Reconstruction of the Base of Skull Defect—Lessons Learned over 25 Combined Years

Dan Rowe¹ James Emmett¹

¹Department of Plastic and Reconstructive Surgery, Princess Alexandra Hospital, Brisbane, Australia

Address for correspondence: Dan Rowe, MBBS, FRACS, Department of Plastic and Reconstructive Surgery, Princess Alexandra Hospital, Brisbane, Australia (e-mail: Danrowe3@gmail.com).

J Neurol Surg B 2016;77:161–168.

Abstract

Keywords

- skull base defect
- perineural spread
- skull base malignancy
- free flap reconstruction
- cerebrospinal fluid leak

With an increased understanding of the pathological processes involved in perineural spread, surgery has come to play a greater role in its management. As skull base techniques have been refined, the reconstructive surgeon has been presented with increasingly complex and voluminous defects requiring repair. To enable such surgery to have acceptable outcomes, attention to form and function is paramount. This article describes the methods of repair, which have evolved over the last 25 years of practice, and that we find to be both reliable and durable. Our accumulated experience is presented as a treatment algorithm, which will aid the skull base reconstructive surgeon to achieve success for the wide variety of defects encountered with these patients.

Introduction

Surgical management of clinical perineural infiltration, also called perineural spread (PNS), is a comparatively recent surgical innovation. Previously, PNS was treated with curative or palliative radiotherapy or by observation alone. Some resection of PNS of the trigeminal nerve to the gasserian ganglion results in skull base defects with exposure of the dura to the sinuses and allows cerebrospinal fluid (CSF) leaks. Without reconstruction of these defects, patient mortality would be very high. Complications include potentially life-threatening meningitis and intracranial abscess. Reconstruction of these defects in a systematic and effective manner is an absolutely essential component of the surgical management.

The essential requirements of such a reconstruction are reliability and vascularity of the tissue used, provision of bulk where required to fill dead space, and primary healing. The decision-making process and the technical expertise of the reconstructing surgeon are essential to ensure that complication rate remains low. Attention to detail, surgical finesse, and delicate handling of the tissues are essential attributes of the skull base reconstructive surgeon. It is important that critical sutures are placed correctly as there is often only one chance of securing the flap properly. Surgical closure of the skull base is usually done in layer upon layer to try and prevent a CSF leak and close dead space. Microvascular anastomoses, as in all free flaps, need to be done with great

care to avoid unnecessary returns to theater, as reoperations usually result in poor inset and associated leaks. Attention to detail in this endeavor is critical to reducing complications.

Correct selection of the flap required is vitally important to ensure a very high success rate. Flap losses and complications are very difficult to treat, and it is best to aim to minimize complications as part of the planning process. A skill set drawing from a wide range of surgical experience in both the head and neck region and elsewhere in the body, with a variety of flaps to select from, both locally and regionally and as free flaps, is essential. Reconstruction may involve one or more flaps from different areas. During the resection, defects that were expected preoperatively can change dramatically and the reconstructive surgeon needs to be able to adapt to the changing situation. The decision on which reconstruction to choose ultimately is made after the resection is done and the defect fully defined.

Surgical Planning

One of the most demanding aspects of surgery in the skull base is the variability in the surgical pathway. That is to say, the final defect can be somewhat different from that intended in preoperative work-up. This requires of the reconstructive surgeon a wide range of skills and abilities to achieve a good outcome for the patient. Without correct choice of flap and

meticulous attention to detail in the inset of that tissue, complications are almost universal.

