Free-Flap Reconstruction of Skull Base and Orbital Defects

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Abstract

Keywords

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- skull base surgery
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Orbital and anterior skull base defects present a significant challenge for reconstruction due to the complexity of the anatomy and the need for separation of intracranial and extracranial contents in this area. While endoscopic techniques have revolutionized the treatment of many anterior skull base defects, microvascular free tissue transfer is a viable option for large volume defects not suitable for traditional open approaches or for cases where endoscopic techniques have failed. The various free tissue transfer techniques for anterior skull base and orbit, as well as the advantages and disadvantages, are reviewed.

Since the first described open skull base resection of transsphenoidal pituitary surgery by Schloffer in 1907, the world of skull base surgery and reconstruction has evolved tremendously.¹ With the advent of endoscopic sinus surgery, the pendulum of skull base surgery shifted away from open approaches. Advances in technology, including high-speed drills and endoscopic technique refinements, have expanded the endoscopic endonasal approaches to the cranial base, with continued paradigm shift away from open procedures. Nonetheless, patients with extensive skull base involvement with anticipated large soft tissue defects continue to require more extensive, robust reconstruction to avoid postoperative complications.

Similarly, the paradigm of reconstructive surgery has shifted away from regional and pedicled flaps with the introduction of microvascular free tissue transfer techniques in the 1980s. In skull base and orbital defect reconstruction, there is a need to seal the meninges from the rest of the upper aerodigestive tract using a dural seal that is watertight and

overlying vascularized tissue. Ketcham et al demonstrated early on that skin graft duraplasties lead to unacceptably high cerebrospinal fluid (CSF) leak rates, leading to recognition that well-vascularized tissue is necessary to obtain a robust dural seal.² Free-flap reconstruction has been demonstrated by several studies to be superior to pedicled flaps in terms of complications rates with more reliable healing. Overall rates of complications have been reported to be anywhere between 11.5 and 63%.^{3–15} Importantly, the trend of overall complications appears to be decreasing since initial reports in the early 1990s. Nelgian et al demonstrated that free-flap complication rates were 33.5% compared with pedicled flap complication rates of 75%.⁹ The gravitation pull and rotational arc limitations of many regional flaps are thought to contribute to the higher rates of wound dehiscence and other complications. For these reasons, free tissue transfer has replaced regional or pedicled flap reconstruction for large skull base defects.

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There are a few large series studies looking at large open skull base defect reconstructions, and the available literature generally incorporates a few types of free tissue transfer. The topic poses various challenges to study; perhaps, foremost is the rarity of a large anterior skull base defect including the orbit. The equivalent outcomes of many studies using different free tissue transfer donor sites is a testament to the fact that more than one technique can be appropriate for each case. Perhaps what is more important for success is the personal experience and familiarity of the microvascular surgeon involved in these cases.

Indications and Objectives

While the majority of large open skull base defect reconstructions are secondary to the ablation of locally aggressive malignant lesions, there are other indications including severe osteoradionecrosis with chronic infection, and occasionally trauma particularly in ballistic injuries. There are also reports of using free tissue transfer for massive CSF leaks unable to be managed conservatively.¹⁶ The primary goal of free tissue transfer is to facilitate restoration of a watertight barrier between the intracranial and extracranial contents. Accomplishing this objective will help limit the development of complications including persistent CSF leak and infectious sequelae such as meningitis. Restoration of reasonable form and function and elimination of dead space are secondary goals that can be met with free tissue transfer.

Anatomical Considerations

The skull base forms the floor of the cranium and separates the brain from the rest of the face. The skull base can be divided into three sections: the anterior, middle, and posterior cranial fossae. The bones that comprise the skull base include the frontal, ethmoid, sphenoid, temporal, and occipital bones. In the pediatric population, skull growth must be considered. The calvarium grows rapidly in the first 4 years of life, after which the growth slows down and ultimately rises again right at puberty. After the ossification of the sphenoccipital synchondrosis in the early teenage years, calvarial growth arrests.

Classification of Defects

In 1994, Irish et al classified the skull base defects into three respective regions.⁶ Region 1 includes the anterior defects, orbital roof, superior nasal cavity, cribriform plate, and frontal bone. Region 2 includes lateral defects involving the infratemporal pterygopalatine fossae and communicates with the middle fossa. Region 3 involves posterior defects, which are within or around the temporal bone and extends to the middle or posterior fossa. Generally, region 3 defects are limited to bone of the squamous temporal bone, mastoid, and occipital areas. Discussion of orbital and anterior skull base defects lies mainly in region 1, but at times it can include region 2 if the defect is extensive. Dural defects are repaired when possible, and fat graft bolsters are used to help with a dural seal. Local flaps such as temporalis or temporal parietal fascia can be used

for vascularized tissue coverage. Free tissue transfer is rarely necessary and generally reserved for extensive scalp defects associated with posterior fossa bony defects.

