surg. 2008;61(5):481–92.
11. Petruzzo P, Kanitakis J, Badet L, et al. Long-term follow-up in composite tissue allotransplantation: in-depth study of five (hand and face) recipients. Am J Transplant. 2011;4:808–16.
12. Murray JE. Organ transplantation (skin, kidney, heart) and the plastic surgeon. Plast Reconstr Surg. 1971;47:425.
13. Lantieri L, Hivelin M, Audard V, et al. Feasibility, reproducibility, risks and benefits of face transplantation: a prospective study of outcomes. Am J Transplant. 2011;11(2):367–78.

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In addition, the authors wish to cite the following sources as they were also used to write this chapter:

- Virtual 3D tumor marking-exact intraoperative coordinate mapping improve post-operative radiotherapy, Essig H, Rana M, Meyer A, Eckardt AM, Kokemueller H, von See C, Lindhorst D, Tavassol F, Ruecker M, Gellrich NC, Radiat Oncol. 2011 Nov 16;6:159. https://doi.org/10.1186/1748-717X-6-159.

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