

Osseointegrated Implants and Prosthetic Reconstruction Following Skull Base Surgery

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Abstract

Keywords

- ▶ skull base defects
- ▶ tumor ablative surgery
- ▶ osseointegrated implants
- ▶ prosthetics

Rehabilitation following ablative skull base surgery remains a challenging task, given the complexity of the anatomical region, despite the recent advances in reconstructive surgery. Remnant defects following resection of skull base tumors are often not amenable to primary closure. As such, numerous techniques have been described for reconstruction, including local rotational muscle flaps, pedicled flaps with skin paddle, or even free tissue transfer. However, not all patients are appropriate surgical candidates and therefore may instead benefit from nonsurgical options for functional and aesthetic restoration. Osseointegrated implants and biocompatible prostheses provide a viable alternative for such a patient population. The purpose of this review serves to highlight current options for prosthetic rehabilitation of skull base defects and describe their indications, advantages, and disadvantages.

Maxillofacial prosthetics refers to an area of dentistry dedicated to the restoration of skull base and maxillofacial defects acquired from tumor ablative surgery, trauma, or congenital defects. Anatomically, the skull base is complex and conceptually intricate due to its three-dimensional (3D) morphology. Although once considered a defect area prone to significant morbidity and poor quality of life, surgical advancements over the past decade have helped curb these fears. Prostheses have proven to be a valuable adjunct in skull base reconstruction, as these can restore function and cosmesis. The goal of this review article is to highlight current options for prosthetic rehabilitation of skull base defects with an emphasis on the advancements and limitations in the field of prosthetic reconstruction.

Preoperative Planning

Patients undergoing treatment for skull base tumors often require interdisciplinary collaboration between several clinical specialties to receive comprehensive management.¹ Presurgical planning involves a concerted dialogue between the surgeons and the various disciplines of speech therapy, medical oncology, and radiation oncology. This patient population requires special needs not only for treatment but also for reconstruction and follow-up care. Prior to ablative surgery, the maxillofacial prosthodontist should be consulted to offer input regarding a patient's capacity for functional rehabilitation.

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Multiple factors must be considered when reconstructing a skull base defect site, including size, location, and amount of adjacent supporting tissue. Large defects with abundant local tissue may be more successfully repaired with surgery than a prosthetic.² In the setting of malignancy, the alternative use of prostheses may be beneficial if tumor surveillance is desired to prevent recurrence of disease. Another consideration is the timing of reconstruction, which can be relevant in traumatic cases or young patients born with congenital malformations.³ Patients' age in congruence with their anticipated growth must be accounted for as well. Certain prosthetics can be uniquely crafted to accommodate facial features during different growth stages.

There are specific objectives that must be fulfilled to achieve successful skull base reconstruction. These include (1) replacement of lost skin coverage, (2) watertight repair of dural defects if present, (3) intermediate placement of vascularized tissue between exposed dura and adjacent spaces, (4) provision of stable skeletal support where areas of craniofacial skeleton have been removed, (5) obliteration of dead space, and (6) rehabilitation of cranial nerve injuries. A thorough analysis of imaging studies, computed tomography (CT), or magnetic resonance imaging (MRI) will assist in planning for the reconstruction.

Finally, the psychological state of the patients must be assessed throughout the reconstructive process; so, their goals and expectations are delineated and realistic.⁴ When microvascular free tissue transfer plays a role in the reconstructive paradigm, patients can expect an extensive postoperative hospital course with the potential for revision surgery and complications.⁵ A cost-benefit analysis of patients' desires, surgical requirements, and expected outcomes must be performed as a part of the preoperative workup. In cases of attenuated survival or elderly patients with significant comorbidities, one can argue the best option would be to pursue prosthetic rehabilitation.^{6,7}

Prosthetic Design and Principles

The creation of an ideal facial prosthetic addresses various factors, such as flexibility, durability, color matching, biocompatibility, hygiene, and thermal conductivity.⁸ The broad categories of materials used include methacrylates, polyurethane elastomers, and silicone elastomers. These are all clinically inert materials, which can absorb pigmentation to match color and texture of surrounding structures.⁹ Recently, silicone has become the most widely used material given its soft and flexible nature. The silicone elastomer can retain body temperature without distortion and can be stretched until transparent to blend with adjacent skin.

Advancements over the years in 3D printing technologies have tremendously improved skull base reconstruction. These digital imaging modalities can predict preoperatively a patient's defect and allow for the creation of customizable patient-specific prosthetics.¹⁰ CT and MRI scans can also now be converted to a rapid prototyping model that can be printed in wax or acrylic.¹¹ These models can be further modified or even duplicated with other prosthetic materials.