The complexity of the three-dimensional (3D) orbital anatomy gives rise to unique challenges to reconstruction. A shared goal is to separate the intracranial and extracranial spaces. In addition to the need for separating the intracranial contents from the nasal cavity, in extensive maxillectomy defects involving horizontal and vertical buttresses of the midface, there is also the need to separate the oral cavity from the intracranial space. The contour of the orbital rim, facial symmetry, and volumes should be maintained as best as possible.

Free Tissue Transfer Techniques

Soft Tissue Flaps

Rectus Abdominis

Literature often cites the workhorse of free tissue transfer reconstruction of the skull base as the rectus abdominis free flap. Most available case series include a variety of free flaps used. The rectus abdominis free flap has a reliable anatomy and vasculature, with the blood supply coming from the deep inferior epigastric artery that arises from the external iliac artery.

Pryor et al reviewed 13 patients who underwent rectus abdominis free-flap reconstruction following orbital exenteration with skull base or maxillectomy defect.¹⁷ O'Connell et al describe 68 cases of free tissue transfer for scalp and lateral temporal bone defects, of which 11 were rectus abdominis.¹⁸ Browne and Burke discussed that one of the additional benefits of orbital reconstruction using the rectus abdominis free flap is the lack of need for bony reconstruction given the extensive soft tissue bulk transferred.¹⁹ The rectus when used as a perforator flap has several distinct advantages including minimizing donor-site morbidity, as described by Marchetti et al.²⁰ More recently, Kang et al describe a perforator-based rectus free tissue transfer with the advantages of a long pedicle (average 13.4 cm), moldable adipose tissue, and volume control due to limited muscle harvest and subsequent atrophy.²¹

The advantages of the rectus abdominis include tendinous intersections that help facilitate fixation to the skull base, adequate bulk allows obliteration of complex 3D dead spaces, and versatility to be used with or without skin paddle, depending on the degree of bulk demand. The disadvantage of the flap includes large abdominal scar, variable bulk of the flap if skin is used, and susceptibility of patients to postoperative hernia formation. —**Fig. 1** demonstrates a case by the senior author (Y.D.) demonstrating the use of this flap in a typical case following orbital exenteration.

Anterolateral Thigh

The anterolateral thigh flap (ALT) has been described more recently as a reasonable alternative to the rectus abdominis with relatively low donor-site morbidity.^{22,23} The blood supply is the descending branch of the lateral femoral circumflex

Fig. 1 This patient had a squamous cell carcinoma involving the orbit and underwent maxillectomy with orbital exenteration with rectus free-flap reconstruction. (A) Orbital defect. (B) Maxillectomy and palatal defect. (C) Immediate postoperative appearance. (D) Postoperative result after 6 months.

artery. Advantages include two team approach, minimal donor-site morbidity, volume control when minimal muscle is harvested, and the reliability of the flap. The main disadvantage to this flap is the variability of the pedicle, and if harvested as a fasciocutaneous flap, it can have a lack of adequate volume for obliteration of dead space in the skull base. It has been cited for use in both anterior and lateral skull base defects.

Hanasono et al in their study described 34 patients who underwent ALT with an average flap size 138.7 cm² for skull base reconstruction with a 29% complication rate and no flap loss. The authors advocate the flap as robust and easy for two-team approach given the distance from the head and having the ability to simultaneously harvest a saphenous vein for length and to be used as a cable grafting facial nerve if needed.²² Malata et al reported on 12 patients for lateral skull base defects also with no flap losses.²³

Lateral Arm Fasciocutaneous

The lateral arm fasciocutaneous free flap is yet another alternative soft tissue flap. The blood supply comes from the posterior radial collateral artery. This has been described by Malata et al particularly in female patients as the donor-site scar is less noticeable than the ALT.²³ One major advantage of this flap is that it does not sacrifice a major artery that supplies

the hand. The disadvantages include short pedicle length unless the flap is designed very distally as a lateral forearm flap. Largo et al describe a folded position of this flap with osteodermal sutures for anterior and middle skull base defects with good outcomes.²⁴

Radial Forearm

The radial forearm has been demonstrated to be a reliable workhorse flap in the reconstruction of the face and orbit in the study by Disa et al. While in their series, the rectus was almost exclusively used for skull base reconstruction, they did use the radial forearm in 3% of cases.²⁵ Its blood supply is the radial artery and its perforators. Advantages of this flap include its reliability and ability to allow flap folding and shaping of the flap into complex defects. The major disadvantages are significant donor-site morbidity and sacrifice of a major supplying vessel to the hand. This can be overcome by reconstructing the radial defect with a reverse vein graft, commonly a cephalic vein or saphenous vein graft. Yeo et al have reported a dual-layer technique using both a radial forearm free flap and a pericranial flap to reconstruct an anterior skull base defect in a patient who previously underwent radiation therapy.²⁶ We describe a case where this was used for an anterior skull base and orbital defect (→Fig. 2).

