Immediate Single-Stage Reconstruction of Complex Frontofaciobasal Injuries: Part I

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Abstract

Objective To determine if immediate (within 6 hours of adequate resuscitation) single-stage repair of complex craniofacial injuries could be accomplished with acceptable morbidity and mortality taking into consideration the cosmetic appearance of the patient.

Patients and Methods A total of 26 patients (19 men, 7 women) ranging in age from 8 to 58 years with Glasgow Coma Scale scores of 5 to 15 all had a combined single-stage repair of their complex craniofacial injuries within 6 hours of their admission. After initial assessment and adequate resuscitation, they were evaluated with three-dimensional computed tomography of the face and head. Coronal skin flap was used for maximum exposure for frontal sinus exenteration as well as dural repair, cortical debridement, calvarial reconstruction, and titanium mesh placement.

Results Neurosurgical outcome at both the early and late evaluations was judged as good in 22 of 26 patients (85%), moderate in 3 of 26 (11%), and poor in 1 of the 26 (3.8%). Cosmetic surgical outcome at the early evaluation showed 17 of 26 (65%) to be excellent, 4 of 26 (15.5%) to be good, 4 patients (15.5%) to be fair, and 1 patient (3.8%) to be poor. At the late reevaluation, the fair had improved to good with an additional reconstructive procedure, and the poor had improved to fair with another surgery. There was no calvarial osteomyelitis, graft resorption, or intracranial abscess. Complications included three patients (11%): one (3.8%) had tension pneumocephaly and meningitis, one (3.8%) had delayed cerebrospinal fluid leak with recurrent attacks of meningitis, and one had a maxillary sinus infection (3.8%) secondary to front maxillary fistula.

Conclusion The immediate single-stage repair of complex craniofacial injuries can be performed with acceptable results, a decreased need for reoperation, and improved cosmetic and functional outcomes.

Keywords

- craniofacial trauma
- orbital fracture
- titanium mesh

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Introduction

Complex craniofacial injuries have traditionally been managed in three separate stages because of the perceived risk of infection and neurologic deterioration. Initially, urgent craniotomy is performed for the evacuation of hematomas, debridement of cortical contusions, and repair of the dura followed by secondary orbitofacial repair in 7 to 10 days. Cranioplasty is delayed for 6 to 12 months. This staged approach evolved because conventional teaching suggests that extensive cranial reconstruction has a documented risk of infection of at least 15%.¹

Cosmetic considerations were outweighed by the potential risk of neurologic deterioration during the prolonged anesthesia that is required for the acute repair of complex orbitofacial fractures. Thus early single-stage repair of these injuries appeared to involve several risks considered unacceptable to the patient.²

By using recent advances in surgical and anesthetic techniques, there is the potential to complete single-stage craniofacial repair with acceptable morbidity and improved cosmetic outcome in complex craniofacial trauma. It has been reported that contaminated bone fragments can be replaced with an infection risk of just 3.6% as long as they are adequately cleaned, disinfected, and immobilized to allow fusion with surrounding calvaria.³

Advances in neuroanesthesia allow for its prolonged administration without deleterious effects on the neurologic outcome of the patient. Given these advancements, techniques designed for elective craniofacial procedures can be applied to early single-stage craniofacial repair with less technical difficulty than is required for delayed surgery. Furthermore, abundant evidence in the plastic surgical literature demonstrates that early facial repair will result in an improved functional and cosmetic outcome.⁴

The main complication neurosurgeons face when managing anterior cranial base fractures is cerebrospinal fluid (CSF) leak and meningitis. Dural tears are common because of the firm adherence between the dura and the cranial base.⁵ Dural lesions and CSF leaks have been identified in 10 to 30% of cranial base fractures.⁶

Although transcranial repair reported by Dandy⁷ to close craniobasal fistula remained the mainstay of management for a long time, the endoscopic approach might be less effective in certain clinical situations compared with more extensive intracranial procedures.⁸

Endonasal endoscopic repair of CSF rhinorrhea is therefore often limited to specific cases, such as the presence of rhinorrhea due to a precisely located small tear and the absence of associated brain injuries requiring surgical treatment.⁹ However, Patel et al suggested the ability to harvest pericranial flap endoscopically and use it to cover the entire ventral skull base endonasally.¹⁰

Cranial operative procedures began without bone replacement, but as time passed and more varied operative approaches developed with larger bone removal, replacement of removed bone became commonplace for both safety and cosmetic concerns. Initially, suture material was used, then

stainless steel wire, and more recently, metal plating and titanium mesh systems have been proposed.¹¹ They offer the advantage of more secure stabilization for more rapid and complete bone healing with a superior cosmetic appearance.¹²

Study Objective

This prospective study evaluated whether immediate single-stage repair of complex craniofacial injuries could be performed with acceptable morbidity and mortality in patients with relatively significant head injuries.

