Vascularized Flaps for Anterior Skull Base Defects

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KEYWORDS

• Vascularized flaps • Skull base reconstruction • Nasoseptal flap • Pericranial flap • Temporoparietal fascia flap • Free tissue transfer

KEY POINTS

- Vascularized flaps are the gold standard for skull base reconstruction, are highly reliable, and have a low morbidity.
- The nasoseptal flap is the most used flap for skull base reconstruction and can be used to reconstruct defects of the anterior skull base, parasellar region, and the clivus.
- When the nasoseptal flap is not available, other options include the inferior turbinate flap, middle turbinate flap, pericranial flap, temporoparietal fascia flap, and free tissue transfer.

INTRODUCTION

Reconstruction of the skull base following endoscopic or open skull base surgery poses a challenge for both rhinologists and neurosurgeons. A wide variety of techniques exist to address these issues to avoid complications such cerebrospinal fluid (CSF) leak, meningitis, or other intracranial complications. Smaller defects can typically be managed by utilizing nonvascularized reconstructive techniques. Commonly used options may include free mucosal grafts, fascia grafts, fat grafts, cartilage or bone grafts, and synthetic materials. Nonvascularized grafts are discussed in article Grafts and Non-vascularized Repair Materials for Anterior Skull Base Defects and are typically employed for smaller defects and low-flow CSF leaks.[1] They rely on plasmatic imbibition and neovascularization from surrounding tissues. For this reason, these grafts are typically avoided in patients with prior irradiation or infection, due to the high risk of reconstructive failure.

In contrast, vascularized flaps are a much more robust reconstructive option due to their axial blood supply. For larger, more complex defects with a high risk of CSF leak

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Abbreviations
CSF cerebrospinal fluid
NSF nasoseptal flap

and infection, vascularized flaps are the preferred method of skull base repair.[2] Prior studies have found that postoperative CSF leaks were significantly lower when vascularized grafts (6.7%) were used compared with free grafts (15.6%).[3] Studies have also reported success rates as high as 94% to 95% for high-flow CSF leaks that were repaired using vascularized flaps.[4] With all reconstructions, some factors have been identified that may portend poor outcomes, including poor nutrition status, smoking history, radiation exposure, elevated body mass index, and defect location.[5] Overall, vascularized flaps are the cornerstone for reconstruction and are particularly useful for larger defects, high-flow CSF leaks, patients who have undergone previous irradiation, and in revision cases with persistent CSF leak. This article will review the most utilized vascularized flaps for skull base reconstruction.

VASCULARIZED FLAPS

A variety of vascularized flaps exist for reconstruction of anterior skull base defects. These options are enumerated below, along with the nuances, advantages, and pitfalls of each surgical technique.

Nasoseptal Flap

The nasoseptal flap (NSF) was first described by Hadad, Bassagasteguy, and Carrau and colleagues in 2006.[6] This technique utilizes a vascularized flap based on the posterior septal branch of the sphenopalatine artery to reconstruct large dural defects of the anterior, middle, clival, and parasellar skull base. It has since become a widely adopted and essential tool—often referred to as a "workhorse" flap—for skull base reconstruction. One of the major advantages of the NSF is its vascular supply, which is particularly beneficial in patients with a history of radiation therapy. This axial blood supply allows for more reliable healing and reduces the risk of flap failure. The flap can be tailored to fit a wide range of defect sizes and contours, making it especially versatile. Moreover, the NSF can be harvested to include mucosa from the nasal floor and the lateral nasal wall, providing a larger, vascularized flap for complex, 3 dimensional defects.[7] As a result, it is commonly used by both rhinologists and neurosurgeons for a variety of skull base defects, offering effective reconstruction with minimal morbidity to the sinonasal cavity.

The pedicle of the NSF is the posterior septal branch, a terminal branch of the sphenopalatine artery. The sphenopalatine artery enters the nasal cavity through the sphenopalatine foramen, giving rise to several septal branches that supply the posterior and inferior nasal septum.[8] The posterior septal branch typically takes a horizontal course along the sphenoid rostrum, traveling near the inferior aspect of the sphenoid sinus ostium and just superior to the choana (**Fig. 1**). This anatomic course must be carefully considered during sphenoidotomy. Accidental injury to the vessel during inferior dissection can compromise flap vascularity, leading to flap necrosis and failure. Typically, the incisions are made with needle-tip cautery to achieve hemostasis. The incision can be taken superiorly to include the majority of the nasal septal mucosa and can be brought anteriorly to the mucocutaneous junction. If additional width is needed, the flap can be taken onto the nasal floor and along the lateral nasal wall within the inferior meatus. When this extended flap is harvested, care must be taken not to injure the soft palate musculature and Hasner's valve within the inferior meatus.

