Chapter 23

PARANASAL SINUS FRACTURES

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INTRODUCTION

Frontal sinus trauma may be blunt or penetrating, with frontal sinus fractures representing 6% to 12% of craniofacial fractures.[1,2] Two-thirds of patients with frontal sinus trauma may have sustained concomitant injuries to other facial structures.[3] Contemporary algorithms for classification and management of frontal sinus trauma are largely based on civilian injury patterns, which carry a trend toward high-velocity blunt trauma.[1,2,4,5]

War trauma yields a higher incidence of penetrating injuries due to the preponderance of blast and missile trauma.[6–8] Open craniomaxillofacial fractures may comprise up to 75% of injuries to the craniomaxillofacial skeleton.[6] Additionally, given the proximity of the frontal bone to the cranium and orbits, concomitant brain and/or eye injury is not uncommon with penetrating or blunt frontal trauma. In a recent review of concomitant cranial and ocular combat injuries, nearly half of all patients with both cranial and ocular combat injuries requiring surgical intervention also underwent frontal sinus repair, obliteration, or cranialization.[8] Another contemporary review of facial trauma following improvised explosive device blasts identified trauma to the forehead aesthetic subunit as a "danger zone" in massive facial trauma, which was defined as injury to three or more facial units.[9] Because massive facial trauma is associated with elevated Injury Severity Scores and an increased rate for blood transfusions in war trauma, early assessment of these patients may help identify patients who require rapid transport to higher levels of care.[9] Prompt evaluation by neurosurgery and ophthalmology is important to optimize the care of patients with significant frontal sinus and skull base trauma with potential or associated cranial or orbital injuries.

ANATOMY

Comprehensive knowledge of the surgical anatomy of the frontal sinus is important for appropriately managing frontal sinus fractures resulting from either blunt or penetrating injuries. Absent at birth, the frontal sinuses begin developing after age 2. Most patients develop a pair of frontal sinuses, which are not fully formed until ages 15 to 20.[10] However, 8% to 15% of patients may only develop one frontal sinus, and 5% have complete aplasia.[10,11] The frontal sinus is a three-dimensional structure composed of an anterior table, a posterior table, and a floor. The *anterior* table provides the skeletal contour of the forehead, brow, and glabella. The *posterior* table is the anterior portion of the anterior cranial fossa, separating the frontal sinus from the anterior cranial fossa. The medial portion of the orbital roof creates the floor of the frontal sinus. The frontal sinus outflow tract (FSOT), also known as the frontal recess, is the funnel-shaped space that connects the frontal sinus to the anterior ethmoid sinuses.[11] The frontal ostium is the apex of the FSOT. The frontal sinus is lined with mucosa, which provides mucociliary clearance from the frontal sinus via the FSOT.

Frontal sinus fractures may be classified as nondisplaced or displaced fractures involving the anterior table, the posterior table, or both. Accurate classification also requires identification of FSOT involvement.

DIAGNOSIS: CLINICAL AND IMAGING STUDIES

Clinical diagnosis of a frontal sinus injury is based on physical examination findings. In the presence of blunt trauma, significant forehead edema may make clinical diagnosis difficult. Penetrating trauma is often more conspicuous. Pertinent clinical findings include supraorbital distribution anesthesia or paresthesia, forehead laceration, contour irregularity, and hematoma. Frontal sinus fractures may be suspected with bone fragments present in a laceration, cerebrospinal fluid (CSF) rhinorrhea, supraorbital/frontal bone stepoffs, or crepitus.

Radiographic assessment with computed tomography (CT) scan in patients with head injuries is required to evaluate their intracranial status. Given the complex three-dimensional anatomy, frontal sinus fractures are best diagnosed with a thin-cut (1.0–1.5 mm) CT scan in axial, coronal, and sagittal planes if available and if time allows. The axial images allow clear assessment of the anterior and posterior tables, whereas the coronal images define the sinus floor and anterior skull base. The sagittal images add the necessary dimension to fully assess the FSOT. Three-dimensional CT reconstructions are valuable in visualizing any external contour deformity that may not be appreciated on physical examination or on two-dimensional CT images. A radiographic finding of pneumocephalus suggests posterior table and/or skull base fracture.

