The versatile extended pericranial flap for closure of skull base defects

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OBJECTIVE: **We sought to demonstrate the technical aspects of the extended pericranial flap and its versatility in reconstruction of a variety of skull base defects.**

STUDY DESIGN: **We conducted a retrospective chart review of 32 patients who underwent reconstruction of skull-base defects with an extended pericranial flap by the senior author (Y.D.) from September 1997 to July 2003.**

METHODS: **Patients with skull base defects after trauma or extirpative surgery were reconstructed with either a lateral- or an anterior-based vascularized extended pericranial flap. Variables and outcomes measured included: the size and anatomical location of the defect, need for other flaps, preoperative and/or postoperative radiation therapy and/or chemotherapy, bone flap necrosis, hardware exposure, wound dehiscence, postoperative cerebrospinal fluid (CSF) leak, and meningitis.**

RESULTS: **There was no evidence of flap failure, 2 cases of transient (3 to 4 days) CSF leak without resultant meningitis, 3 patients with hardware exposure, and 2 patients with hydroxyapatite infection. The 2 transient cases of CSF leak both resolved without further surgical intervention or the placement of a lumbar drain.**

CONCLUSION: **Both the lateral and anteriorly based extended pericranial flaps are reliable and versatile flaps associated with minimal morbidity and a low rate of complications when used to reconstruct defects of the anterolateral skull base.** (Otolaryngol Head Neck Surg 2004;130:704-11.)

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Anterolateral skull base surgery for benign and malignant lesions often results in significant defects of the craniofacial skeleton and surrounding soft tissues, allowing for potential free communication between the extracranial and intracranial compartments. Tumor resection and trauma can result in bone and dural defects, with subsequent contamination of the intracranial compartment with bacterial flora from the upper aerodigestive tract. It is necessary to separate these compartments in order to prevent the potential complications of cerebrospinal fluid (CSF) leak, meningitis, bone flap necrosis, hemorrhage, and exposure of hardware. Successful outcomes in skull base surgery are dependent on primary healing at the surgical site; therefore, many surgeons believe that reconstruction of the skull base is most appropriately accomplished with vascularized tissue. Several authors have previously written about the vascularized pericranial flap as a reliable and versatile flap that is used to solve many difficult reconstructive dilemmas in the head and neck.[1-8] The pericranial flap has been used as a sling to support the brain, as a dural seal to prevent CSF leakage, as vascularized tissue to eliminate empty dead space, and as a barrier to separate the nasal, middle ear, and skin flora from the brain.[1,5,6] Briant et al[2] used an extensive, unilateral pericranial flap in 4 patients to repair craniofacial defects. Thaller and Donald[3] used an anterior-based pericranial flap in fourteen trauma patients to obliterate the frontal sinus. In this article, we present our experience with the extended pericranial flap in 32 patients with a wide range of craniofacial defects and describe a simple, reliable, and efficient technique for harvesting such an extended flap.

PATIENTS AND METHODS

A retrospective chart review was conducted at a tertiary referral medical system on a consecutive set of patients who underwent reconstruction of a skull base defect by the senior author (Y.D) with an extended pericranial flap from September 1997 to July 2003. Patient demographics, outcomes, follow-up, and complications were recorded. Thirty-five patients met the criteria for this study; however, only 32 charts were complete and available for review. Each patient was noted to have one of the following indications for surgery and reconstruction: an extensive frontal sinus injury from trauma (n = 8), a large mucocele with anterior cranial fossa erosion (n = 4), or skull base lesion (n = 20). Each of the above was treated with surgery and reconstructed with a vascularized extended pericranial flap.

Anatomy

The soft tissue of the scalp can be divided into 5 distinct layers: skin, subcutaneous tissue, galea aponeurotica, subgaleal loose areolar tissue, and periosteum. The subcutaneous layer is composed of dense connective tissue, through which the major sensory nerves of the scalp travel. The subcutaneous layer is firmly adherent to the overlying skin and the underlying galea.