Surgical Reconstruction with Native Tissue

Large skull base defects necessitate the establishment of a foundation on which implants and prosthetics can be placed. This foundation may involve local or regional flaps or free tissue transfers.

Auricular/Temporal Bone

Reconstruction of temporal bone resections can vary from simple closure of the external auditory canal to free tissue transfer for extensive defects. The ideal reconstructive method is dictated by the type of primary lesion and tissue invasion. In particular, resection of cutaneous malignancies that involve the temporal bone often results in substantial skin and soft tissue defects of the lateral skull base with exposure of bone and/or dura.¹² Adequate soft tissue coverage in such cases is the key. Skin grafts, temporalis flaps, temporoparietal fascial flaps, local rotational cutaneous flaps, lower island trapezius flaps, pectoralis flaps, free flaps (including radial forearm, rectus abdominis, latissimus dorsi, and anterolateral thigh flap [ALT]), and a combination of the aforementioned have all been described.¹²⁻¹⁴ In irradiated fields with recurrent disease affecting the auricle, local tissue coverage is prone to failure and may not be adequate, necessitating the use of myocutaneous flaps, such as the lower island trapezius flap.¹⁵

Involvement of the auricle presents a unique challenge, for which prosthetic reconstruction offers a potential solution. Total auriculectomy defects are simpler to rehabilitate than partial auriculectomy defects. Surgical alterations to enhance prosthetic prognosis are sparing of the tragus, which allows a seamless transition from native ear to prosthesis by concealing the anterior margin behind the posterior flexure, and lining of the defect with a split-thickness skin graft. The area of the defect must be flat or concave for the prosthesis to fit properly and aesthetically. For placement of anchoring osseointegrated implants (OIs), the recipient bone must be well vascularized and have adequate thickness (greater than 2.5 mm) to support the load of the prosthesis.¹⁶⁻¹⁸

Orbit/Nose

Extensive skull base surgery may often violate the orbit. For the successful fabrication and engagement of an orbital prosthesis, care must be taken to attain sufficient depth of the defect.¹⁹ Thus, free tissue transfers should be used with care when filling an orbital defect, particularly when the adjacent orbital walls are left in situ and if no subsequent irradiation is planned. However, lateral and medial facial orbital defects can be resurfaced with flaps, such as the radial forearm or a thinned ALT. The bony inferior orbital rim should be recreated and have the stability to support a prosthetic load. This can be achieved with bone grafts harvested from the rib in conjunction with rectus abdominis flaps. A split-thickness skin graft is placed to line any exposed bone of the orbital cavity and create an adhesive base for the implant. Importantly, the eyelid must be resected and the position of the eyebrow maintained for the most aesthetic result.²⁰⁻²³

Nasal resections are often reconstructed with regional flaps, such as the paramedian forehead flap. However, prosthetic rehabilitation may be preferred in the irradiated field and can provide an acceptable functional and aesthetic result. As with the orbit, prosthetic prognosis is improved when there is sufficient access of the prosthesis to the defect. Specifically, residual elements such as the nasal bones, ala, and anterior nasal septum that render restoration of proper size and symmetry difficult may need to be removed. Grafts or flaps can be used to maintain the normal position and contour of the nasolabial folds and upper lip.^{20–22} A split-thickness skin graft placed to line the nasal floor and any exposed bone would also limit contracture and elevation of the upper lip and provide a stable platform for the nasal prosthesis.

Maxillary/Midface

The midface encompasses the most prominent features of the face and separates the oral cavity from the orbital cavity. Commonly, midface defects are complex 3D defects involving both soft and bony tissues. The ultimate objectives are to separate the oral, sinonasal, orbital, and intracranial cavities; eliminate dead space and cover exposed dura; restore the functions of speech, swallowing, and mastication; replace the skeletal framework; and achieve the best cosmesis possible.

