INTRODUCTION

Reconstruction of the skull base is typically a multistep process involving a variety of different tissues including soft tissue, bone, and dura. The ultimate goal is to create a functional seal that separates the intracranial and extracranial compartments in a watertight fashion to prevent cerebrospinal fluid (CSF) leak and meningitis, and to obliterate dead space, while optimizing cosmesis and function. In the age of minimally invasive surgery, the latter is more easily realized with endoscopic technique. The term "expanded endonasal approach" (EEA) has now come to describe all approaches that access the anterior, middle, and posterior cranial fossa without the same morbidity that traditionally surrounds open craniofacial approach.1 The development of image guidance systems, intraoperative nerve monitoring, and cost effective imaging have made this technique safe and practical. Elderly patients with multiple comorbidities stand to benefit the most from minimally invasive approaches that can shorten hospital inpatient duration and decrease recovery times.1 Nonetheless, patient selection remains paramount in preventing uncommon, but significant morbidity. Early complications can include infection (meningitis, osteomyelitis, abscess, etc.), pneumocranium, dural exposure, and CSF leak, while late complications involve facial deformity, nasopharyngeal stenosis, trismus, orbital malposition, malocclusion, or nasal obstruction.2 Presurgical planning and conversion to an open technique are critical in certain cases to prevent these complications. In particular, the increasing expertise of free tissue transfer over the past decade has produced a steady drop in complications, and yields a large amount of vascularized tissue in a region with relatively few dependable local vascular flaps.2

Initially, endonasal surgery was considered inadequate for achieving traditional en-bloc resection of tumors with negative margins.1 Patel et al. confirmed negative margins as an independent predictor of overall survival (65.7% vs. 32.8%, p<0.0001, CI: 1.8-2.9) in a series of 1,307 patients who underwent open craniofacial resection.3 However, negative margins are extremely difficult to achieve even in the setting of adequate exposure. In a follow-up study, Cohen et al. reported a 17% incidence of positive margins in both endoscopic and open resections of craniofacial tumors, indicating no additional benefit of achieving negative margins with open versus endoscopic technique.4 One must consider that while other studies have corroborated these results, higher grade tumors are more likely to be stratified into open resection and more research is needed before they may be considered equally well suited for endoscopic techniques.1 Although short-term data suggests comparable outcomes between the two approaches, long-term survival data is not available and some tumors such as esthesioneuroblastoma have been known to recur close to a decade after resection.5

PREOPERATIVE EVALUATION AND INDICATIONS

The initial workup for endoscopic skull base reconstruction should consider the defect size, need for bone restoration, extent of skin, mucosal, and soft tissue involvement. Other factors such as infection status, intracranial pressure, and surgeon experience are considered. History of radiation to the region, and also future postoperative radiation must both be considered and anticipated. Poorly vascularized structures will not tolerate radiation therapy resulting in delayed wound healing and potentially life-threatening complications including intracranial complications.26 The amount of anticipated dural involvement should also be recognized, as a postoperative watertight seal to prevent CSF leak is the most important goal of reconstruction. When possible, vascularized tissue should be utilized to repair these defects as it can help prevent desiccation from the respiratory tract.2 If the patient has
received previous radiation, or is anticipated to require future therapy, then nonvascularized grafts such as bone graft should be covered in vascularized tissue. Finally, it is important to assess any expected cranial nerve deficits following the resection and employ any reconstruction options that could facilitate rehabilitation of swallowing, speech, or facial movement.

Most surgeons would agree that very few skull base defects mandate bony replacement unless there is not adequate vascular tissue to cover the exposed dura. In one prospective study, Lee et al. showed no statistical difference between an underlay (turbinate composite graft, turbinate mucosal graft, or Dura substitute) and an overlay (free turbinate graft) technique for successful repair of endoscopic CSF leak (87.5% vs. 91.3%, p = 0.792). If the defect was >1 cm, a turbinate composite graft including bone was used for the repair.

True contraindications to a purely endoscopic approach include tumors with orbital involvement, lateral recess of the frontal sinus involvement, anterior table of the frontal sinus involvement, dura involvement beyond the midorbital roof, or facial soft tissue involvement. Endoscopic assisted craniofacial resection can also be considered in these cases. In severe cases, unresectable tumors may occasionally be palliated with endoscopic decompression of critical structures such as cranial nerves or major vessels.

TREATMENT ALGORITHM

Small, favorable defects with bony ledges to support an underlay graft may be reconstructed with a wide range of nonvascularized materials that will be discussed later in the chapter. However, in the setting of large defects without bony ledges, or particularly with any prior or postoperative radiation, the reconstructive plan should involve a vascularized graft (Flowchart 30.1). The choice of flap depends on defect size, defect site, high versus low-pressure CSF leak, and tissue availability (Table 30.1). If there is no CSF leak encountered during the resection, vascular tissue is preferred if the dura is thin, or unlikely to heal, as in the setting of prior or postoperative radiation. If there is a low flow CSF leak encountered (defined as a suspected leak after dural opening without violation of the ventricle or arachnoid cistern), both the site and size of the defect go into the decision making for choosing a secondary flap. In the setting of a high flow CSF leak (defined as violation of the ventricle or arachnoid cistern), the site of the leak is the major determinate (Flowchart 30.2). Larger, more hardy flaps are preferable in the setting of a high flow leak to counter the increased risk of postoperative CSF leak. If the defect size and location are adequate, intranasal vascularized flaps should be explored prior to resorting to endoscopic assisted flaps or open reconstruction.

The nasoseptal flap is the preferred local vascularized flap in skull base reconstruction. When the nasoseptal flap is unavailable, the anterior lateral nasal wall flap is a reliable secondary flap. However, the pedicle may often be compromised in cases of large transcortiform resections. The inferior turbinate flap (posteriorly based) is appropriate for small clival or sellar defects, but is limited by size. Defects >1 cm even in the setting of no CSF leak may require a dermal graft or fat bolster in addition to the flap due to limited bulk. The posteriorly based inferior turbinate flap has a short pedicle and is unable to reach the anterior cranial fossa or suprasellar region. However, the anterolateral nasal wall flap and anteriorly pedicled inferior turbinate flap have sufficient reach for anterior skull base defects. The middle turbinate flap can also be utilized for reconstruction of small (<1 cm) transsphenoidal or anterior cranial fossa defects, but is largely discouraged due to technical difficulty.

When intranasal flaps are not available or when there is a very large skull base defect with high CSF leak, tunneled pericranial flaps or temporoparietal fascia flaps can be used depending on the location. The pericranial flap is harvested on the ipsilateral side of the defect and is ideal for anterior or middle cranial fossa defects. The temporoparietal fascia flap is ideal for middle cranial fossa or lateral nasopharyngeal defects, but is limited in reaching the anterior cranial fossa.

When the above-mentioned flaps are not available, other regional flaps can be utilized, although these have not been studied in a large number of patients. Examples include the facial artery buccinator flap for an anterior cranial fossa defect, the occipital flap for a posterior defect, and the palatal flap.

In theory, a pediced palatal flap can reach all areas of the skull base, but is difficult to harvest and should be used as a last resort due to the lack of sufficient outcome data and donor site morbidity. Lastly, microvascular tissue transfer is utilized for large defects or if local vascular grafts are not available.

Open skull base reconstruction for massive defect (>5 x 5 cm) + large brain parenchyma loss → No → Endoscopic skull base reconstruction

Yes → Moderate brain parenchyma volume loss → Large brain parenchyma volume loss → Intraoperative CSF leak

Radial FF → 1. ALTFF → 2. Rectus FF → 3. Latissimus pedicled or FF

High flow (see Chart 30.2) → Low flow

Defect site → Transellar → Anterior cranial fossa

Fat obliteration of sphenoid sinus → Vascular tissue flap

Defect size → Large > 2 cm → Small < 1 cm

Vascular tissue flap → Fascia → Fat (batch-plug technique)

Mucosal graft → Sinus obliteration with fat → Vascular tissue flap → Do nothing → Extracranial reconstruction

Source: Modified from Patel et al.