The galea aponeurotica is a layer of dense fibrous tissue that fuses with the frontalis muscle anteriorly and the occipitalis muscle posteriorly and is contiguous with the temporoparietal fascia at the superior temporal line.[5] The temporoparietal fascia, also referred to as the superficial temporal fascia, then continues inferiorly, where it merges with the superficial musculoaponeurotic system of the face.[9,10]

Beneath the galena aponeurotica is a layer of subaponeurotic connective tissue referred to as the subgaleal fascia that has a central dense, collagenous core surrounded by vascularized loose areolar tissue.[9] This layer allows for movement of the galea over the underlying, fixed periosteum.[10]

The “pericranium” is usually defined as the combination of the subgaleal fascia and the adherent periosteum overlying the skull.[1,5,6,11,12] The periosteum has an outer fibrous layer with numerous blood vessels and nerves and an inner layer composed of numerous dense, and, more cellular, elastic fibers.[6] The pericranium has low osteogenic potential and will usually not regenerate new bone over defects.[1] The pericranium is contiguous with the deep temporal fascia in the temporal region.[6,10,11]

The blood supply to the pericranium is derived from several sources that are located anteriorly, laterally, and posteriorly.[10] The supraorbital, supratrochlear, superficial temporal, greater auricular, and occipital arteries and veins all contribute a significant supply to the pericranium.[3] The major blood vessels of the scalp travel within the galea and the fibrofatty layer just superficial to the galea. Multiple perforating vessels pass from the galea to the pericranium.[5,6,9] Within the pericranium, there is extensive interconnection of axial vessels as well as communication with perforators arising from the calvarium.[9] The pericranium is vascularized anteriorly by the deep divisions of the supraorbital and supratrochlear vessels. Soon after emerging from the bony foramina at the superior orbital rims, both vessels divide into a larger superficial vessel, which traverses the galea, and smaller, deeper vessels, which run cephalad to the pericranium in an axial orientation.[5,6,9]

Laterally, multiple axial vessels have also been demonstrated by Latex injection arising from the superficial temporal artery, which divides approximately 2 cm superior to the zygomatic arch into anterior and posterior branches. The anterior branch of the superficial temporal artery (STA) provides blood supply to temporoparietal fascial, galeal, and galeopericranial flaps.[10] A temporalis fascia–pericranium free flap based on the superficial temporal artery and vein has been used for reconstruction and reconfirms this source as a viable blood supply to the lateral pericranial flap.[13] The middle temporal artery is a branch of the superficial temporal artery that usually originates 0 to 2 cm below the zygomatic arch and runs slightly posterior to the STA. The middle temporal artery then enters the deep temporal fascia immediately superior to the zygomatic arch.[10] It continues its course superiorly and sends some perforators deep, into the temporalis muscle, where it anastomoses with the deep temporal artery (branch of the internal maxillary). This arcade of arterial supply continues superiorly and is responsible for a significant portion of the lateral axial vessels supplying the pericranium as well.[6]

Posteriorly, the occipital artery and the greater auricular artery supply similar axial patterned vessels to the pericranium. Within the pericranium, this multitude of vessels form an extensive anastomotic network that ensures the viability of anteriorly and laterally based flaps.[11] This network also provides the surgeon with the ability to harvest a larger vascularized flap that has multiple arcs of rotation with which the flap can be oriented to fill various defects in both the anterior and lateral skull base.[6]

Surgical Technique

A standard bicoronal incision is used to harvest the pericranial flap and to give access to most of the skull base approaches used in this study. The incision is made 1 to 1.5 cm posterior to the anterior hairline, depending on the patient's hair density and distribution. Care should be observed laterally in the preauricular area to preserve the superficial temporal vessels. Dissection then proceeds in a suprapericranial fashion posteriorly to the occiput. Next, the flap is incised sharply at this level and elevated to the superior orbital rims in a subpericranial fashion with blunt elevators. It is left attached to the anterior scalp to prevent desiccation until it is required. The supraorbital and supratrochlear vessels are freed from their foramen if necessary by using a 2-mm osteotome. This maneuver allows for extended inferior reflection of the bicoronal flap without placing traction on the vessels and nerves. Once the defect is critically examined, the extended pericranial flap is raised from the overlying scalp tissue as a laterally or anteriorly based flap, depending on the side and size of the defect. The pericranium is then incised and elevated off the scalp; however, it remains pedicled to either an anterior (between the space occupied by the supraorbital foramina) or lateral (lateral to the supraorbital rims) source to allow proper vascularization.