Patients and Methods

A total of 26 consecutive patients with complex craniofacial trauma admitted to King Abdul-Aziz specialized center-Taif-KSA between January 2007 and September 2009 underwent combined single-stage neurosurgical-faciomaxillary-plastic surgical repair within 6 hours of their admission after thorough evaluation and adequate resuscitation. All patients who met the inclusion criteria—a large bone defect or depression associated with brain herniation, massive CSF rhinorrhea, open cranial trauma, surgically controllable extra-axial hematoma or destruction of the paranasal sinuses, regardless of Glasgow Coma Scale (GCS)—were therefore involved in the study. The exclusion criteria were vital instability, severe concurrent injuries requiring thoracotomy or abdominal exploration, and cases with massive diffuse brain edema (GCS < 5) with or without a need for decompressive surgery.

In accordance with our trauma protocol, all patients were assessed systemically and neurologically by a combined trauma team including a general surgeon, thoracic surgeon, neurosurgeon, and plastic surgeon. Ophthalmologists served as consultants in 88.5% of the patients (23 of 26) to assess and follow visual acuity and fields but were not involved actively in any of the surgical repairs.

Diagnosis

The diagnosis of anterior cranial base fractures is based primarily on clinical symptoms such as an apparent CSF leak or periorbital hematoma. High-resolution computed tomography (CT) scanning with 1-mm-thin slices and three-dimensional (3D) reconstruction is an important tool that can identify very small bony defects along the cranial base or indicate dural lesions through indirect signs such as the presence of fluid in the sinuses or pneumocephalus. Moreover, it can evaluate the extent of intracranial pathology and the degree of craniofacial bony injury.

We used the latest classification per Manson et al to categorize our cases. Three frontobasal fracture patterns were identified by them. Isolated linear cranial base fractures constitute type I. Vertical-linear fractures of the skull vault (frontal bone) occur in combination with base fractures, representing type II (vault and base). Comminution of the frontolateral skull vault and orbital roof in association with a linear base fracture constitute type III.¹³

Surgical Technique

All patients had general anesthesia. Perioperative antibiotics consisted of ceftriaxone 1 g intravenously every 8 hours starting immediately after imaging. Gentamycin irrigation 600 mg/L was used throughout the operation and 500 mg metronidazole in an intravenous infusion every 8 hours. The scalp was completely shaved, the scalp and face were prepped with betadine solution, and draping was designed to isolate the injured portions of the face and cranium. We began by positioning the patient with a relaxed head position tilted back 20 degrees within the Mayfield device except for one patient who was on cervical traction. This optimizes brain relaxation, permitting it to fall back away from the anterior cranial base, especially when the frontal lobe is contused or edematous.

Surgery was initiated by the neurosurgical team with a coronal skin flap secured by Raney clips, modified as directed by the plastic and oculomandibulofacial surgical team. A coronal scalp incision was performed, leaving the pericranium intact 13 to 15 cm from the orbital rim for later use in cranial base reconstruction if it was not severely lacerated by trauma. We favor bilateral craniotomy even if radiologic studies show unilateral injuries because dural tears on the contralateral side are common.

The frontal craniotomy was designed for maximal exposure of the frontal sinus, anterior fossa floor, and orbital roof. After elevation of the depressed fragments, the frontal air sinuses were cranialized if possible, the mucosa was then stripped out meticulously, and then the nasofrontal ducts and remaining dead spaces of the sinus were packed with muscle. This technique evolved to use bone chips from the calvarial cancellous bone to induce bony obliteration with secondary ossification in the final eight cases (31%).

In only 4 patients (15.5%) was primary dural repair possible, whereas all of the remaining 22 patients with extensive brain fungation (85%) required intradural and extradural grafts. In these 22 patients, autologous grafts were obtained from temporalis fascia in 14 cases (53.8%), pericranium in 4 cases (15.5%), and fascia lata in 4 cases (15.5%).

Before tightening the last two sutures, an irrigator was introduced; the sutures were pulled tight, and the closure was tested for sealing and the ability to expand. Surgicel soaked with the patient's blood was then layered over the suture line for reinforcement. Individual sutures were used to decrease the risk of catastrophic suture line failure; wide duraplasty is mandatory to avoid brain banding.

With the completion of the intracranial repairs, the faciomaxillary surgery team began reconstructing the orbital rim, initially releasing any trapped soft tissue. Blowout fractures of the orbital roof were reconstructed by the replacement of the dislocated bone, by titanium mesh (in adults) or by resorbable mesh (in pediatrics) in case of a bone defect. This mesh is fixed only by frontal lobe gravity (—Fig. 1). Contouring of the supraorbital margin was achieved with long miniplates and mesh, with or without calvarial bone graft. Reconstruction of the orbital floor was performed using titanium mesh in four patients (15.5%) or by autologous bony graft in four patients.

Fig. 1 Illustrative case 1. (A) Right cranioorbital trauma with congested pulsating eye. (B) Postoperative computed tomography brain and orbit with coronal reconstruction showed a correct position of free titanium mesh against the right orbital roof. (C) The patient recovered full consciousness and is healthy with an intact moving eye.