ENDOSCOPIC SKULL BASE RECONSTRUCTION

Vascularized Tissue

Nasoseptal Flap

The nasoseptal flap has become the workhorse of skull base reconstruction, and revolutionized endoscopic reconstructive surgery. Previously, endoscopic repair of small skull base defects was limited by the unacceptably high rate of CSF leaks, but the introduction of the vascularized nasoseptal flap made large skull base defect repair feasible. Harvesting of the flap involves elevation of the septal mucoperiosteum and mucoperichondrium pedicled on the posterior septal branch of the sphenopalatine artery (Fig. 30.1). The flap is capable of providing 25 cm² of vascular tissue with an ability to reach from lamina to lamina, anteriorly to the frontal recess, and posteriorly to the inferior clivus. While the average defect that can be covered by the flap is 8.64 cm², one can increase the width of the flap to accommodate larger defects by including the nasal floor mucosa. Although the flap has a reported overall CSF leak rate of 3.2–5%, large dural defects, pediatric patients, and prior radiation exposure have been shown to increase this risk. Patel et al. published a prospective series of 150 patients with an overall 4% postoperative CSF leak (four with high flow intraoperative leak and two with a low flow intraoperative leak).

Surgical Technique

One percent lidocaine with 1:100,000 epinephrine is injected submucosally along the septum bilaterally using a 0-degree endoscope that aids with hydrodissection of
<table>
<thead>
<tr>
<th>Technique</th>
<th>Flap Description</th>
<th>Size available</th>
<th>Ideal reconstruction location</th>
<th>Benefit</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endoscopic</td>
<td>Nasoseptal arterial pedicle</td>
<td>25 cm²</td>
<td>All</td>
<td>Large and reliable</td>
<td>Possible nasolacrimal duct injury</td>
</tr>
<tr>
<td></td>
<td>Lateral nasal wall arterial pedicle</td>
<td>&gt; 5 cm²</td>
<td>Anterior cranial fossa to sella</td>
<td>Flap of choice</td>
<td>Flap tends to hold convex shape after harvest</td>
</tr>
<tr>
<td></td>
<td>Anterior ethmoidal arterial pedicle</td>
<td>4.7 cm x 1.8 cm</td>
<td>Frontal sinus to planum</td>
<td>Reliable vascularity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior pedicle</td>
<td>5.4 cm x 2.2 cm</td>
<td>Posterior cribiform plate, sella, clivus</td>
<td>Large</td>
<td>Possible nasolacrimal duct injury</td>
</tr>
<tr>
<td></td>
<td>Middle Turbinate branch of SPA</td>
<td>5 cm²</td>
<td>Small defects of the fovea ethmoidalis, planum, or sella</td>
<td>Can combine with NSF for very large defects</td>
<td>Limited reach posteriorly</td>
</tr>
<tr>
<td>Endoscopic assisted</td>
<td>PCE arterial pedicle</td>
<td>200 cm²</td>
<td>Anterior cranial fossa to sella</td>
<td>Hardy and versatile</td>
<td>Hard to reach posterior cranial fossa</td>
</tr>
<tr>
<td></td>
<td>TPFF arterial pedicle</td>
<td>140-170 cm²</td>
<td>Parasellar region, clivus</td>
<td>Reliable vascularity</td>
<td>Arc of rotation can compromise pedicle with limited reach involving the anterior cranial fossa</td>
</tr>
<tr>
<td></td>
<td>Palatal flap</td>
<td>18 cm²</td>
<td>Planum, sella, clivus</td>
<td>Large and pliable</td>
<td>Technically difficult</td>
</tr>
<tr>
<td></td>
<td>Open Radial forearm</td>
<td>54 cm²</td>
<td>Large defects</td>
<td>Highly reliable</td>
<td>Requires hemiconoral incision</td>
</tr>
<tr>
<td></td>
<td>Rectus abdominis</td>
<td>240 cm²</td>
<td>Large defects</td>
<td>Thin and pliable</td>
<td>Possible CNV injury</td>
</tr>
<tr>
<td></td>
<td>Anterolateral thigh flap</td>
<td>~450 cm² or more</td>
<td>Large defects</td>
<td>Can be harvested as fascial, fasciocutaneous, or osteocutaneous</td>
<td>Donor site morbidity</td>
</tr>
<tr>
<td></td>
<td>Deep inferior epigastric artery</td>
<td>8 x 25 cm with primary closure</td>
<td>Large defects</td>
<td></td>
<td>Can result in abdominal wall hernia</td>
</tr>
<tr>
<td></td>
<td>Descending branch of lateral femoral circumflex artery</td>
<td>~450 cm² or more</td>
<td>Large defects</td>
<td></td>
<td>Variable vessel anatomy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ambulate well postop.</td>
<td>Variable muscle atrophy over time</td>
</tr>
</tbody>
</table>

High flow CSF leak

Defect site

Sellar/transplanar

- Sphenoid sinus
- Fat obliteration
- Vascular tissue flap
  - 1. NSF
  - 2. Posterior ITF
  - 3. PCF
  - 4. TPFF or MTF
  - 5. PF

Transcival

- Small defect <1 cm
- Vascular tissue flap
  - 1. NSF
  - 2. ITF
  - 3. TPFF

- Large defect >1 cm
- Fat obliteration
  - 1. NSF
  - 2. TPFF
  - 3. ITF
  - 4. PF

Anterior cranial fossa

- +Bony ledge
- Vascular tissue flap
  - 1. NSF
  - 2. Anterior ITF
  - 3. ALNWF
  - 4. MTF
  - 5. PCF

- -Bony ledge
- Fascia
  - 1. NSF
  - 2. Anterior ITF
  - 3. ALNWF
  - 4. PCF

Source: Modified from Patel et al.

Fig. 30.1: Vascular anatomy of the lateral nasal wall. Understanding the location of flap pedicle vessels is vital for successful local flap reconstruction.

the septal mucosa. Pledgets soaked in topical cocaine or oxymetazoline are placed in both nasal cavities in direct contact with the inferior turbinate for decongestion.

After adequate decongestion, a 0-degree endoscope is used to assess the surgical field. A middle turbinectomy is performed on the septal flap harvest side if there is limited space available for instrumentation. Using endoscopic scissors, the middle turbinate is transected superiorly along the skull base. Once the superior attachment has been sharply transected, the middle turbinate is removed in its entirety. Next, the sphenoid rostrum is identified. If visualization of the rostrum is obstructed by a large superior turbinate, the inferior half of the superior turbinate is transected sharply with a thru-cutting Blakesley
forceps. The posterior septal branch enters the septal mucosa along the rostrum from a lateral to medial direction. Using a Colorado tipped bovie, a mucosal incision is made along the septum, centered along the sphenopalatine rostrum. A trapezoid shaped incision is made along the septum to maximize the amount of septal mucosa that can be harvested depending on the size of the flap needed (Figs. 30.2A and B). The bovie is then used to make a superior mucosal incision along the superior edge of septum with an extension anteriorly toward the caudal septum. The incision should only go through the septal mucosa and not incise the underlying septal cartilage. Another inferiorly located incision is extended from the inferior edge of the rostrum along the inferior septum from a posterior to anterior direction, paralleling the nasal floor. Next, using a McCullough elevator, a subperichondrial dissection is performed. The septal mucosal flap is then raised in an anterior to posterior direction and can be tucked away in the nasopharynx until the surgical site is ready for reconstruction.

Once the septal flap has been raised, a septraphy with septal cartilage harvest can proceed if necessary. Using a 15-blade, the septal cartilage graft is harvested, leaving 1–1.5 cm of cartilage along the L-strut for dorsal and caudal septal support. The contralateral septal mucosa is left intact. Once the septal cartilage is removed, septal bone can also be harvested. Various septal scissors can be used to transect the superior septal attachment to the skull base. Once the superior septal attachment has been transected, inferiorly located septal bone is removed and set aside for grafting.

Upon the removal of posterior septal bone, a bilateral sphenoidotomy can be easily performed, if necessary. It is important to minimize trauma to the septal mucosa overlying the sphenoid rostrum on the septal flap side to protect the flap pedicle vascularity.

Once the nasoseptal flap is ready for reconstruction, the bony ledge around the defect is cleared of mucosa. An underlay bone or fat graft can be placed if desired. The mucoperiosteal side of the nasoseptal flap is laid into position. Fibrin glue or DuraSeal can be placed for a watertight seal. Gelfoam packing is placed from below to help support the flap in proper position. Merocel packing can be placed and removed after 1–2 weeks.

