Chapter 7
Endoscopic Reconstruction of the Skull Base

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Introduction

Endoscopic skull base surgery has undergone rapid evolution over the past 20 years, largely due to advances in technology, surgical techniques, and training. In the early days of endoscopic skull base surgery, the largest impediment to tackling more complex tumors was an inability to perform adequate reconstruction and prevent postoperative cerebrospinal fluid (CSF) leaks. With the advent of local and regional pedicled vascularized flaps, surgeons' ability to repair defects was greatly improved, thus allowing larger and more complex tumors to be addressed. Despite these advances, a number of clinical scenarios exist where the most commonly utilized flaps may not be available due to previous surgery, direct tumor involvement, or poor vascularity. In light of this, there remains an ongoing development of alternative reconstructive options to use in these scenarios [1–3].

This chapter explores endoscopic skull base reconstruction with special attention to the progressive "reconstructive ladder" from inlays and free allografts to pedicled vascularized options to free tissue transfer. It is important for the comprehensive skull base surgeon to offer a variety of reconstructive options. The choice of reconstructive method will vary, depending on multiple factors such as tumor location and extent, prior therapy, age of patient, size and location of defect, and risk factors for postoperative CSF leak.

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Goals of Endoscopic Skull Base Reconstruction

Endoscopic skull base reconstruction following resection of sinonasal malignancies presents a unique set of challenges. In these cases, achieving an oncologic resection with clear margins is of utmost importance [4]. Extensive removal of bone with large dural defects may limit opportunities for securing grafts and exceed the coverage area of local flaps. Reconstructive options are often limited by prior surgery or the extent of resection [5, 6]. Direct tumor involvement of surrounding sinonasal mucosa, such as the nasal septum or vascular pedicle of the nasoseptal flap, may preclude certain options for reconstruction (Fig. 7.1a, b).

The goals of reconstruction are as follows:

1. Create a watertight barrier between the intracranial contents and sinonasal cavity.
2. Prevent postoperative CSF leak and meningitis.
3. Protect vital structures such as the internal carotid artery (ICA).
4. Minimize delay in progression of patient care from surgery to radiation therapy due to healing concerns.
5. Preserve nasal function (breathing and olfaction).
6. Prevent long-term postoperative sequelae such as mucoceles and sinusitis.

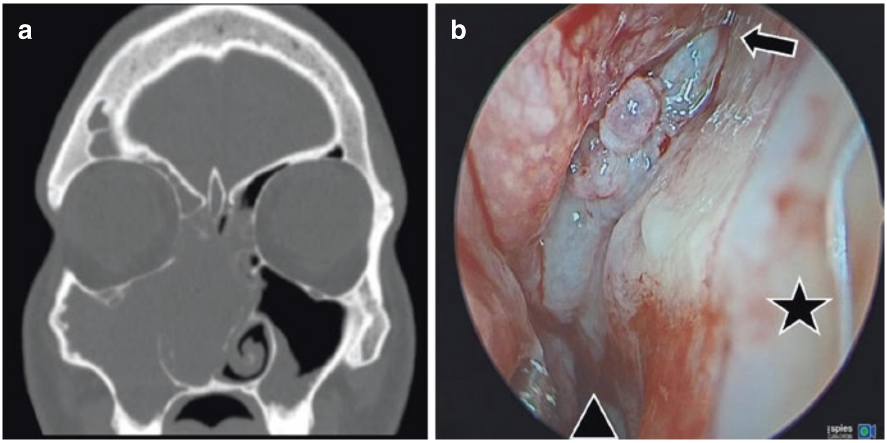

Fig. 7.1 (**a**) Coronal CT scan of sinonasal squamous cell carcinoma with extensive involvement of the nasal septum, and (**b**) clival chordoma with intranasal extension and direct tumor contamination of right nasoseptal flap pedicle (star = nasal septum; triangle = arch of right choana; arrow = os of right sphenoid sinus)

Inlay/Onlay Grafts

Non-vascularized reconstruction is often adequate for small (<1 cm) dural defects. When possible, a multilayered reconstruction is preferred using inlay (intradural) and onlay grafts. Onlay grafts may be placed intracranially (between dura and bone) or extracranially (extradural). Larger defects can be successfully repaired using multilayered non-vascular reconstruction [7], but superior results are achieved with the use of vascularized tissue in combination with fascial grafts in such situations [8].

