Extensive traumatic anterior skull base fractures with cerebrospinal fluid leak: classification and repair techniques using combined vascularized tissue flaps

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OBJECTIVE This article introduces a classification scheme for extensive traumatic anterior skull base fracture to help stratify surgical treatment options. The authors describe their multilayer repair technique for cerebrospinal fluid (CSF) leak resulting from extensive anterior skull base fracture using a combination of laterally pediculated temporalis fascial–pericranial, nasoseptal-pericranial, and anterior pericranial flaps.

METHODS Retrospective chart review identified patients treated surgically between January 2004 and May 2014 for anterior skull base fractures with CSF fistulas. All patients were treated with bifrontal craniotomy and received pedicled tissue flaps. Cases were classified according to the extent of fracture: Class I (frontal bone/sinus involvement only); Class II (extent of involvement to ethmoid cribriform plate); and Class III (extent of involvement to sphenoid bone/sinus). Surgical repair techniques were tailored to the types of fractures. Patients were assessed for CSF leak at follow-up. The Fisher exact test was applied to investigate whether the repair techniques were associated with persistent postoperative CSF leak.

RESULTS Forty-three patients were identified in this series. Thirty-seven (86%) were male. The patients’ mean age was 33 years (range 11–79 years). The mean overall length of follow-up was 14 months (range 5–45 months). Six fractures were classified as Class I, 8 as Class II, and 29 as Class III. The anterior pericranial flap alone was used in 33 patients (77%). Multiple flaps were used in 10 patients (3 salvage) (28%)—1 with Class II and 9 with Class III fractures. Five (17%) of the 30 patients with Class II or III fractures who received only a single anterior pericranial flap had persistent CSF leak (p < 0.31). No CSF leak was found in patients who received multiple flaps. Although postoperative CSF leak occurred only in high-grade fractures with single anterior flap repair, this finding was not significant.

CONCLUSIONS Extensive anterior skull base fractures often require aggressive treatment to provide the greatest long-term functional and cosmetic benefits. Several vascularized tissue flaps can be used, either alone or in combination. Vascularized flaps are an ideal substrate for cranial base repair. Dual and triple flap techniques that combine the use of various anterior, lateral, and nasoseptal flaps allow for a comprehensive arsenal in multilayered skull base repair and salvage therapy for extensive and severe fractures.

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KEY WORDS anterior skull base repair; cerebrospinal fluid leak; frontal sinus; nasoseptal flap pericranial flap; temporoparietal fascial flap; traumatic meningitis
challenges. Access and visualization of the area around the attachment of the crista galli and ethmoid bone may be especially difficult. Multilayered repair of large skull base defects is necessary to prevent delayed brain sagging and CSF leak. The main goal of treatment in surgical candidates is reconstitution of the cranial base anatomy to prevent meningitis and mucocle formation while optimizing cosmetic outcome. There are various reports on and methods for repair of skull base defects. For decades, the use of the pericranial flap has been the means to repair anterior cranial floor defects due congenital disease, tumors, and traumatic injuries. This flap is easy to harvest, seldom requires additional incisions, and quickly incorporates into the surrounding tissue. One drawback is that, in traumatic repairs, 10% to 17% of patients have persistent CSF leak after the initial repair, suggesting possible vascular compromise and subsequent flap failure. However, the pericranial flap cannot only be pedicled anteriorly using supratrochlear and supraorbital arteries but also laterally using superficial and deep temporal arteries. An additional option for a lateral flap is the temporalis muscle flap, which consists of the temporalis muscle (with or without the overlying fascial tissue). This flap can also be elevated along with the pericranium to form a longer and more robust flap. Another widely used flap is the temporoparietal fascia flap, which has been well described in plastic and reconstructive surgery for the head and neck; however, reports of its use in the skull base are sparse.

To evaluate the evolution of our neurosurgical techniques and treatment outcomes for comminuted anterior skull base fractures, we collected and analyzed data on patients who underwent surgical repair of extensive anterior skull base fractures. In this series, we describe the use of various combined vascularized tissue flaps for multilayered repairs of the anterior skull base. We also introduce a useful novel classification scheme to aid in planning the required extent of surgical exposure and the appropriate flap choice for repair.