**Middle Turbinate Flap**

The middle turbinate flap is able to close small defects involving the fovea ethmoidalis, planum sphenoidale, or sella. It is based on the middle turbinate branch of the sphenopalatine artery, and is able to provide approximately 5 cm² of vascular tissue. Simal et al. performed a retrospective analysis of 10 patients who underwent a
middle turbinar flap reconstruction and reported 0 cases of postoperative CSF leak. The flap has somewhat fallen out of favor due to harvesting difficulties. Elevation of the flap requires destabilization of the bony attachment to the skull base and the lateral nasal wall, which can make subperiosteal dissection of mucosal flap technically difficult. Moreover, there has been a reported high rate of variations in pedicle location—as much as 25%—which can make identification and preservation of the pedicle difficult.

Surgical Technique

The middle turbinar on the side of the defect is generally used. Nasal pledgets soaked in decongestant are placed. After adequate decongestion, 1% lidocaine with epinephrine is injected along the anterior, medial, and lateral surfaces of the middle turbinar. A vertical incision is made at the anterior head of the middle turbinar and the mucoperiosteum is elevated from the underlying bone (Figs. 30.3A to C). One must remain in subperiosteal plane to avoid injury to the pedicle. The superior attachment of the middle turbinar to the skull base is sharply transected with a through-cutting Blakesley forceps or septal scissors to minimize the risk of a CSF leak. A rongeur can be used to remove the middle turbinate bone in a piece meal fashion once mucoperiosteum is elevated along the medial and lateral surfaces of the middle turbinate bone. Mucosal incisions are then made along the medial and lateral surfaces of the middle turbinar near the axilla, allowing the flap to open like a book. Careful posterior dissection must be employed to protect the flap pedicle, which is a branch of the sphenopalatine artery. If additional length is needed, the pedicle can be dissected back to the sphenopalatine foramen. Once harvested, the flap can then be stored in the nasopharynx, maxillary sinus, or glued to the lateral nasal wall until needed for the reconstruction.

Inferior Turbinar Flap

The inferior turbinar flap is ideal for patients who have undergone prior surgery that compromises the nasoseptal flap. A posteriorly based inferior turbinar flap, based on the posterior lateral nasal artery, can be used for skull base defects involving posterior cribiform plate, sella, planum sphenoidal, or posterior cranial fossa. However, it has limited reach to the anterior cranial fossa. The posteriorly based inferior turbinar flap is based on the posterior lateral nasal artery, which arises from the sphenopalatine artery (Figs. 30.4A and B). The flap has 5.4 cm length, 2.2 cm width and offers approximately 2.4 ± 1 cm² surface area. Bilateral flaps can be harvested for larger defects. Fortes et al. reported a series of four patients with a posteriorly based flap without any postoperative complications. Patel et al. recommend a fat bolster to be used in conjunction with the inferior turbinar flap in defects >1 cm to increase tissue bulk.

The inferior turbinar flap can also be based anteriorly on the anterior ethmoidal artery or angular artery, and is ideal for anterior skull base defects involving the posterior table of the frontal sinus and extending to the sella.
Figs. 30.4A and B: Surgical technique for posteriorly based inferior turbinate flap. (A) Sphenopalatine artery is identified as it exits the foramen near crista ethmoidalis. Superior and inferior cuts of flap made (dotted line). (B) The inferior turbinate flap is pedicled posteriorly at the sphenopalatine artery. The flap can be rotated posteriorly for reconstruction of sella or nasopharyngeal defect.

Figs. 30.5A and B: Incisions for anteriorly based inferior turbinate flap. (A) The incision for the anteriorly based inferior turbinate flap and (B) the superior extension of the incision to allow for maximal pedicle length and rotation. (AEA: Anterior ethmoidal artery; GPA: Greater palatine artery; ITA: Inferior turbinate artery; LNA: Lateral nasal artery; PEA: Posterior ethmoidal artery; SPA: Sphenopalatine artery).

(Figs. 30.5A and B). It has also been used successfully for nasal lining reconstruction and septal perforation repair.²¹ The flap is reported to have 1.8 cm in width and 4.7 cm in flap length, offering 4.31 cm² of surface area. Amit et al. performed a case series of 10 patients with a high flow CSF leak, in which there were no postoperative CSF leaks and 100% flap survival.²²

Nasal crusting is the morbidity associated with the flap, which resolves over the course of 1–2 months with mucosalization of the field. Great care should be taken to preserve mucosa near the valve of Hasner in the inferior meatus to prevent nasolacrimal duct injury.²³²⁴ The anteriorly based flap should be performed with caution if a Lothrop procedure has been performed, as the vascular supply may have been violated.²⁵ Although a varying amount of inferior turbinate bone can be included in the flap, there is a potential risk of chronic nasal obstruction from atrophic rhinitis when the entire inferior turbinate bone is removed.

**Surgical Technique**

**Posterior Pedicled Inferior Turbine Flap**

The posteriorly based pedicle is located on the superior aspect of the lateral attachment of the inferior turbinate, approximately 1–1.5 cm from the posterior tip of the
The flap is generally harvested on the same side as the defect. Flap harvesting begins with nasal decongestion using nasal pledgets. The inferior turbinate, nasal floor, and inferior meatus are then injected with 1% lidocaine with 1:100,000 epinephrine. The inferior turbinate is first medialized for visualization. The sphenopalatine artery is identified as it exits the sphenopalatine foramen. A limited mucosal incision superior to the lateral attachment of the superior turbinate along the posterior half of the inferior turbinate is made. Submucosal dissection is performed in an anterior to posterior direction until the crista ethmoidalis is identified. The crista ethmoidalis is a reliable landmark that is located 0–3 mm anterior to the sphenopalatine foramen. Once the sphenopalatine artery (SPA) has been identified, a sagittally oriented mucosal cut is made along the superior aspect of the inferior turbinate with a Colorado tip monopolar cautery away from the pedicle. One should avoid injury to the maxillary sinus outflow and attempt to preserve the anterior and posterior fontanelle. An inferiorly placed sagittal incision is made along the inferior ledge of the inferior turbinate. One should avoid injury to the nasolacrimal duct opening in the inferior meatus by not extending the incision past the apex of the inferior meatus. Next, a vertical incision is made along the anterior head of the inferior turbinate connecting the superior and the inferior mucosal incisions. Using endoscopic visualization, the mucoperiosteum is raised in an anterior to posterior direction using either a suction freer or a McCullough elevator. The inferior turbinate bone can also be raised with the flap but if the bone is left preserved, it will mucosalize over time and minimize the potential risk of atrophic rhinitis. The entire inferior turbinate mucosal lining is harvested with a variable additional mucoperiosteum from the nasal floor or fontanelles. Care must be taken to avoid violating the pedicle as it enters the inferior turbinate posteriorly at the superior aspect of the lateral attachment approximately 1–1.5 cm from the posterior tip of the inferior turbinate. The posterior lateral nasal artery should also be preserved as it descends vertically over the ascending process of the palatine bone. Once the flap is raised, it can be manipulated into the site of defect for reconstruction. The mucoperiosteal side of the flap is applied against bare bone or dura. Fibrin glue or DuraSeal can be placed over the flap and gelfoam can be used to support the flap. The nasal cavity with the flap can be lightly packed for 1–2 weeks with a topical-antibiotic covered soft sponge. After removal in 1–2 weeks, the patient should begin nasal irrigations two to three times daily.

**Anterior Pedicled Inferior Turbinate Flap**

After nasal decongestion with nasal pledgets, 1% lidocaine with 1:100,000 epinephrine is injected along the full length of the inferior turbinate, nasal floor, and inferior meatus. The inferior turbinate is first fractured medially using a freer to improve visualization of the inferior meatus. A middle turbinectomy can be performed if there is limited exposure, though it is not always necessary. A needle tip electrocautery device is used to perform a vertical incision anterior to the head of the inferior turbinate from the level of the nasal bone to the nasal floor following the pyriform aperture. A posterior incision is made along the lateral nasal wall following the lacrimal bone immediately anterior to the uncinate process. Between these two incisions lies the pedicle. Sagittally oriented cuts are then made over the superior aspect of the inferior turbinate, as well as inferiorly along the maxillary crest at the junction of the floor of the nose and nasal septum. The mucoperiosteum is elevated in an anterior to posterior direction with a suction Freer Elevator or a McCullough elevator. While performing submucosal dissection near the posterior tip of the inferior turbinate, one can find branches from the sphenopalatine artery, which can be either clipped or cauterized. The bone of the inferior turbinate is left in place for re-epithelialization, which results in mucosalization over time. If the length of the flap needs to be increased, the anteriorly located vertical incision can be extended superiorly, which can provide an extra 1–2 cm of pedicle length. Use of a 30-degree or a 70-degree scope may be helpful for making the superior incision near the skull base to avoid a CSF leak. The superior extension should taper back anteriorly toward the anterior table of the frontal sinus to minimize the risk of narrowing the pedicle mucosal width overlying the anterior ethmoidal artery. The superior extension of the posteriorly located incision along the uncinate should be designed to avoid a mucosal injury around the frontal recess near the axilla of the middle turbinate, which will minimize the risk of frontal sinus obstruction or future mucocele formation.