With that in mind, it would be considered foolish to embark upon a skull base case without a preoperative work-up and plan for the reconstruction, arrived at with careful and close consultation with the resecting surgeon. This is often initiated in the multidisciplinary setting, and takes into consideration both the intended resection and subsequent defect, and the postoperative adjuvant therapy required. It is a rare situation where there is not to be postoperative radiotherapy utilized (only 10% in our series),¹ and this in itself can directly influence the choice of reconstruction. Not infrequently, there are two resecting specialties—neurosurgery and ENT—both of whose reconstructive requirements must be accommodated. The neurosurgeon will be concerned about both the possibility of CSF leak and exposure of the dura to oral or nasal cavities and the associated risk of meningitis. The ENT surgeon will be concerned about both these aspects along with the oronasal function of the patient and providing adequate drainage of any remaining paranasal sinuses. There is obvious overlap in these requirements which is reflected in the common choice of flaps—the workhorse flaps for skull base are often chimeric or pseudochimeric, with several tissue types and structural elements on a single vascular pedicle. The flaps used are both bulky and compliant, and are able to fill large dead spaces of up to several hundred milliliters, but are also able to be contoured, twisted, and contorted to obliterate the multiloculated features of the skull base defect. A single flap must be able to fill the pterygopalatine fossa, seal the adjacent dural defect created by chasing PNS along the trigeminal nerve to or beyond the gasserian ganglion, prevent contamination from the nasal airway but yet maintain that airway, fill the infratemporal fossa, and ideally give an aesthetically acceptable contour to the overlying face, often requiring static facial nerve reconstruction. There may be associated breaches into Meckel's cave and the cavernous sinus, which also must be adequately covered to prevent both CSF leaks and late hemorrhage from infection. In current practice, various hemostatic agents (e.g., FloSeal) are often used to help seal the venous sinuses in the dura, all of which can then harbor infection. A well-designed and well-planned flap will minimize this risk and, potentially, cataclysmic hemorrhage by providing a rich vascular bed overlying these areas to allow assimilation of the hemostatic agents.

Resection of PNS in the trigeminal nerve is not infrequently associated with facial nerve resection (► **Fig. 1**).² This brings into discussion all aspects of facial reanimation, both static and dynamic. In the setting of extensive PNS resections, the role for dynamic reconstruction is limited, as are recipient functional nerves! Most often, a static option is chosen and this can frequently be incorporated into the flap of choice, especially with the rise and ubiquity of the anterolateral thigh (ALT) flap and the circumflex femoral vascular axis. It does take careful planning to allow the same flap to seal the dura with a muscle component, fill a dead space with fat, resuspend a denervated face in a resilient fashion, and provide suitable skin closure on the face or lateral scalp. The ability to

Fig. 1 Inferior approach to Meckel cave. Facial nerve, TMJ, mandible, and zygomatic arch have been resected. Preplating is present for the arch (black arrow). FloSeal is seen covering the dural exposure (purple arrow). Consideration is given to ensure a dural seal, filling the entire dead space, providing static support for the hemiface after CN V resection, and replacing any resected skin (including the external ear in this case).

visualize a three-dimensional construct before it is formed is essential to ensure the various components of the flap align correctly and reach their intended sites of inset.

Hence, there are manifold aspects to consider in the choice of the appropriate flap. An often-neglected consideration is the donor defect, from where the flap raised. This is often reconstructed to some extent in its own right, and certain defects may be precluded in certain patients due to comorbidities, previous surgeries, or other factors. Obviously, the current condition of a donor site must be considered, and often a second tier flap choice is made due to the first preference flap being unusable due to donor site issues.

Flaps

Anterolateral Thigh Flap

This flap has rapidly become a workhorse for skull base reconstruction. Due to the favorable anatomy often described by many authors, it can be aggressively adapted to all manner of defects with little compromise to the integrity of the flap. Due to the usually long pedicle, sometimes even up to 150 mm in length, there is rarely a problem reaching recipient vessels. The long pedicle also allows for folding and optimum positioning of the flap without compromising the microvascular anastomosis.

A component of muscle, usually from vastus lateralis, can be included with relative ease, often on an independent branch of the pedicle, allowing for creative insets for closure of middle cranial fossa defects, especially around the foramen ovale. This muscle can be parachuted via carefully placed drill holes into the remaining bone of the sphenoid, maxilla, petrous temporal bone, and so on, depending on the defect created.

