14 Reconstruction of Maxillary Defects

Baber Khatib, Ashish Patel, Eric J. Dierks, R. Bryan Bell, Melissa Amundson, and Allen Cheng

14.1 Introduction

The maxilla is a pyramidal-shaped bone that is at the crossroads of several compartments of the viscerocranium. It provides the floor of the orbit, supporting its position and serving as the attachment for the inferior oblique muscle. It houses the nasal cavity and maxillary sinuses. It is the superior boundary of the oral cavity and forms a portion of the anterior skull base, separating the neurocranium from the viscerocranium. It provides the bony foundation for the maxillary dentition. It provides the key vertical and horizontal buttresses of the midface. It serves as the insertion points of mimetic muscles and pharyngeal muscles. Therefore, the maxilla's integral role in both facial form and function cannot be overstated.

Total and partial defects of the maxilla can be due to a variety of disease processes. These include ablative defects for neoplasms, both benign and malignant, trauma, osteonecrosis (radiation or medication related), congenital defects, and necrotizing infections.

As with all reconstructive surgeries, the fundamental goals are to establish a return-to-normal or near-normal form and function. For maxillary defects, this includes the following specific goals. Creating adequate support for the globe is important to maintain normal appearance and range of motion. Establishing barriers between the oral cavity, nasal cavity, and paranasal sinuses is essential for preserving normal speech, swallowing, and breathing. Recreating the horizontal and vertical buttresses of the midface is critical for facial projection and facial height, which in turn is necessary for soft tissue support and normal facial appearance. Recreating the maxillary dentition is an important step to establishing the ability to efficiently chew, speak, smile, and return to normal social interactions.

This chapter will review an approach to evaluation of an anticipated maxillary defect, treatment planning for deciding how to best manage the defect, and key principles in executing the treatment plan.

B. Khatib
Fellow in Microvascular Reconstructive Surgery, Providence Cancer Center, Portland, OR, USA

M. Amundson
Oral and Maxillofacial Surgery, Legacy Emanuel Medical Center, Portland, OR, USA

A. Patel · E. J. Dierks · R. Bryan Bell · A. Cheng (✉)
Oral and Maxillofacial Surgery, Legacy Emanuel Medical Center, Portland, OR, USA

Head and Neck Surgery, Providence Cancer Center, Portland, OR, USA

Oral/Head and Neck Oncology, Legacy Good Samaritan Cancer Center, Portland, OR, USA
e-mail: Chenga@hnsa1.com

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14.2 Surgical Anatomy of the Maxilla

The maxillary bones contribute to the face's horizontal and vertical buttresses by articulating with nine surrounding bones, providing an integral support system of the face. These bones include the lacrimal, palatine, frontal, nasal, zygomatic, ethmoid, vomer, sphenoid, and the adjacent maxillary bones. With its central location and intricate articulations, the maxilla also supports the orbit, houses the maxillary antrum, and forms the floor and lateral wall of the nose. Maxillectomy has the potential of disrupting all three cavities; thus a thorough understanding of maxillary anatomy is key to adequately reconstructing form and function after maxillectomy.

14.2.1 Bony Anatomy

The maxilla can be simply described as a cube: a roof that represents the orbital floor which supports the globe; the floor which represents the palate, separating the oronasal cavities; the lateral wall composed of the zygomatic buttress; and the medial wall representing the lateral nasal wall between the nasal cavity and the maxillary antrum. Anteriorly it incases the maxillary sinus and posteriorly separates the infratemporal fossa. Depending on the Brown class of maxillectomy, each of these theoretical cube walls may be involved.

There are four processes that extend from this cube: the zygomatic process, a lateral pyramidal projection that articulates with the zygomatic bone; the frontal processes, which articulate with the frontal, nasal, and lacrimal bones; the palatine process, a thick horizontal process that articulates with the palatine bone to form the hard palate and floor of the nasal cavity; and, lastly, the alveolar process, which houses the maxillary arch's dentition and is in occlusion with the mandibular dentition.

Medially, the paired maxillae articulate with one another, the ethmoid, vomer and palatine bones, and the inferior concha.

Classically described, the maxilla has three vertical buttresses; these consist of the nasomaxillary, zygomaticomaxillary, and pterygomaxillary buttresses. The nasomaxillary buttress is located between the anterior maxillary alveolus, including the lateral piriform rim, and terminates at the nasofrontal suture. The zygomaticomaxillary buttress, the strongest and thickest of the three, includes the posterior maxillary alveolus, the lateral portion of the zygoma up to the zygomaticofrontal suture. The pterygomaxillary buttress is the junction between the posterior maxilla and the sphenoid bone. In addition, the maxilla is one of the three horizontal buttresses. Accurate reconstruction of these is critical.

14.2.2 Muscles of Facial Expression/Fat Pads

Key muscles of facial expression including the levators, zygomaticus, and orbicularis oris/oculi muscles are attached to the maxilla by the superficial musculoaponeurotic system and the retaining ligaments of the face (e.g., McGregor's patch). The midface houses deep and superficial fat pads that can be used to help reconstruct defects (e.g., buccal fat pad) or mask bony asymmetry (malar fat pad). Preservation of these tissues when possible and adequate resuspension can help facilitate an esthetic outcome.

14.2.3 Soft Palate

The soft palate, composed of the tensor veli palatine, levator veli palatine, palatoglossus, palatopharyngeus and muscle of the uvula, insert onto the maxillary process of the palatine bone. The palatine bone fuses with the palatine process of the maxillary bones to form the hard palate. Disruption of the muscle insertion effects deglutition and phonation. Continuity defects of the maxilla result in hypernasality and misarticulations secondary to distortion of the oronasal resonance balance and tongue to palate contacts [1].

14.2.4 Blood Supply

The major vascular supply of the maxilla comes from terminal branches of the maxillary artery and ascending pharyngeal artery both of which branch off the external carotid artery. Due to the close proximity of the maxillary artery branches to the pterygoid plates and posterior maxilla, they are the most commonly injured vessels in LeFort osteotomies [2, 3]. Care must be taken when performing the posterior osteotomy of the pterygomaxillary fissure, a cut ideally left to last, so the maxilla can be quickly mobilized should the need for hemorrhage control be required. In addition, the descending palatine arteries can be a source of delayed bleeding due to tears or pseudoaneurysms at the time of surgery. The descending palatine artery branches from the third portion of the maxillary artery and enters the greater palatine canal and divides into the greater and lesser palatine arteries. Adequate perfusion to the maxilla remains mainly from the ascending pharyngeal artery when the descending palatine sutures are divided. Preservation of this vessel is preferable during lymphadenectomy.

14.3 Classification of Maxillary Defects

An ideal classification scheme for maxillary defects should be simple, account for both effects on form and function, and guide reconstruction. This ideal remains elusive, evidenced by how many different classification schemes that have been published by radiation oncologists, surgeons, and prosthodontists, none of which having been universally adopted.

The earliest classification scheme was by Dr. G. Ohngren in the 1930s. Dr. Ohngren described a plane that bisects the maxillary sinus that starts at the medial canthus and extends to the mandibular angle. Lesions anterior and inferior to "Ohngren's line" were thought to represent a more indolent or benign disease. Lesions posterior and superior to this plane were thought to be more aggressive or malignant [4]. This scheme focused primarily on anticipating disease behavior and biology as, at that time, it was felt that surgical resection was ineffective. Consequently, Ohngren, a proponent of radiation and "endothermy," made no effort to classify the resulting defects [5].

In 1978 Aramany, a maxillofacial prosthodontist, published two articles, the first classifying post-extirpative maxillary defects and the second on how to obturate them. This is likely the first classification based on surgical defects with the intent on guiding prosthetic rehabilitation [6, 7].

Spiro et al. popularized a classification based on the surgical ablative procedure: limited, subtotal, and complete maxillectomies [8]. The greatest strength of this schema was that it provided a descriptive framework for planning surgical resection that was simple and easy to put into practice. However, because the schema did not include stratification of the oral defect, orbital defect, or malar defect, it is limited in its usefulness for reconstructive treatment planning.

In 2000, Brown et al. published a classification system that was the first to describe the defect in a system that would lend naturally to decisions on reconstruction using contemporary techniques, including both prosthetic and surgical options [9]. In the initial iteration of the Brown classification, they included criteria for stratifying the vertical defect, the laterality, and alveolar defect, allowing for anticipation of the reconstructive challenges both surgically and prosthetically. This was widely felt to be the most useful for reconstructive surgeons because it laid down a mental framework for thinking about the problems that would have to be addressed with the reconstruction.

Dr. Okay, a maxillofacial prosthodontist, along with his surgical colleagues Drs. Buchbinder and Urken, believed that both the palate and remaining dentition should be used to describe horizontal defects, as the dentition provides support, retention, and stability to any prosthesis. In their classification, they also included descriptions of the orbit and zygoma, reflecting their role in facial appearance [10].

Cordeiro and Santamaria built on Spiro's classification and subdivided maxillectomies into partial/limited (type I), subtotal (type II), total with preservation of orbital contents (type IIIa), total with orbital exenteration (type IIIb), and orbitomaxillectomy (type IV) and provided various reconstructive options for each [11]. However, their update did not include descriptions of the maxillary alveolus.

In 2010, Brown et al. published a revised classification accounting for both the vertical and horizontal (functional) defects of the maxilla in a stepwise gradient that coincided free flap selection while also adding a section for isolated naso-maxillary defects [12]. Brown et al. further elaborated upon the relationship between the sizes of the dentoalveolar/oral defect and anticipated prosthetic challenges. These dentoalveolar defects are divided into four categories: a central palatal defect (Class A), ½ or less of the unilateral palate and alveolus (Class B), anterior maxillary defect (Class C), and greater than ½ palatal alveolar defect (Class D) (Fig. 14.1). In contrast to the algorithm published by Cordeiro et al. that primarily recommended soft tissue free flaps with occasional non-vascularized bone grafts (n = 100 74% rectus myocutaneous flap, 6% radial forearm osteocutaneous), Brown et al. advocated for the use of composite osteocutaneous free flaps (n = 147 36% soft tissue free flap, 63% osteocutaneous free flap), which allows for endosseous implant placement and a bony foundation for a fixed prosthetic solution for dental rehabilitation while also adequately separating facial compartments and maintaining support of the soft tissue envelope.

For these reasons, the authors favor the revised Brown classification of maxillectomy defects. The remainder of this chapter will discuss evaluation and treatment planning using this classification as its framework.

