Chapter 5
Reconstruction and Rehabilitation After Surgical Ablation of the Paranasal Sinuses

Avinash V. Mantravadi, Michael G. Moore, and Jessica A. Yesensky

Introduction

Reconstruction and rehabilitation of the paranasal sinuses and palatomaxillary region has a long and rich history with several periods of evolution over multiple specialties. The first retentive dental prosthesis was identified in patients as early as 2500 BC, and Lusitanus is credited for describing what is now routinely known as the palatal obturator in 1560 [1]. For many years, palatal obturators and other prosthetics have been utilized for separation of the oral and nasal cavities to preserve normal speech and swallow mechanisms, and for restoration of the form of the midface with good results. With modern advances in imaging modalities and ablative techniques, the extent of resection of additional structures including the premaxilla, body of the zygoma, orbital floor, and skull base made more apparent the limitations of prosthetic rehabilitation. In addition, an inability to manipulate an obturator due to age or functional limitations, trismus related to prior treatment or resection of the pterygoid plates, resection of a large amount of premaxilla, or patients' desire not to have to manage a removable prosthesis drove the development of new reconstructive techniques. Throughout the 1980s and 1990s, a rapid expansion of microvascular free tissue transfer options led to far greater diversity in options available for reconstruction. Recent advances in implantable materials, three-dimensional (3D) modeling, and virtual surgical planning have provided a greater number of tools available to the reconstructive surgeon. While palatal obturators and prosthetics remain widely used to provide excellent functional and cosmetic rehabilitation after ablative surgery of the midface, there has been a dramatic rise in the use of local flaps and free tissue transfers in recent years. This provides

A. V. Mantravadi (✉) · M. G. Moore · J. A. Yesensky
Department of Otolaryngology-Head and Neck Surgery, Indiana University School of Medicine, Indianapolis, IN, USA
e-mail: avmantra@iu.edu

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the surgeon who may encounter a wide variety of defects with an equally diverse array of reconstructive options.

Defect Analysis

Following ablation of sinonasal malignancies, the type, extent, and complexity of the defect depend on a number of factors such as the size, location, and histopathology of the primary lesion. Moreover, when considering options for reconstruction, certain patient factors must be taken into account including medical comorbidities, body habitus, status of dentition, and any previous local irradiation therapy or planned adjuvant therapy.

The goal of any reconstruction is to create a safe, stable wound with the ability to rehabilitate the patient as close to their premorbid condition as possible. Aims of the repair include creating separation of the oral and sinonasal cavities; achieving a watertight repair of any skull base defect; restoration of lost structural support of the maxillary buttress system including the orbital floor; maintaining oral competence and functional dentition to allow for postoperative mastication, deglutition, and speech; obliterating any created dead space; and resuspending any adynamic facial soft tissue in an effort to optimize postoperative appearance (Fig. 5.1).

Fig. 5.1 This intraoperative photo demonstrates a defect following transfacial resection of a T3N1M0 right-sided maxillary sinus squamous cell carcinoma. Note that the lateral and anterior projecting elements were preserved but there is loss of the central aspect of the orbital floor (a titanium orbital floor implant has been placed) as well as half of the hard palate. Reconstruction in this instance was performed with an anterolateral thigh (ALT) musculocutaneous free flap to repair the palate defect and provide lining to the right lateral nasal wall while also obliterating the right cheek dead space

Because of the heterogeneous nature of wounds that can result following resection of sinonasal tumors, precise defect analysis is critical in order to optimize the quality of the repair. Multiple maxillectomy classification systems have been developed aiming to help guide the approach to rehabilitation [2, 3]. The following should be assessed prior to determining the approach to repair: loss of structural support of the midface and/or orbit, loss of epithelial surfaces (palate and/or nasal mucosa, external skin), the presence or absence of exposed or resected dura, the presence or absence of the anterior (premaxilla and nasal spine) or lateral (zygoma) projecting elements, and the amount of remaining maxillary dentition.

Within the following sections, we will outline approaches to reconstruction, ranging from prosthetic rehabilitation, requiring little to no additional surgery, to complex, multicomponent repair using composite free tissue transfer. In some instances, combinations of these techniques will be needed in order to achieve optimal results.

Approaches to Rehabilitation and Reconstruction

Prosthetic Rehabilitation

For patients with defects involving the lower maxilla and hard palate, the use of a dental obturator may be an option for rehabilitation. In fact, when controlling for the vertical dimensions of defects and the use of adjuvant therapy, there was no difference found in the Health-Related Quality of Life for patients managed with maxillectomy obturators compared to flap reconstruction [4]. Advantages of obturators include precise closure of oronasal communication, the lack of donor site morbidity that would result from a free flap harvest, and the ability to more closely monitor the resection bed for local recurrence.

While this approach may be well suited for many individuals, there are certain criteria that need to be met. First, it is necessary to have adequate stable maxillary dentition remaining in order to retain the prosthesis. Okay et al. outlined what defects are best suited for prosthetic rehabilitation and what may require definitive repair [3]. In the absence of more posterior maxillary teeth, maintenance of the ipsilateral canine tooth has been shown to significantly improve the ability to retain a stable obturator by minimizing the fulcrum force created by mastication. In instances where the patient is edentulous or they lack adequate dentition to retain an obturator, the use of osseointegrated implants has been shown to improve masticatory and oral function and reduces discomfort with chewing compared to those using a conventional obturator [5]. A further requirement is sufficient native support of the orbital contents as maxillary obturators are not well suited to assist with orbital support in instances where the floor has been resected.

In addition to functional maxillary obturators, prostheses can also be created to assist in camouflage in instances where an orbital exenteration and/or a total rhinectomy are performed. In these circumstances, the use of mirrored images from the unaffected normal anatomy is often helpful to allow for the most realistic result. Prostheses may be affixed with adhesives, external devices such as arms of glasses, or even clasps that bind to osseointegrated implants.

In instances where an obturator is being considered, it is important to have the patient seen by the prosthodontist soon after the initial oncology evaluation in order to obtain a dental impression. This impression allows for the fabrication of a plaster model where the proposed resection can be outlined (Fig. 5.2). Close communication is then needed between the prosthodontist and the ablative surgeon in order to develop a prosthesis that can be placed at the time of surgery to allow for resumption of oral nutrition, postoperatively. Development of the prosthesis may take between 1 and 2 weeks, so early involvement of the prosthodontist is critical to avoid delay. Moreover, if placement of osseointegrated implants is needed, an oral surgeon should be included in the planning.