The cutaneous and subcutaneous component can likewise be tailored to the defect extensively. The vascular anatomy of the ALT allows aggressive thinning if required, but a large flap

can likewise be taken, doubled over, or rolled up to create a large volume mass to obliterate dead space and restore contour. Despite extensive bony resection, the ALT alone often allows for complete restoration of contour, without the postoperative atrophy associated with muscle flaps used for the same purpose (►Fig. 2).

If the facial nerve has been resected, either dynamic or static reconstructions can be incorporated into the ALT. An innervated segment of vastus lateralis can be taken and connected to the facial nerve stump, if available. Unfortunately, there are often no recipient nerve stumps to use for muscle innervation and dynamic reconstruction, so a static sling is used. Up to five separate fascial “tails” can be fashioned to allow suspension of the upper and lower lips, nasolabial fold and modiolus, the alar base, and the lower eyelid. However, the eyelid is best supported with an independent slip of fascia, as the contortion required to direct the fascia toward the medial canthus limits the remaining inset of the flap.

- Skin, fat, fascia, and muscle all very customizable to the defect
- Often ability to have completely independent paddles of skin, fat, and muscle, with or without fascia
- Good pedicle length to reach cervical recipients

Vertical Rectus Abdominis Myocutaneous/Rectus Abdominis Flap

Once a relative workhorse of reconstruction for base of skull (BOS) defects, the rectus abdominis muscle and myocutaneous flap has been largely superseded by the ubiquitous ALT. It is less tailorable, and often excessively bulky in the Caucasian population, restricting the ability to use this flap to give both a functional and aesthetically acceptable reconstruction. In cases where an extensive soft tissue and bony resection is required along with resection of perineural disease, its large volume and stable fat component can be of use. As is well recognized in breast reconstruction, the abdominal fat tends to undergo ptosis over time, which can be a liability in the BOS, leading to what we refer to as the “molten wax” appearance (►Fig. 3C) as the flap descends toward the neck

Fig. 2 Typical defect for lateral temporal bone resection with extensive skin loss, and resection of the facial nerve and TMJ. An ALT flap was utilized with incorporated fascial slings.

Fig. 3 (A) Extensive defect with orbital exenteration, maxillectomy, temporal craniotomy (short arrows), and lateral nasal resection. Long arrow shows septal mucosa. Dotted line is oral mucosal defect. Skin was used for the oral lining, whereas the nasal lining was left to heal by secondary intent. A secure seal was attained with bone anchored sutures and careful soft tissue inset around the mucosal defects. (B) Early postoperative appearance after VRAM reconstruction with no slings. The orbit has been filled with rectus abdominis and fat, and muscle used to cover the lateral craniotomy. (C) Ten months post-op demonstrating “melted wax” appearance due to lack of facial support and the gravitational susceptibility of the VRAM. (D) Appearance after flap revision and fascial slings. The melted wax appearance has been largely reversed and oral continence restored.

over time. This problem is far less with the ALT, due to the different fat and fibrous septal structures of the lateral thigh.

However, in situations where a relatively large segment of muscle alone is required, the long pedicle length and long well-vascularized muscle can be of great use. When there is no cutaneous defect associated, and especially if dural exposure or even a dural breach is required (►Fig. 1, 4), the rectus abdominis muscle-only flap is king. It is not excessively bulky and hence grafting is not required to close the integument, but is large enough to cover all manner of approaches to Meckel cave and the gasserian ganglion. It can be split into two separate longitudinal “tongues,” utilizing the medial and lateral divisions of the deep inferior epigastric artery to maintain vascularity to both. These tongues can be inset independently to cover both the foramen ovale and the pterional craniotomy required for a dual approach to the cave (►Fig. 5). As always, meticulous attention to multilayered inset is required to avoid CSF leaks (►Fig. 4).