A number of allografts are popular as inlays for dural reconstruction. Among others, these include DuraGen (Integra Lifescience Corporation, Plainsboro, New Jersey, United States), DuraMatrix (Stryker Corporation, Kalamazoo, Michigan, United States), and Alloderm (Lifecell Corporation, Branchburg, New Jersey, United States). These materials are generally considered for use as part of a multilayered reconstruction and are rarely indicated for use by themselves. This type of inlay largely serves as a scaffold to allow new ingrowth of dura across the defect [8].

Fascia lata is widely utilized as an inlay for large or high-flow defects. This can easily be harvested from the anterolateral thigh and provides a large, thick, impermeable barrier. It can be placed as an inlay itself or can be fashioned into a “button-like” configuration to be used as a combination inlay–onlay graft [9]. The benefits of this graft are that it is an autograft with a large surface area and heals reliably. When needed, a fat graft can also be harvested from the same site. The main drawback is potential donor site morbidity (cosmesis, hematoma, infection, muscle herniation).

Fat grafts may also play a role in reconstruction, albeit less so for large defects following sinonasal malignancy surgery, especially in an irradiated tissue bed. However, these have an important role in transclival approaches. In patients who have undergone extensive transclival approaches for tumors such as clival chordoma or petroclival chondrosarcoma, the use of fat grafts as part of the multilayer reconstruction is associated with reduced rates of transclival pontine encephalocele formation [10] (Fig. 7.2).

Free Mucosal Grafts

Free mucosal grafts have been used for decades to address small spontaneous CSF leaks and have high success rates for small low-flow defects [8, 11]. A number of areas are suitable donor sites for free mucosal grafts. If the middle turbinate is routinely resected as part of the approach, this mucosa can provide a sizeable graft. Alternatively, the nasal floor allows for harvest of a large flat piece of mucosa that

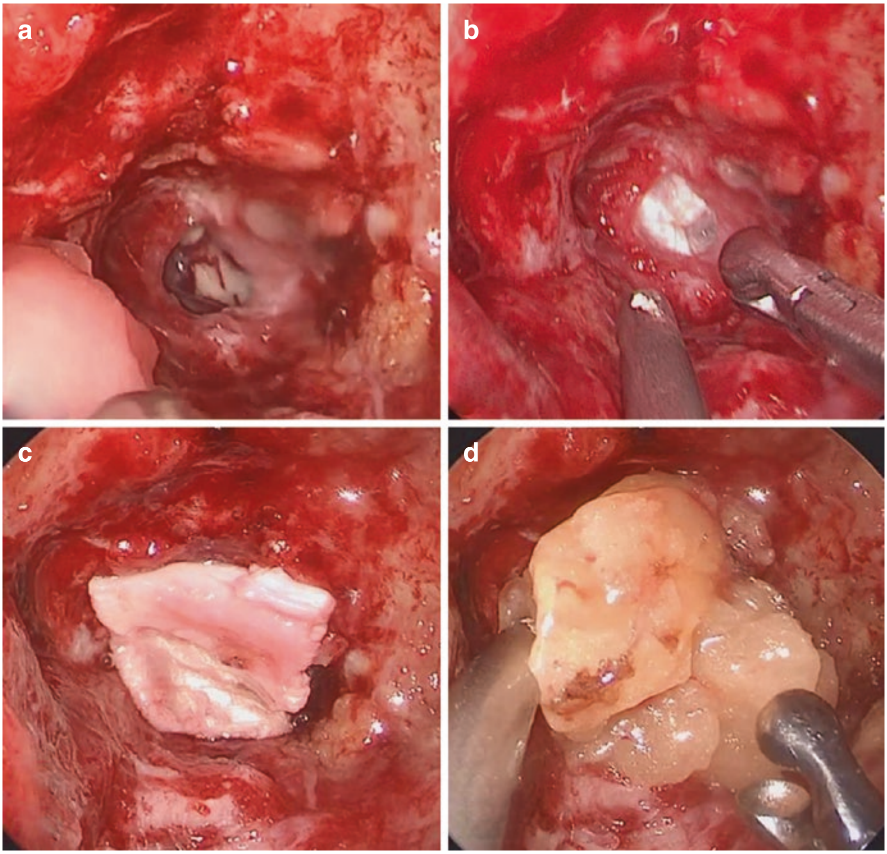

Fig. 7.2 Foundational inlay/onlay reconstruction following transdural clival chordoma resection: (**a**) clival dural defect; (**b**) fascia lata inlay; (**c**) fascia lata onlay; (**d**) fat graft onlay

is pliable; this donor site tends to heal well with minimal morbidity for the patient (Fig. 7.3). These grafts are well-incorporated into the surrounding mucosa by approximately 8 weeks postoperative [6, 11–13]. When harvesting them, it is important to err on the side of harvesting a larger size graft, as they may undergo a reduction by approximately 20% in size between harvest and placement [5, 14].