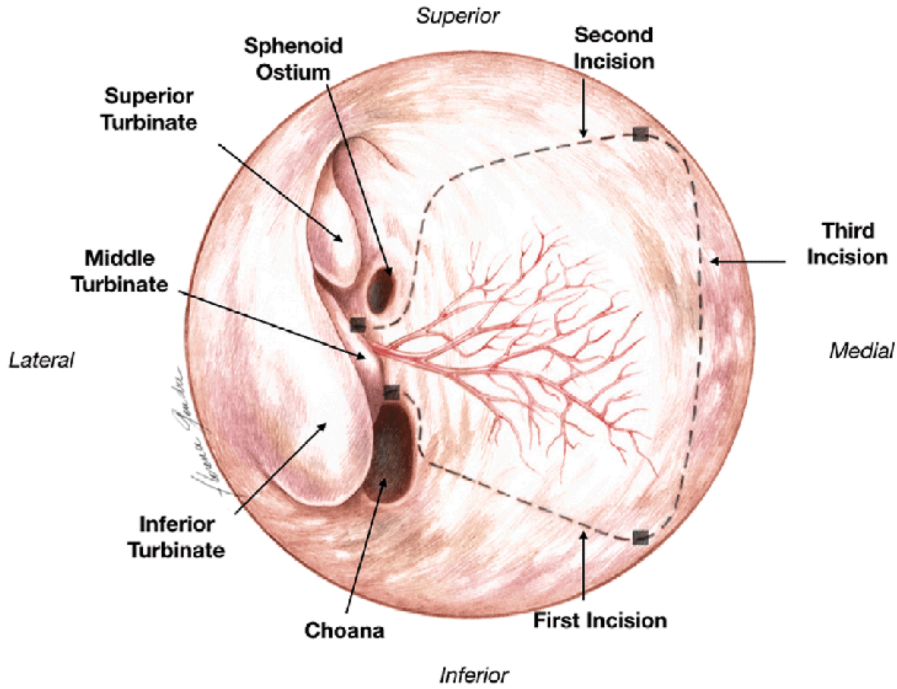

Fig. 1. Posterior septal branch of the sphenopalatine artery which runs horizontally between the choana and the sphenoid sinus ostium. This figure depicts the harvest of a nasoseptal flap which only involves the nasal septum. However, the nasal floor and lateral nasal wall can easily be included in this flap, thus increasing its size significantly. (*From* Reuter G, Bouchain O, Demanez L, et al. Skull base reconstruction with pedicled nasoseptal flap: Technique, indications, and limitations. J Craniomaxillofac Surg 2019;47(1):29–32. https://doi.org/10.1016/j.jcms.2018.11.012. Permission obtained via Creative Commons.)

Once the flap is harvested, it can be tucked into the nasopharynx to prevent obstruction of the surgical field during other portions of the procedure. If a clival procedure is being performed, a maxillary antrostomy can be performed to allow for placement of the flap within the maxillary antrum until it is needed for skull base reconstruction.

In the original study by Hadad and colleagues, the NSF was shown to be highly effective in preventing CSF leaks. Among 43 patients treated, only 5% experienced flap failure or postoperative CSF leak.[6] The main causes for complications are a narrow or short flap, which is inadequate to reconstruct the skull base defect, reverse placement of the flap, flap ischemia, incomplete removal of sphenoid sinus mucosa, poor flap adhesion to the donor site, and ineffective packing or support of the flap.[9] Some studies have reported other complications, including epistaxis, nasal obstruction, hyposmia, crusting, dryness, and septal perforation.[10] The most feared complication includes flap necrosis, as it compromises the reconstruction and can lead to recurrence of CSF leaks or intracranial complications.

Some patients may be poor candidates for the NSF for skull base reconstruction. Any tumors extending into the nasal septal mucosa, sphenopalatine artery, or its branches would be contraindicated for NSF harvest. Prior posterior septectomy, sphenoidotomy, and sphenopalatine artery ligation will often prevent NSF harvest on the ipsilateral side. Prior septoplasty, however, is not a contraindication for NSF harvest, but may complicate flap elevation due to scarring of the tissue planes.[11]

Inferior Turbinate Flap

Although the NSF is the main choice for anterior skull base reconstruction, it may not always be available, especially during revision surgeries or when a lesion affects the nasal septum, which prevents its use. In such cases, other vascularized flaps should be considered, such as the inferior turbinate flap. When this flap is posteriorly pedicled, it relies on the inferior turbinate artery, a terminal branch of the sphenopalatine artery.[12] An anterior pedicled inferior turbinate flap, based on the anterior ethmoid artery, has also been described. However, given its orientation, it has limited utility for anterior skull base reconstruction and is more suitable for nasal reconstruction after Mohs micrographic surgery or repair of nasal septal perforation.