Free tissue transfers are well suited for reconstruction of large entry wound defects, and the freedom of their design and inset allows for great versatility in functional reconstruction. The choice of the ideal free flap is contingent upon the extent of the defect. Type I and II defects can be reconstructed with the radial forearm free flap (preferable for its flexibility, safety, and reliability) and combined with either a small portion of radius or bone graft if bone is required.²⁴ Type III and IV defects require bulkier tissue, and the rectus abdominis, latissimus dorsi, and scapular free flaps are viable options. In addition, perforator flaps, specifically the ALT flap, are now frequently the primary choice for any head and neck soft tissue defect.^{25–28}

Bone-containing flaps are another option for reconstruction, particularly when the defect involves the maxillary arch, orbital floor, or maxillary buttresses. Successful reconstruction requires an osseous component that transmits occlusal forces to the cranium, resists resorption, and allows functional and cosmetic rehabilitation with OI.²⁹ Options include flaps containing fibula, iliac crest, and rib, such as the latissimus dorsi and rectus abdominis flaps. The fibular free flap has several advantages. It provides a sufficient length of bone that can be segmented to reapproximate the contour of the alveolar ridge.³⁰ In addition, its bicortical configuration and superior vertical height make it the ideal choice for OI placement. Thus, for complex reconstructions of extensive defects in the midfacial area, microvascular free tissue transfer in combination with extraoral implants and craniofacial prosthetic work may yield more reasonable functional and aesthetic outcomes and improve the quality of life.^{31–33}

The reconstructive surgeon can utilize various surgical techniques to optimize prosthetic rehabilitation. For instance, split-thickness skin grafts or allogenic material can be placed into maxillary defects, allowing an excellent scar tissue band for retention of the OI prosthesis and improved

oral hygiene.^{20,34} All raw surfaces, potential support surfaces, and useful undercuts should be lined with skin grafts to enhance engagement with prostheses.

Retention Systems/Osseointegrated Implants

Prior to the concept of osseointegration, facial prostheses were often mechanically anchored to spectacles or even secured through anatomical undercuts in the early 20th century.³⁵ Complications with these older retention systems led to advancements in prosthetic anchoring. Medical adhesives were developed as an easy-to-use alternative. However, these often lose their bone strength as the adhesive weakens over time, requiring reapplication every 4 to 8 hours. Patients with active lifestyles are poor candidates, as the adhesive-based prosthesis can be easily dislodged with constant movement.³⁶ Low compliance and patient dissatisfaction with daily-applied prosthetic adhesives fueled interest in other anchorage methods.³⁷

An alternative method involves craniofacial endosseous implants. Advantages of such implants include easier maintenance of the prosthesis, avoiding the need for skin adhesives and tunnels that often limit patient activity, and allowing for improved hygiene, patient comfort, and satisfaction; higher retention rates; increased accuracy and stability of prosthesis placement; and longer lifespan of the facial prosthesis.^{38,39} Implant success rates are largely dependent on the implant location and the target tissue's radiation status. Rates vary from 81 to 100% in the mastoid region, 45 to 100% in the orbit, and 46 to 100% in the nasal floor.³⁵

Two critical processes must occur for successful rigid fixation of an alloplastic implant to bone: osteoinduction and osteoconduction.⁴⁰ The terms osteoinduction, osteoconduction, and osseointegration are infrequently used correctly. Osteoinduction is the process by which osteogenesis is induced, a phenomenon regularly seen in any bone healing process.⁴¹ It implies the recruitment of immature cells and the stimulation of these cells to develop into preosteoblasts. Implants introduced into the bone within the defect site trigger osteoinduction. After the implants are placed, osteoconduction begins, which refers to the development of bone growing on a surface. This depends on the action of differentiated bone cells, which originate either in preexisting osteoblasts or cells recruited from mesenchymal cells by osteoinduction.⁴² Therefore, in the practical sense, osteoconduction relies significantly on previous osteoinduction as is regularly seen in the case of bone implants. Osseointegration refers to the stable anchorage of an implant achieved by direct bone-to-implant contact.⁴³ In craniofacial implantology, this mode of anchorage is the only one for which high success rates have been reported.

Osseointegration came into favor during the 1970s when Swedish physicians discovered that titanium was biocompatible with bone.⁴⁴ The bone-anchored hearing aid was the first application outside the oral cavity of a bone-anchored implant. This device allows sound energy to be transmitted directly to the skull base via an attachable vibrator, and with this development ushered in a new era of hearing rehabilitation. With time, physicians discovered several benefits with bone-

anchored hearing aids over traditional bone-conduction hearing aids, including superior sound transmission and decreased skin pressure.⁴⁵ Not long after the implantation of bone-anchored hearing aids, osseointegrated abutments were crafted to anchor prostheses for the nose, ear, orbit, and midface in the reconstruction of craniofacial defects.⁴⁶ Bone-anchored implants are now a mainstay of prosthetic fixation for auricular defects and have also been successfully incorporated into the armamentarium for the rehabilitation of other craniofacial defects.^{35,39,47,48}

Several mechanisms exist that allow coupling of the OI with the external prosthesis. Such examples include bar-clip attachments, ball attachments, and magnetic retention.^{49,50} Bar-clip retention remains the most widely used for facial prostheses and provides the strongest bond. However, magnetic retention offers strong attractive forces in small and inconspicuous shapes that are preferred for craniofacial deficits.⁵¹ For example, orbital and nasal prostheses are almost exclusively retained in place by magnets. Bone-anchored prostheses typically last from 3 to 5 years compared with 1 to 3 years for an adhesive-retained prosthesis.