Methods

After review and approval from the University of Oklahoma Health Science Center institutional review board was obtained, we reviewed the clinical and radiological records of all patients who underwent surgical repair of anterior skull base fractures between 2004 and 2014 at this institution. We reviewed the mechanism of injury, clinical findings on admission, and initial imaging findings, including assembled fracture location, fracture characteristics, and associated intracranial lesions and outcomes.

Diagnostic Procedures

All patients underwent high-resolution CT examination upon admission. Serial axial CT images of the head, facial bones, and cervical spine were obtained (without administration of a contrast agent) to assess intracranial pathology and fractures of the cranium, cervical spine, and face. Patients with fractures involving the sphenoid wing and carotid canal underwent CT angiography of the head and neck to evaluate possible vascular injury. One patient with a delayed CSF leak who presented with meningitis required the use of radionuclide cisternography to confirm the presence of the CSF leak and identify its location.

Classification

Fractures were classified into 3 groups (Classes I–III), based on the posterior extent of the fracture along the anterior skull base (Fig. 1). Fractures were classified to aid neurosurgical planning and to accurately anticipate the extent of exposure needed to adequately prepare the appropriate vascularized flap for repair. Class I fractures were defined as involving only the frontal sinus or frontal bone. Patients with involvement of only the anterior table were excluded from the study because they did not meet criteria for the surgical approach. All patients with Class I fractures had comminuted fractures. Class II fractures were defined as those extending to the ethmoid cribriform plate. Class III fractures were defined as those extending to the sphenoid bone or sinus.

Surgical Anatomy and Exposure

Surgery was performed as soon as possible to lessen the risk that patients would develop meningitis. Until 2010, a lumbar drain was placed routinely prior to surgery. However, in 2010 the management philosophy of our institution changed, and this practice was abandoned. Instead, we adopted a more aggressive intraoperative approach that used endoscopy and microscopy for identification and repair of the skull base. If a patient required intracranial pressure monitoring and drainage, an external ventricular drain was placed before the operation, and intracranial pressure was managed prior to the procedure.

All patients underwent a standard bifrontal craniotomy with both intra- and extradural exposure. Following a bicoronal incision and subgaleal dissection, the pericranial flap can be designed and created.

A standard anteriorly based pericranial flap may be developed; however, this flap has several disadvantages for some repairs of anterior skull base fractures. Often the source of traumatic injury damages the pericranium in this area (Fig. 2). This compromises the vascular supply from the supraorbital and supratrochlear arteries, potentially obviating this flap design in some cases (Fig. 3). Also, when an anteriorly based flap is inset, a gap must be left in the bone flap and superior orbital rims to maintain perfusion to the pericranial flap. Initially, glabellar fullness will result, secondary to tissue bulk of the pericranial flap. After tissue edema subsides, a gap may be evident, which often becomes a source of poor cosmesis. Therefore, the vascularized flap design evolved recently into a laterally based flap.

The temporalis muscle flap comprises the temporalis muscle, overlying temporalis fascia, and attached pericranium, with vascularization from the anterior and posterior deep temporal arteries. For this flap, the parietal pericranium is incised contralateral to the pedicle of the flap, and a blunt subperiosteal dissection ensues to the level of the zygoma and the vascular pedicle contain-
Combined vascularized tissue flaps for skull base fracture repair

III fractures, a vascularized flap of 15–20 cm can be dissected, and the entire anterior skull base can be covered. The pedicled fascia/pericranial sheet is usually sufficient for skull base reconstruction; the temporalis muscle itself is not used for reconstruction and is sutured back to the anterior part of the temporal fossa to help decrease post-operative temporal fossa hollowing and poor cosmesis (Fig. 4). The temporoparietal fascial flap, or galeal flap, is another lateral flap that is highly vascularized from the superficial temporal vessels, and it has been well described. Both flaps are rarely compromised in trauma patients and provide an excellent source for repair of skull base defects.