MANAGEMENT ISSUES AND ALGORITHM

Frontal sinus fracture management strategies depend on clinical and radiographic assessments of the anterior table, the posterior table, the FSOT, and the dura. Assessment of these anatomical structures guides the head and neck surgeon in establishing the three key functions of the frontal sinus:

1. restoring the preoperative facial aesthetics;
2. avoiding long-term sinus complications (eg, mucocele), chronic rhinosinusitis, or osteomyelitis; and
3. isolating the neurocranium and preventing a CSF leak.

Although these three elements are paramount, managing frontal sinus and skull base fractures in a deployed environment also requires an assessment of political factors and the military situation outside of the treatment facility. The head and neck surgeon must understand the nature and stage of the conflict, the general capabilities and limitations of the host nation medical system, and the patient's military occupation and primary duties. For example, a Marine who works in administration and sustains an anterior table frontal sinus fracture playing basketball during the nation-building phase of a conflict is treated differently than a soldier in an infantry unit who sustains the same injury during a firefight in the combat phase of a conflict. The former would benefit from an open reduction and external fixation and convalescence in theater, whereas the latter is best served by evacuation to a higher level of care for treatment.

Wounded American and coalition service members often require different care than host nation patients and enemy combatants. American and coalition patients are often the most straightforward to manage in a deployed environment. In a fluid tactical setting, damage control surgery is performed. Neurosurgical and ophthalmological injuries are addressed; facial wounds are copiously irrigated, judiciously debrided, and closed primarily; and the patient is then transferred to a higher level treatment facility. In a more protracted conflict, less complex frontal sinus fractures may be treated in theater, thus allowing the patient to convalesce with his unit in a limited duty status and thereby minimizing disruption to unit personnel. Anterior skull base injuries—with the exception of rare, nondisplaced fractures without a CSF leak—require evacuation out of theater.

Host nation patients are usually the most challenging to care for, especially when their medical system is overly stressed and inadequate. Because of the limited time and resources at a Role 3 medical treatment facility, all necessary treatment is provided during one operation, if possible. These patients often have one operation and hospitalization for very complex, life-threatening injuries. Thoracic, abdominal, and orthopaedic injuries are treated based on priorities established by the trauma surgeon. The treatment priority for head and facial injuries is usually the brain, the globes, and then the maxillofacial region. Concurrent surgeries by different specialties occur when space allows and within the parameters of the patient's overall medical condition.

Skull base reconstruction has significantly improved over the past 20 years, driven largely by advances in surgical treatment of skull base neoplasms. Large skull base defects following tumor extirpation are usually treated with microvascular free-tissue transfer that is the safest, most economical procedure.[12] However, this procedure has not been widely adopted in combat settings because of inadequate resources and time constraints. Regional flaps (eg, the pectoralis major flap) are an option, but are often impractical because of a concurrent chest or thoracic injury. Local flaps are usually the best option in a deployed environment. When available, a pericranial flap is an excellent means of isolating the intracranial contents. Unfortunately, penetrating head injuries often disrupt the pericranium, thus an alternative method (eg, temporalis fascia, tensor fasciae latae, or a dura substitute) is required.[12] For bone reconstruction, titanium mesh is malleable, is biocompatible with soft tissue and mucosa, undergoes osseointegration, and is readily available in the operating room.[13] A calvarial bone graft is also an option, but volume loss due to resorption is a potential long-term complication. Regardless of the materials used, a multilayer closure is essential. Definitive cranial reconstruction for decompressive craniectomy patients or patients with large frontoorbital bar defects may be delayed and surgically addressed at a later time using free flaps and bone grafts.[14]