After tumor removal, or reparative brain surgery in the case of posttraumatic skull base defects, the extended pericranial flap may be used to cover defects of the cribriform plate, ethmoids, sphenoid sinuses, and the superior, inferior lateral, and medial orbital walls. The extended flaps may also cover calvarial bone grafts and seal the anterior and middle cranial fossa from the nasal and pharyngeal cavity by being sutured as far posteriorly as the middle cranial fossa. Typically, the flap is secured with resorbable sutures to the osseous margin of the defect through small 2-mm tunnels fashioned in the bone. Next, basting sutures are applied to affix it to the underlying dura or dural construct. Finally, if there is significant dural grafting or repair that is required, tissue glue (Tisseal; Baxter Corporation, Glendale, CA) is applied to the margins of the flap to seal it. The senior author does not believe that skin grafting of the nasal aspect of these flaps is necessary or helpful, and thus, none of our series of patients had skin graft placement.

Indications for frontal sinus obliteration or cranialization in our study included 1) a significant nasofrontal duct injury, 2) a displaced posterior wall injury of greater than 50%, or 3) a posterior table fracture associated with a large dural tear or a CSF leak. During frontal sinus cranialization or obliteration, an anterior- or a lateral-based pericranial flap is introduced into the frontal sinus cavity and folded upon itself in an accordion fashion to obliterate the dead space within the sinus or that created by cranialization, thereby further reinforcing the separation of the intracranial from extracranial compartments.

Before flap insertion into the anterior or middle cranial fossa, a 3-mm opening is made between the 2 bone edges to allow proper blood supply and to prevent flap compression. Flaps may be sewn to areas in the anterior and middle cranial fossa as necessary to hold them in proper position, and to minimize the chance of CSF leakage. Bone flaps are then rigidly fixed in place with miniplates (Fig 1 to 3). The coronal flap is closed over suction drainage, which is removed on either the first or second postoperative day.

RESULT

Thirty-two patients had complete data that were retrospectively analyzed. Each of these patients had 1 of the following indications for surgery and reconstruction: an extensive frontal sinus injury from trauma ($n = 8$), a large mucocele with anterior cranial fossa erosion ($n = 4$), or a skull base lesion ($n = 20$) (Table 1). Each of the above was treated with surgery and reconstructed with an extended pericranial flap. Fourteen of the skull base lesions were benign and 6 were malignant in nature. The average patient age was 42.3 years (range, 18 to 88 years), and there were 18 men and 14 women. The mean follow-up period for this study was 15.8 months (range, 3.0 to 57.8 months). When trauma patients are removed from

Fig 1. Extended pericranial flap harvested to the level of the occiput via a standard bicoronal incision.

this equation, the mean follow-up was 20.4 ± 14.9 months.

For the purposes of this study, width was measured in a medial to lateral dimension, and length was measured in an anterior-to-posterior dimension. The average defect width was 4.5 ± 1.8 cm, and the average defect length was 3.4 ± 1.6 cm. Of the 32 extended pericranial flaps, 9 were anteriorly based, 16 were pedicled from the right lateral blood supply, and 7 were pedicled from the left lateral blood supply. Two patients received preoperative radiation therapy, and 6 patients received postoperative radiation therapy. Two patients had received preoperative chemotherapy, and 1 patient received postoperative concomitant chemotherapy and radiation therapy. Nineteen patients received 30 g (range, 5 to 80 g) of hydroxyapatite cement for a cranioplasty as part of their procedure. Six patients had a temporalis flap in combination with their extended pericranial flap.

Throughout the follow-up period there were no indications of flap failure. Fiberoptic endoscopy was completed at 2-week follow-up, revealing a well-healed and mucosalizing nasal surface of the vascularized extended pericranial flap without evidence of cerebral herniation or CSF leakage. These findings were reconfirmed by fiberoptic endoscopy and radiographic imaging (computed tomography scanning and magnetic resonance imaging) during subsequent follow-up.