After the tissue flaps have been dissected, a standard bifrontal craniotomy is performed with or without frontoorbital osteotomies to improve the working angles. Using the operative microscope, the endocranial surface of the skull base is inspected for additional dural lacerations. The frontal sinus is cranialized in a standard fashion, making sure to remove the mucosal surfaces to avoid mucocele formation. The pericranial flap is placed extradurally along the anterior floor of the skull and sutured microsurgically to the dura for a watertight seal. A posteriorly releasing incision must be made in the laterally based temporalis flap to allow proper rotation into the cranial cavity (Fig. 5).

Endoscopic endonasal dissection and repair with a nasoseptal flap are performed for extensive fractures involving the sphenoid and ethmoid sinuses with large defects or as a salvage procedure when other flaps have been used and patients have persistent CSF leaks. The utilization of this flap has been well described. Following flap place-

FIG. 1. Illustration demonstrating the fracture classification scheme. A: Class I exocranial surface—extensive comminuted fracture of the anterior and posterior tables of the frontal sinus. B: Class I endocranial surface—posterior to anterior view showing a lateral comminuted fracture limited to the anterior and posterior walls of the frontal sinus without extension into the ethmoid bone or the sphenoid bone. C: Class II exocranial surface—fracture extending down the frontal sinus and back through the ethmoid bone. D: Class II endocranial surface—fracture down the lateral posterior wall of the frontal sinus into the ethmoid–cribiform plate complex without extension into the sphenoid bone. E: Class III exocranial surface—fracture along the lateral and calvarial portions of the frontal bone, with involvement of the orbits and orbital roof, ethmoid bone, and sphenoid bone. F: Class III endocranial surface—extensive comminuted fractures involving bilateral frontal bone and ethmoid bone, with extension into the sphenoid bone and sinuses. Copyright Barrow Neurological Institute, Phoenix, Arizona. Published with permission. Figure is available in color online only.

FIG. 2. Comminuted frontal bone fracture obviating anteriorly based pericranial flap design due to severe vascular compromise of the supraorbital and supratrochlear arteries. The temporalis fascia–pericranial flap intended to be used for anterior skull base repair is based on the left superficial and deep temporal perforators. Figure is available in color online only.
ment, concurrent treatment of associated facial fractures is completed.

Results

Patient Population

Forty-three patients were identified. Their demographic characteristics and the mechanisms of injury are summarized in Table 1. The most common clinical finding was periorbital edema, which was present in 21 (49%) of the patients. Other clinical findings are summarized in Table 2. The patients’ neurological presentation varied widely; the mean Glasgow Coma Scale score was 9.8 (range 3–15).

The most common anterior skull base fracture site was the frontal sinus, which was fractured in 41 (95%) of the 43 patients (Table 3), followed by involvement of the ethmoid cribiform plate (in 27 patients [63%]). Associated facial fractures were present in nearly 39 patients (91%). Six patients had Class I fractures, 8 had Class II fractures, and 29 had Class III fractures; thus, most patients in this series had posteriorly extensive anterior skull base injuries.

Following fractures, the most common intracranial pathology was pneumocephalus, which was found in 30 patients (70%). The remaining intracranial pathological findings are described in Table 4.

Surgical Management and Outcome

The average time from admission to surgery was 5 days. Hematoma evacuation was required in 5 patients (12%), and another 5 (12%) required external ventricular drain placement. Placement of a permanent ventriculoperitoneal shunt was performed in 3 patients (7%). Associated facial fractures were repaired during the same operation in 18 patients (42%).

Anterior skull base repair results are listed in Table 5. All 6 patients with Class I fractures underwent repair of dural tears, frontal sinus obliteration with removal of the posterior table, and nasal outflow tract obliteration. An anteriorly based pericranial flap was used exclusively for repair in all patients with Class I fractures, and no patient with a Class I fracture had a persistent CSF leak. Thirty-three patients (77%) received an anterior pericranial flap alone, and 10 patients (including 3 with salvage flaps) (23%) had multiple flaps; 1 with Class II fractures and 9 with Class III fractures.