The algorithmic approach to frontal sinus fracture repair that is used in civilian trauma is also applicable to combat-related injuries, with some modifications. In general, the algorithm is simpler and shorter because observation with treatment as needed is not possible in host nation patients without a robust medical safety net. Although the inclination is to focus only on the anterior and posterior tables, the frontal recess is the key structure that requires evaluation and attention (Figure 23-1). Host nation patients with anything more than a very mild frontal recess injury are at high risk

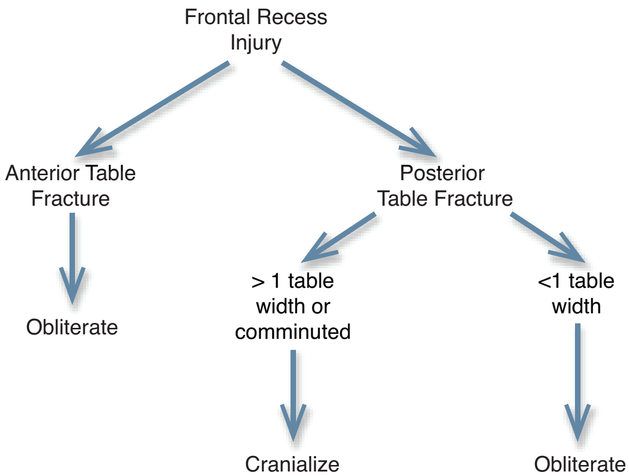

Figure 23-1. Treatment algorithm for frontal sinus fractures with a frontal recess injury.

of chronic frontal sinus complications and should therefore undergo frontal sinus obliteration.

Treatment of isolated posterior table fractures of the frontal sinus is controversial. Historically, if the posterior table has a fracture displaced more than one table width or is comminuted, the frontal sinus would be cranialized or obliterated. However, recent animal studies have shown that isolated, displaced (greater than one table width) posterior table fractures with an intact FSOT/nasofrontal duct rarely cause mucoceles.[15] Consequently, for those patients sustaining isolated displaced posterior table fractures with an intact FSOT and no CSF leak, observation should be considered. Furthermore, observation is indicated for the rare patient with a nondisplaced posterior table fracture and an intact anterior table (Figure 23-2).

Anterior table fractures are treated to restore aesthetics and prevent long-term sinus complications. Nondisplaced anterior table fractures are not uncommon, especially with modern ballistic helmets. This type of facture can be safely observed because the forehead contour is not significantly affected, and the function of the frontal sinus is not jeopardized. Rigid fixation may be performed if the anterior table is displaced, but the FSOT is spared and the mucosa is minimally disrupted. Obliteration of the frontal sinus may be indicated for displaced anterior table fractures that are associated with significant mucosal disruption and compromise of the FSOT.

Consultation and communication with a neurosurgeon and an ophthalmologist prior to repairing the maxillofacial fractures are critical to avoid further cranial or orbital injury and to coordinate care. The globes should be protected with either a tarsorrhaphy or corneal shields. Pressure on the brain, either from retraction or repair, is also avoided. Most combat-related frontal sinus and anterior skull base fractures have associated lacerations that provide ready access for treatment. Occasionally, a bicoronal incision may be required for fractures because of blunt trauma. The wounds are copiously irrigated, and all foreign bodies and nonviable bone fragments are removed. The