Two patients were noted to have a transient minor CSF leak, lasting only 3 to 4 days. These patients were observed, with spontaneous resolution of the leak without the need for further surgical procedures or a lumbar drain. One of these patients has been followed for more than 1 year and the other for nearly 3 years, and there has been no recurrent leakage or meningitis.

Three patients were found to have hardware exposure during the first 24 months of follow-up. Two of these patients had postoperative radiation treatment, one of whom also had acquired immunodeficiency syndrome and continued to abuse tobacco products throughout his treatment course. The third patient also used tobacco products perioperatively, as well as vigorous early postoperative nose blowing despite our recommendations to the contrary and failed to heal his glabellar area until local flaps were used to alleviate the problem. Two patients were found to have an infection of the hydroxyapatite material used for cranioplasty and orbitoplasty. One of these patients had documented pathologic foreign body reaction noted to the hydroxyapatite cement on specimen removal. One other patient had minor lateral orbital rim exposure in an area well away from the pericranial flap. This area was closed with a local flap in this patient with a history of both irradiation and 3 previous skull base surgeries performed elsewhere in the past.

Overall, 7 (21.9%) of 32 patients had minor complications. Four of these 7 patients had combined modality treatment for their disease, likely compromising blood flow to the scalp and orbital and maxillary regions. There were no major complications and no deaths as a result of the procedures performed.

DISCUSSION

Excision of neoplasms from the anterolateral cranial base often results in communication between the intracranial and extracranial compartments. CSF leakage is the most common complication of skull base surgery.[14] Other common complications include hemorrhage, flap necrosis,

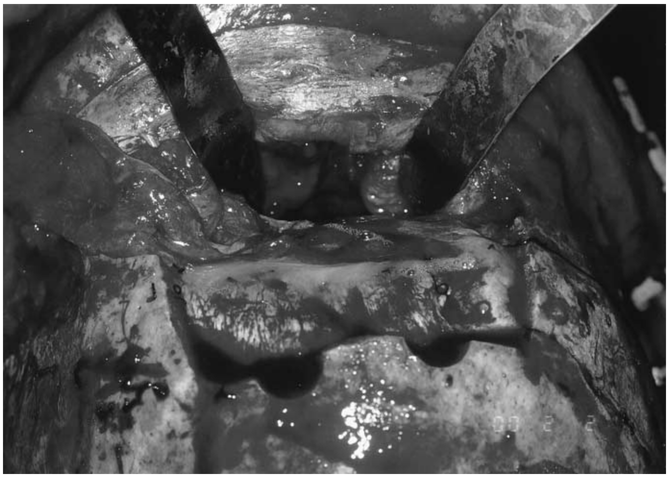

Fig 2. Laterally based pericranial flap (coming in to view from the left side of the patient) sewn into position to cover a large anterior skull base defect following subcranial approach for neoplasm.

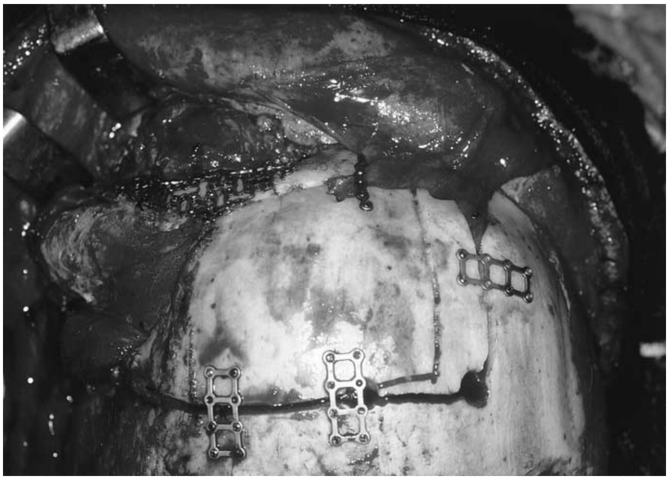

Fig 3. Extended pericranial flap has been inset and bone flaps replaced in patient undergoing an extended orbitozygomatic approach for a multiply recurrent cavernous sinus and orbital apex neoplasm. An extra 3 mm of bone was drilled from the margins of the defect at the level of the pericranial flap to decrease the chance of postoperative pedicle compression.

