

Panorama of Reconstruction of Skull Base Defects: From Traditional Open to Endonasal Endoscopic Approaches, from Free Grafts to Microvascular Flaps

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Abstract

Introduction A substantial body of literature has been devoted to the distinct characteristics and surgical options to repair the skull base. However, the skull base is an anatomically challenging location that requires a three-dimensional reconstruction approach. Furthermore, advances in endoscopic skull base surgery encompass a wide range of surgical pathology, from benign tumors to sinonasal cancer. This has resulted in the creation of wide defects that yield a new challenge in skull base reconstruction. Progress in technology and imaging has made this approach an internationally accepted method to repair these defects.

Objectives Discuss historical developments and flaps available for skull base reconstruction.

Data Synthesis Free grafts in skull base reconstruction are a viable option in small defects and low-flow leaks. Vascularized flaps pose a distinct advantage in large defects and high-flow leaks. When open techniques are used, free flap reconstruction techniques are often necessary to repair large entry wound defects.

Conclusions Reconstruction of skull base defects requires a thorough knowledge of surgical anatomy, disease, and patient risk factors associated with high-flow cerebrospinal fluid leaks. Various reconstruction techniques are available, from free tissue grafting to vascularized flaps. Possible complications that can befall after these procedures need to be considered. Although endonasal techniques are being used with increasing frequency, open techniques are still necessary in selected cases.

Keywords

- ▶ skull base
- ▶ cerebrospinal fluid leak
- ▶ dura
- ▶ reconstruction
- ▶ endoscopic surgery
- ▶ pedicled flaps

Introduction

Skull base defects can derive from both traumatic and non-traumatic causes. In the traumatic group, nonsurgical trauma is the most common overall, and surgical (iatrogenic) damage is a minor cause. In the nontraumatic group, skull base erosion can be caused by high intracranial pressure due to tumor obstruction or from malignant neoplasms. Less commonly, skull base defects may be caused by radiotherapy or

infections. Spontaneous cerebrospinal fluid (CSF) leaks (idiopathic) can also occur.

As resections for skull base pathology become more complex, the resultant defects require more difficult and extensive reconstructions. This principle has become the pillar for most skull base reconstruction techniques, from traditional open to novel endoscopic endonasal or other minimally invasive approaches. The approach for reconstruction of skull base defects should be guided by the size and



location of the defect, flow of the CSF leak after resection, history of radiation or previous sinonasal surgery, and the experience of the surgical team.

Over the past 15 years, significant advances in surgical and reconstructive techniques have evolved in the treatment of multiple extradural and intradural skull base lesions via expanded endoscopic endonasal approaches (EEAs), adding complexity to the reconstructive paradigm.

Literature Review

Evolution of Reconstruction “from above” to Reconstruction “from below”

The presence of a wide variety of available surgical techniques poses the question if it is better to access skull base lesions via traditional transcranial routes or via minimally invasive expanded EEAs. Historically, transcranial resection has been considered the gold standard for surgical removal of numerous suprasellar lesions.¹

In 1907, Herman Schloffer performed the first transsphenoidal surgery.² In 1916, Cushing reported the first successful removal of a tuberculoma sellae meningioma via a unilateral subfrontal approach. In 1950, Norman Dott introduced the lighted nasal speculum retractor. Continuing the trend, Gerard Guiot introduced the X-ray film intensifier and fluoroscopy and pioneered image guidance surgery in 1956. In 1965, Jules Hardy introduced the use of the microscope in skull base surgeries, and in 1971, Donald Wilson introduced “keyhole surgery,” transitioning the trend to minimally invasive surgery.³ Resection of skull base tumors has evolved to integrate modified skull base techniques such as supraorbital, orbitozygomatic, and orbitopterional approaches.

Regardless of the surgical technique, the primary objectives of skull base tumor resection remain the same: gross total tumor resection with adequate decompression and preservation of surrounding structures, prevention of future recurrence, support of the brain and orbit, complete separation of the cranial cavity from the sinonasal tract, elimination of dead space, and a watertight seal to avoid the consequences of CSF leaks, such as meningitis and pneumocephalus.