Free mucosal grafts have a limited role, however, in more complex cranial base reconstruction following endoscopic sinonasal resection of malignancy. Typically, mucosal grafts are reserved for smaller defects in combination with an inlay fascial graft. In a large systematic review of reconstruction of large dural defects, free mucosal grafts were shown to have a 15.6% leak rate and vascularized reconstructions were shown to have a 6.7% leak rate [8]. In addition, because they have no direct blood supply, it is likely that they do not afford as much protection for vital anatomic structures to endure radiation therapy, such as the ICA.

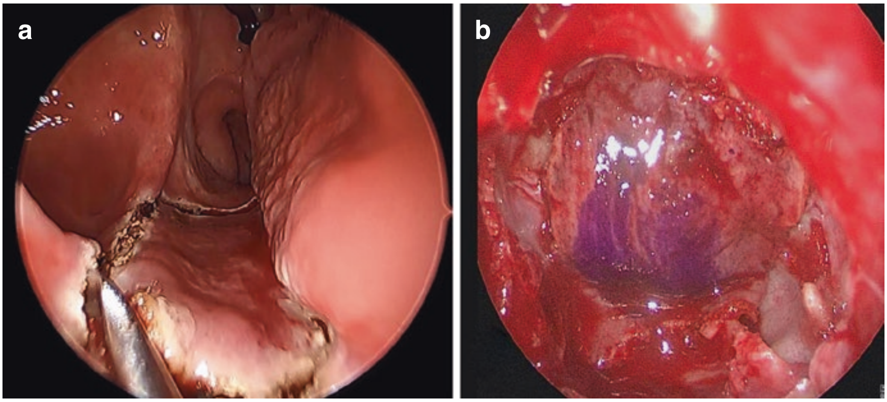

Fig. 7.3 (**a**) Harvesting a free mucosal graft from right nasal floor and (**b**) placement of free mucosal graft over trans-sellar defect. Note the purple ink marking the mucosal surface, ensuring proper orientation of the graft upon placement

Pedicled Vascularized Intranasal Flaps

The development of intranasal pedicled flaps significantly propelled the field of endoscopic skull base surgery, as larger and more complex defects were able to be repaired successfully. The current workhorse flap of skull base reconstruction is the posterior pedicled nasoseptal flap (NSF), or Hadad-Bassagasteguy flap. This was first described in 2006 [15] and is based on the posterior septal artery, a branch of the sphenopalatine artery. The NSF has a large surface area and wide range of motion, suitable for coverage of defects from orbit-to-orbit and from the posterior table of the frontal sinus to the sella. For complex reconstruction following resection of sinonasal malignancy, the NSF is typically utilized as part of a multilayer reconstruction [11, 16, 17].

For approaches to the anterior cranial base and sella, the NSF can be stored in the nasopharynx during surgery to protect its pedicle. However, when approaches to the posterior cranial fossa are utilized, such as transclival and transodontoid approaches, the flap must be mobilized and placed into the maxillary sinus to allow for safekeeping during the tumor resection. It is essential that all mucosa surrounding the cranial base defect is completely removed and the NSF carefully positioned and unfurled so that there is good circumferential contact with the surrounding dura and bone. The NSF is typically well incorporated into the surrounding mucosa by a few weeks postoperative (Fig. 7.4). Utilization of the NSF is not without morbidity, most notably at the septal donor site, with complications including prolonged crusting, septal perforation, saddle nose deformity, olfactory loss, and flap necrosis [18–22]. The donor site morbidity of an NSF can be minimized by covering the exposed cartilage of the anterior septum with a free mucosal graft or performing a reverse septal flap utilizing the posterior septal mucosa of the contralateral septum [23, 24].