There were 8 patients with Class II fractures. In one of these patients, the anterior pericranium was severely compromised, so a dual flap technique was used. A laterally based flap was placed and then the uncompromised
anterior pericranium proximal to the pericranial laceration was used for repair of the frontal sinus (Fig. 4). One patient with a Class II fracture that was repaired with an exclusive anteriorly based flap experienced persistent leak, which was discovered one month after discharge and resolved with a lumbar drain.

There were 29 patients with Class III fractures. The dual flap technique was used for 3 of these patients, but the laterally based flap was designed and extended over the sphenoid fractures as well as over the comminuted ethmoid. Two patients with Class III fractures were treated with a triple flap technique that consisted of the anteriorly based pericranial flap for the frontal sinus, a laterally based temporoparietal fascial flap for repair of ethmoid and sphenoid bone defects, and an additional nasoseptal flap for the exocranial surface. None of these patients who underwent multiflap repair had persistent CSF leakage.

Four patients with Class III fractures who underwent repair with purely anteriorly based pericranium had persistent CSF leakage. Three of these patients required salvage endonasal endoscopic augmentation and use of a nasoseptal flap for reconstruction of the skull base. The salvage repair time frame ranged from 1 to 3 months after discharge. In the other patient with a Class II fracture and a persistent leak, the leak was managed successfully with a lumbar drain.

Postoperative Complications and Outcomes

The mean follow-up time was 14 months (range 5–45 months). For the 31 patients with available follow-up data, the mean Glasgow Outcome Scale score was 4.4 (range 1–5, with 5 corresponding to minor neurological deficits). Most of these patients (n = 21) had a score of 5, with 3 being the next most common score (n = 6). One patient had a score of 1, and 3 had a score of 4.

The postoperative course of 2 patients was complicated by meningitis (5%). In both cases, an Enterococcus species grew in the patients’ drains, and the infections were treated successfully with intravenous antibiotic therapy.

No patients had postoperative neurological deterioration attributable to increased cerebral edema or hematoma. Only 1 patient died; this was on postoperative Day 7 after surgical repair due to a middle cerebral artery infarction that was present preoperatively. Local wound infection occurred in 2 patients. One patient developed chronic wound dehiscence, and another developed nasal cellulitis a year after surgery. At follow-up, no patients had developed mucoceles. Three patients required a second operation for closure of skull scalp defect.

Five (12%) of the 43 patients developed CSF leak after surgical repair. All 5 patients had Class II or Class III fractures and underwent repair with only an anterior pericranial flap (Table 5). No patient treated with a primarily combined flap (dual flap or triple flap technique) or with endoscopic repair required reoperation, had persistent postoperative CSF leak, or developed meningitis. Based on the Fisher exact test, there was no statistically significant association between the postoperative CSF leak and the repair strategy (p < 0.31).

Discussion

Indications for Surgical Treatment

Dural tears and CSF leaks are commonly encoun-
tered in skull base fractures and are 5 to 6 times more frequent in the anterior than in the middle or posterior skull base. Ethmoid–cribriform plate fractures are the most common. The preponderance of ethmoid–cribriform plate fractures can be explained by the thin fragile dura over the cribriform plate and its firm adherence. Additionally, the ethmoid is porous in relation to the other skeletal bones; therefore, even low-impact trauma can result in ethmoid fractures.

CSF fistulas occur in 10% to 30% of patients with skull base fractures, and from 7% to 30% of patients with posttraumatic CSF leakage develop meningitis.

The first successful CSF repair was reported in 1926 by Dandy, who used a fascia lata autograft to seal the posterior wall of the frontal sinus. Posttraumatic meningitis is the major concern in patients with a skull base fracture and a CSF leak. The overall rate of infection ranges from 1.3% per day for the 1st week after a skull base fracture to 8.4% per year after the first 6 months.

Sakas and colleagues reported a significantly higher infection rate in patients who had CSF rhinorrhea lasting longer than 8 days. In light of the high incidence of meningitis and mortality rates of 18.8% to 25%, the rapid identification and treatment of CSF fistulas are critical to reducing long-term morbidity and mortality. When a dural leak can be sealed successfully, the risk for meningitis decreases from 85% to 7% over 10 years. Although the spontaneous resolution of CSF fistula is possible, the risk for meningitis must be weighed against potential surgical morbidity and mortality. However, recurrent CSF leakage after initial spontaneous cessation may occur and is associated with a 30% rate of recurrent meningitis and increased mortality. Spontaneous resolution is also less likely in cases of extensive, comminuted anterior skull base fractures, especially those involving the ethmoid and sphenoid sinuses.