14.4 Evaluation

The reconstructive surgical consultation starts with taking a good history. The disease being treated is determined, paying attention to the anticipated extent of the defect given that disease's natural history. For malignant or benign neoplasms, this would entail determining the size of the tumor and the planned ablative defect. Particular attention should be paid to the magnitude of the oral defect, the areas of lost facial support, the extent of involvement of the nasal cavity and paranasal sinuses, whether the globe would be included, and whether intracranial involvement would be expected. For trauma with composite avulsive defects, in addition to the obvious extent of the injury, the mechanism of injury should be considered. Ballistic injuries, particularly those that involve explosions or high-velocity ballistics, can be complicated by a much larger zone of injury than initially observed. These may manifest with progressive dieback of hard and soft tissues. These may also affect the viability of potential recipient vessels for microvascular anastomoses. In short, the disease process needs to be

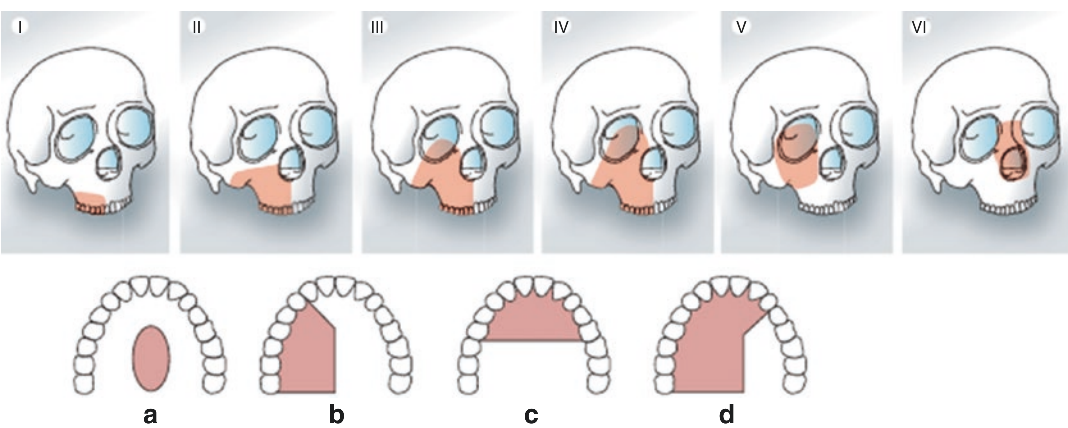

Fig. 14.1 Classification of vertical and horizontal maxillectomy and midface defect. Vertical classification: I—maxillectomy not causing an oronasal fistula; II—not involving the orbit; III—involving the orbital adnexae with orbital retention; IV—with orbitol enucleation or exenteration; V—orbitomaxillary defect; VI—nasomaxillary defect. Horizantal classification: a—palatal defect only, not involving the dental alveolus; b—less than or equal to 1/2 unilateral; c—less than or equal to 1/2 bilateral or transverse anterior; d—greater than 1/2 maxillectomy. Letters refer to the increasing complexity of the dentoalveolar and palatal defect, and qualify the vertical dimension

investigated in order to adequately anticipate and plan for the resultant defect.

A thorough review of the past medical history is important. Several comorbid conditions affect the available treatment options. Free flap surgery is lengthy, and any systemic health issues that would complicate tolerating long surgery and anesthetic times need to be evaluated and optimized. Peripheral vascular disease can affect the flap options available. Malnutrition increases the risk of poor wound healing and flap failure [13]. Early identification of severe nutritional deficiencies may allow for preoperative optimization. Cigarette smoking and alcoholism also contribute to these problems.

The physical examination includes a detailed facial examination, head and neck examination, oral examination, and examination of potential flap donor sites. For the facial examination, special attention is paid to facial proportions, facial dimensions, and shape. For the oral examination, special attention is paid to assessing the occlusion, the number of and health of remaining teeth, and the amount of gingival show on full animation. In addition to the size and shape, the components of the defect must be assessed, specifically whether the external skin, oral mucosa, the globe, and bone will be absent.

Most of these patients already have had extensive anatomic imaging for evaluation of the disease process. In addition to these, if not already ordered, a maxillofacial CT (non-contrast) with fine cuts (less than 1.25 mm) is obtained. A cone beam CT can also be used, although the quality of the information for computer surgical planning is not quite as good. At this point, the authors already have a sense of what reconstructive option will most likely be used, so the relevant imaging study for the flap donor site will be ordered as well. For example, the fibula osteocutaneous free flap is very often used. A CT angiogram of the bilateral lower extremities is ordered to assess the distal arterial runoff as well as provide patient-specific skeletal data for computer planning.

If primary placement of implants is being considered, dental impressions of both arches are also obtained. Previously, the patient would also have to have a scan while biting on occlusal bite registration with an imbedded fiducial marker to aid in registration of the dental models to the CT scan, but improvements in software and engineering have made this unnecessary.

14.5 Reconstructive Options

14.5.1 Dental Obturators

Obturation is the use of a custom dental appliance to separate the maxillectomy defect and oral cavity from the nasal and paranasal cavities. It is the most commonly used approach for maxillectomy defects worldwide [14]. In order for an obturator to be successful, it requires that it be crafted to engage enough facial and dental undercuts to maintain adequate retention during function. It must be well adapted to the mobile soft tissues to create a seal for it to adequately separate the nasal cavity and paranasal sinuses from the oral cavity. This is essential for preventing nasal regurgitation and hypernasal speech. It must have adequate support from the remaining tissues or implants such that it will not move excessively during mastication. Many advocate removal of the inferior turbinate to prevent an impediment to this support.

The definitive obturator has two main components, a metallic framework and an acrylic resin obturator bulb. The metal framework helps resist the torsion and cantilever forces between the defect and remaining retentive tissue, not unlike a removable partial upper denture [15, 16].

Traditional obturators are very similar to a tooth- and tissue-borne removable partial dentures with the addition of the obturator bulb. Support of the obturator is primarily from the remaining hard palate and partially by the remaining teeth. Retention depends upon stress-relieving clasps around the remaining teeth.

In many patients, the remaining hard palate and teeth are insufficient for adequate retention, stability, and/or support. The incorporation of traditional and zygomatic endosseous dental implants can mitigate these shortcomings by creating a fixed foundation for retention and support that can be distributed across the arch. The use of implants can allow for obturation of even Brown Class II d defects (Fig. 14.2a–f (Courtesy of Dr. Brian L. Schmidt MD, DDS, PhD, FACS)).

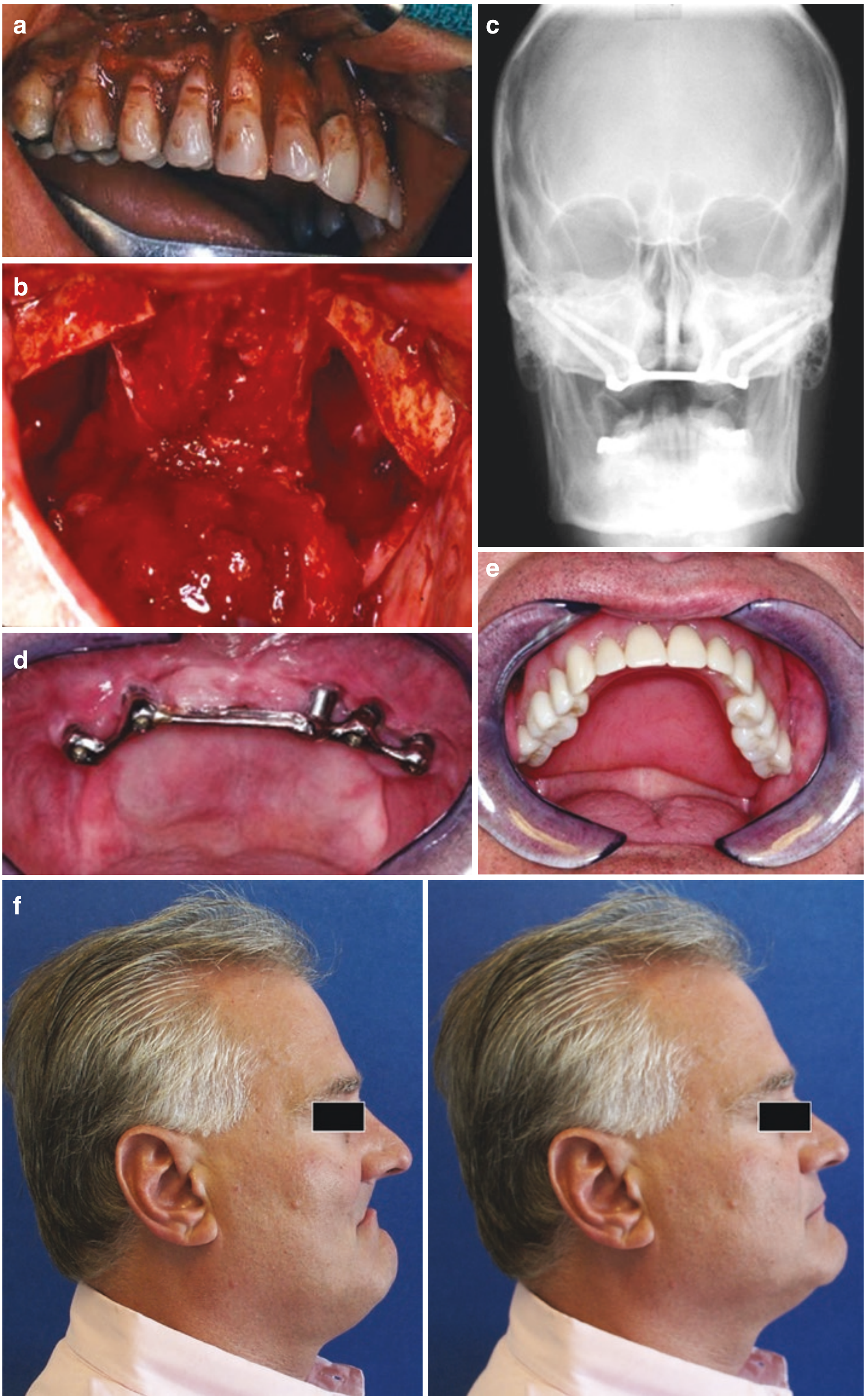

Fig. 14.2 Courtesy of Dr. Brian L. Schmidt MD, PHD, DDS. (**a**) Forty-six-year-old male with rhinocerebral mucormycosis presenting with gross mobility of maxilla. (**b**) Brown Class II d maxillectomy after debridement. (**c**) Quad-zygoma implants placed. (**d**) Custom bar fabrication for zygomatic implants. (**e**) Final prosthesis 2-year follow-up. (**f**) Excellent midface projection 2-year follow-up

There is some debate among reconstructive surgeons and maxillofacial prosthodontists around obturation versus reconstructive surgery. Proponents for obturation note the early return to function, esthetics of immediately replacing dentition, simplicity of treatment, and the ability for tumor surveillance.

Breeze et al. recently assessed quality of life and patient satisfaction between patients who received prosthetic obturation compared to reconstructive surgery. They found no difference in those metrics, regardless of the size of the vertical defect or whether or not patients received postoperative radiation [14]. However, other studies have demonstrated improved patient satisfaction, speech, and swallowing in palatal defects greater than 50% reconstructed with free flaps [17, 18]. Of note, the obturator comparison group was not stratified by implant versus tooth-tissue-borne appliances. There is also data suggesting that the age of the patient affects their acceptance, with younger patients having a harder time with obturators [19].