The main disadvantages of the inferior turbinate flap are its limited arc of rotation and its small size, thus limiting its use to smaller reconstructions. Choby and colleagues described the extended inferior turbinate flap, which uses the nasal floor mucosa to increase flap size. During this technique, the superior limit of this flap was the inferior portion of the maxillary antrostomy, and the medial limit was the junction of the nasal septum and the floor. During this dissection, a small back cut along the head of the inferior turbinate is made to help facilitate flap elevation.[12] When making the incisions, care should be taken to make the posterior incisions just anterior to the Eustachian tube and posterior to the sphenopalatine artery. In contrast, when making the superior incision, the mucosal cut should start just anterior to the sphenopalatine artery (**Fig. 2**A–E). Additionally, some surgeons have described using a combined inferior turbinate and NSF to allow for increased size of the flap.[13,14] Although it is uncommonly utilized for anterior skull base reconstruction, an anteriorly based inferior turbinate flap based off the anterior ethmoid artery has been described and can be used to reconstruct defects of the anterior skull base. This flap is typically reported to measure about 5 cm $\times$ 2 cm, restricting its application to smaller skull base defects.[15,16]

Temporoparietal Fascia Flap

The temporoparietal fascia is a superficial fascial layer that lies between the subcutaneous tissue and the deep temporalis fascia over the temporalis muscle. It is in continuity with the galea and frontalis layer within the forehead and scalp and is primarily supplied by the superficial temporal artery, which divides into anterior and posterior branches. The temporoparietal fascia flap has multiple indications in head and neck reconstruction, including reconstruction of the auricle and microtia defects, correction of temporozygomatic contour deformities, orbital reconstruction, and cranial base reconstruction.[17] In 2007, Fortes and colleagues described the transpterygoid transposition where the flap is passed through the transpterygoid space, into the sinonasal cavity (**Fig. 3**A–F).[16] They initially exposed it via a hemicoronal incision, taking care not to damage the temporoparietal fascia, which lies just superficial to the subcutaneous tissue. This plane can be difficult to dissect and is highly vascular. Dissection is usually performed sharply or with electrocautery to aid in bleeding control. However, using electrocautery does risk damage to hair follicles and possible alopecia. Once the subcutaneous tissue is widely undermined, the temporoparietal fascia is circumferentially incised, taking care not to injure the vascular pedicle. Attention is paid to the location of the frontal branch of the facial nerve, which lies just deep to this fascial layer, as excessive anterior dissection may injure this nerve. Once the flap is elevated, the deep temporal fascia over the temporalis muscle is incised. A tracheostomy dilator is passed into the infratemporal fossa and through the transpterygoid space until it is visualized endoscopically through a posterior maxillary wall defect. The flap is