It is important that the mucoperiosteum side of the flap faces the defect. The defect site should be debrided of mucosa along the margins to expose bare bone prior to flap placement. Inferior turbinate flaps can be secured with absorbable sutures when used in nasal lining reconstruction, septal perforation repair, or palatal fistula repair.

If the flap cannot be readily secured with a suture, DuraSeal or fibrin glue with layers of gelfoam packing can be applied.
Fig. 30.6: Incisions for anterior lateral nasal wall flap. Notice similarity between anteriorly based inferior turbinate flap with an extension of the inferior incision over the nasal floor (black arrow). The anterior incision near the inferior meatus should avoid the nasolacrimal duct opening. (ST: Superior turbinate; MT: Middle turbinate; IT: Inferior turbinate).

for support. The nasal cavity with the flap can be lightly packed for 1–2 weeks with a topical-antibiotic covered soft sponge. After removal in 1–2 weeks, the patient should begin nasal irrigations two to three times daily.

Anteriorly Based Lateral Nasal Wall Flap

The lateral nasal wall flap is a recently described option for reconstruction from the crista galli to the tuberculum sella when the nasoseptal flap is unavailable. It is similar in design to the anteriorly pedicled inferior turbinate flap, but extends along the lateral nasal wall and the nasal floor, offering more surface area (Fig. 30.6). Based off the lateral nasal artery (which arises from facial artery) and anterior ethmoidal artery, the flap can be combined with a nasoseptal flap for coverage of large defects. A recent series by Hadad et al. reported on three patients who underwent the lateral nasal wall flap with uneventful postoperative courses. However, the flap tends to hold the shape of the inferior turbinate after harvest, and may require manipulation to accomplish adequate inset.

Potential morbidity from the flap includes transient crusting until the donor site is fully mucosalized, and nasolacrimal duct injury.

Surgical Technique

Nasal pledgets are used to decongest the nose. One percent lidocaine with 1:100,000 epinephrine is injected along the lateral nasal wall, inferior turbinate, inferior meatus, and nasal floor. The inferior turbinate is fractured medially for visualization. An anterior vertical incision is made from the caudal edge of the nasal bones following the anterior border of the piriform aperture, and extended inferiorly to the superior aspect of the head of the inferior turbinate (Fig. 30.7). A posterior vertical incision is made along the lacrimal bone anterior to the uncinate process. The posterior incision is then extended in a sagittal orientation along the superior aspect of the inferior turbinate, just inferior to the uncinate. The inferior half of the middle turbinate can be removed to improve visualization if necessary. At the most posterior aspect of the superior sagittal incision, the sphenopalatine artery must be clipped or cauterized. The crista ethmoidalis is a useful landmark to identify the sphenopalatine artery. From the posterior tip of the inferior turbinate, an incision oriented in the coronal plane is carried from the superior aspect of the inferior turbinate, inferiorly through the posterior end of the turbinate, and on to the junction of the septum and the nasal floor. The vertical anterior incision is extended down along the anterior head of the inferior turbinate and
onto the floor of the nose to the junction of the septum. The two coronal incisions are then joined by a sagitally oriented incision that follows the maxillary crest along the inferior aspect of the septum. During harvesting of this flap, the nasolacrimal duct should be protected by curving the anterior incision around the duct, or by making an elliptical incision around it. A mucoperiosteal flap is raised with a suction Freer Elevator or a McCullough elevator in an anterior to posterior direction starting from the anterior head of the inferior turbinate. Once the medial aspect of the turbinate has been raised, the lateral aspect (meatal aspect) is raised. This flap is then carried onto the lateral nasal wall while carefully sparing the nasolacrimal duct. The elevation of the flap is then connected onto the nasal floor. The mucosa is removed from the bony margins of the defect. Once the entire flap has been raised from the lateral nasal wall, it can be laid along the skull base defect. An underlay cartilage or bone graft can be placed if desired. The mucoperiosteal side of the flap should contact the defect. Fibrin glue or DuraSeal and layers of gelfoam should be applied. A Foley catheter or soft sponge packing may be employed for additional support and left in place for 1–2 weeks.

**Pericranial Flap**

The endoscopic pericranial flap has become a good alternative if the intranasal vascular flaps are unavailable or undesirable due to size limitations. It is ideal for large anterior skull base defects with high flow CSF leaks. The pedicle is based on the supraorbital and supratrochlear arteries, and can extend back from the orbital rim to the occiput on only one vessel. Due to some loss of flap length with the rotation of the flap into the nasal cavity, excess length should always be harvested. As the flap is rotated into the frontal sinus, there is a potential risk of frontal sinus obstruction that could result in future sinusitis or mucocele formation. For this reason, the procedure is usually accompanied by a Draf III procedure, which allows unilateral drainage of both sinuses should one side become scarred shut postoperatively. Although the technique does require a glabellar incision, meticulous closure and careful preoperative placement of the incision in a natural skin crease can minimize the amount of noticeable scarring on the face. This flap, after its introduction by Zanation et al., appeared to be used more frequently for large skull base defects with high flow CSF leaks. A case series by Patel et al. reported no flap failures in 16 patients.

**Surgical Technique**

Preoperatively, the patient’s hair is parted for a 2 cm port incision located in the midline and a second 1 cm lateral port incision made near the superior attachment of the temporalis fascia (Figs. 30.8A to I). A 1 cm horizontal glabellar incision is also planned to aid with endonasal placement of the flap. A Doppler is used to identify the location of the supraorbital and supratrochlear arteries.

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**Figs. 30.8A to C:** Pericranial flap harvest. (A) Pericranial flap is harvested using two access ports placed behind the hairline similar to an endoscopic brow lift. A surgeon can also use a bicoronal incision with an open approach to harvest the pericranial flap. Green dotted line marks the area of the planned pericranial flap harvest. Blue dotted line marks subgaleal dissection pocket that must be larger than the size of the pericranial flap for an adequate exposure. (B) The incision is carried down to the subgaleal plane and an elevator is used to create a subgaleal pocket down to the supraorbital rim using an angled endoscope. Be aware of the supratrochlear and supraorbital vessels that must be preserved. (C) A sagittal view of the subgaleal plane dissection on top of the pericranium.
Figs. 30.8D to L: (D) A 1cm horizontal incision is made in the nasion or in a natural skin crease near midline brow to assist in rotating the flap into the nasal cavity. Patient needs to have already undergone Draf III procedure. (E) A drill is used to enter the nasal cavity at the nasion by drilling along the nasofrontal suture line. (F) The opening should be wide enough to not constrict the flap blood supply. (G) Pericranial flap is raised in the subperiosteal plane (H) after incising the flap with a Bovie along its medial, lateral and posterior aspects. Lateral incision is medial to the temporal line. Avoid injury to the frontal branch of the facial nerve. (I) The pericranial flap is flipped inferiorly while leaving the supraorbital and supratrochlear vessels intact. (J) The pericranial flap has been pulled through the nasion incision. (K) The pericranial flap is transposed endonasally (L) through the nasofrontal suture line bony defect using an endoscope.
The pedicle width is approximately 3 cm. It is important to avoid crossing the midline to preserve the pericranial flap on the opposite side. Once the port incisions are made, dissection is performed in the subgaleal plane using an endoscopic brow lift set. This dissection can also be carried posteriorly to increase flap length. Once the dissection is carried to approximately 2 cm above the supraorbital rim, attention is turned to performing a subperiosteal dissection, isolating the pericranial flap. Two small vertical incisions at the medial and lateral margins of the planned pericranial flap are made through the pericranium to reach the subperiosteal plane. The subperiosteal plane dissection is carried anteriorly down to the supraorbital rim. Next, the horizontal glabellar incision is made and carried to the periosteum of the nasion. One must be careful not to disrupt the pedicle vessels as they exit from the supraorbital and supratrochlear foramina. From the medial aspect of the flap near the midline, subperiosteal dissection is performed through the glabellar incision until the previously tunneled subperiosteal plane is identified superiorly. Once the subperiosteal plane has been connected, a monopolar cautery with a bent protected tip can be used to incise the flap along the medial, lateral, and posterior aspects while it is still attached to the pedicle at the supraorbital rim. The medial and lateral incisions should extend down to the supraorbital rim to improve flap maneuverability. Next, a diamond bur is used to drill through the nasal bone at the level of the nasion creating a 4 mm (height) × 1.5 cm (width) bony gap to enter the sinonasal cavity as in a subfrontal approach. The flap is then passed through the glabellar incision and placed onto the defect once the bony margin is cleared of mucosa. Fibrin glue or DuraSeal can be applied on top of the flap. The flap is then bolstered into place with layers of gelfoam packing. A soft sponge packing can be placed for support. A drain is placed in the scalp donor site and soft tissue closed in multiple layers.