The disadvantages of the supraorbital keyhole approach include narrower viewing angles with limited maneuvering of instrumentation, especially in patients with optic canal involvement. Although the bilateral frontal and unilateral frontal approaches provide excellent views of critical structures, the bilateral subfrontal approach has been noted to carry a greater risk of CSF leak, olfactory nerve damage, and postoperative brain edema.^{4,5} Additionally, with the pterional approach there can be significant frontal lobe retraction.

The introduction of the endoscope to skull base surgery eliminated many of the previous problems associated with microsurgical techniques. Casiano et al described the first pure EEA for resection of an esthesioneuroblastoma.⁶ Since its introduction, this approach has been internationally utilized for the resection of a variety of skull base lesions.

Important advantages of EEA compared with classical surgical techniques and approaches are the better access to deeply

seated lesions, a more direct exposure of the midline, reduced trauma to brain parenchyma, less manipulation of the neurovascular structures, rapid decompression of the optical structures, and more efficient devascularization of neoplasms from their surroundings.⁷⁻⁹ It is important to acknowledge that when important neurovascular structures are above or surrounding the capsule of the tumor, the EEA is an ideal approach; however, when a major vessel is to be encountered before reaching the surgical target, then open approaches are favored.

For reconstructing skull base defects, it is important to understand the indications and limitations of each approach. Preferably, the same route used for tumor removal should be used to repair the skull base defect, thus avoiding the comorbidity of a second incisional approach. In specific scenarios, gross tumor removal and avoidance of skull base defects can be achieved using the endoscope.

Endoscopic closure of CSF leaks was first described by Wigand in 1981 using free mucosal grafts, and to date, it continues to be the preferred method of CSF leak closure because of its high success rate (90 to 97%).¹⁰ Repairs can be achieved by mucosal grafting or a pedicled flap based on branches of the sphenopalatine, anterior ethmoidal, and facial arteries.¹¹ Also, collagen matrix materials, fascia, or fat can be used as inlay grafts to help seal these defects.

Free Grafts and Pedicled Flaps

A free graft is a tissue cut from one site and transplanted to another site. A pedicled flap is tissue that is left attached to its donor site and transposed to a new location keeping its “pedicle” intact. Prior to the routine use of vascularized tissue flaps for skull base reconstruction, free grafts of biologic or synthetic material were used primarily in a multilayer approach. Reconstructive allografts include DuraGen (Integra Lifescience Corporation, Plainsboro, New Jersey, United States) and Alloderm (Lifecell Corporation, Branchburg, New Jersey, United States), dural sealants such as DuraSeal (Confluent Surgical, Inc., Waltham, Massachusetts, United States), and fibrin glue. These materials are still part of the armamentarium for skull base reconstruction.

The middle turbinate is the most common donor site for the harvesting of intranasal free grafts. Other non-nasal free grafts, such as temporalis fascia, fascia lata, and palatal mucosa, can be used. After ~8 weeks, these flaps are completely integrated within the surrounding tissue. It is recommended that the free graft be 25% larger than the defect, because there is a 20% reduction in size.¹² Free grafts have the advantage of easy harvest with low donor site morbidity.

Among pedicled vascular flaps, the posteriorly pedicled nasoseptal flap or Hadad-Bassagaisteguy flap (NSF) is the “tip of the spear” of most endoscopic skull base defect repairs (► **Figs. 1 to 3**).¹³ However, there are other intranasal pedicled flaps such as inferior turbinate flaps^{11,14} and middle turbinate flaps,¹⁵ each with its own advantages and disadvantages.