In our series of 43 patients, several patients (7%) with chronic and persistent CSF leaks requiring subsequent conclusive reoperation and repair were referred to us after a delay to treatment. Compared with immediate surgical repair, observation has been proven to lead to considerably higher risk for development of meningitis. We therefore recommend prompt surgical repair in patients with extensive fractures to avoid infection and related complications. Radionuclide cisternography was used in only 1 patient, who had a chronic CSF leak. We believe that this imaging modality is usually not indicated.

### Table 2. Clinical findings in 43 patients with anterior skull base fractures

<table>
<thead>
<tr>
<th>Finding</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periorbital edema</td>
<td>21 (49)</td>
</tr>
<tr>
<td>Periorbital ecchymosis</td>
<td>19 (44)</td>
</tr>
<tr>
<td>Epistaxis</td>
<td>17 (40)</td>
</tr>
<tr>
<td>Sluggish or nonreactive pupils</td>
<td>12 (28)</td>
</tr>
<tr>
<td>Hemotympanum</td>
<td>8 (19)</td>
</tr>
<tr>
<td>Ophthalmoplegia</td>
<td>3 (7)</td>
</tr>
<tr>
<td>CN VII palsy</td>
<td>3 (7)</td>
</tr>
<tr>
<td>Meningitis</td>
<td>3 (7)</td>
</tr>
<tr>
<td>Otorrhea</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Visible brain matter</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Seizure</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Proptosis</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Rhinorrhea</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Decorticate posturing</td>
<td>1 (2)</td>
</tr>
</tbody>
</table>

*CN = cranial nerve.*

### Table 3. Locations of anterior skull base fractures in 43 patients

<table>
<thead>
<tr>
<th>Location</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal sinus</td>
<td>41 (95)</td>
</tr>
<tr>
<td>Orbital plate of frontal bone</td>
<td>28 (65)</td>
</tr>
<tr>
<td>Ethmoid cribriform plate</td>
<td>27 (63)</td>
</tr>
<tr>
<td>Sphenoid sinus/sella turcica</td>
<td>21 (49)</td>
</tr>
<tr>
<td>Temporal bone</td>
<td>13 (30)</td>
</tr>
<tr>
<td>Sphenoid wing</td>
<td>12 (28)</td>
</tr>
<tr>
<td>Carotid canal</td>
<td>11 (26)</td>
</tr>
<tr>
<td>Foramen</td>
<td>1 (2)</td>
</tr>
</tbody>
</table>

### Table 4. Intracranial pathology associated with anterior skull base fractures in 43 patients

<table>
<thead>
<tr>
<th>Pathological Finding</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumocephalus</td>
<td>30 (70)</td>
</tr>
<tr>
<td>Subarachnoid hemorrhage</td>
<td>25 (58)</td>
</tr>
<tr>
<td>Subdural hemorrhage</td>
<td>23 (53)</td>
</tr>
<tr>
<td>Intraparenchymal hemorrhage</td>
<td>17 (40)</td>
</tr>
<tr>
<td>Cerebral edema</td>
<td>12 (28)</td>
</tr>
<tr>
<td>Hemorrhagic contusions</td>
<td>11 (26)</td>
</tr>
<tr>
<td>Intraventricular hemorrhage</td>
<td>10 (23)</td>
</tr>
<tr>
<td>Epidural hematoma</td>
<td>9 (21)</td>
</tr>
<tr>
<td>Midline shift</td>
<td>9 (21)</td>
</tr>
<tr>
<td>Carotid dissection</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Subfalcine herniation</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Transventricular herniation</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Uncal herniation</td>
<td>1 (2)</td>
</tr>
</tbody>
</table>
Fracture Classification and Treatment Strategies

Major challenges of anterior skull base repair include not only reconstruction of the defect but also the decision making about the extent of the surgical approach (endoscopic, open, or a combination thereof) and the appropriate reconstruction strategy (choice of vascularized flap). Prior classification schemes for categorizing fractures of the anterior skull base have sought to associate fracture location with long-term risk for meningitis.37,49 Our classification is based on the greatest posterior extent of the fracture and is used for surgical planning, thereby allowing anticipation of required exposure, repair extent, and flap choice.