**Transpterygoid Transposition of a Temporoparietal Flap**

The temporoparietal flap can be transposed into the nasal cavity through a temporal-infratemporal soft tissue tunnel and a transpterygoid window (type A approach) as a secondary alternative to the intranasal flaps and the pericranial flap.\(^9,30\) The flap is based on the anterior branch of the superficial temporal artery, and is very reliable (Figs. 30.9A and B). The flap can also be folded on itself for multilayer coverage.\(^31\) Due to the limitation of rotation, this flap is not ideal for anterior skull base defects. However, it is becoming more popular for large defects in the sella, clivus, or nasopharynx with high flow CSF...
leaks. It offers a large amount of pliable graft material. A thorough history should be taken with particular attention to previous temporal artery biopsy or prior scalp radiation, both of which could lead to donor site ischemia and scalp necrosis.\textsuperscript{31} Due to transection of the vidian nerve in the transpterygoid approach, the patient may have dry eye symptoms postoperatively. Other potential morbidities include alopecia, temporal branch of facial nerve dysfunction, cranial nerve V dysfunction, and internal maxillary artery injury.

For this procedure, surgical anatomy of pterygopalatine fossa and infratemporal fossa regions requires careful attention. Imaginary vertical and horizontal lines intersecting the foramen rotundum and vidian nerve are useful for separating different regions (Fig. 30.10). The middle cranial fossa, petrous segment of the carotid, and the infratemporal fossa reside lateral to a vertical line intersecting the foramen rotundum. Medial to the vertical line intersecting the foramen rotundum and lateral to a vertical line intersecting the vidian canal lie the lateral recess of the sphenoid sinus and pterygopalatine fossa. Medial to a vertical line through the vidian canal (which is in line with the medial pterygoid plate) lies the sinusosal cavity. A horizontal line intersecting the vidian nerve separates the infratemporal fossa and the pterygopalatine fossa (located inferiorly) from the lateral recess and the petrous segment of the internal carotid (located superiorly). A horizontal line intersecting the foramen rotundum separates the petrous segment of the ICA (inferiorly) from the middle cranial fossa (superiorly).\textsuperscript{39}

**Surgical Technique**

Ideally, the donor site should be ipsilateral to the defect, although either side is technically feasible for harvest. If not previously performed in the resection, a total ethmoidectomy, a large mega antrostomy of the maxillary sinus, which removes the majority of the anterior and posterior fontanelle located posterior to the nasolacrimal duct, and a partial inferior turbinectomy are performed. The result should offer a wide view of the lateral and posterior maxillary sinus walls. The sphenopalatine artery and posterior nasal artery are identified and clipped near the sphenopalatine foramen.\textsuperscript{31} The crista ethmoidalis is a useful landmark for the identification of the sphenopalatine artery (SPA). Using a Kerrison Rongeur, the sphenopalatine artery is followed laterally along the posterior wall of the maxillary sinus, exposing the pterygopalatine fossa (Fig. 30.10). The entire posterior wall of the maxillary sinus should be taken down in a medial to lateral direction. Next, the lateral wall of the maxillary sinus is opened to expose the infratemporal fossa. Dissection through the fat pad is performed. The descending palatine artery is identified and clipped. Posterior to the vessels, the vidian nerve is identified and divided to allow displacement of the pterygopalatine ganglion. The pterygopalatine ganglion can be preserved. Next, the anterior aspect of the pterygoid plate is drilled down to create a communicating tunnel to the infratemporal fossa.

Using a hemicoronal incision, the temporoparietal fascia is harvested. After a scalp incision, the temporoparietal fascia is separated from the subcutaneous tissue as the scalp flap is raised anteriorly and posteriorly. The desired size of the flap is determined and elevated free from the underlying deep temporal fascia. Next, the deep temporal fascia is incised and separated from the underlying temporalis muscle. Dissection deep to the deep temporal fascia and superficial to the temporalis muscle will guide the surgeon to the zygomatic arch. A wide tunnel to accommodate the flap is made once the periosteal attachment to the zygomatic arch has been elevated. A soft tissue tunnel is then created through the temporalis muscle. Although Fortes et al.'s group initially used a lateral canthotomy to
dissect medial to the temporalis muscle toward the pterygomaxillary fissure, a more recent report by the group indicates that this incision is likely unnecessary.\textsuperscript{30} Using a percutaneous tracheostomy dilator, the soft tissue tunnel is dilated serially over a guide wire. The flap is then tied to one end of the wire and pulled through the tunnel into the nose (Figs. 30.11A to E). An underlay cartilage or bone graft can be applied, followed by the application of the
temporoparietal fascia flap once the mucosa around the defect margin has been cleared. Fibrin glue or DuraSeal can then be placed for additional support, followed by gentle packing with gelfoam. Gentle nasal packing should be utilized to bolster the flap in place.

The scalp incision is closed in multiple layers with buried 3-0 Vicryl sutures and 4-0 Prolene running sutures. A drain should be placed to minimize the risk of hematoma. A lumbar drain should be considered for 2–3 days in the setting of a high flow CSF leak. The nasal packing can be removed in 1–2 weeks.29

Postoperative Management of Endoscopic Reconstruction

The most significant morbidity associated with endoscopic nasal surgery is chronic nasal crusting. Because mucosa is removed, sinonasal ciliary clearing is affected, and the ability to humidify air is reduced.1 Patients should be treated with frequent saline irrigations (as much as 12 months postoperatively) and in-office debridement to minimize these sequelae.1 Patients should also be instructed to avoid blowing their nose to minimize the risk of pneumocephalus. Depending on the severity of CSF leak, a lumbar drain may be of benefit. When there is a concern of CSF leak, the patient is kept on strict bed rest immediately following the surgery for 3–5 days. Stool softeners help to minimize straining. The patient's activity can be gradually advanced once there is no sign of CSF leak after the lumbar drain has been clamped.