The NSF is a vascular flap composed of mucoperiosteum and mucoperichondrium from the nasal septum, pedicled on the posterior nasoseptal artery. It can cover a wide area of the skull base, from the posterior wall of the frontal sinus to the sella turcica, and from orbit to orbit. It should be used in

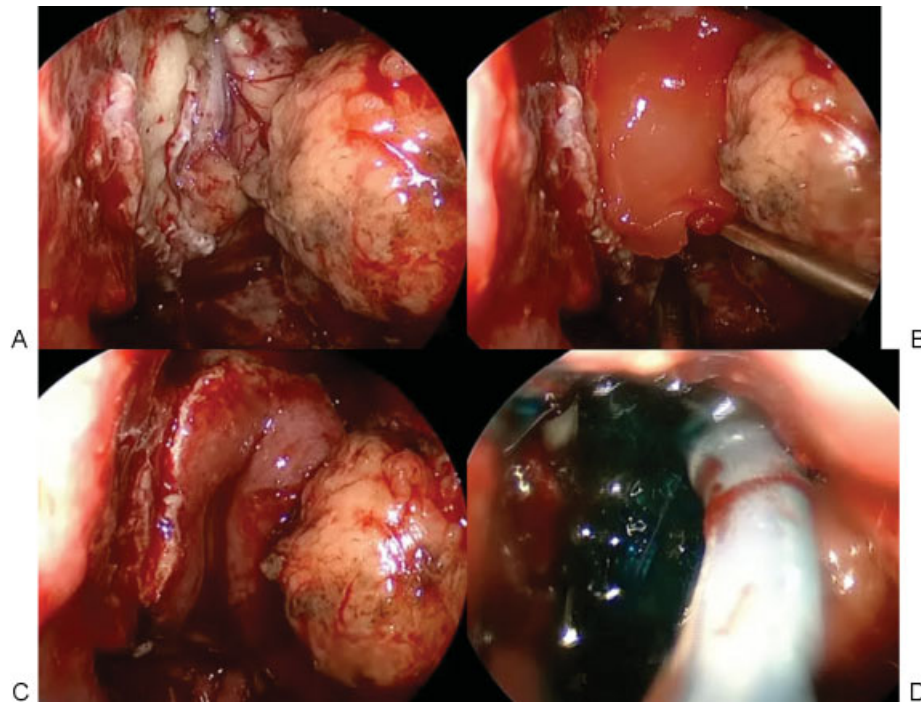


Fig. 1 (A) Unilateral anterior cranial base defect following the resection of a sinonasal malignancy. (B) Inlay placement of DuraGen (Integra Lifescience Corporation, Plainsboro, New Jersey, United States). (C) Positioning of the nasoseptal flap over the reconstruction. (D) Application of DuraSeal (Confluent Surgical, Inc., Waltham, Massachusetts, United States).

conjunction with a multilayer reconstructive approach. The flap should be separated from any nonabsorbable packing with nonadherent material so that the graft is not disrupted upon removal of the packing. Packing is typically left in place for 3 to 5 days. The size of the NSF can be compromised by lesions that involve the cropped area or septal spurs and in patients under 10 years of age where the septum is not fully developed.¹⁶

The NSF is limited in its ability to reach extremely anterior defects, such as those involving the posterior frontal table, frontal break, and anterior cribriform plate. Posteriorly¹⁷ or anteriorly¹⁸ pedicled inferior turbinate flaps or middle turbinate flaps can be considered as a second option for smaller defects when an NSF is not available or not feasible. Terminal

branches of the posterior lateral nasal septal artery supply both. Hadad et al described a modification of the anteriorly pedicle inferior turbinate flaps where dissection of the lateral nasal wall was added (Hadad-Bassagaisteguy flap 2 or HB2).¹¹ The HB2 has the capacity to cover combined defects (transcribriform and transplanum). Patients in whom the NSF is not available are candidates for this reconstructive technique. Its pedicle includes the territory of the facial (angular) artery and the anterior ethmoidal artery. This flap can be modified to have a posteriorly based pedicle to cover defects of the planum sphenoidale, sella, clivus, and nasopharynx.¹⁹ These lateral nasal wall flaps require special surgical endoscopic skills, as they can be difficult to dissect. The success of these reconstruction flaps should be individualized to every patient

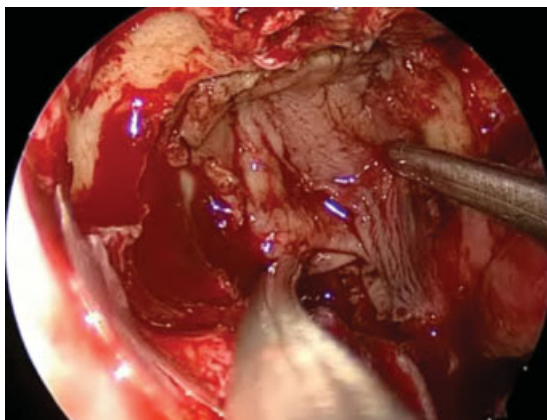


Fig. 2 Positioning of a nasoseptal flap for reconstruction of a planum sphenoidale defect.