Recent technological advances may allow for more rapid and precise prosthetic rehabilitation. Virtual surgical planning can be implemented to simulate the planned resection and mirror images of the opposing unaffected anatomy can allow for accurate estimation of the proposed obturator, while also assisting with placement of implants, when needed. The expanded utilization of computer aided surgery has also greatly enhanced the prosthodontist's repertoire as it may allow for generation of needed materials in as little as 24 hours at some institutions [6]. Moreover, others have described the use of immediate postresection CT imaging to allow for fabrication of a surgical obturator using 3D printing, obviating the need for a preoperative impression [7].

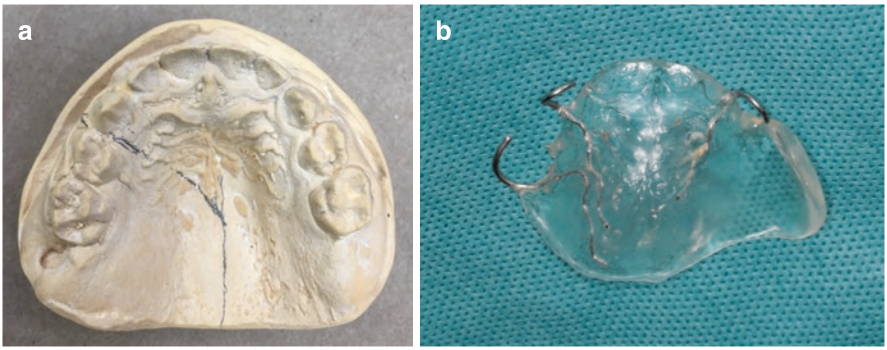

Fig. 5.2 (**a**) This photo demonstrates a plaster model generated from a dental impression with a right posteroinferior maxillary sinus tumor. The proposed resection is outlined in pencil, preserving the ipsilateral canine tooth and extending to the midline of the palate. (**b**) This photo demonstrates the surgical obturator created to be placed after resection. Notice the metal clasps to be used to secure the prosthesis to the patient's remaining dentition. (Images borrowed with permission from Dr. Ben Anderson, Indianapolis, IN)

Skull Base Reconstruction

For sinonasal resections involving the anterior cranial base, a watertight reconstruction of the dura is of upmost importance to avoid cerebrospinal fluid leak, pneumocephalus, and the development of meningitis. In all instances, it is necessary to ensure the surrounding mucosa has been removed to allow for sealing of the repair and avoidance of mucocele formation. When resection and reconstruction is performed endoscopically, small defects can be repaired with a layered closure, often with a tissue allograft followed by a free mucosal graft overlay. Donor sites for free mucosal grafts include the middle or inferior turbinate, the nasal floor, or the nasal septum. For defects in the sphenoid sinus, a free fat graft can be used to augment an allograft closure or obliterate dead space prior to coverage with a pedicled flap.

For larger endoscopic defects resulting in high-flow cerebrospinal fluid leaks, the use of the nasoseptal mucoperichondrial rotational flap has revolutionized the ability to achieve a reliable repair [8, 9] (Fig. 5.3). This technique utilizes the posterior septal branch of the sphenopalatine artery to achieve robust vascularity and has been shown to provide a sturdy repair with rates of cerebrospinal fluid leak ranging from 3.2% to 5% [10, 11]. Primary limitations of this technique are related to its arch of rotation, with an inability to reach defects extending to the frontal sinus. Flap quality and viability may be less reliable with prior significant septal surgery or local external beam radiation. Moreover, in instances where portions of the septum are involved with tumor, careful margin control is necessary in order to ensure there is no residual disease left on the graft. Such grafts can be harvested unilaterally or bilaterally and a posterior septectomy is often required to allow for appropriate graft positioning. Tissue sealant and absorbable packing are often used to fix the repair in place during the initial time of healing. While unilateral harvest is typically tolerated well with little impact on long-term quality of life, described complications include septal perforation, cartilage necrosis, prolonged crusting, pedicle injury,

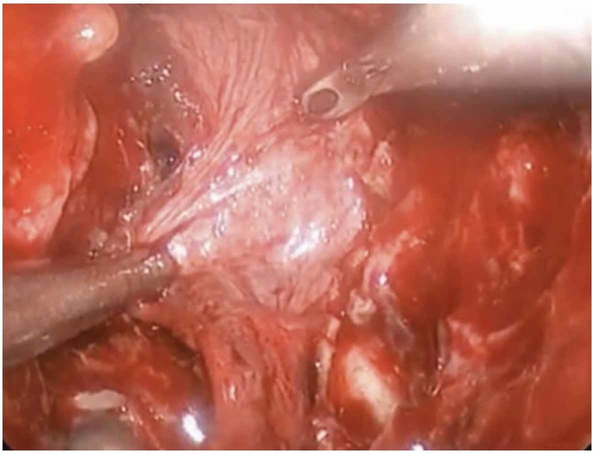

Fig. 5.3 This intraoperative photo demonstrates a right-sided nasoseptal flap being rotated in position to repair a high-output cerebrospinal fluid leak following resection of a mass involving the planum sphenoidale. (Image borrowed with permission from Dr. Jonathon Ting, Indianapolis, IN)

and persistence of the leak [12]. Additional adjuncts for endoscopic repair of large defects include tunneled pericranial and temporoparietal fascial (TPF) flaps, as well as rotational middle or inferior turbinate flaps [13–15].

When using an open approach, small defects of the dura, such as those that occur following resection of the cribriform plate, can be repaired primarily and then reinforced with a secondary layer. The most frequently utilized family of regional flaps in open anterior skull base repair is the pericranial or galeofrontalis group of flaps [16, 17]. These flaps can be harvested open or endoscopically and provide a thin, pliable tissue layer that receives its vascularity from the supraorbital and supratrochlear vessels. Consequently, their use is contraindicated in instances of significant prior forehead surgery where the pedicle may be compromised. Moreover, the reliability may be less in instances of prior external beam radiation. In situations where an orbital exenteration is performed, the flap can be used based on the contralateral vascular pedicle but it may impact the health of the graft and the arch of rotation may be more limited. In all instances, if this flap is to be used, a trough must be created in order to tunnel the graft to the area of repair, typically requiring cranialization of the frontal sinus as the nasofrontal outflow will be compromised.

For more lateral defects or those not crossing the midline, the temporoparietal fascial (TPF) and/or temporalis muscle flaps can be utilized. The TPF flap is based on the superficial temporal artery, which is a lateral blood supply for the same tissue layer as that used in galeopericranial flap repairs. These grafts can reliably be harvested up to the midline of the scalp and rotated into place to assist with reconstruction (Fig. 5.4). In instances of orbital preservation, the graft may be tunneled into place through the pterygopalatine fossa [18].