Radial Artery Forearm Flap

Mentioned mainly for completeness, this flap is rarely utilized in PNS reconstruction. As described in the discussion on

Fig. 4 A VRAM in the process of being inset to the defect (→**Fig. 1**). Muscle has been attached to the galea and cut edge of temporalis (arrow heads). Careful suturing to the pterygoid muscles and adjacent tissue (long arrow). Drill holes will be placed along the bone edge to provide a secure seal with the muscle over the cranial defect (short arrows).

complications and in the algorithm later in the article, this subcutaneous fat and dermis are generally too thin to withstand the rigors of high-dose radiation and draping over bony prominences. As this surgical unit's disease-free survival times have increased,³ more long-term complications have emerged in the patients treated 10 to 15 years ago with radial artery forearm flap (RAFF) reconstructions. Multiple patients have survived their PNS only to require reoperation for osteoradionecrosis and flap erosion through their RAFF.

The RAFF will still be utilized for smaller lateral defects when no local option is present and the ALT is unsuitable. This is usually in the setting of isolated facial nerve PNS requiring a small skin excision and lateral temporal bone resection.

Fig. 5 A similar defect as to that in →**Fig. 1**, but with a twist. The reconstruction has been made much more complicated by the preservation of the zygomatic arch (long arrow)—muscle must be fitted under and around this bone to cover the dural defect (short arrows)—a much more complicated inset than when the bone is resected. Vascular clamps are on the recipient vessels for the flap microanastomosis—internal jugular vein (Thomson clamp) and maxillary artery (double microclamp).

Fibula and Deep Circumflex Iliac Artery Flaps

Mainly required for mandibular reconstruction following mandibular nerve resection, these flaps are occasionally utilized. However, not all mandibular defects require bony reconstruction, and the added complexity of inset, donor-site morbidity, and the sometimes short pedicle of these flaps means that a soft tissue reconstruction is more appropriate for this site. "Letting it swing" is rarely a poor choice when the bony defect is proximal to the angle of the mandible or includes only a short segment of the body, especially in the edentulous and/or older patient. Using either a muscle or, preferably, a fat flap such as the ALT to pad out the anterior mandibular stump, and with careful attention to flap inset and shaping, the amount of collapse and chin shift to the ipsilateral side is minimal, especially if a fibrofatty pad is used instead of muscle.

If dental rehabilitation is to be considered, a bony reconstruction for the mandible is preferred, and we generally utilize the fibula for this. In our experience, this is a more suitable flap, and a modified hemisoleus flap can be raised on the same pedicle to allow better closure of the dural defect often associated with Zone 2 and always with the rare Zone 3 resections. The pedicle is generally longer, and the reliability and utility of associated skin and muscle paddles are better than that of the deep circumflex iliac artery (DCIA).

Latissimus Dorsi

Rarely of use in PNS reconstruction due to its bulk, latissimus dorsi can be used in salvage procedures for complications or in recurrent resections where very large soft and bony tissue defect arises. This flap is often limited by a relatively short pedicle length, however, and is rarely used in our practice.

Defects

As alluded to previously, there is considerable overlap in the defects created for resection of the three divisions of the trigeminal nerve and for resection of the facial nerve toward the brain stem nuclei. We have divided these up for discussion but there is often an element of several defects in each patient, necessitating the "think-on-your-feet" approach to planning.

Lateral Temporal Bone Resection

Required for resection of the facial nerve as far back as the geniculate ganglion, this often large area defect (→**Fig. 2**) is relatively simple in its reconstructive requirements. Removal of the middle ear ossicles can predispose to perilymph leak but this is fortunately rare with modern resection techniques and microsurgery. Regardless, the foot plate of the stapes must be protected and the flap choice must not compromise this. The approximately golf ball-sized bony defect created by drilling of the petrous temporal bone does not need to be filled completely, although the resulting contour is more pleasing if the flap utilized has sufficient bulk to do so.

More challenging in the design, however, is the need to factor in possible nerve grafts and/or static slings for support of the now denervated facial musculature. We prefer to utilize vascularized fascia if possible, and as such the mainstay for

this defect is the ALT. The skin defect that is regularly associated is anywhere from 5 to 15 cm in diameter, all of which is within the capabilities of the ALT. Careful planning will allow for proper vectors of pull with the integrated fascial slings from the bony margins or the defect to the alar, nasolabial fold, modiolus, and lips. It is imperative that the tension in these slings is adequate for facial positioning, but also controlled to prevent compromise of the vascular pedicle.