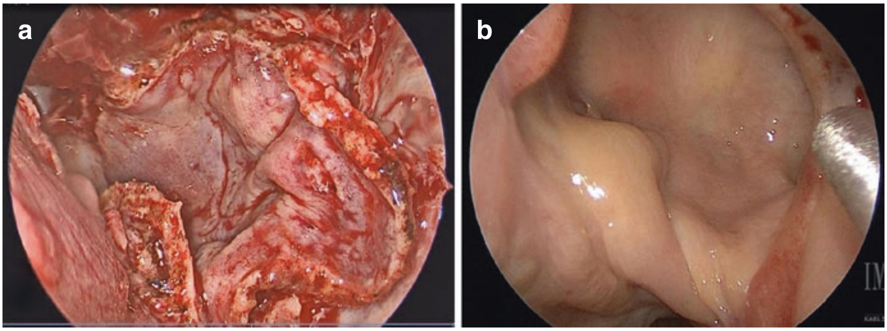

Fig. 7.4 (**a**) Intraoperative positioning of an extended right nasoseptal flap for a left transpterygoid approach to petroclival chondrosarcoma and (**b**) well-healed nasoseptal flap following transclival approach for clival chordoma at 8 weeks postoperative

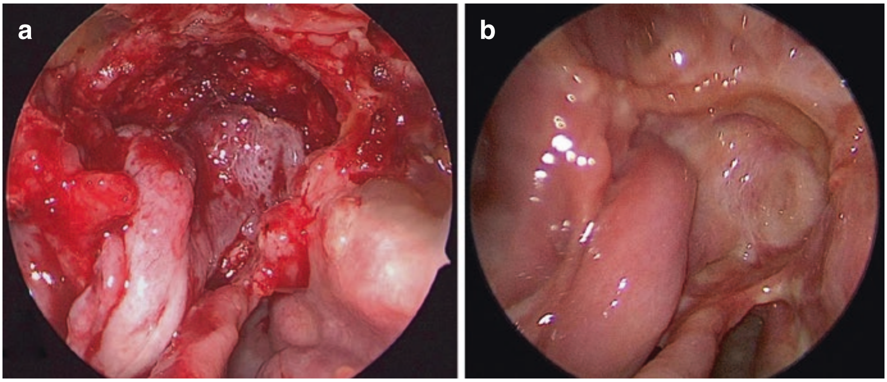

Fig. 7.5 Revision transclival approach for chordoma with nasoseptal flap unavailable due to disruption of bilateral pedicles at previous surgery: (**a**) intraoperative placement of right inferior tubinate flap; (**b**) well-healed right inferior turbinate flap at 6 weeks postoperative. Note that the conchal portion of the flap pedicle retains its original shape and conforms somewhat poorly to the surface of the bone

In cases when the NSF is not available for use, alternative local vascularized flaps are available. The inferior turbinate flap (ITF), or lateral nasal wall flap, is suitable for small to moderate clival and sellar defects (Fig. 7.5). In comparison to the NSF, it has a relatively small surface area and limited reach due to its pedicle being centered on the inferior turbinate artery, a branch of the sphenopalatine artery [2, 25–27]. Dissection of the ITF can be tedious, as the conchal bone of the inferior turbinate is densely attached to the underlying mucoperiosteum of the inferior turbinate mucosa. It should be noted that the ITF can be extended to include mucosa of the nasal floor or even septum, when larger defects are encountered [27].

Although more rarely utilized, additional alternatives exist including the middle turbinate flap, based on the middle turbinate artery, and various flaps of septal and lateral wall mucosa based on the anterior ethmoid artery [2, 11, 26].

Regional Extranasal Pedicled Flaps

When intranasal pedicled options are not available due to tumor contamination or previous surgery, regional extranasal pedicled flaps are an option. Although a number of options have been described including the palatal flap and buccinator flap [5, 28], the two most commonly utilized extranasal options are the pericranial flap (PCF) and the temporoparietal fascial flap (TPFF).

The PCF provides optimal coverage for large midline defects of the anterior cranial base ("endoscopic craniofacial resection") that extend from the posterior table of the frontal sinus to the planum sphenoidale. Such defects often exceed the reach and surface area of a NSF, especially when the NSF has been compromised by resection of the superior nasal septum. The PCF can be harvested as a unilateral hemi-flap or bilaterally as a large single flap [2]. It is based on the supraorbital and supratrochlear arteries which are branches of the ophthalmic artery. Harvest is typically carried out via a traditional bicoronal incision and approach, although endoscopic harvesting has also been described [11, 26, 29]. After harvesting the flap, it is then introduced into the nasal cavity via a nasotomy or osteotomy at the level of the nasion below the frontal sinus and plane of the anterior cranial base as an extracranial PCF. The flap pedicle is displaced to one side when possible to preserve drainage of the frontal sinus via a Draf-3 frontal sinusotomy.