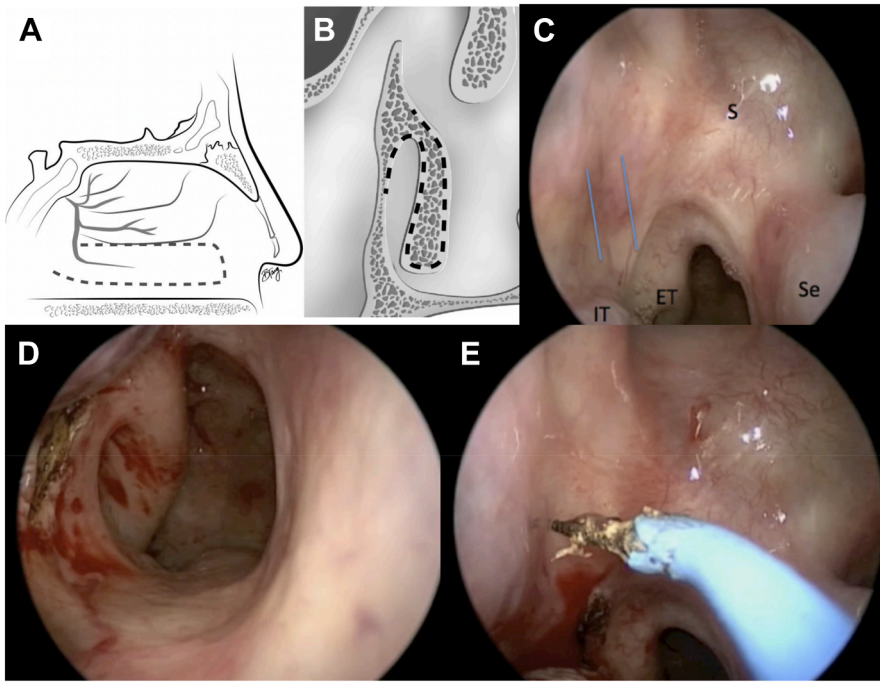

Fig. 2. (*A*) A sagittally oriented diagram depicting harvest of the inferior turbinate flap. Note the location of the vascular pedicle. (*B*) A coronally oriented diagram depicting harvest of the inferior turbinate flap. (*C*) Image depicting the location of the inferior turbinate artery (*blue lines*). IT: inferior turbinate, ET: Eustachian tube, S: sphenoid face, Se: septum. (*D*) Posterior incision which is just anterior to the Eustachian tube. (*E*) Superior incision which is started just anterior to the location of the vascular pedicle. Note that the posterior incision can be visualized in this image and is just posterior to the location of the pedicle. (*From* Yip J, Macdonald KI, Lee J, et al. The inferior turbinate flap in skull base reconstruction. J Otolaryngol Head Neck Surg 2013;42(1):6. https://doi.org/10.1186/1916-0216-42-6. PMID: 23663897; PMCID: PMC3646555. Permission obtained via Creative Commons.)

secured to the dilator or to a guidewire and pulled into the sinonasal cavity using endoscopic instrumentation.

The temporoparietal fascia measures about 17 cm × 14 cm in the average patient and nearly the entire surface of this fascial layer is available for reconstruction.[16] A recent systematic review has suggested that this is a reliable reconstructive option when local intranasal flaps are not available (clinical applicability further detailed in article Open and Endoscopic Open-Assisted Repair of Anterior Skull Base Defects).[18] While this technique can be an excellent option, it may be challenging to reconstruct anterior central skull base defects, as the flap may not be able to reach this far anteriorly. However, some authors have described the "side-door" temporoparietal fascia flap, which can be used to reconstruct anterior central skull base defects by passing the flap to the location of the defect via a pterional craniotomy, thus shortening the distance through which the flap is transposed.[19]

Pericranial Flap

The pericranial flap is an excellent extranasal option for reconstruction of large anterior skull base defects, such as after a craniofacial resection. Typically, the pericranial flap