There are also several system factors that limit the utilization of dental obturators. One is that the expertise required to fabricate dental obturators is highly specialized. Few prosthodontists or dentists have experience with making them. Dental obturators may or may not be a covered benefit by medical insurance, depending on regional norms. If they are not a covered benefit, they can be quite costly. Even if they are a covered benefit, if the reimbursement is either too low, too cumbersome, or both, many prosthodontists who would be able to provide the care decline to do so. The same limitations apply to dental implant-based prosthetic solutions. These barriers to care must be factored into treatment planning decisions.

14.5.2 Free Flaps

Free flaps are the most common form of maxillary reconstruction. Several options are available, which allow for tailoring the reconstruction to the patients' needs. Free flap reconstruction can be performed primarily, allowing for earlier return to function for patients. Free flaps, despite involving lengthy operating room time, are generally highly successful and well tolerated.

The *fibula osteocutaneous free flap* is the flap most commonly used (by the authors) for reconstruction of composite defects of the maxilla. It offers several advantages. It provides bone that is easily osteotomized into complex shapes, especially when computer planning and 3-D printed cutting guides are used. One of the primary challenges of reconstructing Brown Class III or IV defects is restoring malar projection, the piriform buttress, and the alveolar bone, as the axes of each of these struts are in different directions (Fig. 14.3). The ability to segment the fibula into multiple axes is very helpful to addressing this. Another advantage is that the skin flap is based on septocutaneous perforators that allows for flexibility with positioning. It is also thin enough to fold such that portions can be used for oral, cutaneous, and nasal lining, when necessary. The pedicle, depending on the length of the bone required for reconstruction, is usually long enough to reach vessels in the neck without incorporating vein grafts. Furthermore, the donor site is remote from the defect, allowing for simultaneous site preparation and flap harvest.

There are a few disadvantages to the fibula flap. The arterial runoff to the lower extremity is often the first affected by peripheral vascular disease.

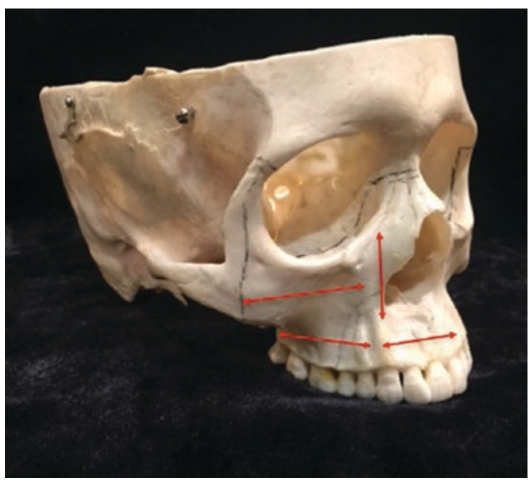

Fig. 14.3 Red arrows on the right maxilla illustrate the differing vectors of the piriform, malar prominence, and anterior and posterior alveolus

The surgical anatomy is more complicated than many of the other flap options available, involving dissection of all four compartments of the lower leg. The scar at the donor site is not easily hidden. Although the bone quality, which is primarily cortical (type I bone with respect to dental implant osseointegration), allows for excellent primary stability following implant placement, it is theoretically less ideal for osseointegration.

Flaps based off of the *subscapular system (scapular flaps, parascapular flaps, scapular osteocutaneous flaps, scapular tip flaps, latissimus dorsi flaps, and chimeric mega flaps)* have the advantage of enormous flexibility. It is ideally suited for Brown Class IV defects, particularly those that extend into the nasomaxillary region and anterior skull base. The ability to have three-dimensionally independently mobile bone, muscle, and skin of large quantities within a single flap enables the surgeon to restore large and highly complex defects. In particular the ability to obliterate the orbit and seal off the cranial fossa with large amounts of vascularized muscle is very useful. The subscapular system is usually spared from peripheral vascular disease, making it a good option when other flap donor sites are not available.

One disadvantage of the subscapular flaps is that harvest often requires placing the patient in some degree of lateral decubitus position. This can make it uncomfortable to perform simultaneous ablative surgery and flap harvest. The scapular bone can be osteotomized, but the segments do not have as many degrees of freedom compared to the fibula. The pedicle length is shorter, especially when using a chimeric flap, making reaching the neck vessels challenging. The bone volume is of variable thickness and is less ideal for placement of dental implants. Although the shape of the scapula is ideal for malar defects, it is challenging to reconstruct both the malar region and the maxillary alveolus.

The *radial forearm free flap* can be used for Brown Class I or II defects that are lateralized and where few teeth are lost and there are no plans to replace them. The radial forearm can be raised as a fasciocutaneous flap or an osteocutaneous flap. The primary advantages are that the radial forearm is a very straightforward flap with a long vascular pedicle and highly reliable skin perfusion and is usually thin and pliable. As a soft tissue flap, it can be used to seal off the nasal cavity and/or maxillary sinus from the oral cavity, restoring normal speech and preventing nasal/sinus leakage. When used as an osteocutaneous flap, some amount of malar and lip support can be provided. When used as a fasciocutaneous flap only, it can be combined with other flaps where the soft tissue of the second flap may be too bulky for the indication. The ideal defect for this is a Brown Class I/II a/b, where the goal is to only seal off the nasal/paranasal spaces, but not to restore bony support.

However, the utility of the radial forearm flap is limited to smaller defects. The bone is insufficient for restoring support of the maxillary buttresses and upper lip for any defect greater than a Brown Class II b. The bone is also insufficient for implant placement. When used as a fasciocutaneous flap only, attempts have been made to place zygomatic implants through the soft tissue into the zygoma [20]. Although this has been done successfully, anecdotally, these implants often suffer from peri-implantitis and require constant vigilance for maintenance. It also doesn't offer a clear advantage over having the implants alone without the soft tissue provided from the flap. When used without the bone, the soft tissue exists somewhat as a tarp over the bony defect. Therefore it also hinders the retention and stability of prosthetic solutions.

The *deep circumflex iliac artery flap (DCIA)* is a very commonly used flap for maxillary reconstruction, heavily favored by Brown et al. It offers several advantages. The shape of the iliac crest is well matched to that of the infraorbital rim and malar region. Creative osteotomies can allow for reconstruction of alveolus as well. Dr. Batstone has presented his modification of the DCIA flap where he uses an osteotomy on a segment of the harvested iliac crest, leaving it pedicled to the iliacus and DCIA artery, and medializes this portion so it approximates the position of the desired neo-maxillary alveolar bone. In this setup, the iliac is oriented with the crest toward the mouth and the cut edge of the iliac wing (inferior) positioned as the inferior orbital rim (Fig. 14.4a–d, courtesy of Dr. Martin Batstone MBBS, BDSc, MPhil(Surg), FRACDS(OMS), FRCS(OMFS)). The internal oblique muscle provides a sizeable muscle flap for obturating defects and/or oral lining. Simultaneous harvest and site preparation are possible.

There are a few disadvantages. The DCIA flap has a comparatively short vascular pedicle, with the upper limit being 6–8 cm depending where the bone is harvested (the further the bone is harvested from the anterior superior iliac spine, the longer the available pedicle). This can still usually reach either the facial or superficial temporal arteries but can be a bit of a stretch. Although a skin paddle can be harvested with the DCIA based on myocutaneous perforators, the skin is fixed to the iliac crest and not independently mobile, reducing its usefulness. The internal oblique muscle can be used for oral tissue lining and will eventually mucosalize. However, the mucosa that grows over the muscle is of the unattached and nonkeratinized variety, which makes it less optimal for implants. The bone quantity is very good but of type IV quality. Therefore, primary stability of implants is not

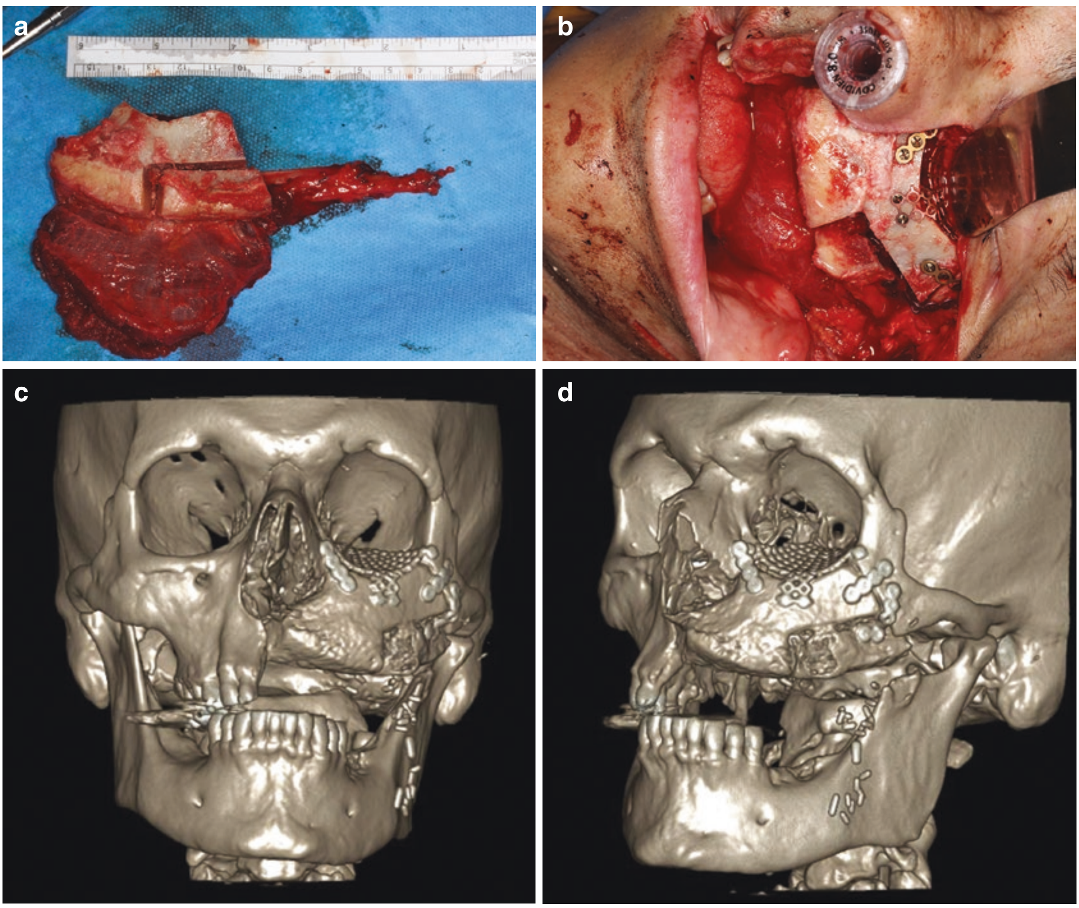

Fig. 14.4 Courtesy of Dr. Martin Batstone MBBS, BDSc, MPhil(Surg), FRACDS(OMS), FRCS(OMFS). (**a**) DCIA harvest with osteotomy of iliac crest, pedicled on the iliacus muscle. (**b**) Reconstruction of anterior and posterior alveoli with thick iliac crest and remainder of ilium harvest reconstructing Brown Class III b defect. (**c**) CBCT showing excellent projection and reconstruction. (**d**) Lateral view

as good as with a fibula. Immediate loading protocols are potentially riskier, although this concern has not been investigated. Interestingly, a recent study suggests that the scapula and DCIA free flaps had higher implant success rates (at 97.6 and 96.9%, respectively) than the fibula free flap (91.7%), although not statistically significant [21].