The TPFF is a laterally based regional option which receives its blood supply from the superficial temporal artery. It requires a fairly extensive external dissection of the scalp in a subdermal plane, usually with a hemicoronal scalp incision carried inferolaterally to the preauricular area [4, 6, 8, 26]. This flap is typically utilized in combination with an endoscopic ipsilateral transpterygoid approach. A tunnel is created via the infratemporal fossa, allowing passage of the flap to the nasal cavity via the maxillary sinus and pterygopalatine fossa. It is ideally suited for sellar and mid-clival defects.

Reconstructive Algorithm

It is useful to develop a reconstructive algorithm based on the size and location of the skull base defect (Fig. 7.6). As mentioned previously, small defects (<1 cm) can be reconstructed using multilayered fascia/fat/mucosa grafts with good success. Small defects, especially at the cribriform plate, can also be reconstructed with a tailored mini-nasoseptal flap that preserves the mucosa of the inferior half of the septum.

Large clival defects pose a special challenge due to the difficulty of getting good apposition of tissue layers inferiorly and the high-flow nature of the intraoperative CSF leak. A four-layer reconstruction is used for such defects, consisting of an inlay collagen graft, onlay fascia lata graft, fat graft, and a vascularized NSF (Fig. 7.7a). The integrity of the reconstruction inferiorly can be strengthened by suturing of the

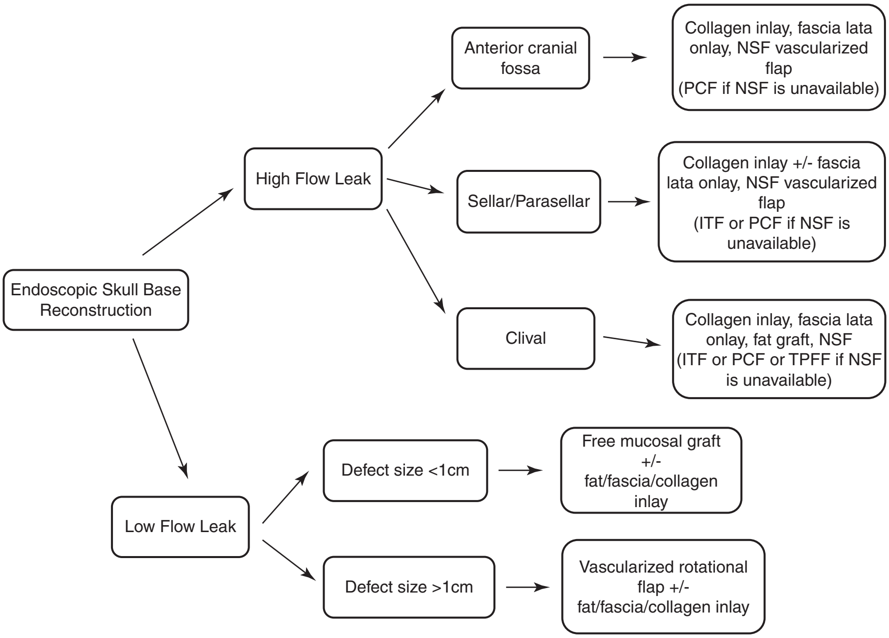

Fig. 7.6 A reconstructive algorithm for endoscopic skull base reconstruction. *PCF* pericranial flap; *NSF* nasoseptal flap; *ITF* inferior turbinate flap; *TPFF* temporoparietal fascial flap