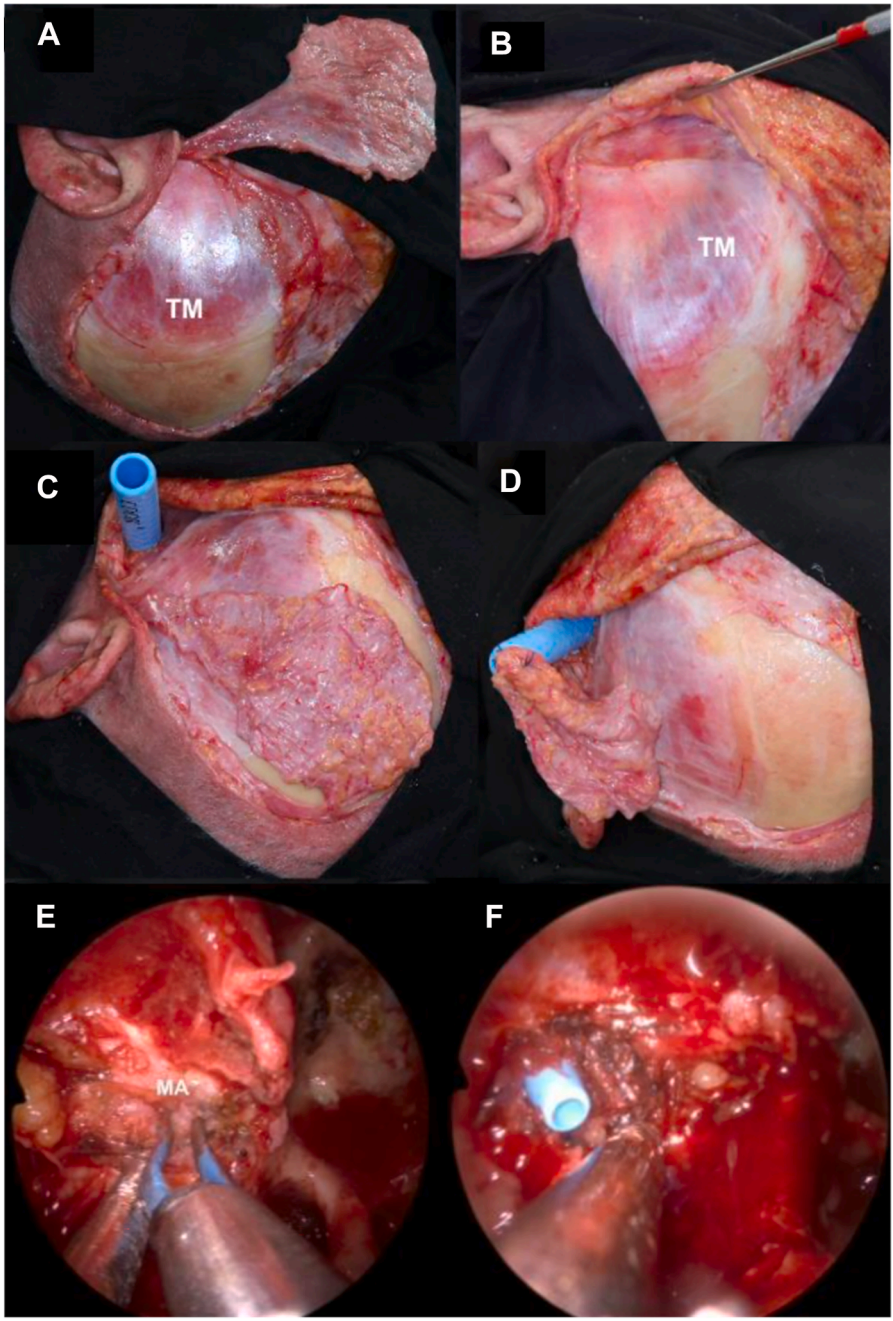

Fig. 3. The harvest and the transpterygoid transposition of the temporoparietal fascia flap. (*A*) Harvest of the temporoparietal fascia flap based of the superficial temporal artery. Note the temporalis muscle (TM) and the overlying fascia. (*B*) Subfascial dissection to expose the temporalis muscle and the infratemporal fossa. (*C*) Placement of a percutaneous tracheostomy dilator through the infratemporal fossa. (*D*) The flap is secured to the dilator. (*E*) Control of the maxillary artery (MA) within the pterygopalatine fossa. (*F*) The tracheostomy

is harvested through an open coronal approach and can be used when performing an open and endoscopic approach. The pericranial flap is an axial flap based on the bilateral supratrochlear and supraorbital arteries, providing a robust blood supply.[20] Additionally, its large size allows for reconstruction of the entire base of the anterior cranial fossa, from the posterior table of the frontal sinus to the planum sphenoidale.[21] Flaps up to 20 cm × 10 cm can be reliably harvested; however, the distal portion relies on random blood supply, limiting this flap's ability to reconstruct clival and high-flow sellar defects.[22]

As stated above, the pericranial flap is typically harvested through a coronal approach. The authors typically elevate the scalp in the subgaleal plane, taking care not to disrupt the underlying pericranium. Once the scalp is fully elevated, the pericranial flap is harvested. Incisions are made at the superior temporal line laterally and connected superiorly across the vertex of the scalp. If additional length is needed, the posterior scalp can be elevated to allow harvesting of a longer flap. Next, the flap is elevated in a subperiosteal plane down to the level of the superior orbital rim, where the neurovascular pedicles reside (**Fig. 4**A–D).[23] An alternate method to raise the flap is achieved by elevating the entire scalp in the subperiosteal plane and subsequently separating the pericranium from the overlying galea. This technique can be beneficial if it is not determined preoperatively if a pericranial flap will be needed for reconstruction, such as when treating frontal sinus pathology or trauma. Once harvested, the flap can be transposed intracranially, extending posteriorly to the level of the planum sphenoidale. Additionally, a bilayer can be created by folding the flap over itself, with one layer against the sinonasal cavity and the other against the exposed frontal lobe. Finally, when securing the frontal bone, care must be taken not to compress the vascular pedicle as it enters the craniotomy defect, and the authors recommend leaving a small gap along the inferior aspect of the bone flap to prevent vascular compromise.

Recent technical advances have allowed for resection of larger anterior skull base lesions without the need for an external craniotomy. While many of these defects can be reconstructed using unilateral or bilateral NSFs, when these flaps are not available, the pericranial flap is a useful reconstructive option. If the entire resection is performed endoscopically, the pericranial flap can be harvested endoscopically, thereby obviating the need for a coronal approach and its potential morbidity (**Fig. 5**A–H). This is performed through 2 or 3 small trichophytic incisions posterior to the hairline, which allows for placement of the endoscope and instruments. The scalp is then widely elevated in a subgaleal plane under endoscopic guidance. Next, needle point monopolar electrocautery is used to incise the pericranial flap along the superior temporal lines. The posterior vertex incision is made, and the pericranium is elevated anteriorly. This is best performed with curved elevators, which allow the surgeon to "pull" the pericranium anteriorly. Once the flap is fully elevated, a 1 cm horizontally oriented glabellar incision is made, and the nasal bones are exposed. A nasionectomy is performed using a drill, and the flap is passed into the nasal cavity through this window and is set into place endoscopically, in an intra- or extracranial fashion.[24] Other

dilator is visualized within the pterygopalatine fossa. It is then removed through the nose, thus allowing passage of the flap into the sinonasal cavity. (*From* Offi M, Mattogno PP, D'Onofrio GF, et al. Temporoparietal fascia flap (TPFF) in extended endoscopic transnasal skull base surgery: clinical experience and systematic literature review. J Clin Med. 2024;13(23):7217. Published 2024 Nov 27. https://doi.org/10.3390/jcm13237217. Permission obtained via Creative Commons.)