Since Wigand59 first reported endoscopic CSF fistula repair in 1981, the use of endoscopic techniques in anterior skull trauma has grown; endoscopic techniques are now used solely or in combination with conventional surgical techniques.26,43 The nasoseptal flap, based off the nasoseptal artery, has increasingly become the workhorse of endonasal skull base reconstruction.25,26,41 Current evidence suggests that endoscopic skull base repair with vascularized tissue is associated with a lower rate of CSF leaks than repair with free tissue graft and results in closure rates similar to those reported for open surgical repair.26,39,54 Endoscopic repair with use of a vascularized pedicled nasoseptal flap is now considered the gold standard for most CSF leak repairs because it is safe and effective.26,43 Sole endoscopic repair is of the greatest use in the absence of associated intracranial trauma and for patients who do not require repair of facial fractures.12,31,35 However, for patients with comminuted frontal sinus fractures and associated facial fractures, open surgery may be necessary to prevent mucocele formation and to achieve good cosmetic outcomes.

Pericranial flaps are traditionally used in open repair of the anterior skull base. They are easy to harvest and are quickly incorporated into surrounding tissue because they are highly vascularized from the supraorbital and supraorbital arteries.41,42,54 However, we found that the pericranial flap may have several disadvantages in patients with extensive anterior skull base fractures. Viable uncompromised pericranial flap is often unavailable if initial trauma or comminuted fracture edges result in pericranial lacerations that compromise the blood supply. Furthermore, the posterior extent of many fractures precludes the use of the anteriorly based pericranium, which is not versatile and may not extend far enough to span large defects across the frontal, ethmoid, and the sphenoid sinuses, which are found in Class II and III fractures. Additionally, when an anteriorly based flap is inset, a gap in the bone flap and the superior orbital rims must be left to maintain perfusion to the pericranial flap. After tissue edema subsides, a gap may be evident that can become a source of poor cosmesis. Therefore, for complex traumatic anterior skull base defects (Class II and Class III), the pericranial design evolved into a laterally based tissue flap. Lateral blood supplies are often uncompromised and have 2 sides available on which to base a lateral vascular pedicle. The superficial, middle, and deep temporal arteries provide the blood supply for these flaps. In our series, we mostly used lateral flaps combining the temporals muscle fascia and the deeper pericranial tissue layer. This combination forms a resilient tissue flap with a rich vascular supply.27 This flap is highly versatile, provides a large surface area with a superior arc of rotation, and may be used with minimal donor site morbidity and excellent cosmetic outcomes. There is scant literature evaluating utilization and classification of combination flaps in traumatic repairs.17

An additional laterally based flap is the temporoparietal fascial flap, which has been used especially in head and neck reconstruction.47 Taha et al.55 described the use of the temporoparietal fascial flap for repair of a large traumatic middle cranial fossa CSF fistula via a middle cranial fossa approach. The risks associated with this flap, however, are its potential to damage hair follicles or skin vascular supply, resulting in postoperative alopecia or scalp necrosis.54 Therefore, we reserve this flap for cases in which repeated

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TABLE 5. Classification and flap use in 43 patients for repair of anterior skull base fractures

<table>
<thead>
<tr>
<th>Type of Flap</th>
<th>Class I (n = 6)</th>
<th>Class II (n = 8)</th>
<th>Class III (n = 29)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior pericranial flap only</td>
<td>6</td>
<td>7*</td>
<td>23†</td>
</tr>
<tr>
<td>Dual flap (anterior pericranial and lateral flaps)</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Triple flap (anterior pericranial, lateral pericranial, and nasoseptal flaps)</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Anterior pericranial and nasoseptal flap</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

* One patient had persistent leak that resolved with a lumbar drain.
† Four patients had a persistent leak that resolved with a lumbar drain.

in patients with acute, extensive trauma. CT scanning is a faster and less expensive tool for diagnosis and surgical planning of acute fractures.