Use of the ALT in the predominantly male patient population usually yields a relatively thin flap, which results in a slightly concave temporal contour, which is not excessively confronting. The auricle is not reconstructed routinely but it is common to have an auricular remnant which is incorporated into the closure. If cable grafting to the facial nerve stumps is considered, it may be possible to utilize one or two vascularized cables from the cutaneous nerves of the thigh, incorporated easily into the flap at the time of raising. If extra volume is required, the flap can be doubled over easily without vascular compromise, de-epithelializing as required. In fact, maintenance of as much native facial and scalp skin is ideal, with the flap often double-breasted under the in-situ surgical access flaps.

If a craniotomy has been required for a dual approach, either the adipocutaneous component can be extended or muscle from vastus lateralis can be incorporated to effect a dural seal.

Lateral Temporal Bone with Infratemporal Fossa

The main consideration in this progression of the resection defect is the added volume, and often included mandibular resection.⁴ Any mandibular component of the resection is usually addressed with a soft tissue fibrofatty pad, to prevent excessive collapse of the remaining mandible toward the resected side. Bony reconstruction is often deleterious due to the loss of the temporomandibular joint (TMJ) and subsequent severe trismus or even complete fusion of the bony flap to the BOS. A "swinging" mandible will always have better excursion than that with an attempted TMJ reconstruction. The only rider on this is in a younger fully dentate patient when an attempt to maintain dental occlusion is worthwhile.

As iterated above, the use of muscle to seal the infratemporal fossa and a fat/skin paddle to fill the space is usually preferred. This is generally an ALT with a section of vastus lateralis, or a VRAM. When a pterional craniotomy is present, the muscle component is meticulously secured to the edges of the bony defect and remaining temporal bone to help protect and seal the dura, with suturing in multiple layers if possible, creating a CSF-tight seal. This muscle is also secured to the pterygoid musculature to obliterate this deepest aspect of the defect (→Fig. 4).

Lateral Defect with Pterygopalatine Extension

The addition of resection of the pterygopalatine fossa and pterygoid musculature does not add much to the complexity of the reconstruction, other than difficulty in inset. The flap planning is usually very similar to the defects where the pterygoids are maintained, other than an increase in defect

volume. However, lack of substantial tissue to anchor the flap requires careful consideration. There may be limited opportunity for drill holes in bony margins due to proximity of vital structures such as the carotid artery. Discussion of the defect with the resecting surgeon scrubbed-in yields invaluable information about potential "anchor points" for the flap, and if planned for, the resecting team can often leave drill holes for flap anchoring. These are routinely few and often tenuous, so the first attempt at inset is usually the only chance for success.

If bony securing points are not available, a "mass obliteration" is required with drain decompression for potential CSF leaks. Great care must be taken with the positioning of this drain to prevent direct suction near a CSF leak or over the foot plate of the stapes if it is preserved or exposed, which it often is. The sheer volume of the flap is then used to apply moderate pressure into the defect and BOS to obliterate dead space. Overlying skin closure completes the "pressure effect," with care to prevent redundancy of skin and negation of this pressure effect. Plating of the zygomatic arch to restore contour and facial width also aids in the retention of the underlying flap. Excessive pressure will lead to compression of the pedicle and inevitable flap failure, and the pedicle must be carefully accommodated in the inset and closure. Indeed, this is true of any of these reconstructive options, as often bony prominences and soft tissue bands will act as kink and compression points, with subsequent flap failure. Excess pressure from replacement of the arch can lead to zonal loss of the flap—often exposing the areas most vulnerable to CSF leak and other complications.