The rectus abdominis free flap is a commonly used free flap, popular among Cordeiro et al.'s group. It is also a fairly simple flap to elevate with minimal donor site morbidity. It can include a large amount of both the muscle and skin, making it useful for obturating the orbit, sinus, and skull base while also replacing the skin.

The main disadvantage is the lack of bone. As such, it does little to establish the midfacial buttresses. In Brown Class III, IV, or II c and d defects, the loss of bone support in the midface results in a sunken in appearance when only reconstructed with soft tissue alone (Fig. 14.5a–c).

14.6 The Role of Technology in Maxillary Reconstruction

For several reasons, maxillary reconstruction is one of the more challenging areas of the face to reconstruct. As described in the section on surgical anatomy, the maxilla has an irregular shape. The plane of the infraorbital rim, piriform rim, zygomatic maxillary buttress, and maxillary alveolar bone are along three different axes. As described above, the reconstructive surgeon will have to also manage separation of the different facial and cranial compartments from each other.

Historically, the ability to successfully reconstruct the complex anatomy of the maxilla required a level of artistic intuition that was achieved by only a small number of very experienced and talented surgeons. Although many surgeons might have been able to perform the essential elements of microvascular reconstructive surgery, few had the depth and breadth of experience that allowed them to craft a flap on the table into an appropriate shape and use it to accurately recreate normative midface appearance.

Over the last decade, the advent of both *computer surgical planning and 3-D printing* has made the ability to reproducibly and predictably achieve high-level reconstructive results accessible to even novice surgeons. Computer surgical planning allows a surgeon to freely plan and adjust both the defect and flap, with unobstructed three-dimensional visualization. 3-D printed cutting guides based on the computer-generated plans transfer the virtual into the real and have simplified the complex closing osteotomies required to recreate the planned shape. Using data sets created from the computer plan, most plating manufacturers offer the ability to fabricate patient-specific *custom reconstruction plates*. These custom plates allow for more rigid hardware to be used despite the irregular shape of the maxilla. They also adapt well to the patient's native bone with much less bending and adjustments required (Fig. 14.6). Computer surgical planning and 3-D printed cutting guides can also aid in primary placement of dental implants. During the planning session, ideal locations for dental implants, with the end restorative goal in mind, can be precisely placed virtually. This position is translated to the patient using the same cutting guides for shaping the bone flap. Taken a step further, combining advances in computer surgical planning for maxillofacial reconstruction with guided dental implant surgery and immediate loading protocols on splinted implants with cross arch stabilization, select patients can have their ablative procedure, facial reconstruction, dental implant placement, and delivery of a fixed provisional hybrid restoration all within the same day. Discussion of this protocol goes beyond the scope of this chapter, but it is described in detail in the literature [22].

Another significant challenge is surgical access. The space in which the reconstructive surgeon must work is small and very tight, even when using a wide-open access with a Weber-Ferguson approach. Once the flap is inset, the view of the entire recipient site is often obscured. This makes it very difficult to properly position any bone flap in three dimensions. In particular, for defects that include the alveolar segment, it is very easy to create yaw, roll, and pitch errors

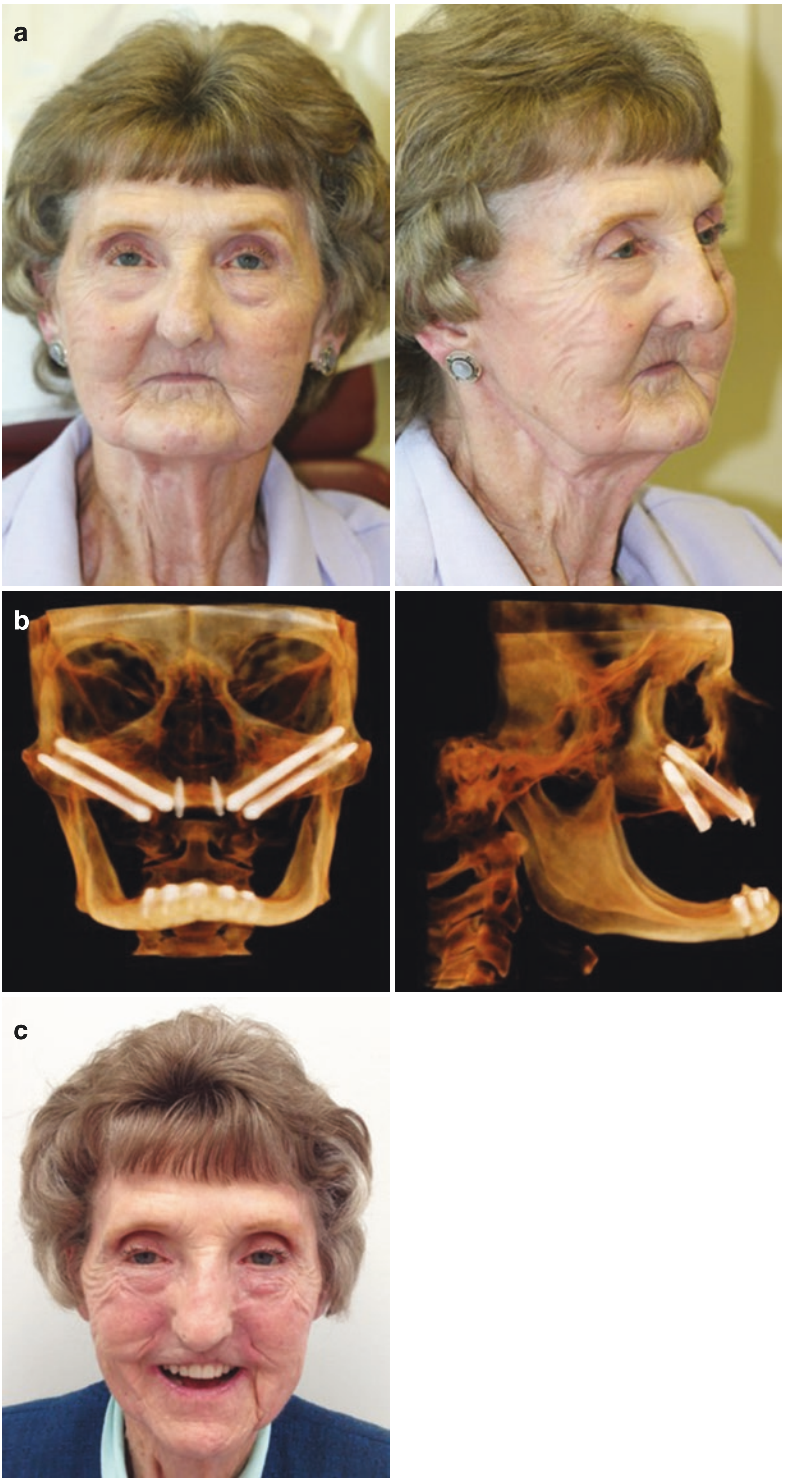

Fig. 14.5 Seventy-eight-year-old female s/p anterior maxillectomy for SCC reconstructed with radial forearm soft tissue flap. (**a**) Note sunken in appearance. (**b**) Later reconstructed with zygomaticus/endosseous implants. (**c**) Three-year postoperative follow-up with excellent function and prosthesis retention

because visual cues that a surgeon would normally use (i.e., during repair of maxillary trauma or orthognathic surgery) to position the neomaxilla are not available (Fig. 14.7).

To a small degree, custom reconstruction plates help with some of the uncertainty. However, with the complex shape of the maxilla and lack of exposure, they only partially mitigate the challenge. *Intraoperative CT* scans and *intraoperative navigation* have been both used, either alone or together. Navigation is somewhat helpful, especially with placement of the bone flaps against the pterygoid maxillary buttress. This is an area where the bone flap is easily placed too lateral (most commonly), too inferior, or, on some occasions, too superiorly. However, navigation becomes less reliable as the surgery goes along. This is because the initial registration is inevitably moved or displaced, inadvertently, during the length of the case. For the authors, intraoperative CT has been the most helpful in identifying errors intraoperatively. Although there are several inconveniences with intraoperative CT (using a special head rest, requiring a lengthy stop in surgery, radiation dosage), the value of confirmation of accurate flap placement while it still can be adjusted is tremendous.

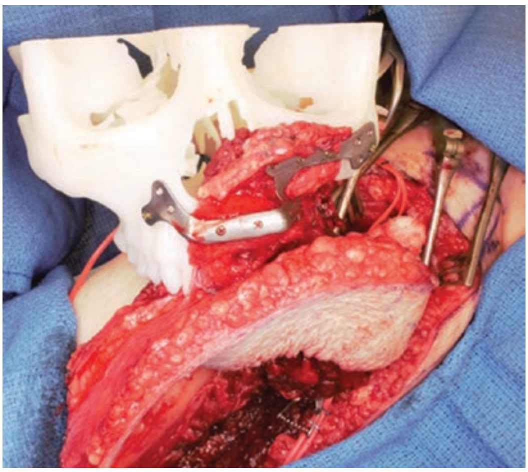

Fig. 14.6 Custom plate used for fibula free flap reconstruction of a high-left Brown II b maxillectomy

14.7 Strategies for Maxillary Reconstruction Using Brown Classification

14.7.1 Brown Class I a: Palatal Defect Only

These defects do not involve an alveolar segment or loss of teeth. As such, the support of the dentition and facial soft tissues is not compromised. The resulting defect does create an oroantral and/

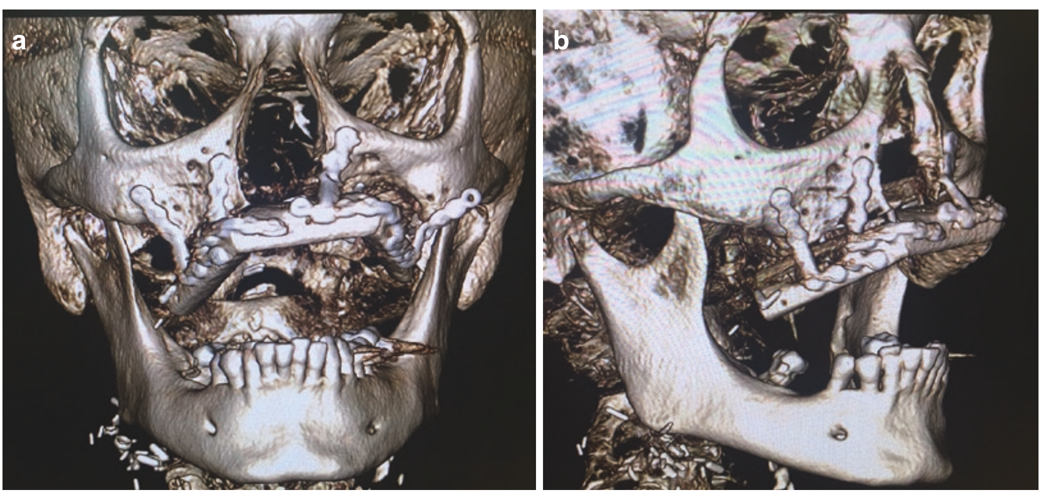

Fig. 14.7 Poor intraoperative position of maxillary fibula segments secondary to loss of anatomical references from advanced MRONJ

or oronasal communication that results in hypernasal speech and nasal regurgitation.