For larger open defects, especially those with an associated orbital exenteration and/or resection of overlying skin, free tissue transfer may be needed. In these instances, typically a precise, layered repair is performed of the dural defect, with consideration of augmenting with rigid support such as septal cartilage, a free bone graft, titanium mesh, or even rotational vascularized bone [19, 20]. A soft tissue free flap can then be used to obliterate the sinonasal/orbital dead space in order to reinforce the reconstruction and also provide a safer wound in the event that adjuvant therapy is needed (Fig. 5.5).

The use of lumbar subarachnoid drains is controversial in situations of skull base reconstruction. Proponents argue that fluid diversion reduces the pressure on the reconstruction, optimizing the chance for achieving a watertight closure. Critics point to the potential for drain-related complications such as pneumocephalus and infection. To date, there are no well-controlled data to demonstrate clear superiority of either approach. It is the authors' preference to avoid drains unless there is an area that cannot be repaired in a watertight fashion at the time of surgery, or in instances of refractory leaks or known elevated intracranial pressure.

Regardless of the approach used, achievement of a watertight skull base repair is paramount to reduce the potential for perioperative complications. The treating surgeon must consider the associated defect as well as patient- and treatment-related factors in order to choose the approach that is best in each individual circumstance.

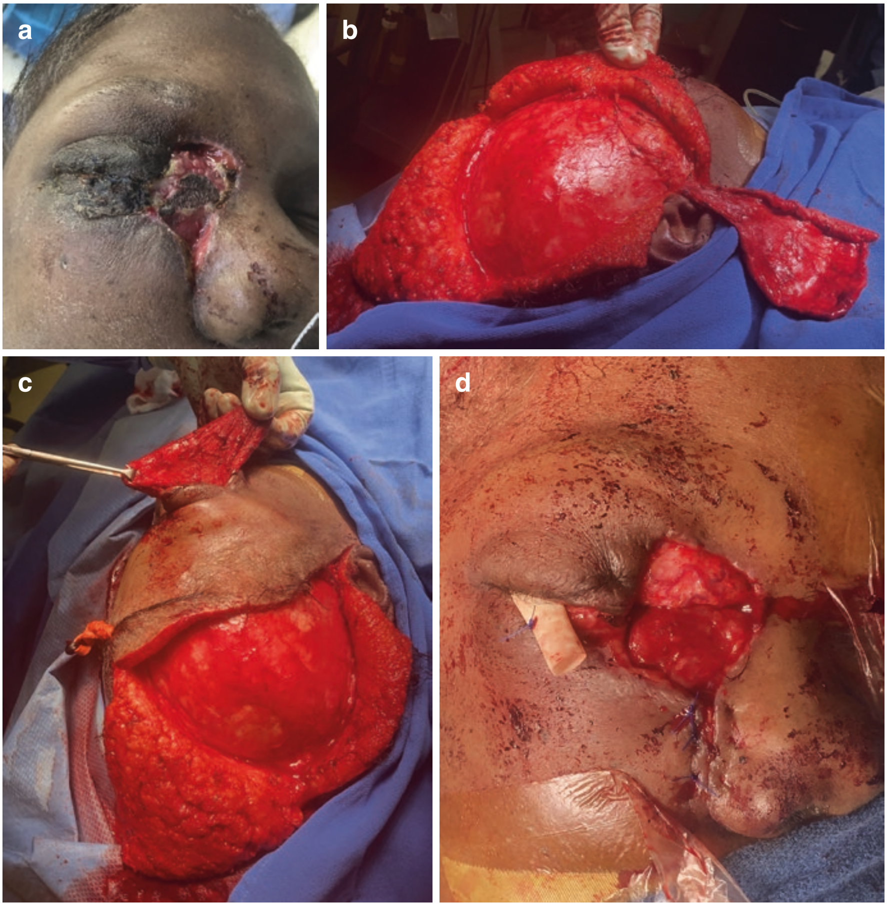

Fig. 5.4 These clinical photos demonstrate the use of a right-sided temporoparietal fascial (TPF) flap for use in repair of a patient with persistent cerebrospinal fluid leaking following a right-sided maxillectomy with orbital exenteration and anterior skull base resection with free flap repair (**a**). The TPF flap was harvested on the superficial temporal vessels (**b**) and rotated into place, tunneling in subcutaneous plane in the right temple (**c**) to obliterate the dead space in the superior right orbit (**d**)

Palate Reconstruction

There have been multiple proposed defect classification schemes developed by ablative and reconstructive surgeons as well as prosthodontists [2, 3, 21, 22]. Classification schemes were developed to describe the complex defects and aid in the reconstructive algorithm to restore function and improve aesthetic outcomes.

The primary goal of palatomaxillary reconstruction is separation of the oral and sinonasal cavities and dental rehabilitation. Isolated palatomaxillary defects do not affect the maxillary structures that provide midface projection or orbital support.

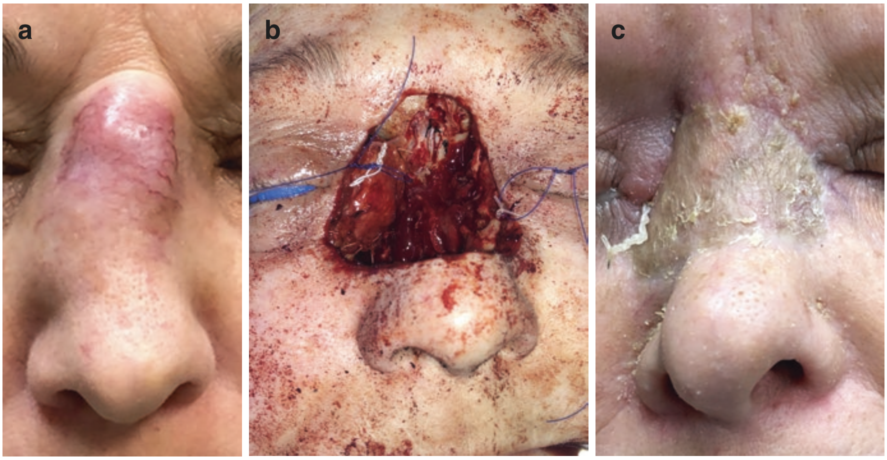

Fig. 5.5 (**a–c**) These clinical photos demonstrate a patient with an advanced squamous cell carcinoma with involvement of the nasal dorsum and medial canthi, bilaterally (**a**). The tumor resection required an open anterior craniofacial resection with orbit preservation. Due to the resection of the nasal skin, the anterior skull base was repaired with direct suture closure of small dural defects at the site of the cribriform resection (**b**). This was then reinforced with a myofascial vastus lateralis free flap and split thickness skin graft. The patient subsequently presented well healed following her adjuvant radiation therapy (**c**)

Traditionally these defects have been managed with prosthetics but advances in free tissue transfer have become important options for reconstructing complex midface defects. Microvascular free flap surgery permits transfer of soft tissue alone or soft tissue plus bone to the defect sites. Postsurgical rehabilitation with dental prosthesis or dental implants plays critical role in flap choice. Soft tissue flaps offer closure and separation of the oral and sinonasal cavities but may not support prostheses. Bone-containing flaps provide closure and a stable base for prosthetics and/or support dental implants.