Although application of OIs is a relatively straightforward procedure, there are patient-specific risk factors for potential complications. Not surprisingly, previous irradiation predisposes to implant extrusion.³⁹ The risk for osteoradionecrosis (ORN) always lingers in previously irradiated patients, prompting some providers to offer hyperbaric oxygen therapy.⁵² In addition, any trauma-induced or spontaneous tissue breakdown can result in a nonhealing wound that leads to ORN. The benefit of vascularized tissue to protect the underlying bone from the harmful effects of radiation cannot be understated. It is prudent to cover the projected implant site with a local flap or free tissue transfer at the time of tumor ablation when postoperative adjuvant radiation therapy is indicated.

Prostheses

Auricular

Auricular defects can be congenital in nature, such as Treacher-Collins syndrome or other second arch insults that result in microtia, trauma, or following ablative cancer surgery. Indications for repair with a prosthesis are based on the extent of the defect, as large areas prove more difficult to repair surgically. Local skin and subcutaneous tissues must remain intact with a rich blood supply to support transplanted autologous grafts.⁵³ Often, several procedures are needed for graft harvesting, tissue expansion, and cosmetic fine tuning, which subject the patient to morbidity and possible complications. An Italian study actually showed bleeding, infection, and hematoma to be more frequent with autologous grafting at the implant and graft site than in an auricular prosthesis.⁵⁴ Furthermore, patient satisfaction is frequently lower due to inconsistent cosmetic outcomes.⁵⁵

If a prosthesis is favored, tragal preservation can help conceal the anterior margin of the prosthesis.⁵⁶ As previously described, OIs can improve retention of the prosthesis and have a high degree of success in the temporal bone.⁵⁷ If a hearing deficit accompanies microtia, use of a bone-anchored hearing aid can offer improvement in bone conduction. Implants can

often be placed into three locations that correspond with the 1, 3, and 5 o'clock positions of the left ear and the 7, 9, and 11 o'clock positions of the right ear. These locations have been shown to lend greater infrastructure support and allow for abutment attachment in a correct high anatomical location.⁵⁸ The temporal bone must retain blood supply and thickness (greater than 2.5 mm) to support the load of the prosthesis. Preoperative CT imaging can help survey the integrity of the temporal bone and map out adequate sites for implants.⁵⁹

Orbital

Following the removal of the eye, an orbital implant is initially inserted into the anophthalmic cavity to provide adequate volume replacement, up to 75% of the original ocular globe, and to restore the aesthetic appearance of a normal eye.⁶⁰ There are two types of implants, integrated and nonintegrated. The former is usually made from porous materials, such as hydroxyapatite, porous polyethylene, and aluminum oxide,⁶¹ while nonintegrated implants consist of nonporous materials, such as polymethylmethacrylate and silicone. Porous materials have gained prominence, since their highly interconnected porous architecture allows for fibrovascular ingrowth of host tissue, improved stability, decreased complication rates, and the option of pegging or posting to enhance the motility of the artificial eye.^{62,63} However, current evidence has very low certainty and is not sufficient to assess the difference in effect between integrated and nonintegrated material orbital implants for treating anophthalmia.⁶⁴

An orbital or ocular prosthesis fits over the orbital implant and under the eyelid. Prostheses are often made of acrylic, glass, or silicone spheres. Prostheses may be either stock or custom made. Stock eyes, while easier to insert, fit inadequately and must be removed several times a day to be cleaned. Custom-made prosthetics, on the other hand, have improved adaptation and subsequently better mobility.⁶⁵ Retention of an orbital prosthesis is most successful with osseointegration.⁶⁶ Adhesive retention should thus be used in patients with incomplete bone growth or low bone density. **—Figs. 1 and 2** show a patient following orbital exenteration for malignancy followed by prosthetic reconstruction.



Fig. 1 A male patient following orbital exenteration for malignancy showing a visible defect in the lateral nasal wall and orbital cavity (Photograph was used with patient's permission).



Fig. 2 Patient reconstructed with orbital prosthesis (Photograph was used with patient's permission).