When a patient has severe intracranial traumatic injury with concomitant cerebral edema, the treatment of increased intracranial pressure should occur prior to repair of the skull base fracture. Repair of the CSF leak and the anterior skull base can usually be initiated within 5 to 7 days after initial stabilization and management. In our series, the average time between hospital admission and surgery was 5 days. Preoperative prophylactic antibiotic treatment has not been shown to be of benefit in this patient population.5 It has been suggested that prophylactic antibiotic therapy may increase the risk of meningitis by altering the normal flora of the sinus mucosa.8,13,14,29 We believe that prophylactic antibiotic treatment is not indicated and that the risk of meningitis is lessened to an acceptable extent by early surgical intervention.
repair surgery may be necessary and the pericranium has already been sacrificed.

We have integrated the use of the surgical microscope and endoscopic techniques for Class II and Class III skull base fractures. The microscope allows minimal retraction of the already injured and edematous frontal lobes, while also allowing effective inspection and repair. None of the patients in our series who underwent a combined endoscopic and microsurgical approach required reoperation or had persistent CSF leak, obviating the need for lumbar drains. Recently, no significant difference was found in the recurrence of CSF leak, the incidence of meningitis, or the duration of hospitalization between patients who did and did not receive lumbar drains. In our practice, we have abandoned routine placement of lumbar drains, given their potential for complications, such as intracranial hypotension and pneumocephalus, especially in posttraumatic patients with increased intracranial pressure and greater potential for herniation.

The use of multiple flaps is determined by fracture extent on preoperative CT. For patients with complex Class II and Class III fractures, we occasionally use dual flap or triple flap repair techniques. The dual flap technique may also be used if microsurgical inspection reveals multiple, large defects; in such cases, the anteriorly pedicled pericranium is used (if available and uncompromised) for frontal sinus repair and the laterally based temporoparietal fascial flap is used for ethmoid and sphenoid fractures. This technique may be further augmented with an endoscopic approach of the exocranial surface and use of the triple flap technique, which includes application of a nasoseptal flap. However, the nasoseptal flap may be reserved for salvage therapy when there is a persistent CSF leak after open repair of the endocranial surface. Persistent CSF leaks after previous attempted repair can be challenging to manage because of the lack of available healthy autologous tissue after failure of a pericranial flap. Five of our patients with more extensive fractures (1 Class II and 4 Class III) and traditional exclusive anterior pericranial repair had persistent CSF leakage. Three required salvage management with additional nasoseptal flap repair, while the other two were managed with a lumbar drain.

Our data, although not statistically significant, suggest that combining an anterior pericranial flap with an additional flap (nasoseptal flap or temporoparietal fascial flap) may lead to prevention of CSF leak. Whether combination flaps or laterally based flaps are truly superior to the anteriorly based pericranial flap alone remains to be determined in further larger studies. Nevertheless, our data indicate that dual flap and triple flap techniques allow for a comprehensive armamentarium for anterior skull base repair and salvage therapy for extensive and severe anterior skull base fractures.

Conclusions

Early and aggressive surgical repair of anterior skull base fractures may be necessary for patients in whom conservative management has failed and for those who present with meningitis or extensive depressed or comminuted fractures. The use of vascularized flaps is an ideal substrate for multilayered skull base repair. Dual flap and triple flap techniques that combine the use of various anterior, lateral, and nasoseptal flaps allow for a comprehensive arsenal in skull base repair and salvage therapy for extensive and severe fractures. When patients meet surgical criteria, these repair techniques result in a low rate of morbidity and no mortality, with excellent functional and cosmetic outcomes devoid of recurrent CSF leaks and meningitis. Knowledge about the surgical anatomy of various flaps for complex skull base defects, and expertise in using them, should be in the armamentarium of comprehensive skull base surgery centers worldwide.

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Disclosure
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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