Options are based on the defect size, location, and remaining dentition. The proposed schemes have classified the defects according to the amount of dentoalveolar and palatal bone that has been resected. As the size of the defect increases, the quality and quantity of remaining palate and dentition for support decreases, which affects reconstructive algorithm [23]. Therefore, a classification scheme that carefully outlines the defects and reconstruction options is pivotal for optimized rehabilitation. Okay et al. set forth a comprehensive classification scheme that will be referenced.

Defects can be classified as involving isolated hard palate without tooth-bearing alveolus. This would correspond with Class Ia defects (Fig. 5.6a). Class Ib refers to defects involving dentoalveolar ridge posterior to the canines or the premaxilla (Fig. 5.6b) [3]. These defects can be rehabilitated with obturator, local flaps, or soft tissue free flap. Obturator is the easiest and quickest means of rehabilitation and facilitates easier postoperative surveillance exams, allowing for direct visualization.

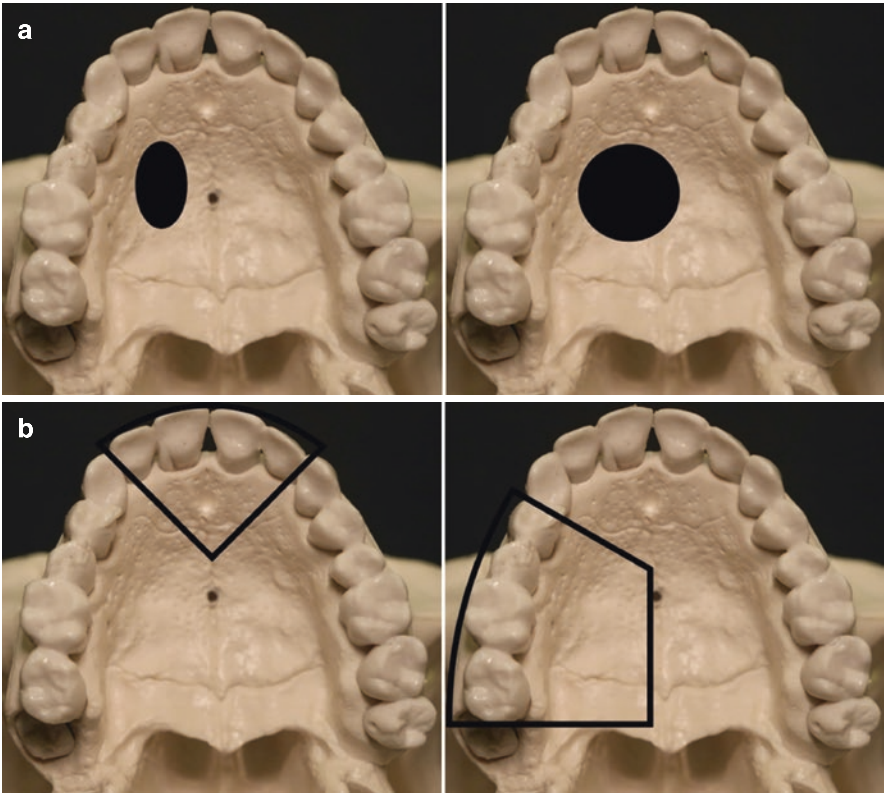

Fig. 5.6 (**a**) Class Ia defect: isolated hard palate without tooth-bearing alveolus. (**b**) Class Ib defect: dentoalveolar ridge posterior to the canines or the premaxilla

Collaboration between surgeons and prosthodontists greatly improves the functional and aesthetic outcomes of the devices. Local flaps can successfully close smaller defects, while free tissue transfer is reserved for larger defects. Local flaps include palatal island, buccal fat pad, and temporoparietal and facial artery musculomucosal (FAMM) flaps. If surgical reconstruction is planned, soft tissue flaps without bone can be utilized, like fasciocutaneous radial forearm flap. Further dental rehabilitation can be achieved with partial dentures fitted over the soft tissue reconstruction.

Class II defects include any portion of the dental-bearing maxillary alveolus with one canine and less than 50% of the palatal surface (Fig. 5.7) [3]. These maintain midface support and projection through retained maxillary buttresses and zygomatic arch. There is reduced stability due to less remaining palatomaxillary bone and dentition. As a result, it is more challenging to create a functional prosthesis. Free tissue transfer with soft tissue alone or bone-containing flaps are mainstays for reconstruction. Moreno et al. reported better functional speech and swallowing outcomes in patients with large palatal defects that underwent surgical reconstruction versus obturators [23]. Fasciocutaneous radial forearm flaps are low profile, yet offer adequate soft tissue coverage. Musculocutaneous flaps provide more bulk, but in the select individuals can be used for these defects. Subsequent dental rehabilitation after soft tissue flaps remains limited. Bone-containing flaps reestablish the dental arch and afford the opportunity for dental implantation. The most commonly used flaps will be discussed below.

Defects involving more than 50% of the palatomaxillary bone and including both canines are categorized as Class III (Fig. 5.8) [3]. These defects are best restored through bone-containing free flaps. Soft tissue flaps can be utilized; however, subsequent oral and dental function is severely limited.