Nasal

In extensive full-thickness defects of the nose, particularly in elderly subjects or patients with poor general health status, the use of a nasal prosthesis represents an acceptable alternative to surgical reconstruction, especially when the entire nasal pyramid is affected.^{5,67}

While osseointegration has significantly improved nasal implant retention, its success is contingent on the available bone stock.^{31,68–70} Traditionally, implants are inserted into the floor of the nasal cavity or glabella. Limitations in the quality or quantity of the recipient bone can compromise the stability or cause dislodgement of an implant with functional movements such as mastication.^{31,70} Several studies have evaluated the effect of zygomatic implants in supporting a nasal prosthesis.^{71–73} The density and volume of the zygoma facilitate osseointegration,⁷¹ and the location of the zygo-

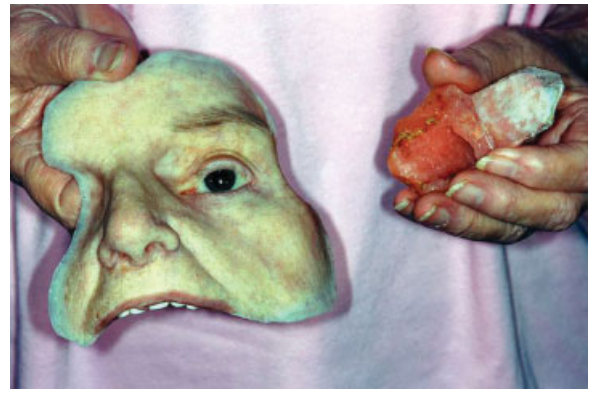


Fig. 4 Photograph of designed midface and orbital prosthesis and mounting system.

matic implant is often not in the field of radiation therapy, further contributing to implant success.⁷²

The manufacturing of a nasal prosthesis involves taking an imprint of the affected area, producing a cast from the imprint, casting the final prosthesis, and painting the details that give the prosthesis its unique appearance.⁷⁴ Typically made of polydimethylsiloxane, a nasal prosthesis is flexible and mobilizes with the skin. As with other prostheses, a nasal prosthesis may be fixed anatomically to existing structures (bony undercuts), mechanically (to spectacle frames), chemically (glued-on nasal prosthesis), or, as discussed before, surgically, using osseointegrated retention systems.^{75,76} One of the drawbacks of a nasal prosthesis is that it does not provide a definitive solution, since both the surrounding area and the prosthetic material itself are subject to increased rigidity and altered appearance such as discoloration over time.⁷⁴

Maxillary/Midface

With extensive maxillary defects involving the palate and facial tissue, surgical intervention with skin grafts and osteocutaneous free flaps may not produce the most desirable outcome.⁷⁷



Fig. 3 A female patient following extensive midfacial and orbital resection for malignancy and reconstruction with initial soft tissue flap (Photograph was used with patient's permission).



Fig. 5 Placement of mounting system in central portion of face (Photograph was used with patient's permission).



Fig. 6 Photograph of patient following placement of prosthesis (Photograph was used with patient's permission).

Such defects are also inadequately addressed by obturators, since the ability to stabilize an obturator framework diminishes with an increase in size of the maxillary defect and a decrease in remaining dentition and palatal supporting area.⁷⁸ In cases when soft tissue is unavailable to form a seal with the prosthesis, OIs are indicated for insertion and fixation of the prosthesis. Three to four implants are typically required for sufficient support.⁷⁹ The zygomatic buttress, supraorbital rim, vomer, and horizontal part of the hard palate are stable recipient sites.⁵⁶ It is critical to preserve any remnant palate, premaxilla, and/or adjacent abutment tooth for stability and retention of the prosthesis.⁸⁰ Forces that affect the fit of a prosthesis must be considered and include the downward gravitational forces, upward occlusive forces, and torsional forces involved in functional speech, swallowing, and mastication.^{34,81}

The maxillary prosthesis necessitates individual fabrication for complex midface defects. Alloplastic prostheses provide an obturator function between the orbital, maxillary, and oral cavities, as well as an external coverage. Midface prostheses frequently consist of acrylic, silicone, or other polymers and can be removed, cleaned, and reinserted.⁸² Maintenance remains the greatest factor in influencing patient preference between prosthetic rehabilitation and surgical reconstruction.⁷⁷ ▶ **Figs. 3 to 6** show a patient following multiple surgeries for oncologic resection following reconstruction with a full midfacial and orbital prosthesis.

Conflict of Interest

None.

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