This can be addressed either prosthetically or surgically. Prosthetically, a tooth- and tissue-borne or tissue-borne removable obturator prosthesis can very successfully seal this off. This has the benefit of surgical simplicity but in some patients is not as well tolerated.

This can also be reconstructed using surgical techniques. Depending on the size of the defect, these can be closed by local flaps, regional flaps, or free flaps. Local flaps are better suited for patients who have not received or will not be receiving radiation therapy. For local flaps, Von Langenbeck palatal flaps combined with a septal finger flap can be used effectively for smaller defects. For lateral defects in edentulous patients, buccal fat pad can also be used. A buccal facial artery myomucosal flap is also very helpful. For radiated patients, the authors favor a free flap, with the radial forearm being the simplest.

14.7.2 Brown Class I b–d: Dentoalveolar Defect Only

Brown Class I b–d defects, that is, those that involve the maxillary alveolus without oroantral or oronasal communication, require reconstruction of the dentoalveolar restructures to provide a functional dentition and upper lip support. The tissues lost will be the bone, teeth, and attached gingiva.

For I b and c defects, there are several options. The segment can be replaced entirely by a removable partial denture (Kennedy Class II) if there is remaining native maxillary dentition. Implant-supported solutions are also possible, although they involve creative implant placement and sophisticated prosthetic design. Often there is a dearth of available bone height for implants. Also, there is usually missing keratinized tissue. This can be mitigated by use of short implants splinted together (Fig. 14.8). For defects including the posterior segment, 1–2 zygomatic implants combined with an implant in the anterior maxilla can be used. Palatal grafting on the buccal/labial aspect of the implants may be required to preserve peri-implant health.

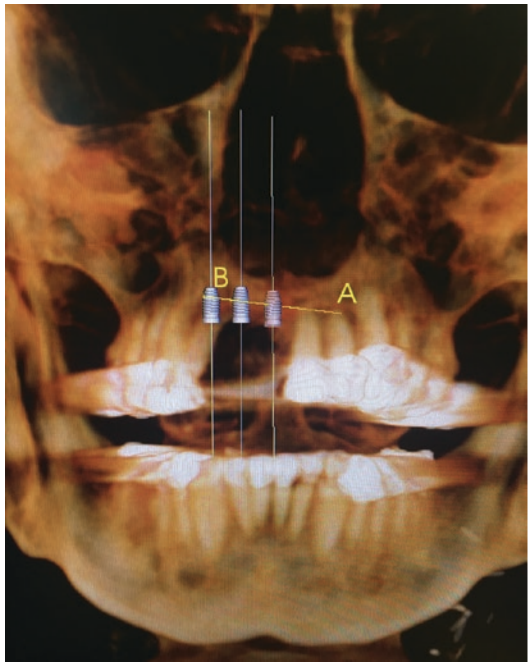

Fig. 14.8 Seventy-year-old male with pT2M0N0 maxillary SCC s/p partial maxillectomy, planned for short splinted dental implants

For Brown Class I d defects, this essentially mimics the clinical scenario of the atrophic maxilla. A removable partial denture remains an option, but retention will be an issue. More likely an implant-supported prosthesis will be required. Four or more splinted dental implants (either angled or including zygomatic implants) can provide a platform for a fixed prosthesis (fixed hybrid, fixed bridge, or overdenture on a bar). Soft tissue may be an issue, and creative use of local palatal flaps or grafts may be necessary to ensure a cuff of attached gingiva around transmucosal portions of the implants.

14.7.3 Brown Class II b: Posterolateral Infrastructure Maxillectomy with Posterior Dentoalveolar Defect

This defect results in an oroantral and oronasal defect in the posterior region and loss of posterior dentoalveolar support. Because the contralateral teeth (if present), hard palate, and alveolus remain, a prosthetic option is still possible.

An obturator can very elegantly be used to obturate the defect, replace the missing dentition, and restore facial support (Fig. 14.9). The advantages and disadvantages have been already described. Implants can aid in retention and support, when necessary.

For very posterior defects where the patient retains premolars, a soft tissue-only flap can be used. This simplifies the reconstruction. Because the piriform rim, the infraorbital rim, and anterior

Fig. 14.9 Eighty-three-year-old female with pT4aN0M0 maxillary SCC. (**a**) Lesion. (**b**) Maxillectomy defect. (**c**) Intraoperative temporary obturator. (**d**) One-year postoperative photo without obturator. (**e**) One-year postoperative photo with obturator

teeth are not lost, there is no loss of facial support. A soft tissue flap can therefore sufficiently separate the maxillary sinus from the oral cavity without the need for bony reconstruction. This does make prosthetic replacement of the posterior teeth much more challenging. A soft tissue flap lacks support for a removable partial denture and will depend entirely on the remaining hard palate to resist chewing forces on the same side of the defect. As mentioned above, Hirsch et al. have proposed the placement of zygomatic implants through a radial forearm free flap in order to provide a platform for an implant-supported prosthesis. Although this can be done successfully, we have largely abandoned this approach, as the soft tissue does not provide much benefit to an obturator supported by zygoma implants, while a flap does complicate implant placement and maintenance significantly.

14.7.4 Brown Class II c–d: Infrastructure Maxillectomy Involving Most of Dentoalveolar Arch

Defects that extend to over half of the maxillary arch, wrapping around and/or including the incisors, require some form of reconstruction of the facial support provided by the piriform buttresses and maxillary teeth to avoid facial disfigurement. Failure to do so leaves patients with a witch's chin deformity, with loss of lower facial height, midface projection, lip support, and nasal support (Fig. 14.5a). The loss of support results in an over-closed mandible that gives the patient a very aged face, relative prognathism, and severely downturned nasal tip.

For Brown Class II defects that are fairly low (infraorbital, malar, and paranasal support intact), leaving sufficient bone in the zygoma on both sides, quad-zygoma implants can be used to support a prosthetic reconstruction, usually an overdenture-type obturator prosthesis. As discussed above, these require a high level of prosthodontic sophistication to fabricate. The availability of such expertise is region dependent (Fig. 14.5b).

The more common solution would be surgical reconstruction, and in this case, a bone flap of some sort is necessary to avoid the abovementioned deformity. The authors prefer the use of a fibula free flap for this purpose. Other groups have advocated differing flaps, all of which have their merits. The scapula tip has been suggested as the ideal shape to replace the entire maxillary hard palate [23]. However, the authors have found the available bone to be insufficient for implant placement when the scapula is used in this way (despite what others have said). Others, including Brown et al., have favored the DCIA flap for these types of defects.

After the consultation visit, a CT angiogram of the lower extremities and a fine-cut CT maxillofacial study are ordered. These files are then uploaded to a third-party computer surgical planning company. Once uploaded, the files are then used to create 3-D computer models for planning. A web-based meeting is scheduled between the surgeons and computer surgical planning engineer. The defect, in the case of oncologic surgery, is planned out. In the case of trauma, an additional ablation is usually planned out to optimize the recipient site for receiving the bone flap. In this case, it is helpful to have cut edges for butt joints. Mobile and/or marginally viable bone segments should be discarded (Fig. 14.10a–f). The fibula is then virtually osteotomized to create the desired shape. For low Brown Class II defects, the focus is on reconstructing the alveolar segments, as the upper piriform rims and zygoma are still present. The maxillary arch is conceptually divided into three segments: the premaxilla and right and left posterolateral segments (Fig. 14.11) (take picture of maxillary arch and draw in these segments) (Fig. 14.10c). The fibula is segmented using closing osteotomies to recreate a similar shape. Particular attention is given to making sure the position of the fibula construct matches the desired position of the neo-maxilla along all three axes. This is very difficult to appreciate accurately in vivo but easily appreciated in simulation. Also, accurate maxillary width is another dimension that is difficult to assess intraoperatively but straightforward on the computer.

The posterior stop of the fibula construct is placed at the pterygoids. This also prevents excessive width of the neo-maxilla. If the ptery-