Fig. 3 Nasoseptal flap fully healed and integrated in the sphenoclival region.

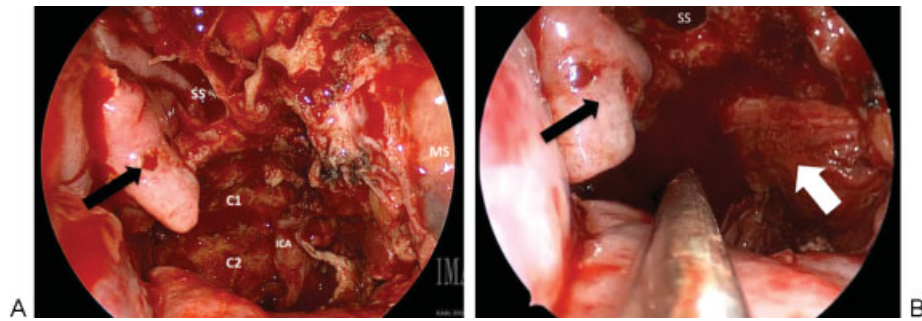


Fig. 4 (A) Defect following an endoscopic nasopharyngectomy. The ICA has been completely skeletonized. The black arrow points to the nasoseptal flap stored in the sphenoid sinus. (B) Reconstruction of the defect with the nasoseptal flap providing coverage for the upper cervical spine (black arrow) and the temporoparietal fascia flap covering the parapharyngeal space and ICA (white arrow). Abbreviations: ICA, internal carotid artery; SS, sphenoid sinus.

needs. Significant crusting can occur, as with other nasal flaps, which usually continues until total remucosalization occurs. Postoperative recommendations are the same as for other reconstructive techniques.

Pedicled extranasal flap options are also available. The use of these flaps arises when the pedicled NSF is not available. Such flaps are harvested from regional areas including the palatal flap, the pericranial flap, facial buccinators flap, and temporoparietal fascial flap.

The palatal flap has a vascular supply derived from the greater palatine artery, providing a 3-cm pedicle that could potentially reach any area of the skull base. This makes it, theoretically, very useful. Nevertheless, this technique has mainly been described in cadaveric studies, making it a resource of last choice.^{20,21}

The pericranial flap was historically used as the first option before the use of endoscopic repairs.²¹ Its pedicle is based upon the supraorbital and supratrochlear arteries, and it is transposed through a small nasionectomy into the endoscopic field. It can cover from the anterior cranial fossa as far as the sella, without reaching the posterior cranial base defects. In the past, this flap was considered to have a negative impact on cosmetics; however, with the use of the endoscope, better visualization and minimally invasive surgery have avoided this problem.²²

The facial buccinator flap is pedicled upon the facial artery after it branches off the external carotid artery.²³ It can be a

solely muscular or a combined myomucosal flap. Transposition of the facial buccinator flap takes place through a maxillary window. It has a coverage area that fluctuates from 2 cm² to 20.76 cm², with an average of 15.90 cm², and it is able to reach the anterior skull base and planum sphenoidale.²⁴ This flap has only been described in cadavers, so the drawbacks are so far theoretical. These include the introduction of oral flora to the surgical field, vascular and nerve injuries, and the most important of them all, variability in flap extensions due to gravitational forces and retraction ability. However, it is important to acknowledge this flap's advantages, such as its extension, the axis of rotation, and the absence of external scars.