Craniotomy

As already described, a dual approach to the resection is often required. Pterional craniotomy usually results in a bony defect on the lower and inferior aspect of the temporal lobe (→Figs. 1, 4, and 5), which cannot be replaced with a native bone plate. This does not require bony reconstruction, but does require suitable soft tissue coverage. Muscle is ideal, with at least a single, near-continuous ring of suture fixation, and preferably a second or even third layer of closure if possible. If a dural breach persists with CSF leak, meticulous care and attention to a CSF-tight seal prevents the common complication of longer-term CSF drainage. This can be managed as described later in this article but is better avoided, if at all possible.

Any cranial bone plate should be replaced and secured in the usual fashion, and covered with the soft tissue reconstruction in a fashion similar to that shown in →Fig. 4. If a dural breach does not exist then a fibrofatty paddle is sufficient for coverage.

Orbit

The orbital exenteration defect for resection of PNS in V1 is likely the easiest of these defects to reconstruct. In the more frail patients in whom a rapid completion is preferred, the eyelids alone may be able to be utilized. These are very thin, however, and it should be avoided if possible, as their ability to withstand radiation is limited. If, however, a segment of

muscle is inserted into the apex of the orbit, it will seal any possible CSF leak from the optic nerve stump or via the orbital fissures if they have been breached, as well as support the eyelid tissues through the subsequent adjuvant treatments, that is, radiation.

In the early patients in our series, an RAFF was often utilized for the larger orbital skin defects following exenteration. Unfortunately, a significant proportion of those who have survived long term have required revision flaps to treat osteoradionecrosis of the orbital rim and bony exposure. This flap has now been displaced in all but the obese patients, by the ALT. Due to its ability to withstand quite aggressive thinning and folding, the ALT is the ideal candidate for the orbital defect, as it can be either very small (2×2 cm) or very large (up to 20 cm) in diameter.

If there are associated bony rim defects from the orbital resection, these are reconstructed with soft tissue (►Fig. 3). This can be any or all of the walls of the orbit and the associated rim, due to tumor invasion of surgical access to chase nerves toward their origins. Rarely is a bone flap utilized. Also, rarely if the orbital floor has been resected to chase the infraorbital nerve, the orbital contents must be supported—usually with a titanium or absorbable orbital floor plate.

Decompression of the apex to prevent collections is mandatory, either by passive gravity drains—Yates or Penrose—or by small gauge suction drains—for example, fluted silicon. If there is a recognized primary CSF leak, suction is best avoided but drainage should still be placed for control of this space. An apical CSF leak can be very troublesome if not recognized, and may ultimately compromise the whole reconstruction. The drain is removed at 5 to 7 days, or sooner if there is no leakage at all. This allows the flap to adhere adequately to surrounding tissues.

Algorithm and Approach

Once the resection is complete and the defect fully defined, final reconstructive choices can be made. Skin defects are not usual with the treatment of PNS alone. Usually, skin defects result from resections of the primary, recurrent, or metastatic tumors which have skin involvement and associated PNS. If created, skin loss can be repaired in a variety of ways, including direct closure, locoregional skin flaps, skin grafting the underlying free flap (often muscle), or a free flap with a skin component. Local skin flaps are used where possible as they provide a better color match. Regional or distant flaps with skin paddles are used for larger skin defects or where there is insufficient local tissue (see ►Fig. 6).

The durability of the skin flap also needs to be considered. Our experience is that the skin flaps used to cover a bony prominence such as an orbital exenteration, with adjuvant radiation, become very thin, leading to exposure of the bone and subsequent osteoradionecrosis. A skin flap with a thicker dermis such as the ALT is preferred. Depending on the bulk of this flap, thinning of the flap may be needed to achieve a reasonable contour of the orbit.

Flap bulk is used to fill dead space both intra- and extracranially. This includes beneath cranial bone flaps, and

usually muscle is the ideal material for this. Fat and/or muscle flaps are used to fill defects in the extracranial location. The muscle component will atrophy significantly, whereas the fat component will retain most of its volume. Selection of muscle and fat components is important when designing a flap and is individualized for each defect depending on the desired final contour.