Titanium mesh was used in 22 patients (85%) for cranioplasty and in 4 patients (15.5%) for orbital floor reconstruction. Resorbable mesh made up of poly-DL-lactide was used in three pediatric patients (11%). Both are

Table 1 Cranial procedures performed in our patients

Procedures	No. of patients	%
Intradural procedure	21	80.5
Cranialization of frontal sinus	18	69
Base repair by pericranium flap	15	57.7
Base repair by bone grafts	15	57.7
Fixation by miniplates	24	92
Titanium mesh cranioplasty	22	85

manufactured by Gebrüder Martin, Tuttlingen, Germany (► **Table 1**).

Closure of the coronal incision was performed according to the condition of the soft tissues. If the soft tissues (skin, muscle, or galea) were intact, closure in layers was achieved using Vicryl 3-0 and monofilament nonabsorbable interrupted suture 3-0 (either nylon or Prolene) occasionally supplemented by surgical staples.

If the soft tissues (skin, galea, or anterior belly of occipitofrontalis) were severely damaged, deficient, or lost, reconstruction with scalp flaps (either rotational or transposition) and a split-thickness skin graft was used for closure of a secondary flap defect.

Final closure was performed by the neurosurgery team and occasionally with help from the plastic team after reinspection of the intracranial compartment for dural laceration, CSF leak, and meticulous hemostasis.

Patients were monitored in the intensive care unit (ICU) postoperatively. Drains were used as needed; we preferred its function as a reservoir rather than under negative pressure. Follow-up CT scans were performed in all cases to assess epidural air, occult hemorrhage, brain reexpansion, and edema within 24 hours of the operation.

Early evaluation of outcome was performed at 1 to 2 months, and late evaluation was completed between 6 and 12 months. Neurosurgical outcome was evaluated according to neurosurgical deficit, convulsions, visual affect, intracranial infections (brain abscess/meningitis), and CSF leak. The plastic outcome was assessed by the operating team based on a five-tier scale designed by Benzil et al.¹⁴

Another independent plastic surgery outcome was assessed based on photos. Preoperative photos were used as a reference. Two-month postoperative photos were used for the early evaluation of aesthetic outcomes. The 6- and 12-month postoperative photos were taken for a late evaluation. Standardized photographs were taken with the patients standing straight. Objective photographic assessment, frontal and side views (left and right) were used for evaluating the aesthetic outcomes by the panel of 8 plastic surgeons and 12 paramedics. Seven criteria were assessed on a 2- or 3-point scale by the panel. The criteria were the symmetry of both sides of the face, frontal area, eyebrow, eyelids, scar status, eye globe position, and bony shape.

The total score was calculated as a sum of the scores of the seven criteria. For statistical analysis, scores of 9 to 10 were considered "excellent," 7 to 8 as "very good," 5 to 6 as "good," 3 to 4 as "fair," and 0 to 2 as "poor." We calculated the average scores recorded by the surgeons and paramedics and compared the net results with the operating team's initial assessment.

Results

Cranial base fractures were located at the ethmoid-cribriform plate in 20 patients (76%), in the posterior wall of the frontal sinus in 18 patients (69%), in the orbital roof in 15 patients (57.7%), in the sphenoid sinus in 13 patients (50%), and in the sphenoid wing in 10 patients (38%). According to the classification of frontobasal trauma by Manson et al, 16 patients (61.5%) had combined fractures involving both central and lateral areas of the anterior cranial base. Additional vault fractures were present in 10 patients (38%); of these, 6 patients (23%) were nondepressed and 4 patients (15.5%) were depressed. Thirteen patients (50%) had substantial pneumocephalus clearly located in the subarachnoid space, and 14 patients (53.8%) had associated brain injuries (► **Fig. 2**). Facial fractures were present in 17 patients (65%) (► **Table 2**).

Traumatic dural tears were located mainly at the ethmoid-cribriform plate in 21 patients (80.5%), at the posterior wall of the frontal sinus in 20 patients (76%), at the orbital roof in 13 patients (50%), and at the planum sphenoidale in 3 patients (11%). Multiple dural lesions were encountered in 18 (69%) of the patients. Overall, dural lacerations were clearly identified in 21 of the 26 patients (80.5%).

Neurosurgical outcome at both the early (1–2 months) and late evaluation (6–12 months) was judged as good in 22 of 26 patients (85%), moderate in 3 of the 26 (11.2%), and poor in 1 of the 26 (3.8%). The presenting GCS among 26 patients was 6 cases (23%) between 5 and 9 (severe head injury) and 20 cases (77%) between 10 and 15 (mild and moderate head injury). At the late evaluation, 18 cases of 20 (mild and moderate head injury) and 4 cases of 6 (severe head injury) regained consciousness without any cognitive deficit. Two patients with moderate head injury (GCS 9 and 11, respectively) and another with a severe head injury (GCS 7) showed average improvement of + 3 GCS with mild to moderate frontal manifestation. One patient with a severe head injury (GCS 6) showed + 2 GCS improvement. This patient did not show progressive improvement because of recurrent infections and uncontrollable seizures and remained in a vegetative state. All patients had an expected neurologic outcome that was predicted by age and presenting GCS score except the last case.