Latissimus Dorsi

The blood supply of the latissimus dorsi (LD) is the thoraco-dorsal artery, which is a branch of the subscapular artery. The advantage of this flap is the large amount of skin and potential muscle volume that may be transferrable. Additionally, the pedicle can be up to 15 cm in length if harvesting up to the subscapular artery itself. The primary disadvantages of this flap are the relative proximity to the head and the patient positioning involved that obviates the ability for a two-team approach, leading to prolonged operative times.

Extremely large skull base defects can be extremely challenging to treat, and chimeric flaps based on the LD and occasionally in conjunction with the subscapular system have been described by Paprottka et al.²⁷ Moyer et al described a case of where the LD was used and vascular bone was avoided due to lack of likely improvement in function or cosmesis given an intact junction between the frontal bar and lateral orbital rim.²⁸

Omentum

The first omental free tissue transfer was described in 1972 for scalp reconstruction and then for skull base reconstruction in 1984.²⁹ Many studies discussing the advantages of the omental free flap for skull base defect reconstruction include the ability to obliterate dead space and restoration of volume and contour, as well as delivery of immune cells, antibodies, and antibiotics as with most vascularized tissue. Disadvantages include need for laparotomy and associated morbidity of postoperative ileus and adhesions. As such, it has been relegated as a salvage flap when others failed. Saltz et al demonstrated the ability to laparoscopically harvest an omentum free flap, decreasing the morbidity of the procedure compared with previously.³⁰ More recently, Costantino

Fig. 2 This was a case where an adenoid cystic carcinoma extended into the skull base and orbit. (A) demonstrates loss of extraocular eye movements on the left as well as significant enophthalmos. (B) shows the extent of the defect involving the entire orbit and frontal sinuses. (C) The frontal sinuses were obliterated with fat, and a (D) mesh cranioplasty was performed. (E) The radial forearm free flap was used to reconstruct the orbit, and (F) the 6-month postoperative result.

et al's study described 13 consecutive patients, with one flap failure that was secondary to infection 1-month postoperatively.³¹

Bony Flaps

Bony flap reconstruction of skull base defects remains a controversial topic. In the anterior skull base with orbital reconstruction, the importance of maintaining orbital rim anatomy can be accomplished with an autologous bone. When an autologous free bone is used, there exists a high risk of bony resorption following transfer. For these reasons, several reports have described osseous free tissue transfer to remedy this problem. For reconstruction of the infraorbital rim, scapula osteocutaneous free flap, fibula free flap, and iliac crest myo-osseous flaps have been described.^{32–38}

Complications

High rates of complications are seen in skull base and orbital reconstruction, largely due to the complexity of the region. Complications are not the focus of this paper and will not be discussed in depth. Often with large skull base defects, there is a risk of infection of the central nervous system. Meningitis is the infection and inflammation of the meninges and carries with it significant morbidity and mortality risk to the patient.

The incidence of this has been reported to be anywhere from 1 to 10% during open craniofacial approaches to skull base lesions.³⁹ Persistent CSF leakage is another complication of skull base surgery and may require additional free tissue transfer or other techniques if not able to be managed conservatively. In conjunction with CSF leak, there may be a herniation of brain tissue or meninges following skull base repair. Mucocoeles may also occur in the frontal sinuses following disruption of the frontal recess, and many of these patients will require functional endoscopic sinus surgery to address these if they develop. Lastly, wound infection can occur particularly following radiation of healthy, vascularized tissue. Devascularized bone flaps require debridement with immediate or delayed cranioplasty.

Cranioplasty Materials

Wire titanium mesh has a long history of low infection rates and proven success. It has been used with bone cement to help bolster the cranioplasty and can be molded to fit the contour as appropriate. In recent years, with the development of virtual surgical planning, it is possible to create customized patient-specific implants using a variety of materials including polymethylmethacrylate, hydroxyapatite, titanium, or other materials such as polyetheretherketone. The senior author (Y.D.)

Fig. 3 (A) Custom implant fabricated using pre- and postoperative computed tomography (CT) scans with (B) reimplantation following initial reconstruction after removal of the cranioplasty titanium mesh.

routinely uses mesh initially (►Fig. 2D) and subsequently created a patient-specific implant based on the postoperative computed tomography (CT) imaging (►Fig. 3). The advantages of the customized implants include a stronger material that cannot be deformed and improved cosmetic outcome due to the perfected contour of the patient's own anatomy.

Conclusion

Orbital and anterior skull base defects are challenging due to their anatomical and spatial complexity. Despite advances in endoscopic approaches and techniques, the need for free-flap reconstruction still remains. Free-flap reconstruction is a good option for large skull base defects involving the orbit and can accomplish multiple goals including eliminating dead space, providing multiple layers of well-vascularized tissue for appropriate closure, and lowering complication rates associated with skull base surgery when compared with regional flaps. Various soft tissue flaps have been described, and several may have advantages of chimeric design to address the goals of complex 3D defects of the orbit and skull base. Optimal outcomes largely depend on the familiarity of the reconstructive surgeon with these various flaps. The use of custom implants is becoming more mundane and is a way to obtain the optimal calvaria contour following extensive resection and reconstruction.

Conflict of Interest

None declared.

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