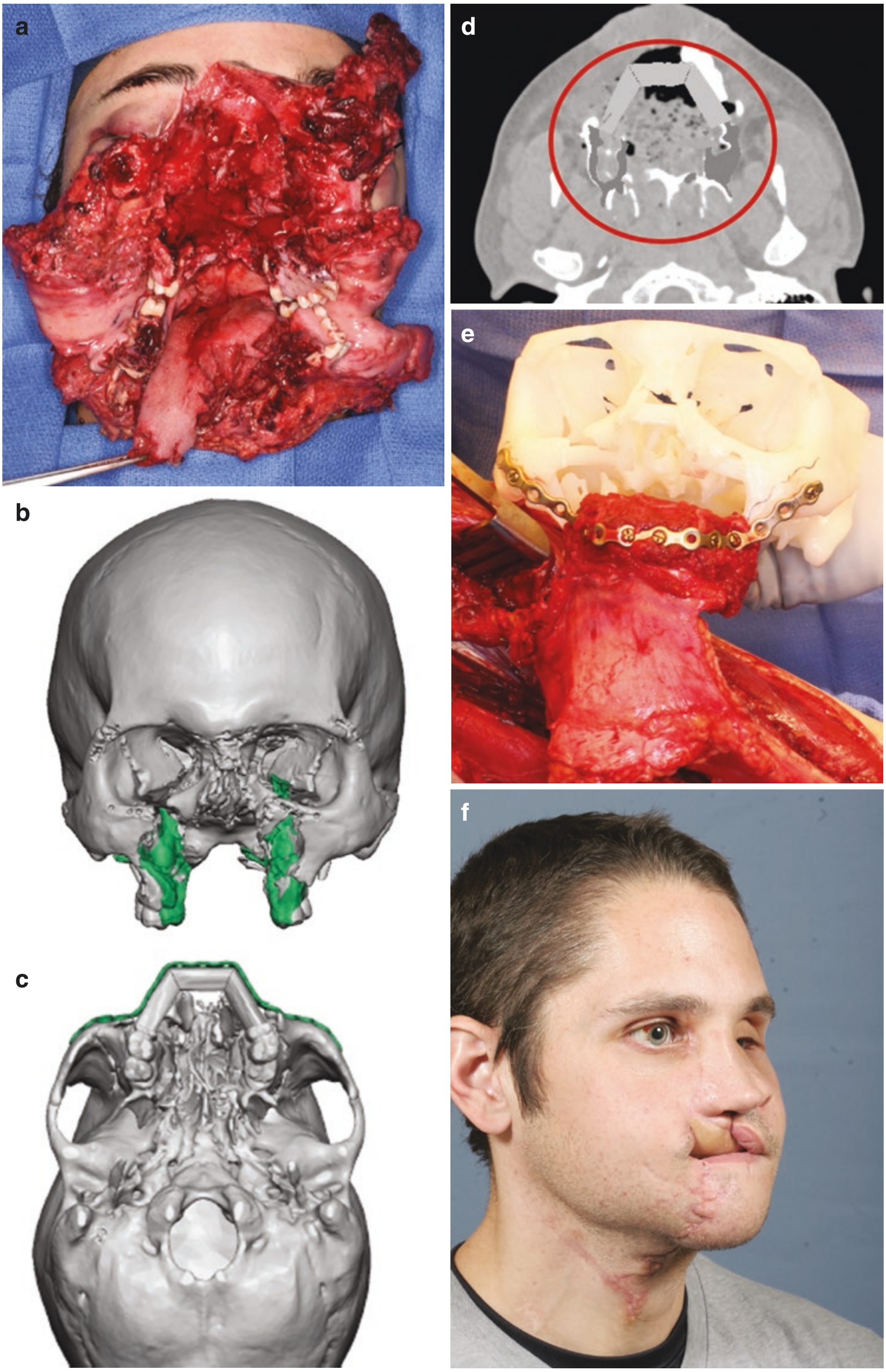

Fig. 14.10 Self-inflicted gunshot wound with shotgun. (**a**) Debridement and stabilization. (**b**) Computer surgical planning—aligning of mobile maxillary segments. (**c**) Computer surgical planning—placement of fibula against pterygoid plates to avoid widening maxilla. (**d**) Intraoperative navigation plan to verify placement. (**e**) Custom plates and stereolithographic models aid in accurate placement of fibula. (**f**) One-year post-op maxillary and mandibular reconstruction with bilateral fibulas and soft tissue revisions

Fig. 14.11 Three segments of the maxillary arch

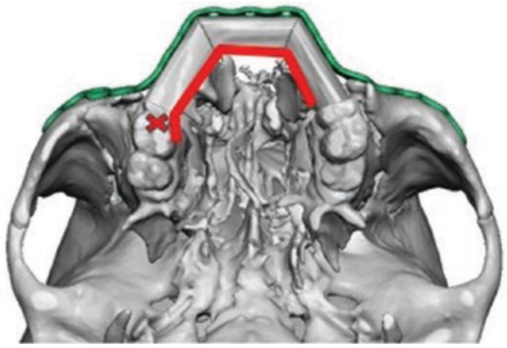

Fig. 14.12 If posterior dentition is left intact and the proximal fibula abuts it, the pedicle risks being kinked as it abuts tooth #3 in this depiction

goid plates remain, the authors often plan to remove them, as they interfere with the path of the vascular pedicle.

Similarly, having remaining posterior dentition on the side of the reconstruction complicates flap inset by creating an area of compression for the vascular pedicle. This is because the lateral aspect of the fibula is the most easily used for plating and thus is typically planned to be facing buccal/labial. The medial aspect of the fibula, where the vascular pedicle runs, is set palatal. Unfortunately, when posterior teeth are preserved they can form a barrier to the vascular pedicle's path to recipeient vessels (Fig. 14.12). The authors have addressed this technical difficulty in a number of ways. One is to simply remove all posterior teeth in that segment. The pedicle can then run posteriorly and then inferiorly along the medial side of the mandibular ramus. One can try to run the pedicle underneath the palatal mucosa along the junction of the horizontal and vertical hard palate toward the soft palate before diving medial to the mandible. However, the attached gingiva of the hard palate is thick, tight, and generally inflexible, so this creates an area where the pedicle is compressed against the bone, especially as postoperative swelling sets in. Another work around is to create a large bone window through the maxillary sinus wall. The pedicle then is run over the fibula, through the window and then through a subcutaneous tunnel on the buccal side of the mandible.

For high Brown Class II defects with loss of the piriform rim and anterior maxilla up to and including the infraorbital nerve, the loss of vertical buttressing presents a problem for fixation and support to the neo-maxillary arch. A biaxial double-barrel arrangement can be used to reconstruct the piriform buttress, infraorbital facial support, paranasal support, and maxillary arch. In designing the second axis, an adequate leash (at least 3 cm) of pedicle is allowed to make the 180-degree turn (Fig. 14.13a). The authors generally make this portion of the flap the most distal from the anastomosis. The rationale is that if the folding results in a partial flap failure, it is of the least consequence and highest potential for retention, if only as a bone graft, being that it is still enveloped in vascularized soft tissue and protected from the oral environment. Keep in mind, during flap harvest, the fibula skin paddle must be harvested off a perforator located over the more proximal segments. Otherwise, they will be facing into the maxillary sinus and will not be able to reach the oral cavity.

From this plan, 3-D printed cutting guides are made to recreate the computer plan in the operating room (Fig. 14.13b).

In the operating room, a Weber-Ferguson or similar approach is used for adequate access (Fig. 14.13c). Prior to flap inset, a tunnel is cre-

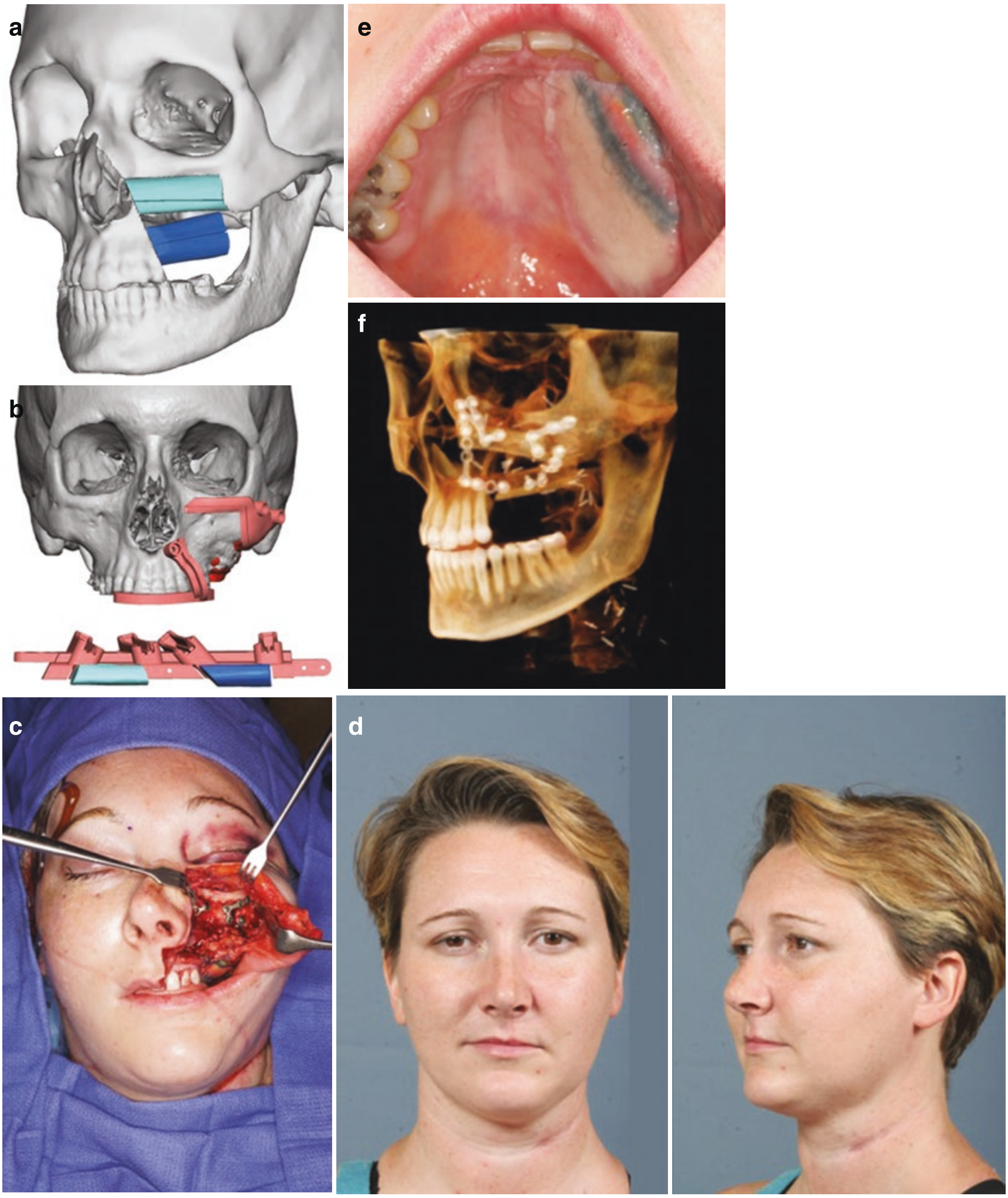

Fig. 14.13 (**a**–**f**) Thirty-three-year-old female with dentinogenic ghost cell tumor. (**a**) Biaxial double-barrel flap technique with 3 cm leash for fibula reconstruction of Class II b defect. (**b**) Maxillary (above) and fibula (below) cutting guides. (**c**) Weber-Ferguson approach to maxilla. (**d**) 1.5 years s/p Brown II b maxillectomy and reconstruction with excellent facial symmetry and projection. (**e**) Adequate bony reconstruction of alveolus for removable partial or endosseous implants. (**f**) CBCT

ated for the vascular pedicle to run from the defect into the neck. If possible, the pedicle is run along the medial aspect of the mandibular ramus, through the lateral pharyngeal space. This is the straightest and shortest route from the maxilla to the neck. It avoids the bends in the vascular pedicle when running it on the lateral aspect of the mandible and over the inferior border. During the flap inset, intraoperative navigation is used to guide the positioning of the neo-maxilla, making sure that the construct approximates the computer plan to avoid roll, yaw, and pitch deformities. After fixation of the flap and completion of the microvascular anastomosis, the final position can be confirmed using intraoperative CT or later with a postoperative CT. The end result provides both adequate facial support and a platform for future implant restoration (Fig. 14.13d–f).

14.7.5 Brown Class III: Infrastructure Maxillectomy Involving Orbital Rim and Floor

The loss of the orbital rim and floor adds considerable challenges to the reconstruction. Removing the orbital rim adds another missing horizontal buttress for facial support. Removing the orbital floor results in a marked enophthalmos that is disfiguring.