Bony resection is either the cranium or the facial skeleton, and each has a different reconstructive requirement. Generally, cranial defects are reconstructed particularly where protection is required, and occasionally for contour defects of the supraorbital bar. Facial bone reconstruction is uncommon with PNS reconstruction. As it is uncommon for the facial skeleton to be resected, except in small areas to allow access to nerves and their branches. The most common example of this is resection of the anterior maxillary wall to allow resection of the infraorbital nerve toward the apex of the orbit. This defect does not require bony reconstruction. Reconstructions need to be of vascularized bone, as usually radiotherapy is needed postoperatively and nonvascularized grafts fare poorly with high dose radiotherapy. Considering the added complexity of this, along with the patient's underlying disease, it is unusual for us to undertake a bony reconstruction. The exception would be where a concurrent resection of an associated tumor mass has resulted in significant loss of structural elements of the facial skeleton or cranial cavity walls, such as with adenoid cystic carcinomas, or when the mandibular branch of the trigeminal nerve is involved.

Trigeminal mandibular branch resection necessitates removal of the body of the mandible. The reconstruction of this defect depends on specific local and general factors. These include age, dentition, preexisting trismus, underlying health, and expected outcome or prognosis. Bony reconstruction is usually with a free fibular flap. The other suitable flap is the DCIA flap.

Dural exposure requires vascularized flap cover. We generally advocate use of a muscle flap but fat or fascia will usually achieve a suitable seal and coverage. Where possible, the flap is sewn to the rim of the bony defect to reduce the risk of CSF leak and reduce dead space.

If there is a dural breach, then it is essential that a waterproof repair of the dura is done. This may be direct closure or may need a fascial graft or flap. If it is not possible to obtain a sealed dura, then the flap repair must be quilted in concentric layers around the breach, taking great care to reduce the potential of a CSF leak and reduce spaces for CSF to collect. The surgeon must be cognizant of the flap vascularity during the quilting process.

When the defect includes a loss of nasal lining or occasionally oral lining (►Fig. 3A), then replacement depends on the size of the defect and how it fits in with the rest of the reconstruction. Usually muscle or a skin paddle is used for nasal and oral lining. Both potentially cause synechiae, but muscle is at greatest risk for this complication. It has been stated that skin paddles for nasal lining lead to malodorous nasal discharge, but we have not encountered significant problems with this. As long as adequate anterior and posterior communications to the airway are maintained, skin

Fig. 6 Algorithm for BOS defect reconstruction. Flap choices are dependent on donor site suitability. Asterisk (*) indicates de-epithelialization when no significant skin defect is present. ALT, anterolateral thigh; BOS, base of skull; DCIA, deep circumflex iliac artery; DIEP, deep inferior epigastric perforator; TAP, thoracodorsal artery perforator.

debris and secretions clear well and do not lead to problems. Postoperative radiation negates any problems with hair growth from the skin paddle.

Lifeboat Flaps/Salvage Procedures

The common complications, in the short term, other than flap vascularity issues, usually relate to failure of the flap inset. This manifests as either a CSF leak or a leak from the aerodigestive tract leading to infection. Occasionally, the original flap can be reutilized to facilitate the new seal, but often new tissue is required. A muscle flap, or at least a flap with a muscle component, is often the best choice. Early reoperation in the infratemporal fossa and adjacent regions is difficult at best due to the friability of the healing tissues and difficulty in achieving a stable inset. Often, two or three key sutures are all that are possible, and possibly no sutures can be reliably placed, with drain-mediated control of CSF allowing a large muscle flap to adhere to all tissues around the region. A lumbar CSF drain is usually required to decrease the flow of CSF from the dural breach, allowing flap adhesion. This dural decompression usually continues for at least 5 days, with the CSF output from the BOS defect preferably having ceased before the lumbar drain is

removed. The BOS drain then remains in place for at least another 48 hours, which is removed if no further leak is detected or allowed to remain for up to a week further if CSF leakage persists. If CSF output is still present when the BOS drain is finally removed, there should only remain an easily controlled CSF "tract" which can be controlled at the skin with a single suture to prevent ongoing leakage. The tract then either obliterates or matures, either way rarely causing problems.