The length of perioperative antibiotics is a hotly debated topic given the theoretical risk of passing instruments through a contaminated nasal field to the intracranial space. Moreover, allografts used to repair the defects can serve as potential infection media. Despite these risks, the rate of central nervous system infection is relatively low. This may be due to under-reporting, as these complications are not well documented. Brown et al. performed a prospective study of 90 patients receiving endoscopic skull base surgery. All of the participants received either 24 or 48 hours of a single antibiotic [cefazolin (87%), vancomycin (10%), or clindamycin (3%)].30 The skull base was repaired through a variety of methods, including allograft placement. There were no documented cases of intracranial infections or meningitis. Twenty one percent of the patients received antibiotics again in the first 3 months of follow-up for intranasal infections, which were all successfully managed on an outpatient basis.31 The authors concluded that limited use of a single perioperative antibiotic should be sufficient in preventing intracranial infections. However, there was no control group included in the study.32 Other studies have confirmed that the use of antibiotics >48 hours beyond surgery confers no further benefit than limited perioperative use of 24–48 hours.33

Nonvascularized Tissues

Small defects <1 cm in diameter with minimal to no CSF leak, and without prior or future planned radiation therapy can be closed with a number of techniques and nonvascularized grafts. Choices include fascia lata or temporalis fascia, cadaveric fascia lata, lyophilized dura, cadaveric dermis, or autologous fat, cartilage or bone graft.6,28 These materials are generally used in conjunction with fibrin glue sealant or DuraSeal and supporting nasal packing. Ideally, the graft, with the exception of mucosal grafts, should be placed between skull base bone and dura. This method reduces the risk of separation of the graft from the skull base resulting in a CSF leak.6 Wormald and McDonagh coined the term “bath-plug” closure in which an autologous fat graft is placed in a defect with a previously placed suture along the length of the fat. As the suture is pulled, the fat is allowed to expand beyond the borders of the defect, and the CSF pressure is used to hold the graft in place.34 If bone is required, septal bone can be placed as an underlay graft. If unavailable, other options include split calvarial bone graft, rib, and iliac crest.6

Alloplastic Materials

The primary goal of skull base reconstruction is to create a seal that will prevent a CSF leak. Whenever possible, primary closure of any dural defect is ideal, usually with a running, locked technique. Fibrin glue or DuraSeal is a good adjunct to this method to ensure a watertight seal. Several sutures fastening the dura to drill holes around the periphery of the craniotomy can help to prevent pneumocephalus.32

Alloplastic materials should be used selectively, and avoided in people with compromised wound healing, active infection, a history of radiation, or anticipated postoperative radiation due to the risk of extrusion.4 In situations where alloplastic materials are not ideal, previously discussed vascularized flaps are the preferred method of reconstruction. There are numerous viable options that have been used in conjunction with vascularized grafts and DuraSeal or fibrin glue in order to create a watertight repair.
Expanded PTFE (PRE-CLIDE Dura Substitute, W. L. Gore & Associates, Inc., Flagstaff, AZ) is a three-layer polymer graft with a porous outer membranes, which can act to stimulate fibroblast ingrowth as well as an inner elastomeric fluoropolymer membrane, which is designed to create a watertight seal. Messing-Junger et al. performed a prospective multicenter trial of 119 patients undergoing CSF leak repair. Of these, 102 had intracranial implantation and 17 had spinal implantation. There were six cases of postoperative CSF leak, and two cases of infection. The authors concluded that the matrix was a safe and effective material in minimizing CSF leak.33

Bejjani et al. described the use of dural substitute derived from porcine small intestinal mucosa. Of 59 patients studied, there was a 1.7% rate of CSF leak, 3.4% rate of wound infection, and no cases of meningitis. The authors concluded that the lack of adverse reactions to the graft with a favorable safety profile made it an acceptable dural repair alternative.34 Comparable results have also been achieved with a similar material derived from acellular bovine collagen.35

DuraGen (Integra Neuroscience, Plainsboro, NJ) is a type I collagen matrix from bovine Achilles tendon, marketed as an onlay graft, which does not require sutures or a watertight seal. Danilsh et al. performed a retrospective review of 101 children treated for Chiari malformation that showed comparable rates of complication between AlloDerm (LifeCell Corp., Branchburg, NJ) and DuraGen with only one postoperative CSF leak in each group. DuraGen closure required significantly less operative time (92 vs. 128 min, p < 0.01). The authors concluded that both materials were acceptable dural substitutes.36

Dura-Guard (Synovis Surgical Innovations, Deerfield, IL) is a glutaraldehyde-processed bovine pericardium graft material that has become very popular in neurosurgery as it is easily prepared, available in large quantities, and is relatively inexpensive.37 Anson and Marchand performed a retrospective analysis of 35 patients implanted with Dura-Guard for dural repair, which had only two postoperative wound infections.38

DuraSeal Dural Sealant System (Covidien, Inc., Bedford, MA) is a polyethylene glycol hydrogel approved by the Food and Drug Administration for watertight closure after traditional dural suturing. In a prospective, randomized, single-blind trial of 237 patients with intraoperative identified CSF leak, there was a similar rate of complications between DuraSeal and a control “standard of care” repair of the dural defect. The DuraSeal group had significantly less preparation and application time.39

MedPor (Porex Inc., Newnan, GA) is a porous polyethylene implant that allows vascular ingrowth and is very malleable. It has become popular for bony defects with complex curvature, including the orbital walls. Other bony reconstructive options include titanium mesh, which can cover larger areas at risk for meningoencephalocele, and with a flap of vascularized tissue can achieve a watertight seal.40 Resorbable plates and screws have become particularly popular for the pediatric population, as they do not impose restrictions on the expanding skull.41

Several other durable compounds have been explored in the past for dural repair, but have somewhat fallen out of favor due to complications. Methyl methacrylate polymerizes quickly into a cement, but in prospective studies was noted to cause tissue necrosis, foreign body reaction, and a high infection rate.42 Hydroxyapatite cement was developed and originally marketed as undergoing incorporation with eventual replacement by osseous ingrowth, but also has been noted to have a high incidence of delayed wound infections.43 A recent study in pediatric craniofacial reconstruction found a delayed infection rate requiring implant removal in 59% of patients, occurring between 4 months and 4 years postoperatively.44 Direct contact with the sinus lining may increase this risk. Incisions should not be closed over the material, as wound dehiscence may lead to implant exposure, especially if the setting of radiation therapy.45

Although alloplastic grafts have been used successfully, it is important to remember that they should be used in carefully selected patients. Despite its ease of availability and lack of donor site morbidity, alloplastic grafts are not ideal in patients with active infection, previous history of radiation, planned postoperative radiation therapy, poor wound healing, or high CSF leak.

**MICROVASCULAR FLAP RECONSTRUCTION FOR COMPLEX SKULL BASE DEFECTS**

Large skull base defects with CSF leaks that are associated with either a large dead space resulting from the loss of brain parenchyma or after failed local flaps pose a significant reconstructive challenge. In the setting of a large volume loss that requires obliteration, one should consider a large pedicled latissimus flap or a microvascular free flap for reconstruction. In the setting of intractable CSF leaks with either failed local flap reconstruction or when there is no appropriate local flap available, our preference...
is to use either a radial forearm or a rectus free flap. The senior author (YD) has examined his experience of 11 intracranially placed free flaps (eight radial forearm and three rectus free flap) in patients who have intractable CSF leaks either after failed local flaps or with massive dead space from brain parenchyma loss. There was no flap failure or major complications. All patients had successful repair of CSF leaks. A keyhole in the lateral frontotemporal region provided a tunnel for the pedicle. The superficial temporal artery was used in all cases. About half of the patients had an inadequate superficial temporal vein and required anastomosis to the retromandibular vein after the parotid gland was mobilized. Other clinical series using free flap reconstruction for complex skull base defects with CSF leaks also report similar success with minimal morbidity and mortality. A mortality rate of 5.7-6.3% has been reported with resolution of CSF leaks. Reported morbidities from these case series include meningitis (2.8%), pneumocephalus (2.8%), seizure (2.8%), and strokes (8.5%).

We use the radial forearm free flap for skull base defects that do not have a large dead space. If there is a large dead space that must be obliterated, we prefer a rectus free flap, which offers a significant amount of fat and tissue bulk. We feel that the anterolateral thigh flap is also another viable option, but one must consider a significant amount of muscular atrophy and decreased tissue bulk over time. Our impression is that the fat from a rectus flap is more resilient.

However, when there are no appropriate vessels available in the head and neck regions for microvascular free flap reconstruction, the pedicled latissimus flap can be an invaluable option. Based on the thoracodorsal artery and vein, the latissimus dorsi flap offers a large amount of tissue, an average dimension of 213.4 cm², and can reach the vertex. However, the elevation requires decubitus positioning, which limits a two-team approach. Moreover, the flap is primarily muscle, which atrophies with denervation, and can potentially result in decreased arm function. There are potential risks of long thoracic nerve and brachial plexus damage. We feel that free flap tissue transfer offers distinct advantages over regional flaps. Heth et al. reported increased late complications seen with regional flaps when compared to free flaps (23% vs. 0%). Neligan et al. reported increased complications due to compromised distal ends of the regional flaps. For these reasons, the rectus free flap is generally preferred over the latissimus dorsi for large defects.