The authors still favor the use of a fibula free flap. As mentioned above, the fibula osteotomies are planned as a biaxial double-barrel flap. Others have described creating 3–5 small segments for the inferior orbital rim, the piriform rim, the zygomatic buttress, and the maxillary alveolus (Fig. 14.14, from Brown et al.). This is enormously complicated and unnecessary. Two segments of fibula, when stacked, are typically enough to recreate the height of the piriform rim (Fig. 14.15), obviating the need to have a third small segment. This is further reinforced when using custom reconstruction plates. The zygomatic maxillary buttress, though important in reduction of fractures, is less essential when restoring defects.

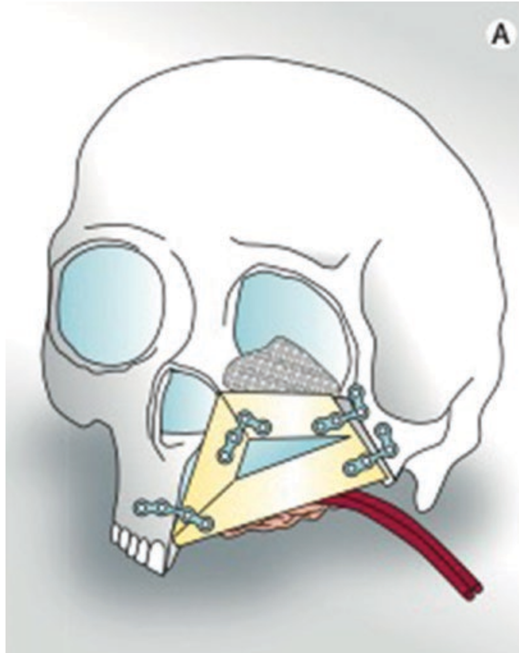

Fig. 14.14 Three-piece fibula for reconstruction of Brown III b defect—from Brown, J.S. and R.J. Shaw, *Reconstruction of the maxilla and midface: introducing a new classification*. Lancet Oncol, 2010. **11**(10): p. 1001–8

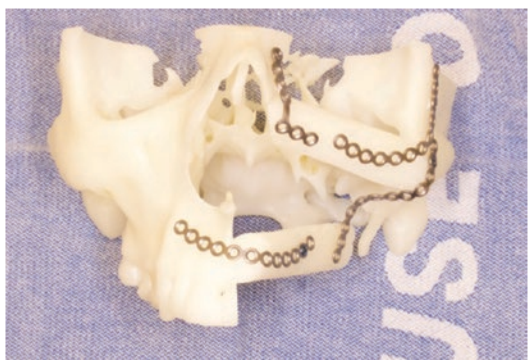

Fig. 14.15 Biaxial double-barrel flap technique with 3 cm leash for fibula reconstruction of Class III b defect

The floor can be reconstructed with a titanium plate, bone graft, or a bone flap. The simplest would be to rebuild the floor with an orbital floor fracture plate fixated to the fibula segment used for the inferior orbital rim. This is ideally covered with a soft tissue flap, particularly if radiation therapy is expected. A bone graft over a plate or by itself can be similarly successful. However, it is also vulnerable to failure due to postoperative radiation therapy. A vascularized scapula tip can also be used for floor reconstruction. If a scapula is used, the lateral border can be also used to replace the infraorbital support. However, this is inadequate for restoration of the maxillary arch.

14.7.6 Brown Class IV: Maxillary Defect with Orbital Exenteration

If an orbital exenteration is performed, the goals of reconstruction, in addition to the elements mentioned above for Brown Class II and III defects, include obturating the orbit and creating a barrier separating the cranial vault (if the resection includes the skull base). In the case of dural exposure or dural defect, a watertight closure should be obtained. A secondary goal would be to prepare the orbit for a future facial prosthesis.

Unfortunately, no one flap can achieve all of these goals satisfactorily. Therefore, the decision has to be made between prioritizing certain goals versus using two flaps. In prioritizing goals, the most essential is obturating the volume defect and separating compartments. To this end, the authors will most frequently use a subscapular system chimeric flap. The latissimus dorsi can be used to obturate the orbit and maxillary sinus and form an adequate barrier against dural repairs. If available, an anteriorly or posteriorly based pericranial flap is folded in to cover the dura as an additional layer of protection. The scapula skin can be used both externally and intraorally to reline missing skin and mucosa. The lateral border of the scapula and scapula tip can be used to reconstruct the malar region and hard palate. However, using this strategy, it is difficult to adequately reconstruct the maxillary alveolus (Fig. 14.16a–d).

If two flaps are to be used, a fibula flap can be used as described for Brown Class III defects, while a soft tissue flap (anterolateral thigh, rectus, or latissimus) is used to obturate the orbit. The challenge here is having adequate vascular access for anastomosis of two flaps that can be reached by the pedicles of both.

14.7.7 Brown Class V: Orbitomaxillary Defect Without Dentoalveolar Defect

In defects isolated to the orbit, bony reconstruction is not necessarily required. The main goal is to obturate the orbit and seal off the paranasal sinuses from the intracranial vault. If the eyelids are preserved, the reconstruction is simplified a bit.

There are two approaches to this. One is to leave a defect cavity and focus on lining the bone of the orbit. This has been referred to as an "open cavity" reconstructive approach. In these cases, a skin graft is placed over the bony walls of the orbit, leaving the orbit "open." This is a simple reconstruction and allows for easy monitoring for tumor recurrence. However, this is not suitable if there is extensive bone resection and/or if there is communication to the intracranial cavity that needs to be sealed off. In addition, if radiation therapy is anticipated, a skin graft will not be resilient enough to withstand that assault.

The more common is the "closed cavity" approach, where the orbit is obliterated. This is the strategy the authors typically use. Soft tissue flaps are ideal for this. In particular, muscle flaps, such as the latissimus dorsi or rectus, are well suited. Muscle flaps, given their vascular nature, are favorable for filling spaces and adhering to bone surfaces. Furthermore, over time these flaps will atrophy, leaving a robust, vascularized lining without the overabundance of soft tissue seen during the initial postoperative phase. This is advantageous for orbital reconstructions as it allows for a nice retentive space for a facial

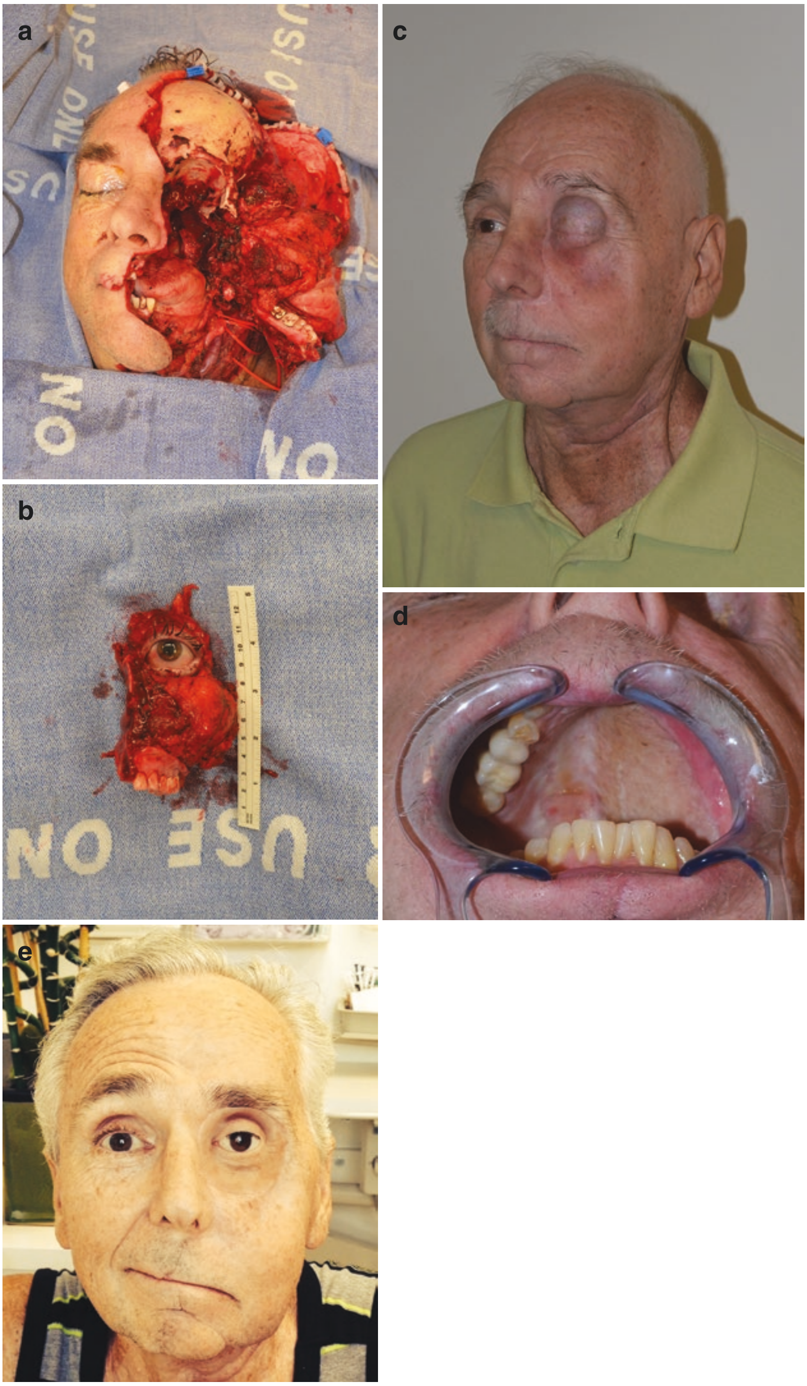

Fig. 14.16 Sixty-eight-year-old male with rpT4bN1M0 SCC of the palate, zygoma, and anterior cranium after radiation therapy s/p cranial resection and Brown Class IV b maxillectomy with orbital exenteration, reconstructed with chimeric subscapular system mega flap. (**a**) Resection. (**b**) Brown IV b maxillectomy. (**c**) Six-month postoperative follow-up. (**d**) Six-month postoperative intraoral. (**e**) Prosthetic in place

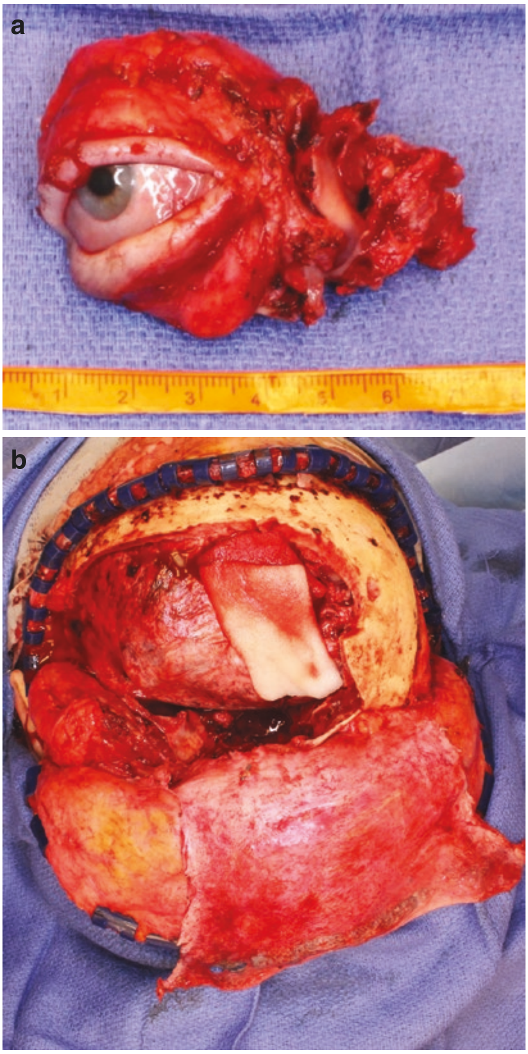

Fig. 14.17 Fifty-eight-year-old female with T4aN0M0 neuroendocrine tumor involving right eye s/p composite resection involving exenteration. (**a**) Orbital exenteration. (**b**) Exposed dura, patient underwent closed approach obliteration of orbit with latissimus free flap

prosthesis to fit into. This is also good for buttressing a dural repair (Fig. 14.17a, b). However, if atrophy of the soft tissue is not desired, an adipofascial flap, such as the anterolateral thigh flap, should be used, as fat atrophies to a much smaller degree.