For the faciomaxillary surgical outcome at the early evaluation, all the hardware used was in a perfect position in the postoperative CT evaluated by the radiologist even for the free orbital mesh kept in position by frontal lobe gravity. No migration was reported in this series, and at the late evaluation there was a case of maxillary sinus infection and hardware exposure.

Fig. 2 Illustrative case 2. (A) Right cranioorbital trauma with severely proptosed right globe and brain fungation. (B) Preoperative computed tomography brain and orbit scan with three-dimensional reconstruction showing comminuted fracture of the frontal bone, roof, and medial wall of the right orbit (associated fracture of the right side of the mandible). (C) The patient recovered full consciousness with a good cosmetically moving blind eye.

Cosmetic Surgical Outcome

The operating team assessment according to criteria by Benzil et al¹⁴ (► **Table 3**) and the independent plastic evaluation by the panel were almost similar. At early evaluation, it showed 17 of 26 patients (65%) to be excellent, 4 of 26 (15.5%) to be good, 4 (15.5%) to be fair, and one (3.8%) to be poor. At late reevaluation, the fair had improved to good with only one additional reconstructive procedure; the poor had improved to fair with more reconstructive surgery. There was no calvarial osteomyelitis, graft resorption, or intracranial abscesses.

Three patients had complications (11%): one (3.8%) had tension pneumocephaly with concurrent meningitis, one (3.8%) had a delayed CSF leak with recurrent attacks of meningitis, and one had a maxillary infection (3.8%) secondary to a front maxillary fistula associated with wound infection and hardware exposure. One patient (3.8%) died 1 month after surgery because of chest infection, and sepsis was reported and excluded from this series.

Table 2 Associated midfacial fractures

Fracture	No. of patients	%
Zygomaticomaxillary fracture (tripod farceur)	4	15.5
Le forte type I	2	7.5
Le forte type II	3	11
Le forte type III	4	15.5
Maxillary fracture	2	7.5
Nose fracture	2	7.5
Total	17	65

Discussion

Craniofacial injuries should be regarded as a single entity, and the repair is often a combined procedure involving the neurosurgeon and the maxillofacial surgeon. First, the dura is repaired, isolating the cranial contents. Then fractures of the cranium and the face are treated following the standard principles of surgery used to correct craniofacial deformities.¹⁵

Because of the particular anatomy of the region, the fracture involves one or more of the frontal, temporal, sphenoidal, ethmoidal, nasal, and zygomatic bones. Eftekhari et al showed that intradural air significantly increases the risk of meningitis, and therefore pneumocephalus must be considered as equivalent to CSF leakage.¹⁶ Particular attention must be paid to sphenoid sinus fractures that can be the site of the CSF leak and associated with carotid or optic nerve injury.¹⁷

A high-resolution CT scan in the horizontal and, when possible, in the coronal plane usually can detect and classify the fracture. CT scan also shows indirect signs of a frontobasal fracture, such as intracranial air and air-fluid level within paranasal sinuses.¹⁸ The complete understanding of the 3D configuration of the fractured segments and their early and definitive repair are the basis for a successful treatment.¹⁹

The efficacy of magnetic resonance imaging (MRI) in localizing CSF fistulae has not been fully evaluated. However, MRI should be performed in selected patients to assess the contents of herniations of the meninges or brain through the cranial base defect.²⁰

The classification of frontobasal fractures is based on their anatomical location and the pattern of bone segmentation and bone displacement. Frontobasal fractures are defined as

Table 3 Cosmetic surgical outcome according to Benzil et al¹⁴

Grade	Criteria	Early	Late
Excellent	Minimal scarring or alteration in facial contours, no contractures or enophthalmos, normal ocular, nasopharyngeal, and mandibular function	17	17
Good	Normal function with two of the following: noticeable scarring without contractures, minimal alterations in facial contours, < 2-mm enophthalmos	4	8
Fair	Normal function with two of the following: conspicuous scarring, alteration in facial contours, > 2-mm and < 4-mm enophthalmos, diplopia in extreme gaze	4	1
Poor	Two or more of the following: conspicuous scarring with alteration in facial contours, > 4-mm enophthalmos, diplopia not in primary gaze with orbital entrapment	1	0
Severe	Any of the following: severe scarring or alteration in facial contour, diplopia in primary gaze, severe mandibular or nasopharyngeal functions	0	0

central, lateral, or combined. Another crucial factor is the involvement of the paranasal sinuses and anterior skull base. Finally the type is referred to as linear or comminuted, with or without bone fragment displacement. These indications are fundamental for a better understanding of the fracture effects and for correct planning of their treatment.²¹

Manson et al published a classification of frontobasal and midface fractures involving the cranial base based on cadaveric experiments and comprehensive clinical experience.¹³ We used Manson et al to categorize our cases because they classified frontobasal fractures into three unique and reproducible patterns based on vector, location, and force. This new classification scheme, paired with known patterns of mid-facial injuries, assists in fully understanding frontofaciobasal

injury and its complications. Moreover, this classification pays attention to impure type II and type III fractures that are associated with a high rate of complications and must be carefully managed.