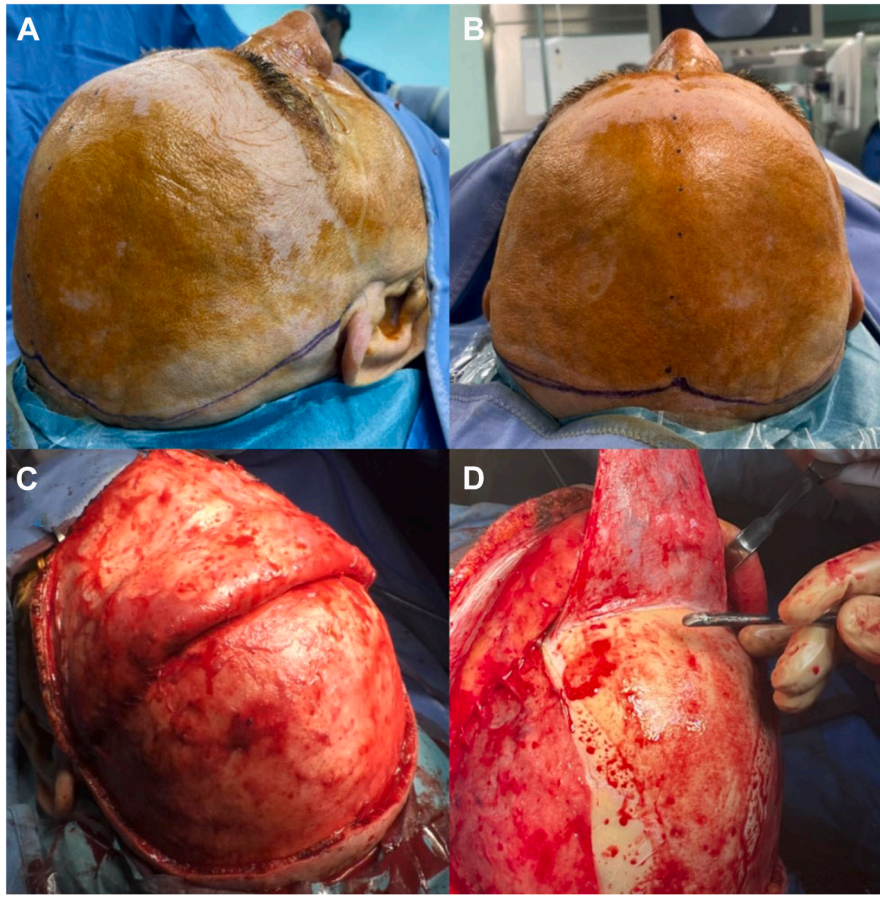

Fig. 4. Figure demonstrating the harvest of a pericranial flap. (*A, B*) Planned coronal incision. (*C*) Elevation of the scalp in a subgaleal plane. (*D*) Elevation of the pericranial flap. (*From* Calvaruso F, Lo Manto A, Bisi N, et al. Pericranial flap-based multilayer reconstruction of endoscopic transcribriform craniectomy for sinonasal malignancies. Laryngoscope 2023;133(11):2942–947. https://doi.org/10.1002/lary.30921. Permission obtained via Creative Commons.)

variations of minimally invasive harvests have also been described, such as through a supraorbital eyebrow craniotomy approach.[25]

A variety of modifications have been described, such as the composite galeal-frontalis pericranial flap, which enables the harvest of a thicker flap. These authors also described using only the bilateral supratrochlear pedicles, sparing the supraorbital pedicles, thereby preserving some scalp sensation.[26] Additionally, reports describe surgeons reconstructing anterior skull base defects with both a pericranial and an NSF, suggesting this may help reduce flap necrosis in patients undergoing postoperative radiation therapy. In a case series of 9 patients, 7 of whom required postoperative radiation therapy, none of the patients in this cohort developed postoperative CSF leak.[27] Finally, the pericranial flap can be an excellent option in revision cases with persistent CSF leak when intranasal flaps are absent or have failed (see article Open and Endoscopic Open-Assisted Repair of Anterior Skull Base Defects for further review).