Commonly used vascularized bone flaps include thoracodorsal angular artery (TDAA flap), which supplies the scapular tip; fibular free flap; osteocutaneous radial forearm; and deep circumflex iliac artery (DCIA flap), which supplies the iliac crest [24–27]. Each flap offers unique advantages for reconstructing the maxilla. The bone of the scapular tip flap offers bone stock that is similar in shape to the palate with a long vascular pedicle. Additionally, the subscapular system allows for chimeric flaps with a variety of soft tissue components. Fibular flaps provide hearty

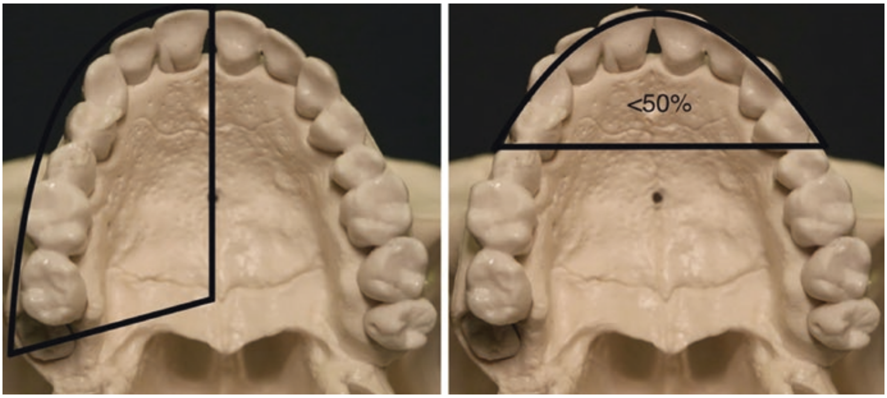

Fig. 5.7 Class II defect: any portion of the dental-bearing maxillary alveolus with one canine and less than 50% of the palatal surface

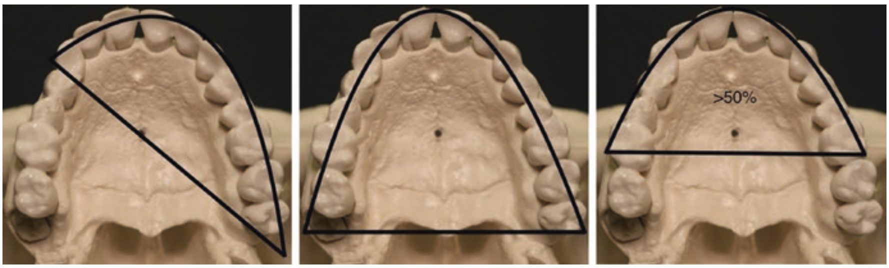

Fig. 5.8 Class III defect: more than 50% of the palatomaxillary bone and including both canines

bone stock that can be contoured to match the defect. A skin paddle can be harvested and aid in reconstruction of the mucosal defect. Both scapular tip and fibular free flap provide vascularized bone flap with minimal donor site morbidity. Iliac crest flap allows for different shapes of bone to be harvested with or without musculocutaneous component. The main disadvantage is related to the structural integrity of the abdominal wall after harvest and delayed ambulation.

Maxillectomy Without Orbital Exenteration

With Orbital Floor Preservation

Maxillectomy defects are characterized according to the components of the palatomaxillary complex that are resected. There have been a number of classification schemes proposed; however, Brown and Shaw created a comprehensive classification for midface defects that adequately describes the complex 3D anatomy [21]. Surgical defects are characterized by the vertical component of the maxilla resected including palate, zygoma, and orbital floor, as well as the horizontal component, describing the palatal defect (Fig. 5.9). The classification scheme elucidates the functional and aesthetic deficits and helps guide decision-making for reconstruction.

Reconstruction after maxillectomy with preservation of the orbital floor, Brown Class III, with free tissue transfer can achieve very good functional and aesthetic results. Any of the previously described vascularized bone flaps will adequately reconstruct this defect. Bulky soft tissue flaps can also be used to fill the defect and effectively separate the oral and sinonasal cavities. Musculocutaneous flaps like anterolateral thigh (ALT), rectus abdominis, and latissimus dorsi flaps provide the bulk to fill the dead space and skin for mucosal closure [22, 26, 28] The disadvantage of soft tissue flaps is that they do not reconstitute midface projection nor provide scaffold for dental rehabilitation.

Chimeric scapular tip with soft tissue component, like latissimus, has become increasingly more common flap used for total maxillectomy with orbital floor preservation. The latissimus can be used to fill the dead space of the defect, while the scapular tip recreates the palatal complex [24, 25]. The advantage is that this flap provides bone and soft tissue in a single flap. Fibular free flap can also be used to recreate the midface and a second soft tissue flap may be necessary to fill the remaining cavity and provide tissue for mucosal closure [28, 29]. An osteocutaneous radial forearm flap is an alternative vascularized bone flap that has become increasingly more popular. The major risk associated with this flap is fracture of the radius.

There is no consensus on the optimal flap choice for these defects. There are limited data to suggest one flap achieves better outcomes, and most literature is retrospective in nature. Flap choice often comes from surgeon preference and comfort with the flap. However, there are several factors that need to be considered when determining reconstructive options. Body habitus is an important factor since excess

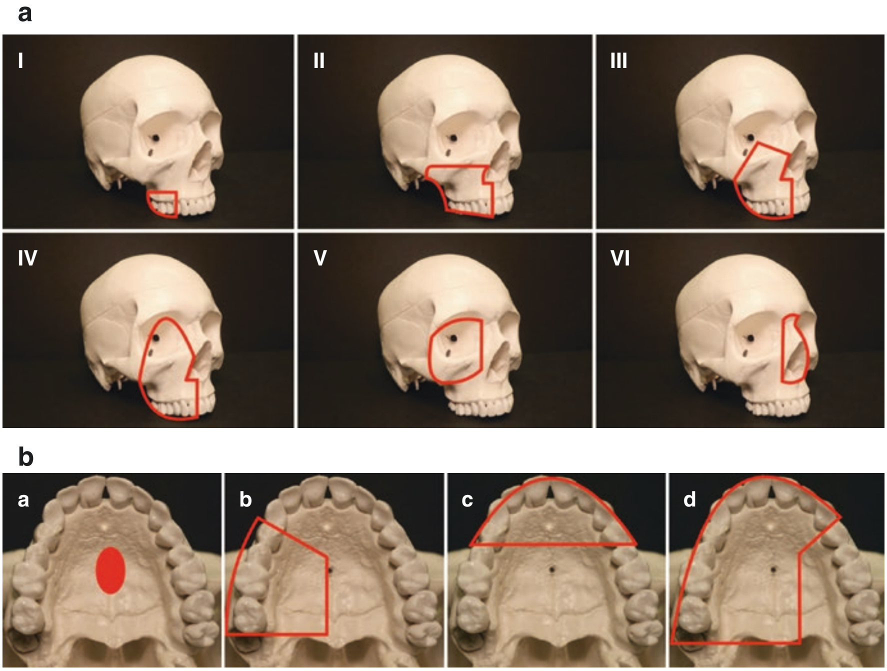

Fig. 5.9 Brown and Shaw modified classification scheme for maxillary and midface defects [21]. (**a**) Vertical classification: I, maxillectomy without oronasal fistula; II, not involving the orbit; III, involving the orbital structures with orbital preservation; IV, with orbital exenteration or enucleation; V, orbitomaxillary defect; and VI, nasomaxillary defect. (**b**) Horizontal classification in order of increasing complexity of dentoalveolar and palatal defect: (a) palatal defect only, not involving alveolus; (b) less than or equal to ½ unilateral; (c) less than or equal to ½ bilateral or transverse anterior; and (d) >1/2 maxillectomy

adipose leads to bulky flaps that can be difficult to fit into a fixed-volume, maxillectomy defect. Inadequate lower-extremity vasculature can limit use of fibular flaps and this is determined preoperatively on CT angiography or Doppler.