Some authors believe intervention in stages allows a worthwhile resolution of the acute brain injury and edema, more thorough ophthalmic assessment, better radiologic delineation of the damage, and time to plan a combined procedure more easily.²² However, the average time of hospitalization of their patients was 23 days.

Timing of reconstructive craniofacial surgery with cerebral edema is somewhat controversial. For mild and moderate head injury, Benzil et al¹⁴ conducted early reconstruction of 13 patients within 24 hours of trauma with a limited range of GCS scores (10–15) and achieved neurosurgical outcome at both early and late evaluation judged as good in 11 of 13 patients (85%) and moderate in 2 of 3 (15%). No patient had a neurologic outcome below that predicted by age and initial GCS score despite the prolonged anesthesia required for single-stage craniofacial repair. No patient required late cranioplasty.¹⁴

These results are almost similar to our mild and moderate group. However, Poole and Briggs recommended a joint comprehensive delayed repair of 48 patients after 2 weeks and reported 3 cases of meningitis, 1 cerebral abscess, 1 late CSF leak, 11 bone graft resorption, and 29 deformities and other complications related to the trauma itself that could not be repaired.²²

However, in a severe head injury (GCS: 5–9), this is the group that needs careful selection to avoid secondary brain insult. From the study of Derdeyn et al, it was observed that patients with intracranial pressure (ICP) < 15 mm Hg on initial evaluation, with no evidence of intracranial hemorrhage, midline cerebral shift, or basal cistern effacement on CT scan, as well as a lower topographic level of facial fracture, were good candidates for surgery. Alternatively, patients who had a GCS ≤ 5, upper-level facial injury, or the presence of intracranial hemorrhage, midline shift, or basal cistern effacement were not good candidates for early surgery.¹⁷

We agree with the assumption of Derdeyn et al regarding patients with GCS < 5 (excluded from our series) associated with ICP > 15 mm Hg with diffuse brain edema and basal cistern effacement. However, for patients with upper facial injury (frontal bone and sinus) still carrying a good prognosis with early repair, we operated on 20 of 26 of them (76%) associated with upper face injury. Therefore, we do not think upper face injury is a contraindicating factor. The assumption is the presence of a midline cerebral shift because of associated epidural hematoma or depressed fracture with extra-axial collection. We evacuated six patients with epidural hematoma (23%) and elevated four of depressed fracture (15.5%) with midline shift prior to the reconstructive surgery at the same session.

In an experimental study conducted in south Florida, the authors examined whether wound closure by replacement of skull flap and bone wax would allow aesthetic reconstruction of the skull damage induced by traumatic brain injury (TBI) without causing any detrimental effects to the cortical tissue.

Although the immediate reconstruction provided normalized skull structure, it exacerbated cortical damage compared with the groups that received no skull reconstruction in both the moderate and severe TBI models. Although they did not significantly differ in the moderate TBI model, the animals that received reconstruction with bone wax and bone flap displayed significantly larger cortical damage than the bone wax only. Moreover, the study added the information that the immediate skull reconstruction produced an upregulation of the edema marker aquaporin-4 staining that likely prevented the therapeutic benefits of brain swelling and resulted in larger cortical infarcts. TBI animals that had a 2-day delay in reconstruction showed significantly reduced edema and infarcts compared with those exposed to immediate repair. The south Florida group concluded that immediate, but not delayed, skull reconstruction may exacerbate TBI-induced cortical damage and it warrants a careful consideration of aesthetic repair of the skull in TBI.²³

In our series, 22 of 26 patients had extensive dural tear and massive brain fungation, 13 (50%) involving the right lobe, 3 (11%) involving the left lobe, and the remaining 6 (23%) involving both. We noticed that the brain loss compensated to some extent for the intracranial hypertension, and the dura was closed without any tension in all cases. Those who needed decompressive surgery were excluded from this series. In our experience, careful selection of the borderline cases, thorough neurologic evaluation, perfect radiologic assessment, and surgeon experience improve the outcome. Recently, correlating the presenting GCS after adequate resuscitation, CT findings, and preoperative ICP helped us make a decision regarding the appropriate timing of reconstruction. However, the intraoperative findings may guide the surgeon to change the plan from full reconstruction to decompressive surgery.