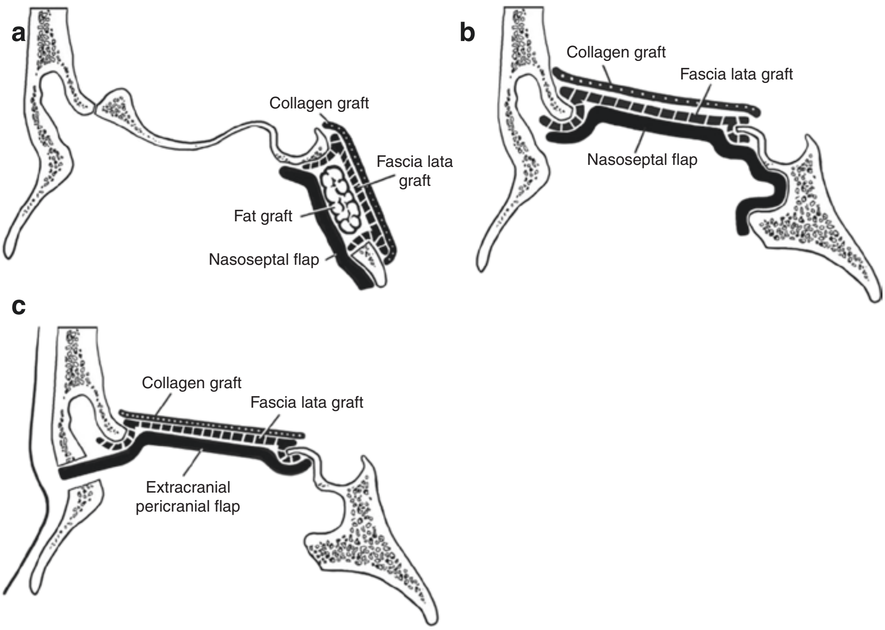

Fig. 7.7 A multilayer reconstructive algorithm demonstrating (**a**) clival defect repair; (**b**) anterior cranial base defect repair with nasoseptal flap; (**c**) anterior cranial base defect repair with extracranial pericranial flap

fascia lata to the retropharyngeal fascia. The V-Loc suture (Ethicon, USA) facilitates a running stitch that doesn't require the difficult task of tying [30]. The first backup for vascularized tissue if an NSF is unavailable or fails is an ITF or lateral nasal wall flap. If neither of these flaps are available, a TPFF or extracranial PCF may be utilized [2].

For large defects of the anterior cranial base, our preferred reconstructive method is a multilayer reconstruction using an inlay collagen graft, onlay fascia lata graft, and a vascularized NSF (Fig. 7.7b). When an NSF is inadequate or unavailable, an extracranial PCF substitutes for the NSF (Fig. 7.7c). The larger surface area of the PCF is ideal for simultaneous reconstruction of the orbit when periorbita is resected for an oncologic margin.

Postoperative CSF Leak

Ultimate success of the reconstruction includes addressing risk factors for postoperative CSF leak and proper recognition and repair when a leak occurs. Elevated intracranial pressure is a primary source of failure and is associated with patient activity, prior surgery, obesity, obstructive sleep apnea, and aseptic meningitis [31]. CSF pressure may be lowered postoperatively with the administration of acetazolamide or CSF diversion. A randomized trial of CSF diversion in patients undergoing endoscopic endonasal surgery of the skull base with high-flow defects demonstrated a clear benefit of CSF diversion with a lumbar spinal drain for large anterior and posterior fossa defects but not for sellar/suprasellar defects [32]. Prompt recognition and treatment of a postoperative CSF leak with endoscopic surgical techniques will shorten the exposure time and lessen the risk of meningitis.

Free Tissue Transfer

Free flap reconstruction plays a vital role in extensive cranial base defects when other options are limited or when adequate local blood supply is severely compromised in cases such as osteoradionecrosis. When bone is required, such as large orbital defects, fibula free flaps or scapular tip free flaps may be utilized for their combination of bone and soft tissue [4, 6, 11]. When only soft tissue is required, anterolateral thigh (ALT) flaps and radial forearm free flaps (RFFF) are commonly utilized. The ALT has the advantage of added soft tissue bulk when needed while the RFFF has a long pedicle length and pliable thin tissue to orient into challenging defects. When an ongoing CSF leak occurs in an area of severe compromised vascularity, such as osteoradionecrosis following adjuvant radiotherapy, free tissue transfer can allow for introduction of fresh blood supply from surrounding arterial sources to help improve the chances of healing the leak.

Conclusion

Endoscopic skull base reconstruction has undergone extensive evolution over the past 20 years. A multitude of options currently exist for reconstruction including avascular grafts, local vascularized flaps, regional vascularized flaps, and free tissue transfer. The choice of reconstructive method is individualized depending on patient characteristics, reconstructive needs, available reconstructive options, and experience of the surgeon. The risk of postoperative CSF leak can be minimized with the use of vascularized tissue and appropriate utilization of CSF diversion.

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