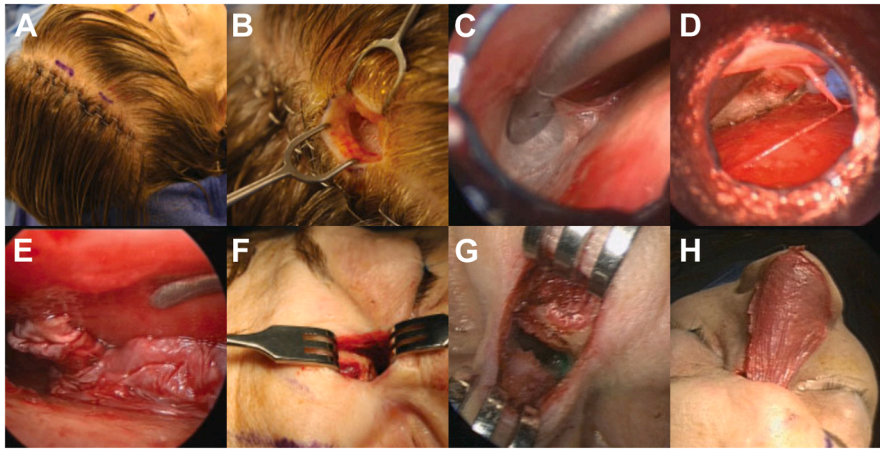

Fig. 5. (*A*) Planned incisions along scalp for endoscopic access. (*B*) Incision down to subgaleal plane. (*C*) Elevation within subgaleal plane. Note the loose areolar fibers during this dissection. (*D*) Needle point electrocautery used to make incisions along the pericranium. (*E*) Pericranial flap elevated. (*F*) Glabellar incision used to access the nasion. (*G*) Nasionectomy performed to create a window to the sinonasal cavity. (*H*) Pericranial flap tunneled through glabellar incision. Flap is then tunneled through nasionectomy to allow for endonasal reconstruction of the skull base. (*Reproduced from* Zanation AM, Snyderman CH, Carrau RL, et al. Minimally invasive endoscopic pericranial flap: a new method for endonasal skull base reconstruction. Laryngoscope. 2009;119(1):13–8. https://doi.org/10.1002/lary.20022 with permission.)

One potential concern with the endoscopic pericranial flap is the development of postoperative sinus opacification and mucocele formation. This issue is typically encountered only during the endoscopic approach, as the posterior table of the frontal sinus is anatomically preserved. In these cases, the flap pedicle traverses the frontal recess, thereby obstructing the frontal sinus outflow tract. In contrast, when an open approach is performed the frontal sinus is cranialized. A recent article found that 62.5% of patients with available postoperative radiology follow-up were noted to have sinus opacification, but 93.3% of those patients remained asymptomatic. In this series, one patient who developed symptoms was noted to have a mucocele eroding the orbit and required a Draf III frontal sinusotomy.[28] This case suggests the need for interval postoperative imaging to monitor for the development of this complication.

Local Vascularized Flaps

A variety of other local flaps can be designed to help reconstruct the skull base. One example is the inferiorly based rhinopharyngeal flap, which can be helpful to reconstruct clival and craniovertebral junction defects and can be combined with the NSF for larger defects.[29] Other nasopharyngeal flaps have also been described to help reconstruct the skull base.[30,31] Additionally, a superiorly based middle turbinate flap can be used to repair anterior fossa CSF leaks.[32] Posteriorly based middle turbinate flaps have been used to repair skull base defects when the NSF is not available.[33] Finally, a lateral nasal wall flap, which is a posteriorly based flap similar to the inferior turbinate flap but incorporates tissue along the nasal sidewall, can be used to repair skull base defects.[34,35] While these flaps are not commonly utilized, they may be options in specific clinical situations. One disadvantage of some of these flaps is that they can be difficult to harvest and may be insufficiently large to reconstruct certain defects.

Free Tissue Transfer for Skull Base Reconstruction

Free tissue transfer for skull base reconstruction is a very useful adjunct for reconstructing large skull base defects when other options are unavailable, such as in revision cases in which local and regional flaps have been previously used or sacrificed during tumor resection. The major benefit of free tissue transfer is the robust blood supply of the flap and the ability to tailor the flap to the size and shape of the defect.