We believe that immediate surgical repair improves the functional outcome because it prevents infection by avoiding accumulation of secretions in the paranasal sinuses and by reducing the time of contact between contaminated regions and intracranial contents. It gives better cosmetic and functional results by avoiding scar tissue formation and resorption of bony edges, and it facilitates the nursing in severely ill patients and reduces hospital stay. In our series, the average hospital stay was 13 days.

Reconstruction of the dura initially started with a fascia lata graft but evolved to use temporalis fascia and pericranium. We preferred to use either temporalis fascia in 14 cases (53.8%) from the surgical field or even fascia lata in 4 cases (15.5%) and saved the pericranium intact to use it as free flap isolating the sutured basal dura from the anterior skull base. Moreover, we stopped using fascia lata because the generous surgical field can provide us with an abundance of graft to use without adding surgical incision or drains. We used pericranium to reconstruct dura in four patients (15.5%) with severely lacerated pericranium and could not serve as free flap.

The pericranial flap is easily harvested and versatile. Using this vascularized tissue added protection by providing an

extra barrier between the intracranial cavity and the frontal bone and sinonasal tract. This technique is inexpensive, safe, and effective, and it should be considered when cranialization of the frontal sinus is performed. The vascularized tissue promotes fast and complete healing.¹⁹

In 19 of 26 patients (73%), supplementary bone grafting was necessary. Iliac bone grafts were used in 6 patients (23%), split calvarial grafts were used in 12 (46%), and 1 patient (3.8%) had a full-thickness graft. Split calvarial grafts were preferred because of the easy accessibility to a large donor area with a variety of contours and no additional pain or scarring at the donor site. In addition, these grafts have the advantage of less resorption and greater strength than endochondral bone.¹⁹ When adequate calvarial fragments were not available because of fracture and/or contamination, iliac bone was used. Titanium mesh was used in 22 patients (85%); 10 (38%) had both autologous bony graft and titanium mesh to improve cosmetic appearance.

Although autogenous bone grafts are the materials of choice for cranioplasties, acquisition of such bone grafts usually requires another incision, and pain prevents autogenous bone from being obtained from sites such as the ribs. Bone flaps removed from the cranium of the patient or bone obtained from a bone bank have the risk of being absorbed after implantation.²⁴

Using titanium mesh to reconstruct craniofacial defects has several advantages. Titanium has excellent biocompatibility and generates a minimal inflammatory reaction. Furthermore, titanium is safe and produces minimal imaging artifact on MRI and CT scanning. Titanium mesh is easy to shape and contour while providing reasonable stability. Small bony fragments may be individually attached to the mesh by simply drilling a hole and lag-screwing the bone to the mesh, reducing the need for a bone graft.²⁵

The obvious problem with a metallic cranioplasty in a small child is how it will be affected by growth and development of the skull. In response to this challenge, a variety of manufacturers have developed devices made of bioabsorbable materials.²⁶ These materials typically retain their rigidity and resistance to fracture for 6 months, but by 12 months after implantation, the materials have disappeared.²⁷ We used resorbable mesh in three (11%) pediatric patients (< 12 years of age), and they were very compatible and well placed over the orbital roof by frontal lobe gravity.

The management of orbital fractures aims at minimizing and preventing early and late complications. The goal of intervention is to prevent vision loss and to minimize later problems such as persistent diplopia and disfiguring globe malpositioning.²⁸

Orbital floor fractures can increase the volume of the orbit with resultant hypoglobus and enophthalmos. The inferior rectus muscle or orbital tissue can become entrapped within the fracture, resulting in tethering and restriction of gaze and diplopia.²⁹

In cases of unilateral orbital defects, the faciomaxillary team used a preoperative 3D CT reconstruction tool that helps measure and study the unaffected side and creates manual mirror image reconstruction to the deformed side.³⁰

Postoperative Complications: Avoidance and Management

We had three complicated patients based on infection represented (11%), and our results compare favorably with historical data in which an overall infection rate for a staged repair would be 12.5 to 17.7%. Moreover, it is less than the results of Benzil et al,¹⁴ who reported 15% as an infection rate in a single-stage repair. This difference may be due to the number of patients (we had twice as many) or because we needed to operate more urgently on our patients (within 6 hours of resuscitation).

Our first patient started with postoperative tension pneumocephalus that was followed by meningitis. Tension pneumocephalus occurs when air is allowed to enter the epidural or subdural space and cannot escape, generally secondary to a ball-valve leak from below.³¹ Avoidance begins with a meticulous watertight closure of the dura: fixation of the pericranial graft to bone by multiple independent mini-screws bolstered by a small film of field hematoma and Gelfoam. Suction drains should be avoided because they may result in air being sucked up through the ethmoid into the cranium. This permits the reexpanding brain to do so independently of the flap and produces a multilayered stratified closure.³² Clinically, our patient had a declining neurologic status. A CT scan demonstrated sequestered air that had expanded since a previous examination with compression of the frontal sinus and basal cisterns. Immediate temporizing was performed by placing an intravenous catheter through an existing burr hole to allow trapped air to escape. By day 6, this patient had meningitis that was managed by a repeated lumbar tap and intrathecal injection of 10,000 units penicillin G and 8 mg gentamycin for 3 days. Eventually the patient improved and recovered.