With Orbital Floor Resection

Ablative resection of the orbital floor is frequently required in high-grade tumors to achieve a negative margin. This situation typically mandates free tissue transfer for reconstruction in some form, whether this involves soft tissue only or with bone.

Failure to adequately address the critical support structure for the globe may result in enophthalmos, globe ptosis, diplopia, dystopia, and facial deformities. Early attempts to support the globe with soft tissue only, including skin grafts, and fascial or muscular slings, frequently failed to prevent such outcomes [30]. Obturators alone have limited utility in support of the orbital floor, particularly given the vertical height required from the prosthesis to support both the palate and the orbital floor and the degree of mouth opening required to accommodate such a device.

In the setting of orbital floor resection alone with preservation of the orbital rim, the orbit may be supported with the use of an alloplastic implant, such as titanium mesh, porous polyethylene, or smooth nylon foil. The remainder of the palatomaxillary complex may be reconstructed with free tissue transfer in the standard fashion as previously discussed, provided there is adequate soft tissue coverage of the inferior aspect of the implant to prevent contamination from the nasal cavity and risk for subsequent extrusion (Fig. 5.10).

Resection of both the orbital rim and floor during maxillectomy presents a unique challenge with a number of potential reconstructive options available, without a clear superior technique. Primary considerations are preservation of the horizontal symmetry of the orbit with floor support, and restoration of normal orbital rim contour and projection. This can be accomplished with alloplastic implants or free bone grafts in combination with soft tissue flaps, or with rigid reconstruction with osteocutaneous free flaps. When using alloplastic implants for orbital reconstruction, care must be taken not to extend the implant to the rim to avoid thinning of the overlying soft tissue, contracture, and extrusion. In patients undergoing radiation, there are concerns with titanium meshes due to the risk of entrapment of orbital structures causing diplopia or extrusion. Rates of extrusion are variable but range from 10% to 25% [31–34]. Some have advocated for modified techniques that include placement of free fascia as an interface between the mesh and the orbit to decrease this risk, or coverage of the mesh with a fasciocutaneous flap in combination with prosthetic obturator for the palate [35, 36]. Regardless of the technique selected, of paramount importance is adequate soft tissue coverage of implants and fixation hardware, either by maintenance of an adequate native soft tissue envelope or with the utilization of pedicled or free soft tissue flaps.

Free bone graft is frequently utilized for reconstruction of both the rim and floor. The split calvarial bone grafts from the frontal bone plate and iliac crest donor sites are commonly used due to their optimal shape for recreating the contour of the

Fig. 5.10 This patient with a large osteoblastic osteosarcoma of the left maxilla underwent maxillectomy and resection of orbital floor contents. Reconstruction was completed with an alloplastic implant for the orbital floor and soft tissue reconstruction of the palatomaxillary defect. Note that while the orbital height was preserved, the patient developed lower-lid ectropion over time, a noted complication of orbital floor reconstruction

orbital floor; however, other sources including split rib have been described. Bone graft provides an autologous source of rigid fixation with a smooth surface for the mobile orbital contents above. After appropriate contour to the defect, bone graft may be fixated to the zygoma and nasal bones with titanium miniplates or wires [31, 37]. The remainder of the defect is reconstructed with free tissue transfer, with adequate soft tissue coverage of fixation hardware as noted earlier. Autologous bone has been theorized to have a lower extrusion rate, particularly when utilized in place of titanium mesh for reconstruction of the orbital rim; however, this has not been definitively demonstrated.

Free tissue transfer with bony reconstruction of the orbit is now frequently performed, and may be combined with palatal and premaxillary bony reconstruction as well with multiple bone segments. Many of these flaps have the added benefit of a skin paddle that can be used to obturate the palate. A wide variety of flaps have been utilized, each with unique attributes that may be tailored to an individual patient. The fibula donor site is most commonly utilized and offers a long vascular pedicle and potential for numerous bone segments for reconstruction of the orbital rim, zygomaticomaxillary buttress, and premaxilla. However, the large bone stock may be challenging to contour to reconstruct the orbital floor posteriorly, and as a result it is often used for rim reconstruction with or without an alloplastic implant for the floor. The osteocutaneous radial forearm, scapula/scapula tip/latissimus, and iliac crest have all been described with generally comparable outcomes [38–41].

Maxillectomy with Orbital Exenteration

Goals of reconstructing Brown Class IV defects, involving the entire maxilla and orbital contents with or without skull base resection, include obliteration of maxillectomy cavity with separation of the oral and sinonasal spaces, and potential reconstruction of the skull base. It is important to note that many of the tumors that require total maxillectomies are aggressive and have poor prognosis; therefore creating a safe, well-healed cavity for adjuvant treatment is paramount. Some reconstructive surgeons are proponents of soft tissue flaps for these defects [28, 42]. Musculocutaneous flaps like rectus, latissimus, and ALT are the most frequently utilized flaps. Soft tissue flaps, when used alone, effectively eliminate the defect and separate the cavities. Others propose the use of bone-containing flaps in order to reconstitute midface or palate for stability and dental rehabilitation [27, 43]. Scapular tip with latissimus flap is most commonly used vascularized bone flap for this defect [26]. Other combinations of the scapular flap can be used as well. Osteocutaneous fibular flaps do not provide adequate volume of soft tissue to fill the dead space and would require an additional soft tissue flap. Bones from fibular flaps do however provide stable base for dental implants. In many cases, there is little utility in reconstructing the orbital floor with the removal of the orbital contents.

The orbital defect can be filled with soft tissue to obliterate the cavity and achieve adequate aesthetic results [44]. Rehabilitation with orbital prosthesis may be limited by the bulkiness of the soft tissue. Select cases in patient who are younger and have less aggressive tumors, could benefit from orbital floor reconstruction with bone flaps or orbital floor implants.

Brown Class V defects, orbitomaxillary resection with preservation of palate, can be reconstructed with soft tissue alone. Musculocutaneous or free muscle with skin graft can be used to fill the cavity.