Prior to harvesting a free flap, one must identify reliable donor vessels. A radial forearm free flap has around 15-22 cm pedicle length and using a transcervical keyhole placed in the lateral frontotemporal region, the pedicle can be tunneled out. Anastomosis with the superficial temporal vessels is easily performed. The retromandibular vein is a viable option if the superficial temporal vein is not available. The flap can be tunneled through a large opening in the anterior wall of the maxillary sinus and through cheek soft tissue to reach the facial vessels, although pedicle length often limits this approach. The rectus free flap does not have sufficient pedicle length to reach the facial vessels and requires anastomosis to the superficial temporal vessels.

One can assess for the availability of the superficial temporal vessels with palpation in the preauricular region or with a Doppler. If a patient lacks bilateral vessels, interposition vein grafts should be utilized to make up for the lack of pedicle length. Both the external jugular vein and saphenous vein serve as viable graft options. With interposition grafts, a free flap in the skull base can easily reach neck vessels. We generally prefer facial artery and vein anastomosis with a second vein anastomosis to external jugular vein, especially for a large flap. If these vessels are unavailable, one can consider anastomosis to the lingual artery or transverse cervical artery. Although the superior thyroid artery has been used at times, we feel that the blood flow from this branch is not always reliable. For vein anastomosis, one can consider end-to-side anastomosis to internal jugular vein if there is no viable branch identified. When interposition vein grafts are being used, it is important to avoid exposure to mucosa or saliva as the grafts are more prone to infection. As such, the grafts should be tunneled through facial skin, instead of being tunneled through the sinuses. Graft infection can result in thrombosis of the pedicle and a flap failure.

**Radial Forearm Free Flap**

The radial forearm free flap is utilized for wide range of defects. It is a fasciocutaneous, fascial subcutaneous, or osteocutaneous free flap. The use of the radial forearm free flap is advantageous for skull base reconstruction because it provides thin well-vascularized watteright tissue. Other benefits include relative ease of harvest, low donor site morbidity, and relative ease of insetting.

The radial artery is based off of the radial artery and its perforators (Figs. 30.12A and B). The brachial artery divides into the radial artery and ulnar artery in the
Figs. 30.12A and B: Vascular anatomy of the radial forearm. An Allen's test must be performed preoperatively to ensure adequate retrograde blood flow through the deep palmar arch.

antecubital fossa. The two arborize and meet in the hand in the superficial and deep palmar arch systems. Allen's test must be performed preoperatively to verify adequacy of the ulnar artery flow to provide perfusion to the hand. The Allen's test is conducted by occluding both the ulnar and radial arteries and alternating their release and verifying perfusion of hand. Care must be taken to preserve the ulnar artery during the flap harvest to avoid ischemic compromise of the hand. The radial artery is located in the lateral intermuscular septum found between the brachioradialis and flexor carpi radialis. The recurrent radial artery, which is the site of the first branch of the radial artery, limits the length of the pedicle. The superficial venous system and/or venae comitantes can be utilized as vein grafts. The superficial venous system is highly variable (Fig. 30.13). A split thickness skin graft (STSG) is placed at the donor site. Undesirable aesthetic outcome from scarring of the forearm is cited as a disadvantage to this flap. Additional donor site morbidities can include exposed tendon, sensory loss, and neuromas. Exposed tendon can be prevented by proper skin grafting techniques and by covering of tendons with adjacent muscle. Painful neuromas of the harvest site are rare.31

Radial Forearm Free Flap Harvesting Technique

An Allen's test must be performed preoperatively to check for sufficient blood flow to the hand. The patient's non-dominant hand is generally preferred. The entire arm, including the fingers and lower half of upper arm, are prepped sterilely with the palm facing up. The surgeon sits on the radial side (where the thumb is pointing). A tourniquet is placed above the elbow. The radial artery pulse is palpated and the free flap skin flap is designed overlying the pulse (Fig. 30.14). The most distal skin incision is designed at least 1 cm proximal from the base of the wrist. Proximal to the planned skin flap, a curvilinear incision is extended proximally to the antecubital fossa. The tourniquet is turned up to 250 mm Hg. The
skin incision is made just through dermis with a 15 blade. Dissection starts where the curvilinear incision has been made. Using a 15 blade, dermis is separated from the underlying fatty subcutaneous tissue, similar to raising a full thickness skin graft. The cephalic vein is identified and left down as the flap is raised. Once the dissection along the proximal skin flaps has been performed in an open book fashion, the dissection continues along the radial side of the distal incision near the wrist. Using a Metzenbaum scissors, dissection is performed superficial to muscular fascia. The superficial branch of the radial nerve will be seen in line with the base of the thumb. This nerve can be seen exiting under the brachioradialis muscle. The nerve is carefully separated from the free flap and placed laterally away from the flap. Preservation of the superficial branch of the radial nerve is important to preserve the sensation to the dorsum of the hand. Once the nerve has been dropped down, subfacial dissection is performed and attention is turned to identify the pedicle. It is extremely important to not separate the pedicle from the overlying skin flap. The radial vessels are identified between the brachioradialis muscle and the flexor carpi radialis muscle in the intermuscular septum. The radial artery and two venae comitantes are identified and ligated. Once the pedicle has been identified, the ulnar side of the skin flap is raised while preserving the paratendon. The flap is raised in a distal to proximal direction. Along the radial aspect of the flap, a retractor is placed to retract the brachioradialis muscle laterally, improving the visualization of the intermuscular septum and the pedicle. At all times, the pedicle should be visualized. It helps to hold the free flap out of the surgical bed in one’s hand as the flap is lifted. The pedicle is followed in a distal to proximal direction. There will be multiple muscular

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**Fig. 30.13:** Venous outflow of radial forearm.

**Fig. 30.14:** Radial forearm flap design: Radial artery pulse is palpated and marked out on the skin (seen as a purple line). The skin flap is designed 3-4 cm on either side of the artery. The flap should include the cephalic vein for an additional vein drainage. Avoid designing the skip flap overlying the ulnar artery to protect the vessel and to avoid hand ischemia.
perforators, which can be ligated. The pedicle is followed proximally until the branching point of the ulnar artery is identified. The free flap must be harvested distal to the ulnar artery branching point to preserve perfusion to the hand. Once the flap has been lifted and attached only by radial vessels and the cephalic vein, the tourniquet is released. The surgical bed and the flap are checked for bleeding and hemostasis is achieved. Next, the cephalic vein is transected proximally and ligated. The distal end of the cephalic vein is assessed for adequate outflow. If there is poor outflow, either one or both of the venae comitantes are used for vein anastomosis, although they are smaller in diameter and technically more challenging for anastomosis. Once the veins are disconnected, the pedicle artery is tied off proximally. The flap is gently milked of excess blood. Tsai solution can be used to flush the radial artery until clear solution is seen exiting from the veins, flushing any remaining venous blood.

The donor site is closed using a STSG from the patient's thigh. Meticulous hemostasis is important. Exposed bare tendons located within the skin donor area are covered with underlying muscle wrapped on top of the tendons. A drain is placed proximally underneath the curvilinear skin flaps which are reapproximated using 3-0 Vicryl buried sutures. The skin is closed with 4-0 Prolene sutures. A STSG secured to the skin donor defect site using 4-0 chromic sutures. Multiple 1-1.5 mm stab incisions are made in the skin graft to allow drainage of any underlying fluid collection. The skin graft is then covered in a thick layer of topical antibiotic ointment and a Xeroform dressing is applied. The patient's wrist is then wrapped in a Kerlex dressing. A volar splint is placed from the fingers to the antecubital fossa to immobilize the wrist for 7 days to optimize STSG uptake. When applying the splint, the patient's hand should be in a neutral position without excessive flexion or extension and positioned as if holding a cup. The wrist dressing and casting should not be excessively tight, to avoid compartment syndrome.

**Rectus Free Flap**

Rectus abdominis free flap is very useful in skull base reconstruction due to its ease of harvest, bulk, reliability, and versatility. It has one of the largest potential surface areas of skin perforators of any free flap. The rectus abdominis is most often a musculocutaneous flap when used as a free flap graft. The flap can be harvested without subcutaneous and/or skin if the overlying tissues are too bulky.

A wide range of flap paddle design exists including a paddle along the entire vertical length of the muscle or a transverse design including crossing midline at the periumbilical region. The latter has the advantage of decreasing muscle bulk. The flap is harvested with the anterior rectus sheath to allow for watertight closure of defects. The sheath and tendinous inscriptions of the rectus muscle provide robust tissue that allows for suturing of graft to skull base defects.