Infection in the deep wound bed is addressed in a similar manner, with early recognition and drainage/washout the key to a successful salvage. If the original reconstruction contained muscle, this can sometimes be reutilized or repositioned to obliterate dead space and facilitate a seal from the aerodigestive tract. If this is not possible or the original reconstruction did not include muscle, a new flap may be required, although in our practice this is rare.

Occasionally, air leaks into the reconstructed area are encountered due to breaches in the paranasal sinuses and aerodigestive tract. Often, these are managed conservatively, with the obvious precautions against raised upper airway pressures. Rarely, the flap inset may need to be revised or even a new flap utilized.

In most instances of severe complication, the cause can be traced back to either poor flap choice or inadequate flap inset, or both. Although a rare situation, a new reconstruction may need to be considered, utilizing a different tissue type, better inset and flap security, and better control of CSF leakage. Although the temptation is to avoid further free flap surgery, the locoregional options such as pectoralis major are usually inadequate to reach the full defect, falling short of the often-problematic greater wing of the sphenoid defect, and should generally be avoided for BOS salvage surgery. A large muscle flap with a long pedicle such as rectus abdominis is usually the best choice.

Conclusion

Skull base defects following resection of PNS of malignancy present a unique collection of progressively more complex defects depending on the extent of disease and nerves involved. The necessity to fill a complex defect, prevent CSF leak, and provide a functional reconstruction is paramount for the patient to have an acceptable outcome.

As skull base techniques have progressed to allow for more advanced resections and better cure rates, the reconstructive surgeon has also had to modify and create more novel methods of reconstruction. As most patients now survive for many years posttreatment, the long-term effects of radiotherapy must be taken into account for the type of reconstruction. This has led to a decrease in the long-term reconstructive revision rates, which we initially encountered on occasion.

The algorithm provided will hopefully help reconstructive surgeons decide on the type of repair that is required for the multitude of defects encountered with this disease process. It is also hoped that this work has demonstrated that cosmetically acceptable outcomes can be obtained in the surgical treatment of PNS.

Pitfalls

- Inadequate attention to detail in the original flap design—choice of the “easy” flap rather than the “correct” flap

- Poor inset allowing for early CSF leak
- Failure to accept complications early and rectify surgically—opting for conservative management of what will only be resolved surgically

Pearls of Wisdom

- Careful three-dimensional thinking and planning to ensure flap will fit the defect and obliterate all spaces.
- Choose a reliable, well-vascularized flap that you know well.
- Meticulous attention to detail of the inset and focus on key defects. There is only one good chance at inset to the bony skull base.
- If you can see CSF, *seal it* and *drain the space*.
- Begin with the end in mind. Careful planning to avoid complications.
- Work with like-minded head and neck surgeons and neurosurgeons. Their attention to detail is as important as that of the reconstructive surgeon.

References

- 1 Warren TA, Nagle CM, Bowman J, Panizza BJ. The Natural History and Treatment Outcomes of Perineural Spread of Malignancy within the Head and Neck. *J Neurol Surg B* 2016 (e-pub ahead of print). doi: 10.1055/s-0036-1579777
- 2 Warren TA, Whiteman DC, Porceddu SV, Panizza BJ. Insight into the epidemiology of cutaneous squamous cell carcinoma with perineural spread. *Head Neck* 2016 (e-pub ahead of print). doi: 10.1002/hed.24453
- 3 Warren TA, Panizza B, Porceddu SV, et al. Outcomes after surgery and postoperative radiotherapy for perineural spread of head and neck cutaneous squamous cell carcinoma. *Head Neck* 2014 (e-pub ahead of print). doi:10.1002/hed.23982
- 4 Essig GF, Kitipornchai L, Adams F, Zarate D, Gandhi M, Porceddu S, Panizza B. Lateral Temporal Bone Resection in Advanced Cutaneous Squamous Cell Carcinoma: Report of 35 Patients. *J Neurol Surg B Skull Base* 2013;74(1):54–59