Special Considerations

Reconstructions of defects of the midface and/or anterior cranial base are some of the most challenging within the spectrum of head and neck surgery. In addition to the three-dimensional complexity of the associated defects and the precision that is needed to provide a safe, optimal repair, special considerations also must be made to allow for adequate pedicle length and to reduce the risk of vascular compression of kinking, postoperatively.

For patients receiving free flap reconstruction of the midface and anterior skull base, careful planning of recipient vessels and design of the vascular tunnel is needed in order to achieve a successful result. First, ideal recipient vessels should be in close proximity to the repair and be of adequate caliber and quality for use. The facial artery and common facial vein are the most commonly utilized vessels in midface reconstruction and they can often be prepared above the mandibular notch, with careful dissection away from the adjacent marginal mandibular branch of the facial nerve. The superficial temporal artery and vein can be used as well; however, the caliber is less robust and the quality of the vein is less reliable.

In order to reach recipient vessels, an adequate tunnel must be prepared from the site of the defect to the neck or preauricular area. In instances where facial recipient vessels are being used, especially when the reconstruction extends to the lateral maxilla or zygoma, a coronoidectomy should be considered in order to increase the size of the tunnel and reduce the risk of vascular compression.

Regarding the vascular tunnel, there are numerous options, all with distinct advantages and disadvantages:

1. Subcutaneous: This plane is elevated immediately superficial to the platysma and superficial musculoaponeurotic system (SMAS).
    (a) Advantages: Ease of elevation; reduces risk to facial nerve branches.
    (b) Disadvantages: Worse cosmetic result due to the subcutaneous cheek swelling generated by the pedicle.
2. Subplatysmal/sub-SMAS: The subplatysmal plane is started in the neck and is continued in a sub-SMAS elevation in the cheek or temple.

   (a) Advantages: Relative ease of elevation.
   (b) Disadvantages: Facial nerve branches are at increased risk for injury/stretch. The swelling from the pedicle also may be noticeable on the cheek, depending on the flap used.

3. Parapharyngeal: A plane is created immediately deep to the medial pterygoid muscle, allowing the pedicle to be passed deep to the mandible through the parapharyngeal space.

   (a) Advantages: Ease of elevation and elimination of the risk to facial nerve branches. There is no cheek swelling created from the bulk of the pedicle.
   (b) Disadvantages: Not all defects and flaps are appropriately oriented to allow for pedicle passage through this tunnel. There also is a risk of pedicle kinking and/or compression depending on the geometry created by the repair.

Finally, in nearly all cases of free flap repair of the midface and skull base, patients should be consented for a possible vein graft in the event that there is inadequate pedicle length provided by the transferred graft. In these instances, the lower aspect of the greater saphenous vein near the medial malleolus is often an ideal choice. When a graft is utilized, it should be carefully oriented in order to ensure flow is following the anatomic path of the vein to avoid obstruction from valves within the vessel.

Summary

There are a number of anatomic factors that have allowed for the adaptation of numerous reconstructive techniques for the palatomaxillary region and paranasal sinuses. Its fixed position at the roof of the oral cavity makes any reconstruction independent of gravity drainage of saliva, minimizing fistula risk and contamination. Its overall immobility (relative to the mandible) allows for use of prosthetics with excellent results. There is little critical muscle at risk for loss during surgical ablation, such that the potential for nearly full functional rehabilitation is excellent.

There are numerous options available for reconstruction, ranging from prosthetics and alloplasts to bone grafts, local flaps, and free tissue transfer. With such diversity in potential techniques available, no single technique is universally superior. Surgical decision-making must therefore take into account tumor factors including degree of resection and need for adjuvant radiation, as well as patient factors including overall preoperative functional status, comorbidities, and remaining dentition. Specific reconstructive technique must be selected with the ultimate goal to create a safe, stable wound separation of oral, nasal, and intracranial cavities, with optimal oral and dental rehabilitation and cosmetic outcome.

References

1. Cardelli P, Bigelli E, Vertucci V, et al. Palatal obturators in patients after maxillectomy. Oral Implantol (Rome). 2015;7(3):86–92. Published 2015 Apr 13.
2. Brown JS, Rogers SN, McNally DN, Boyle M. A modified classification for the maxillectomy defect. Head Neck. 2000;22(1):17–26.
3. 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(4):352–63.
4. Buurman DJM, Speksnijder CM, Engelen BHBT, Kessler P. Masticatory performance and oral health-related quality of life in edentulous maxillectomy patients: a cross-sectional study to compare implant-supported obturators and conventional obturators. Clin Oral Implants Res. 2020. https://doi.org/10.1111/clr.13577.
5. Breeze J, Rennie A, Morrison A, Dawson D, Tipper J, Rehman K, Grew N, Snee D, Pigadas N. Health-related quality of life after maxillectomy: obturator rehabilitation compared with flap reconstruction. Br J Oral Maxillofac Surg. 2016;54(8):857–62.
6. Soltanzadeh P, Su JM, Habibabadi SR, Katt Adiyii MT. Obturator fabrication incorporating computer-aided design and 3-dimensional printing technology: a clinical report. J Prosthet Dent. 2019;121(4):694–7.
7. Tasopoulos T, Chatziemmanouil D, Karaiskou G, Kouveliotis G, Wang J, Zoidis P. Fabrication of a 3D-printed interim obturator prosthesis: a contemporary approach. J Prosthet Dent. 2019;121(6):960–3.
8. Hadad G, Bassagasteguy L, Carrau RL, Mataza JC, Kassam A, Snyderman CH, Mintz A. A novel reconstruction technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. Laryngoscope. 2006;116(10):1882–6.
9. Kassam AB, Thomas A, Carrau RL, Snyderman CH, Vescan A, Prevedello D, Mintz A, Gardner P. Neurosurgery. 2008;63(1 Suppl 1):ONS44–53.
10. Liu JK, Schmidt RF, Chaudhry OJ, Shukla PA, Eloy JA. Surgical nuances for nasoseptal flap reconstruction of cranial base defects with high-flow cerebrospinal fluid leaks after endoscopic skull base surgery. Neurosurg Focus. 2012;32(6):E7. https://doi.org/10.3171/2012.5.FOCUS1255.
11. Zanation AM, Carrau RL, Snyderman CH, Germanwala AV, Gardner PA, Prevedello DM, Kassam AB. Nasoseptal flap reconstruction of high flow intraoperative cerebral spinal fluid leaks during endoscopic skull base surgery. Am J Rhinol Allergy. 2009;23(5):518–21.
12. Soudry E, Psaltis AJ, Lee KH, Vaezafshar R, Nayak JV, Hwang PH. Complications associated with the pedicled nasoseptal flap for skull base reconstruction. Laryngoscope. 2015;125(1):80–5.
13. Patel MR, Taylor RJ, Hackman TG, Germanwala AV, Sasaki-Adams D, Ewend MG, Zanation AM. Beyond the nasoseptal flap: outcomes and pearls with secondary flaps in endoscopic endonasal skull base reconstruction. Laryngoscope. 2014;124(4):846–52.
14. Fortes FS, Carrau RL, Snyderman CH, Prevedello D, Vescan A, Mintz A, Gardner P, Kassam AB. The posterior pedicle inferior turbinate flap: a new vascularized flap for skull base reconstruction. Laryngoscope. 2007;117(8):1329–32.
15. Harvey RJ, Sheahan PO, Schlosser RJ. Inferior turbinate pedicle flap for endoscopic skull base defect repair. Am J Rhinol Allergy. 2009;23(5):522–6.
16. Stiernberg CM, Bailey BJ, Weiner RL, Calhoun KH, Quinn FB. Reconstruction of the anterior skull base following craniofacial resection. Arch Otolaryngol Head Neck Surg. 1987;113(7):710–2.
17. Snyderman CH, Janecka IP, Sekhar LN, Sen CN, Eibling DE. Anterior cranial base reconstruction: role of galeal and pericranial flaps. Laryngoscope. 1990;100(6):607–14.