and bone graft and hardware extrusion. Reconstruction of such resulting defects with vascularized flaps remains the preferred method.[1,2,5,7,8,14] The use of vascularized tissue for reconstruction also offers the benefit of a timely and safe delivery of postoperative radiation therapy when patients require combined modalities.[5]

In reconstructing skull base defects, the surgical objectives should be to 1) obtain a leak-proof dural seal, 2) obliterate dead space and provide vascularized tissue for coverage, 3) cover exposed vasculature and nonvascularized grafts with vascularized tissue, 4) suspend or support neural structures, preventing prolapse, 5) reconstruct bony and soft tissue defects, (6) maintain function, and 7) optimize aesthetic outcomes.[14] The extended pericranial flap is ideally suited to either directly or indirectly accomplish all of these goals because of the ease with which it can be harvested, its predictable vascular anatomy, and its anatomic versatility. Harvesting the flap in an extended fashion as described in this article allows for an extra 10 to 14 cm of flap length, which will increase the surface area that may be covered with this flap. It also allows for folding of the flap on itself, providing for multilayer coverage of even large skull base defects.

TABLE 1. Pathologic distribution of patients

Pathology	No. of Patients
Skull base trauma	8
Mucocele	4
Meningioma	4
Squamous cell carcinoma	2
Rhabdomyosarcoma	1
Invasive fungal sinusitis	1
Cemento-ossifying fibroma	1
Fibrous dysplasia	1
Esthesioneuroblastoma	1
Cranial nerve III Schwannoma	1
Neurofibroma	1
Hemangioma	1
Giant cell tumor	1
Hemangiopericytoma	1
Inverting papilloma	1
Pituitary adenoma	1
Sinonasal undifferentiated carcinoma	1
Osteoma	1

One of the first reported uses of the pericranial flap was by Wolfe,[15] who elevated the pericranium and used the vascularized tissue to cover bone paste and rib grafts for cranial reconstruction in 3 patients. This method was believed to provide stable coverage and to prevent graft migration. Johns et al[1] used the anteriorly based pericranial flap in 4 previously irradiated patients to reconstruct craniofacial deformities from malignancies involving the nose, ethmoid sinuses, maxilla, and orbits extending into the anterior cranial fossa. The anterior cranial fossa floor was reconstructed with the pericranial flap, which was sutured to the deepest portion of the resection, acting as both a sling and dural seal. A split-thickness skin graft was placed on the nasal surface of the flap. None of the patients had brain herniation or complications from their flap. In our experience, we do not believe that skin graft application to pericranial flaps is required or helpful in accomplishing our outlined goals.

Argenta et al[6] presented the cases of 6 patients with various defects from benign lesions between the cranium and sinuses that were reconstructed with either anterior or lateral vascularized pericranial flaps. They reported a successful dural seal and separation of the sinuses from the anterior cranial fossa in each patient, although the length of follow-up was not noted.

Price et al[12] used a pericranial flap in 14 patients with a variety of tumors, 6 of whom required a combination of surgery with either chemotherapy or radiation therapy. Five other patients had previous treatment with either chemotherapy or radiation before surgical excision. The pericranium in this study was incised transversely 10 to 15 cm superior to the supraorbital rims, and the authors found the length to be sufficient to extend to the anterior clinoid processes, to allow closure and separation of the anterior cranial fossa and sinonasal cavity. A skin graft was used to the nasal surface of each of these flaps and survival was noted in each. No patients were noted to have CSF leakage or meningitis. The only compromised flap reported in this study occurred in a patient who was treated with preoperative cisplatin and 5-fluorouracil and postoperative radiation therapy (6400 rad). The patient continued to use tobacco throughout his treatment. During his radiation therapy course, the patient's pericranial flap sloughed and resulted in dural exposure. In the end, reconstruction of the defect was successful with a latissimus dorsi free flap.[12] It is important to note that the authors theorized that the pericranial flap could be compromised by the close proximity of the reapplied bone flaps and progressive postoperative edema. We believe that leaving a 3-mm defect in the bone edges on the side that the pericranial flap enters into the skull base defect prevents this potential problem. We have noted no evidence of pericranial flap compromise. In addition, such a small 3-mm defect is not aesthetically important and seems to result in no significant long-term deformity.