14.7.8 Brown Class VI: Nasomaxillary Defect

The nasomaxillary defect, which may be limited to the nasal-orbito-ethmoid (NOE) region or extend to include a medial maxillectomy and total rhinectomy, is one of the most challenging facial defects to reconstruct.

For defects limited to the nasal-orbito-ethmoid region, separation of the anterior cranial cavity from the paranasal sinuses is essential. A thin soft tissue flap, such as the radial forearm, is very suitable. The loss of bony support at the NOE can be rebuilt with free bone grafts harvested from the cranium (Fig. 14.18a–c).

For total rhinectomy defects, as above, there are two general strategies to approaching this: prosthetic versus surgical reconstruction. Of the two, the prosthetic will more consistently lead to a result that approximates a normal appearance (Fig. 14.19a, b). A skilled maxillofacial prosthodontist can do much more with plastics than a surgeon can with a blade. The retention of this prosthesis can be aided by the strategic placement of dental implants (Fig. 14.20a–d). Because these implants are made for oral use and not intended to have transcutaneous elements, peri-implant soft tissue irritation is a problem that requires regular cleaning to keep under control.

Surgical reconstruction of the total rhinectomy defect is a topic that goes well beyond the scope of this chapter. There are several descriptions in the literature of different techniques [24–26]. Generally, there are the following components that need to be addressed: the nasal lining, the nasal framework, and the external lining. The nasal lining, for total rhinectomy defects, can be reconstructed with a radial forearm free flap. The nasal framework can be reconstructed using cartilage grafts harvested from the conchal bowl of the ear, the nasal septum, a rib, or a combination. Shaping of the grafts into a framework must include a dorsal

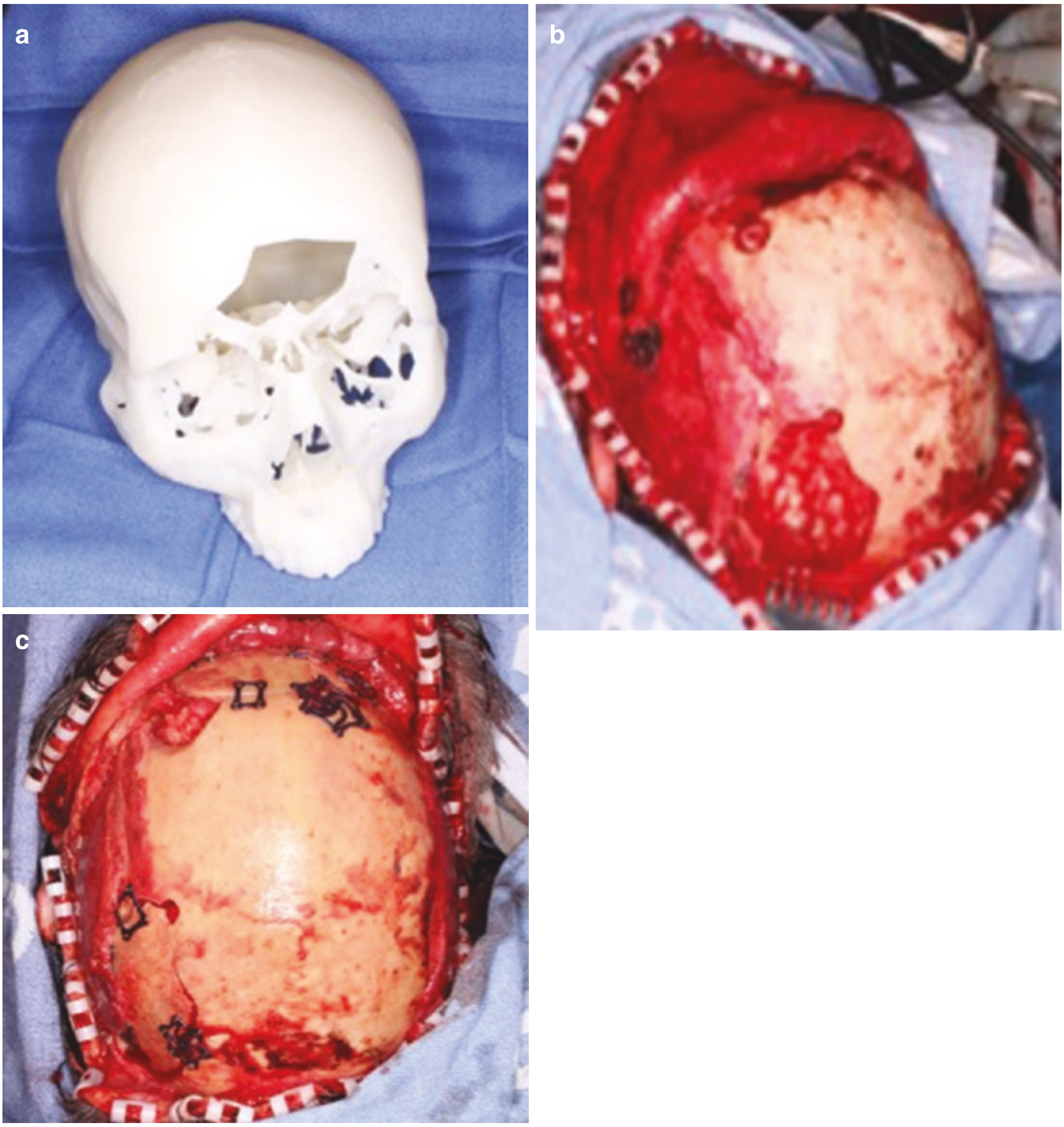

Fig. 14.18 Sixty-year-old male with sinonasal melanoma planned for composite resection of anterior frontal sinus and ethmoid sinus. (**a**) Computer surgical planning with cutting guides for anterior craniectomy. (**b**) Full-thickness cranial bone harvest using cutting guide. (**c**) Inner table at donor site, outer table with excellent fit over the anterior cranium and NOE

strut, a columellar strut, and the lower lateral nasal cartilage. The external skin is best reconstructed using a paramedian forehead flap. Depending on the size of the defect, this may benefit from tissue expansion to allow for a large enough flap to cover the new nose. Prelaminated radial forearm flaps have also been used and described.

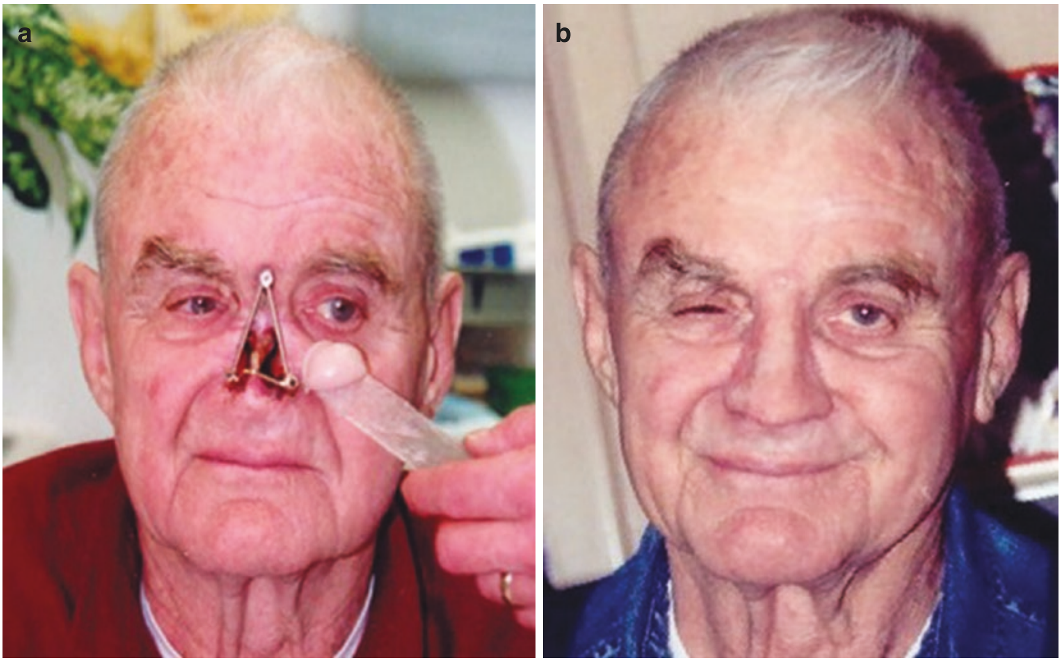

Fig. 14.19 Sixty-year-old male with melanoma of nasal dorsum s/p total rhinectomy. (**a**) Craniofacial implants with custom bar in place. (**b**) Excellent esthetics and color match of prosthesis

14.8 Conclusion

The maxilla is an area central to the face and at the crossroads of several functionally and esthetically complex areas. As such, defects of the maxilla can be quite diverse and reconstruction of these defects quite complicated. The revised Brown Classification scheme is helpful in identifying the critical elements of reconstruction for any given maxillary defect. Reconstruction of maxillary defects will employ either prosthetic-only solutions, surgical reconstructive solutions, or, in many cases, a combination of these. The reconstructive surgeon must have a diverse armamentarium of flap choices to be able to sufficiently address the wide range of possible defects. The surgeon must also be well versed in requirements for prosthetic success. Surgery is hampered by the limited access and the distance between the defect and the neck vasculature. Technological advances such as computer surgical planning, intraoperative navigation, intraoperative CT, printed cutting guides, and custom reconstruction plates all aid in improving the reproducibility of good outcomes, but do not replace thoughtful treatment planning and skillful execution.

Fig. 14.20 Sixteen-year-old female s/p shotgun injury to the face. (**a**) Original injury. (**b**) Ten years after initial reconstruction. (**c**) Craniofacial implants placed after multiple soft tissue revision surgeries. (**d**) Prosthetic in place, reconstructing the Brown V and VI defects

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