Understanding of the anatomy of the rectus sheath and of local vasculature is important in fully utilizing versatility of this flap and to prevent complications. The muscle originates in the pubis and inserts on the costal cartilages of the fifth, sixth, and seventh rib. The deep superior epigastric artery and the deep inferior epigastric artery provide blood supply rectus abdominis angiosome. The deep superior epigastric artery is a branch of the internal mammary artery, and the deep inferior epigastric artery is a branch of the external iliac artery. The pedicle is found along the deep lateral aspect of the rectus abdominis muscle. The deep inferior epigastric artery is utilized most often in free flap reconstruction because it supplies a larger territory of perforators and is a larger and longer pedicle (Fig. 30.15). Perforators are present within approximately 3 cm of the umbilicus. Venous anatomy is analogous to the arterial anatomy. The facial layers and thickness of rectus abdominis muscle vary along the vertical length. No posterior rectus sheath is present above the costal margin. Below the arcuate line, at approximately the level of the anterior superior iliac spine, the posterior rectus sheath is composed of only transversalis fascia (Figs. 30.16A and B). Herniation of abdominal contents is likely to occur if the harvest is carried below this level and no augmentation is preformed. Closure of surrounding anterior rectus sheaths can be utilized to prevent incisional hernia formation.\(^{31}\)

**Rectus Free Flap Harvesting Technique**

Prior to harvest, the desired vessels for anastomosis should be selected. Due to a relatively short pedicle length, the superficial temporal vessels are commonly employed, but interposition vein grafts can be used to reach the facial artery and vein if the superficial temporal vessels are not available. By designing the rectus flap more cephalically near the costal margin, one can also increase the pedicle length. The flap is designed in the periumbilical region. Deep inferior epigastric vessels run deep to the rectus muscle and enter the flap from an inferior to superior
Fig. 30.15: Vascular anatomy of rectus abdominis flap based on the deep inferior epigastric artery and vein.

Figs. 30.16A and B: Abdominal wall musculature: Transverse sections through the anterior abdominal wall (A) above the arcuate line. Notice contributions from the aponeuroses of the transversus abdominis and internal oblique muscles to the posterior sheath. (B) below the arcuate line. The transversalis fascia is the sole contributor to the posterior sheath.
direction. Skin incisions are designed to hug the midline
along linea alba, extending around the umbilicus. The
inferior border of the flap is placed superior to the arcuate
line to minimize the risk of weakening the abdominal
wall. The arcuate line is located approximately at the level
of the anterior superior iliac spine.

Skin is incised starting from the superior border of
the flap. The incision is carried deep until the anterior
rectus sheath is reached. The sheath is glistening white
in appearance. An incision is made in the anterior rectus
sheath along the superior border of the exposed rectus
muscle. A plane superficial to the muscle is followed lat-
erally until the linea semilunaris is reached, where the
lateral border of the muscle can be identified. At this bor-
der, careful dissection along the deep surface of the rectus
muscle is performed from a superior to inferior direction
as the muscle is retracted medially. The dissection must
remain superficial to the posterior rectus sheath above
the level of the arcuate line and superficial to the trans-
versalis fascia below the level of the arcuate line. Careful
blunt dissection superficial to the transversalis fascia is
performed to avoid a bowel injury. It is imperative to not
detach the deep inferior epigastric vessels as they enter
the rectus muscle. We generally do not perform intramus-
cular dissection of the pedicle. Due to a relatively large
size of the vessels (2–4 mm), the deep inferior epigastric
vessels (artery and venae comitantes) are easily visualized
along the deep surface of the rectus muscle. Once identi-
fied, the pedicle is followed more inferiorly to the takeoff
point from the external iliac artery and vein. The pedicle
vessels are isolated by carefully lifting the vessels from the
rectus muscle inferior to where the vessels enter the mus-
cle. This will allow creation of a safe soft tissue dissection
plane for incising through the muscle along the inferior
border of the flap. The pedicle should be visualized at all
times while the muscle is being incised to ensure the flap
pedicle is not being twisted or injured. Once the inferior
border of the rectus muscle and skin has been released,
other borders of the flap are released in a similar fashion
until the entire flap is isolated on the pedicle. The proximal
end of the pedicle is tied with a 2-0 silk suture. The flap
is gently milked of excess blood and the artery can be
flushed with Tsai solution until clear fluid is seen exiting
the venae comitantes.

The donor site is closed with 0-Prolene sutures, reappro-
ximating the anterior rectus sheath in a running
fashion. A long strip of thick acellular dermal matrix
(AlloDerm, Dermamatrix) is laid on top of the closure.
To provide an additional layer of support, the acelular
dermal matrix is then secured to the underlying ante-
rrior rectus sheath with 0-Prolene sutures. Two drains
are placed into the surgical bed and the subcutaneous
layer is closed with buried 2-0 Vicryl sutures. Skin can be
closed with either skin staples or 3-0 Prolene sutures and
removed 10–14 days. An abdominal binder is placed and
worn by the patient for 1–2 weeks.

Flap Inset and Vessel Anastomosis Technique

The epithelial layer of the flap is removed carefully with a
15 blade or sharp tissue scissors. The pedicle of a radial
forearm free flap runs close to the skin and one must be
extremely careful to not injure the pedicle. Due to the
expected postoperative brain edema, only approximately
one half the space between the retracted brain tissue and
skull base is filled with the flap. Fat from the rectus tissue
can be trimmed prior to vessel anastomosis. However, the
muscle portion of the flap is trimmed only after revascu-
larization of the flap for an accurate assessment of the
tissue volume.

If the dura is intact, the flap is laid over the defect and
secured with bone tunnel-securing absorbable sutures.
The inset is performed to overlap the skull base margin
by at least 5 mm. If there is a significant dural defect,
de-epithelialized free flap can be sewn directly onto the
flap. The flap pedicle is tunneled through a previously
created keyhole in the lateral frontotemporal region. The
hole must be sufficiently large enough to minimize the
risk of kinking or compressing the pedicle.

Using a microscope, vessels are prepared by removing
the vessel adventitia about 2–3 mm from the cut end. The
vessel ends are aligned with vessel clamps. The vessels
should not be under a significant amount of stretch or
tension and should have a gentle curvature to optimize
blood flow. Under microscopic visualization, 9-0 nylon
sutures on BV130-4 needles are used for anastomosis in a
simple interrupted fashion. The clamps are then released
to check for a leak, which can be repaired with additional
simple interrupted sutures. The vessels are checked for
patency by milking proximally and distally from the anas-
tomosis site. One should see brisk filling of blood across
the anastomosis site. A Cooks internal Doppler probe is
placed around the artery for postoperative monitoring,
secured with small hemoclips. Additionally, an external
Patients are generally kept on strict bed rest for the first 5–7 days. Brain edema is monitored with serial neurologic examinations and computed tomographic scans in the early postoperative period. All patients are treated with perioperative antibiotics and steroids.

**ILLUSTRATIVE CASE**

A male patient suffered a gunshot wound to the skull base with massive loss of brain parenchyma involving the frontal lobe (Fig. 30.17). Initially, the patient had an emergent craniotomy and debridement performed by neurosurgery. Due to a massive dural injury, the patient developed an ongoing massive CSF leak. The patient underwent debridement of the brain parenchyma and skull base using a gull wing approach (Fig. 30.18). In light of the massive dead space and an ongoing CSF leak, a rectus free flap reconstruction was performed. The flap was trimmed to reconstruct about one half the space between the remaining brain parenchyma and skull base. It was sewn directly to the remaining dura for the CSF leak repair and anastomosed to superficial temporal vessels (Figs. 30.19 and 30.20). A keyhole was not needed due to the lack of cranial vault. The patient suffered no significant worsening of neurologic status with a successful resolution of the CSF leak. Postoperative computed tomography imaging demonstrated a significant reduction in the dead space (Fig. 30.21).
Fig. 30.19: A rectus free flap can be seen after it has been secured to the skull base defect and the remnant dura. Patient had a successful resolution of the CSF leak.

Fig. 30.20: The rectus free flap pedicle is seen after it has been anastomosed to the superficial temporal artery and vein.

Fig. 30.21: Postoperative CT scan demonstrates rectus free flap located in the left frontotemporal region with a significant reduction in dead space.

REFERENCES