The second patient presented with recurrent meningitis and delayed CSF rhinorrhea. This patient presented with recurrent meningitis and right nostril intermittent CSF rhinorrhea 6 months post surgery (late evaluation). A 1-mm sliced 3D CT revealed a small defect on the right side of the cribriform plate of ethmoid bone. The patient had reconstruction by the double intra- and extradural approach and the pericranial flap fixed to bone. No rhinorrhea was observed over a 1-year follow-up.

The third patient presented initially with severe trauma to his right side of the facio-cranium with severe destruction of the right orbit and complete avulsion of his right eye. This patient was explored immediately and operated on as usual, and a full-thickness graft was used to separate the hardly grafted dura from the right injured maxillary sinus. We did not choose a split graft for this case because its resorption would have been disastrous.

This patient had a copious postoperative CSF leak filling the site of the destructed right orbit and maxillary sinus area. The patient was kept in the ICU in a full sitting position with head extended and a daily lumbar tap. By the fifth day the patient had early signs of meningitis and we when started an intrathecal injection of 10,000 units penicillin G and 8 mg gentamycin for 3 days, but the patient did not respond, and

his fever increased along with neck rigidity. We continued the lumbar tap and changed to 10 mg vancomycin intrathecally for a further 5 days. Eventually the patient improved and recovered without any cognitive deficit. At the late evaluation, the patient complained of continuous discharge, exposed hardware, and tenderness over the right maxilla. The patient was imaged and reoperated. A fistulectomy done for the frontomaxillary fistula and maxillary sinus was opened and drained with removal of all remaining infected mucosa. The patient is doing well and has been scheduled for a custom reconstruction with artificial eye implantation.

CSF diversion is advocated by many authors and considered useful because it reduces ICP and CSF leakage, thereby preserving the position of the graft and facilitating the process of adhesion.²¹ This can be achieved by performing serial spinal taps or by placing a lumbar drain. Although lumbar drainage is more physiologic than spinal taps, it is not without risks that include headache, nausea, vomiting, pneumocephalus, meningitis, and even cerebral herniation.³³ We preferred repeated spinal taps that may be more traumatic and less efficient in preventing sudden spikes in CSF pressure, but they are associated with a smaller risk of infection. Therefore, rather than placing a postoperative lumbar drain, we performed lumbar CSF taps for two patients with meningitis (7.6%).

Conclusion

This prospective study suggests that immediate single-stage intervention to fix complex craniofacial injuries can be performed with acceptable morbidity and mortality. The practice of staged repair and delayed craniofacial reconstruction needs to be reevaluated. Functional and cosmetic outcome is improved, and the need for multiple major operations is reduced.

References

- 1 Theogaraj SD. Management of facial injuries following craniofacial trauma. In: Becker DP, Gudeman SK, eds. *Head Injury*. Philadelphia, PA: WB Saunders; 1989:348
- 2 Gruss JS, Phillips JH. Complex facial trauma: the evolving role of rigid fixation and immediate bone graft reconstruction. *Clin Plast Surg* 1989;16(1):93-104
- 3 Lauritzen C, Lilja J, Vällfors B. The craniofacial approach to trauma. *Ann Plast Surg* 1986;17(6):503-512
- 4 Gruss JS. Naso-ethmoid-orbital fractures: classification and role of primary bone grafting. *Plast Reconstr Surg* 1985;75(3):303-317
- 5 Friedman JA, Ebersold MJ, Quast LM. Post-traumatic cerebrospinal fluid leakage. *World J Surg* 2001;25(8):1062-1066
- 6 Yilmazlar S, Arslan E, Kocaeli H, et al. Cerebrospinal fluid leakage complicating skull base fractures: analysis of 81 cases. *Neurosurg Rev* 2006;29(1):64-71
- 7 Dandy WE. Pneumocephalus. *Arch Surg* 1926;12:949
- 8 Wakhloo AK, van Velthoven V, Schumacher M, Krauss JK. Evaluation of MR imaging, digital subtraction cisternography, and CT cisternography in diagnosing CSF fistula. *Acta Neurochir (Wien)* 1991;111(3-4):119-127
- 9 Nachtigal D, Frenkiel S, Yoskovitch A, Mohr G. Endoscopic repair of cerebrospinal fluid rhinorrhea: is it the treatment of choice? *J Otolaryngol* 1999;28(3):129-133