Snyderman et al[5] reconstructed 30 patients with defects in the anterior cranial base using lateral and anteriorly based pericranial, galeopericranial, and galeal scalp flaps. Nineteen of these patients were reconstructed with pericranial flaps alone. Of the 30 patients, 57% received prior therapy of surgery and/or radiation therapy. The median follow-up time was 13 months. The authors experienced only 3 transient (2 to 3 days) CSF leaks, all resolving without surgical intervention. They reported no cases of postoperative meningitis. The nasal surfaces of all flaps mucosalized uneventfully without the use of skin grafts. In contrast to Snyderman et al's[5] low complication rate, Neligan et al[14] reported on a series of 90 patients with skull base defects reconstructed with local, pedicled, and free tissue transfers. Pericranial flaps were used in 25% of the patients. The complication rate for local flaps was reported as 20.4%, including 14.8% with CSF leak, 3.7% with meningitis, and 9.3% with abscess formation.[14] Unfortunately, there was no description of which patients had undergone previous treatment with modalities such as surgery, radiation, or chemotherapy. The authors concluded that microvascular free tissue transfer was the safest and most economical procedure when faced with moderate to large composite defects in the cranial base.[14] We believe that our present data support the use of local and pedicled flaps in skull base reconstruction and that the use of free tissue transfer is unnecessary in the vast majority of extirpative skull base surgery.[1,2,5,6,12]

Briant et al[2] described a contralaterally based pericranial flap that was "more extensive than the anteriorly based flaps." These authors used a myoosseous flap based on the temporalis muscle for access and a contralateral laterally based pericranial flap for reconstruction of 4 patients. Access was gained through a standard bicoronal incision and dissection was carried out in a subgaleal plane. The pericranium was then incised, except for its lateral pedicle at the temporalis muscle, and elevated from the supraorbital rims to the occiput. They noted bleeding from the incised edges of the extended pericranial flap. No long-term complication (including CSF leakage and meningitis) related to the use of these pericranial flaps was noted.

Thaller and Donald[3] began using an anteriorly based pericranial flap to obliterate traumatized frontal sinuses. They raised flaps up to 14 cm anterior to posterior and as wide as 10 cm. They folded the flaps in an accordion-type fashion within the frontal sinus after adequate removal of the frontal sinus mucosa. Although the range of follow-up was 6 months to 3 years, the authors described no complications. Ducic et al[4] used a similar procedure to obliterate traumatized frontal sinuses; however, they used a laterally based extended pericranial flap. Mean follow-up was 1 year, and no complications were encountered. Thaller and Donald[3] and Price et al[12] stated that they easily achieved flaps of 14 to 15 cm in length. In the present study, patients achieved flaps that were at least 10×20 cm, regardless of the pedicle location.

CONCLUSIONS

Both lateral- and anterior-based extended pericranial flaps may be raised from the superior orbital rims to the occiput without complication. Both flaps were reliable and successfully used to reconstruct a wide variety of anterior and lateral skull base defects. Both lateral and anterior based extended pericranial flaps were successfully used as a sling to support the brain, as a dural seal to prevent CSF leakage, as vascularized tissue to eliminate empty space, and as a barrier to separate nasal and skin flora from the brain. While minimal extracranial wound complications did occur, there were no reports of meningitis, or bone loss. Two patients experienced a transient CSF leak that resolved without lumbar drain placement or surgical intervention. When examined by fiberoptic nasal endoscopy, all nasal surfaces of the vascularized pericranial flaps had mucosalized, and there was no herniation of cerebral contents noted by physical or radiographic examination.

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