Multiple options are available for reconstruction. Preoperatively, it is critical for the microvascular surgeon and skull base surgeon to establish a shared understanding of the expected size of the skull base defect, thereby enabling the microvascular surgeon to select an appropriate flap and tailor its dimensions for reconstruction. The anterolateral thigh free flap is an excellent option for large defects. It can be extremely bulky, which may be advantageous in certain situations when obliteration of dead space is required, but it poses difficulties in reconstructing smaller defects. The rectus abdominus free flap is another option with similar characteristics. The latissimus dorsi flap is an excellent option when the defect is large, but a thinner, more pliable reconstruction is needed. The significant disadvantage of this flap is the inability to harvest it in a supine position, and thus, this must be taken into consideration preoperatively. The radial forearm free flap is another example of a thin, pliable flap for reconstructing a small defect.[36] More recently, a fascia lata free flap has been described, which allows for an extremely thin but pliable reconstruction.[37] Some centers have described using the fascia lata free flap for surgical management of refractory skull base osteoradionecrosis.[38]

A variety of vessels are available for anastomosis of free tissue transfers for anterior skull base reconstruction. The most utilized ones are the facial artery and the superficial temporal artery. However, some surgeons utilize more centrally located vessels such as the angular artery or the superior trochlear artery.[37,39] Additionally, minimally invasive techniques have been described in which surgeons tunnel the vascular pedicle to the site of anastomosis, thus allowing for smaller exposures.[40] These novel techniques are especially amenable for endoscopic reconstructions, but care must be taken to avoid kinking of the pedicle, which could lead to flap compromise.

Traditionally, free tissue transfer is the last option on the reconstructive ladder for a skull base surgeon. However, with advances in endoscopic techniques and microvascular free tissue transfer, some centers are using free flaps earlier within the reconstructive algorithm, given their reliability and high success rate.

DISCUSSION

Vascularized flaps for anterior skull base reconstruction have become the gold standard method after both open and endoscopic skull base surgeries, especially when an intraoperative CSF leak occurs. Several options are available, and it is the skull base surgeon to select the most suitable flap for each patient. Usually, there are multiple effective reconstructive techniques. The methods outlined here serve as general guidelines for skull base surgeons. As always, individual patient factors may cause a surgeon to differ from these guidelines in a specific clinical situation.

The NSF flap is the most commonly used due to its ease of harvest, large size, low morbidity, and excellent outcomes. It is often ideal for reconstructing the clivus, parasellar region, and anterior skull base. However, it is not suitable in cases of large septal perforations, vascular pedicle injury, insufficient flap size for large defects, previous NSF reconstruction, or tumor involvement of the flap or its vessels—particularly given the impact on oncologic outcomes. If only one side of the septum is tumor free and the

cartilage is unaffected, the opposite side may be used. Mild septal involvement can be assessed intraoperatively with frozen biopsies, but there is a risk of false negatives. Use this method only when margins are clearly negative and with caution.

If the NSF is not available and the defect is small, a posteriorly based inferior turbinate flap may be used, though it is unsuitable for large defects. For extensive anterior skull base defects, a pericranial flap is highly effective and relatively straightforward to harvest via an open approach, though it poses a small risk to the facial nerve. Endoscopic harvest can mitigate this.

For posterior defects like the clivus, the temporoparietal fascia flap is a good option. It requires careful technique due to its vascular plane, but once harvested, it can be transferred intranasally.

In complex cases or revision surgeries in which other options are unavailable or too limited, microvascular free tissue transfer is reliable. This requires coordination with a microvascular surgeon and consideration of patient positioning, especially for flaps like the latissimus dorsi free flap are utilized. In most cases, an open approach and endoscopic techniques with tunneling for vascular anastomosis are also possible (discussed further in article Open and Endoscopic Open-Assisted Repair of Anterior Skull Base Defects). These advanced options are typically last-resort choices due to their complexity and associated morbidity.

SUMMARY

Skull base surgery has evolved significantly over the last 30 years with the introduction and refinement of endoscopic techniques. In this new era of skull base surgery, the reconstructive options within a skull base surgeon's armamentarium have grown significantly, as the ability to reliably and safely harvest vascularized flaps became possible with endoscopic guidance. Although a variety of flaps have been described, the NSF is still the primary workhorse for most reconstructions. When this flap is not available, other options include the pericranial flap, inferior turbinate flap, and the temporoparietal fascia flap. Finally, when no other options are available, microvascular free tissue transfer is a reliable method to reconstruct the skull base.

CLINICS CARE POINTS

- Vascularized flaps have become the gold standard for skull base reconstruction due to their reliability with a low rate of postoperative CSF leak, ease of harvest, and low morbidity.
- The NSF is the most commonly utilized flap and can reconstruct defects throughout the majority of the anterior skull base.
- Other flaps, such as the pericranial, inferior turbinate, or temporoparietal fascia flaps should be considered when the NSF is not available or when its use is contraindicated.
- When no other reconstructive option is available, microvascular free tissue transfer can be a reliable technique to reconstruct the anterior skull base.

DISCLOSURES

K. McKinney is a member of the Sanofi Speakers Bureau and serves as a consultant for Neurent Medical and Sutter Medical Technologies, USA. There are no other disclosures for the remaining authors.

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