The temporoparietal flap is a good reconstructive option for defects of the sella, parasellar area, and clivus (→ Fig. 4). The superficial temporal artery supplies the flap. It requires a broad dissection, both endoscopically and externally. The pterygopalatine fossa is dissected, the vidian nerve is sectioned, and the anterior aspects of the pterygoid plates are drilled. Externally, a hemicoronal incision is carried down to the level of the hair follicles, a wide tunnel beneath the superficial layer of the deep temporalis fascia is created, and a lateral canthotomy incision is used to expose and separate the temporalis muscle from the lateral orbital wall and pterygomaxillary fissure, creating a tunnel that communicates the temporal, infratemporal fossa, and endoscopic transpterygoid approach. A portion of the lateral wall of the



Fig. 5 (A) Lateral skull base defect following the excision of a parotid malignancy extending to the jugular foramen. (B) Reconstruction of the defect with a pectoralis myocutaneous rotational flap.



Fig. 6 (A) Lateral skull base defect following the excision of a cutaneous malignancy with extension to the temporal bone and middle cranial fossa. (B) Dural reconstruction was performed with suturable DuraGen (not shown; Integra Lifescience Corporation, Plainsboro, New Jersey, United States). The residual craniotomy bone flap was repositioned and the soft tissue and skin defect were reconstructed with a radial forearm free flap.

maxillary sinus is removed to open a wide communication with the infratemporal fossa, thus establishing communication between the flap and the skull base.

The temporalis muscle is a good reconstructive option for intratemporal fossa defects. It is helpful in separating the intracranial/extracranial spaces and provides sufficient bulk to obliterate the dead space created by the resection of infratemporal fossa/nasopharyngeal pathology. For those lateral skull base defects that require skin as well as soft tissue bulk, the pectoralis major myocutaneous flap still remains a viable option (→Fig. 5).

Success rates of pedicled flaps approximate 95%, which makes them a reliable reconstruction option for skull base defects.²⁵ However, when the size and location of the skull base defect to be repaired exceeds the excursion limits of the pedicled flap, free flaps can be considered.

Free Flaps

The rectus abdominis myocutaneous flap has been commonly used in skull base reconstruction. Its blood supply is the inferior epigastric artery and vein. The insertion of the muscle is detached and the harvest is completed. The major disadvantage of this flap is its bulkiness due to the width of the

subcutaneous tissue of the abdominal wall. Also, there is risk of a ventral hernia owed to abdominal wall weakness.

The radial forearm flap is a fasciocutaneous flap supplied by the radial artery and vein. It is very pliable, which makes it versatile for skull base defect reconstruction (→Fig. 6). The flap has a very long pedicle, which allows for usage of neck vessels as recipient vessels. Although it is very rare, hand ischemia can occur because of radial artery sacrifice. In our experience, when the physical exam suggests poor hand perfusion during occlusion of the radial artery, Doppler ultrasonography is helpful in determining the patency of the palmar arch. The anterolateral thigh has become the preferred free flap by many reconstructive surgeons; however, in our practice we still favor the forearm free flap due to pedicle length.

Osteocutaneous free flaps can be used in cases where significant orbital reconstruction is required. In our experience, the stacked fibula free flap reconstruction is very versatile in orbitomaxillary reconstruction (→Fig. 7).²⁶ Other osteocutaneous options include the scapula and hip bones with respective overlying skin.



Fig. 7 (A) Maxillectomy and orbital rim defect following the excision of a maxillary sinus sarcoma. (B) Inset of a stacked fibula free flap for reconstruction of the orbit and maxilla.

Postoperative Care

Postoperative images should be obtained in all patients within 24 hours of surgery. Patients are told to avoid all Valsalva-type responses. Patients are followed in the office every 2 to 4 weeks for removal of crusting and disruption of any synechiae and to spot signs of possible CSF leaks. Once the reconstruction appears healed, the patient is allowed to resume regular activities.