18. Fortes FS, Carrau RL, Snyderman CH, Kassam A, Prevedello D, Vescan A, Mintz A, Gardnes P. Transpterygoid transposition of a temporoparietal fascia flap: a new method for skull base reconstruction after endoscopic expanded endonasal approaches. Laryngoscope. 2007;117(6):970–6.
19. Ramakrishnan VR, Terella AM, Poonia S, Chiu AG, Palmer JN. Osseous repair in minimally invasive reconstruction of anterior skull base defects. J Craniofac Surg. 2017;28(1):36–9.
20. Zeiler FA, Kaufmann AM. Vascularized rotational temporal bone flap for repair of anterior skull base defects: a novel operative technique. J Neurosurg. 2015;123(5):1312–5.
21. Brown JS, Shaw RJ. Reconstruction of the maxilla and midface: introducing a new classification. Lancet Oncol. 2010;11:1001–8.
22. 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(6):1874–84.
23. Moreno MA, Skoracki RJ, Hanna E, Hanasano MM. Microvascular free flap reconstruction versus palatal obturation for maxillary defects. Head Neck. 2010;32:860–8.
24. Mertens C, Freudlsperger C, Bodem J, Engel M, Hoffmann J, Freier K. Reconstruction of the maxilla following hemimaxillectomy defects with scapular tip grafts and dental implants. J Craniomaxillofac Surg. 2016;44(11):1806–11.
25. Park SJ, Jeong WJ, Ahn SH. Scapulartip and latissimus dorsi osteomyogenous free flap for the reconstruction of a maxillectomy defect: a minimally invasive transaxillary approach. J Plast Reconstr Aesthet Surg. 2017;70(11):1571–6.
26. Triana RJ Jr, Uglesic V, Virag M, et al. Microvascular free flap reconstructive options in patients with partial and total maxillectomy defects. Arch Facial Plast Surg. 2000;2:91–101.
27. Brown JS. Deep circumflex iliac artery free flap with internal oblique muscle as a new method of immediate reconstruction of maxillectomy defect. Head Neck. 1996:18412–21.
28. Hanasono MM, Lee JC, Yang JS, et al. An algorithmic approach to reconstructive surgery and prosthetic rehabilitation after orbital exenteration. Plast Reconstr Surg. 2009;123:98–105.
29. Chang DW, Langstein HN. Use of the free fibula flap for restoration of orbital support and midfacial projection following maxillectomy. J Reconstr Microsurg. 2003;19:147–52.
30. 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(3):646–53. https://doi.org/10.1097/00006534-199909030-00005.
31. 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(6):1874–87. https://doi.org/10.1097/00006534-199811000-00011.
32. Sun J, Shen Y, Li J, Zhang ZY. Reconstruction of high maxillectomy defects with the fibula osteomyocutaneous flap in combination with titanium mesh or a zygomatic implant. Plast Reconstr Surg. 2011;127(1):150–60. https://doi.org/10.1097/PRS.0b013e3181fad2d3.
33. 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. https://doi.org/10.1097/SAP.0b013e318246e895.
34. Le Clerc N, Baudouin R, Carlevan M, Khoueir N, Verillaud B, Herman P. 3D titanium implant for orbital reconstruction after maxillectomy [published online ahead of print, 2019 Nov 27]. J Plast Reconstr Aesthet Surg. 2019:S1748-6815(19)30502-9. https://doi.org/10.1016/j.bjps.2019.11.014.
35. Motiee-Langroudi M, Harirchi I, Amali A, Jafari M. Reconstruction of midface and orbital wall defects after maxillectomy and orbital content preservation with titanium mesh and fascia lata: 3-year follow-up. J Oral Maxillofac Surg. 2015;73(12):2447.e1–5. https://doi.org/10.1016/j.joms.2015.08.011.
36. Hashikawa K, Tahara S, Ishida 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(3):963–7. https://doi.org/10.1097/01.prs.0000200623.91956.66.

37. Chen CM, Cordeiro PG. The tongue-in-groove technique for orbital floor reconstruction after maxillectomy. Plast Reconstr Surg. 2008;121(1):225–32. https://doi.org/10.1097/01.prs.0000293865.28595.75.
38. Trosman SJ, Haffey TM, Couto RA, Fritz MA. Large orbital defect reconstruction in the setting of globe-sparing maxillectomy: the titanium hammock and layered fibula technique. Microsurgery. 2018;38(4):354–61. https://doi.org/10.1002/micr.30199.
39. Shipchandler TZ, Waters HH, Knott PD, Fritz MA. Orbitomaxillary reconstruction using the layered fibula osteocutaneous flap. Arch Facial Plast Surg. 2012;14(2):110–5. https://doi.org/10.1001/archfacial.2011.1329.
40. 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. https://doi.org/10.1016/j.joms.2010.01.008.
41. 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(10):1295–302. https://doi.org/10.1002/hed.20874.
42. 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;129:124–36.
43. Futran ND, Wadsworth JT, Villaret D, et al. Midface reconstruction with the fibula free flap. Arch Otolaryngol Head Neck Surg. 2002;128:161–6.
44. Joseph ST, Thankappan K, Mathew J, Vijayamohan M, Sharma M, Iyer S. Defect components and reconstructive options in composite orbitomaxillary defects with orbital exenteration. J Oral Maxillofac Surg. 2014;72(9):1869.