- 10 Patel MR, Shah RN, Snyderman CH, et al. Pericranial flap for endoscopic anterior skull-base reconstruction: clinical outcomes and radioanatomic analysis of preoperative planning. *Neurosurgery* 2010;66(3):506–512; discussion 512
- 11 Burstein F, Cohen S, Hudgins R, Boydston W. Frontal basilar trauma: classification and treatment. *Plast Reconstr Surg* 1997; 99(5):1314–1321; discussion 1322–1323
- 12 Francel PC, Persing JA. Microplating and screw systems for cranial bone fixation. *Clin Neurosurg Instrumentation, Technique, and Technology* 1993;32(4):683–686
- 13 Manson PN, Stanwix MG, Yaremchuk MJ, Nam AJ, Hui-Chou H, Rodriguez ED. Frontobasal fractures: anatomical classification and clinical significance. *Plast Reconstr Surg* 2009;124(6):2096–2106
- 14 Benzil DL, Robotti E, Dagi TF, Sullivan P, Bevivino JR, Knuckey NW. Early single-stage repair of complex craniofacial trauma. *Neurosurgery* 1992;30(2):166–171; discussion 171–172
- 15 Asano T, Ohno K, Takada Y, Suzuki R, Hirakawa K, Monma S. Fractures of the floor of the anterior cranial fossa. *J Trauma* 1995; 39(4):702–706
- 16 Eftekhari B, Ghodsi M, Nejat F, Ketabchi E, Esmaeili B. Prophylactic administration of ceftriaxone for the prevention of meningitis after traumatic pneumocephalus: results of a clinical trial. *J Neurosurg* 2004;101(5):757–761
- 17 Deryn C, Persing JA, Broaddus WC, et al. Craniofacial trauma: an assessment of risk related to timing of surgery. *Plast Reconstr Surg* 1990;86(2):238–245; discussion 246–247
- 18 Sakas DE, Beale DJ, Ameen AA, et al. Compound anterior cranial base fractures: classification using computerized tomography scanning as a basis for selection of patients for dural repair. *J Neurosurg* 1998;88(3):471–477
- 19 Katzen JT, Jarrahy R, Eby JB, Mathiasen RA, Margulies DR, Shahinian HK. Craniofacial and skull base trauma. *J Trauma* 2003;54(5): 1026–1034
- 20 Antonelli V, Cremonini AM, Campobassi A, Pascarella R, Zofrea G, Servadei F. Traumatic encephalocele related to orbital roof fractures: report of six cases and literature review. *Surg Neurol* 2002; 57(2):117–125
- 21 Madhusudan G, Sharma RK, Khandelwal N, Tewari MK. Nomenclature of frontobasal trauma: a new clinico-radiographic classification. *Plast Reconstr Surg* 2006;117(7): 2382–2388
- 22 Poole MD, Briggs M. Cranio-orbital trauma: a team approach to management. *Ann R Coll Surg Engl* 1989;71(3):187–194
- 23 Glover LE, Tajiri N, Lau T, Kaneko Y, van Loveren H, Borlongan CV. Immediate, but not delayed, microsurgical skull reconstruction exacerbates brain damage in experimental traumatic brain injury model. *PLoS ONE* 2012;7(3):e33646
- 24 Miyake H, Ohta T, Tanaka H. A new technique for cranioplasty with L-shaped titanium plates and combination ceramic implants composed of hydroxyapatite and tricalcium phosphate (Ceratile). *Neurosurgery* 2000;46(2):414–418
- 25 Gear AJL, Lokeh A, Aldridge JH, Migliori MR, Benjamin CI, Schubert W. Safety of titanium mesh for orbital reconstruction. *Ann Plast Surg* 2002;48(1):1–7; discussion 7–9
- 26 Imola MJ, Hamlar DD, Shao W, Chowdhury K, Tatum S. Resorbable plate fixation in pediatric craniofacial surgery: long-term outcome. *Arch Facial Plast Surg* 2001;3(2):79–90
- 27 Kosaka M, Uemura F, Tomemori S, Kamiishi H. Scanning electron microscopic observations of 'fractured' biodegradable plates and screws. *J Craniomaxillofac Surg* 2003;31(1):10–14
- 28 Mathur N. Orbital fractures: otolaryngology and facial plastic surgery - e medicine, 2007.
- 29 Cohen AJ. Orbital floor fractures (blowout) Treatment and Management, Medscape 2014.
- 30 Bell RB, Markiewicz MR. Computer-assisted planning, stereolithographic modeling, and intraoperative navigation for complex orbital reconstruction: a descriptive study in a preliminary cohort. *J Oral Maxillofac Surg* 2009;67(12):2559–2570
- 31 Hegazy HM, Carrau RL, Snyderman CH, Kassam A, Zweig J. Transnasal endoscopic repair of cerebrospinal fluid rhinorrhea: a meta-analysis. *Laryngoscope* 2000;110(7):1166–1172
- 32 Scholsem M, Scholtes F, Collignon F, et al. Surgical management of anterior cranial base fractures with cerebrospinal fluid fistulae: a single-institution experience. *Neurosurgery* 2008; 62(2):463–469; discussion 469–471
- 33 Casiano RR, Jassir D. Endoscopic cerebrospinal fluid rhinorrhea repair: is a lumbar drain necessary? *Otolaryngol Head Neck Surg* 1999;121(6):745–750