Complications

Complications arising from skull base reconstruction can be direct or indirect, or perioperative and late postoperative. Also, complications can occur depending of the type of flap used. The nasoseptal flap can lead to displacement of the olfactory epithelium, persistent nasal crusting, and sphenoid sinus obstruction due to the pedicle's orientation. Special areas of skull base reconstruction like the frontal sinus, the orbit, or major neurovascular structures must have special consideration. Complications from external incisions like alopecia, pain, hypesthesia, and/or infections can arise.²⁷ Crusting is the most common symptom after skull base reconstruction (3 to 4 weeks of duration),²⁸ followed by nasal discharge, which is associated with more complex dissections.²⁹ Resections of large portions of mucosa, such as the inferior turbinate, could lead to atrophic rhinitis. Improvement in nasal quality of life is usually achieved 4 months after surgery in most cases and in 6 months for more complex cases.³⁰ The use of endoscopic skull base techniques usually does not significantly contribute negatively to nasal quality of life scores; however, careful perioperative planning must be preformed to avoid such complications.

Early complications (<28 days postoperatively) of microvascular free flaps include partial or total flap loss, CSF leak, infection, pneumocephalus, facial nerve lesion, blindness, seizures, and complications derived from long surgical procedures. Late complications (>28 days postoperatively) include palatal fistula, wound infection, meningitis, intracranial abscess, ectropion, enophthalmos, orbital dystopia, persistent diplopia, and facial cellulitis. Prior radiotherapy is a statistically significant predictor of wound complications, and the existence of medical comorbidities is the only independent risk factor for death.³¹ The incidence of local and/or systemic postoperative complications following microvascular reconstruction of the skull base ranges between 30 and 40%.³²⁻³⁶ Mortality rates are close to 4.7% following craniofacial resection.³¹

Discussion: What Reconstruction Should Be Used?

The reconstructive technique largely depends on the approach used for resection and the nature of the resection. Both extradural or intradural tumor resection might be necessary. In the extradural surgery, the primary reconstructive goal is coverage of the defect to facilitate healing. Intradural tumor surgery can be *extra-arachnoidal* (pituitary surgery) or *intra-arachnoidal* surgery (where an intraoperative CSF leak can always be expected). Intra-arachnoidal

surgery can be further divided into high-flow and low-flow leaks depending on whether a cistern was directly opened.

The risk for postoperative CSF leak often depends on the location and size of the defect. It is always important to have in mind factors that increase the risk of postoperative CSF leaks: obesity (associated with high ventricular pressure), pathology being treated (craniopharyngiomas), Cushing disease, and history of radiotherapy (poor state of tissue healing) or prior surgery with compromise of local vascularized tissue reconstructive options.

Location of the skull base defect is the key factor in determining the type of reconstruction to be used. In a recent systematic review,³⁷ the authors suggested that anterior fossa lesions can be repaired with inlay grafts, because the pressure from the brain could hold the material in position and avoid its migration; defects of the tuberculum sellae or the clivus are best reconstructed with pedicled flaps due to their proximity to the anterior brain cisterns and ventricles.

In general, low-flow CSF leaks or small defects (<1 cm) are consistently repaired using multilayered free grafts, reconstructive allografts, and dural sealants with success rates > 90%.³⁷⁻³⁹ Vascularized skull base reconstructions for large dural defects (>3 cm) involving wide dural and arachnoid dissection, high-flow CSF leaks, and poorly vascularized beds (defects) have a clear and significant advantage over free grafting in the prevention of postoperative CSF leaks.^{37,38,40}

When open techniques are utilized, the extent of injury to the entry point needs to be assessed and reconstructed accordingly. With free flaps being more reliable in recent years, they should be considered and utilized whenever possible as they provide excellent functional and cosmetic results.

Final Comments

Skull base surgery has been revolutionized by the use of the endoscope. Endoscopic skull base surgery techniques have advanced considerably in recent years mainly because of advances in instrumentation and imaging. Skull base reconstruction of endonasal defects has not been left behind; however, it still remains a challenge. The introduction of vascularized flaps for endonasal reconstruction has improved the outcomes in several series, but it requires a technique that is able to recapitulate the morphology of the cranial base while simultaneously withstanding the forces exerted by the brain, brainstem, and CSF compartment. Although endonasal techniques are being used with increasing frequency, open techniques are still necessary in many cases and should remain an important part of the armamentarium. Microvascular reconstructive techniques are an excellent option in cases where extensive reconstruction is needed.

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