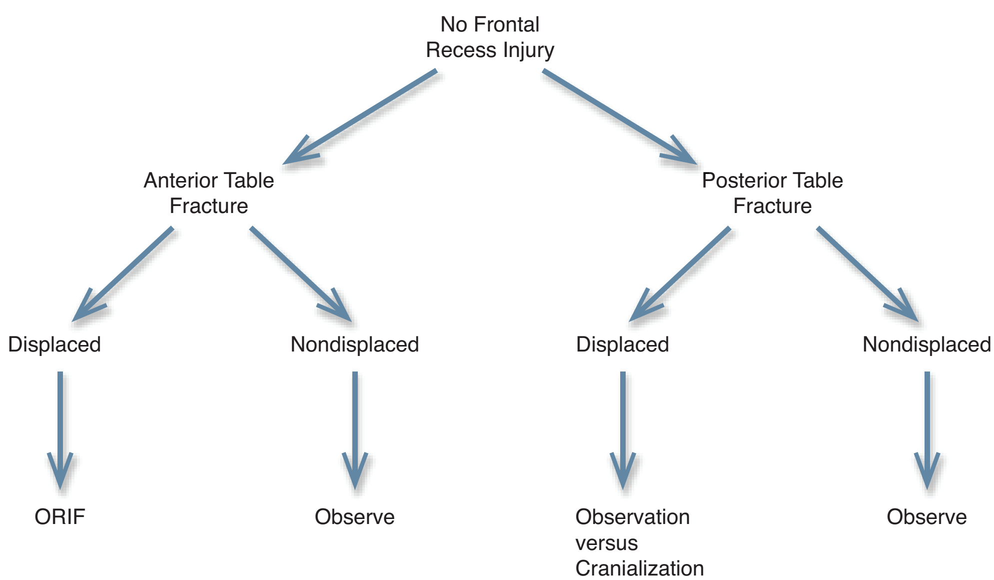

Figure 23-2. Treatment algorithm for frontal sinus fractures without a frontal recess injury.
ORIF: open reduction internal fixation

Figure 23-3. Abdominal fat harvested for frontal sinus obliteration.

frontal recess is then visually inspected to confirm the radiographic findings of patency or occlusion. Endoscopic approaches and techniques are not applicable in the deployed environment due to resource and time constraints.

Both obliteration and cranialization require removal of all frontal sinus mucosa and occlusion of the frontal sinus ostia. A drill with both cutting and diamond burrs is the ideal tool for this task. However, because a drill is often unavailable in a Role 3 facility, periosteal elevators and curettes can be used. Meticulous removal of all mucosa is critical to avoid chronic infections and mucocele formation. The frontal recess is then occluded with a temporalis muscle plug or covered with bone fragments. Most anterior skull base injuries involve the frontal recess and posterior table. The frontal sinus is usually cranialized, and the frontal recess is occluded in the reconstruction. It is important to remove all posterior table bone during cranialization.

Abdominal fat is the easiest and most available material for frontal sinus obliteration. Harvesting is done through a left lower quadrant incision or the laparotomy incision in patients with penetrating abdominal wounds. If possible, the fat is harvested in a single piece with minimal electrocautery (Figure 23-3).[4] The fat should fill the entire frontal sinus without placing undue tension on the anterior or posterior tables. Bone reconstruction is performed with a combination of miniplates and titanium mesh as needed. As in skull base reconstruction, titanium mesh is ideally suited for reconstructing the comminuted fractures associated with combat injuries. The final and often most time-consuming step is soft-tissue closure, which is usually performed with a combination of primary closure and local advancement flaps.

SUMMARY

Treating combat-related frontal sinus and anterior skull base fractures is challenging because of their intimate relationship with the brain. The head and neck surgeon must always keep in mind the primary goals of protecting the brain, avoiding long-term complications, and restoring aesthetic contour. The medical challenge is usually compounded by the military and political situations, and the limited resources of a deployed environment. Fortunately, the complexity of these reconstructions and the opportunity to collaborate with both neurosurgeons and ophthalmologists make these cases very rewarding.

CASE PRESENTATIONS

Case Study 23-1

Presentation

An Iraqi policeman was medically evacuated to the emergency department at the Air Force Theater Hospital on Balad Air Base, Iraq, with massive facial trauma from a vehicle-borne, improvised explosive device. The patient was intubated in the field, sedated, and his vital signs were stable. On examination, he had multiple facial injuries, primarily on the left, including a disrupted left globe (Figure 23-4). CT demonstrated a severely comminuted frontal recess and left anterior table frontal sinus fracture, including the superior orbital rim and orbital roof (Figure 23-5). The posterior table was intact, and there was no intracranial injury. There was a displaced nasal fracture.

Operation

The patient underwent an enucleation of the left globe by the ophthalmologist. The frontal sinus mucosa, along with multiple glass fragments, was removed. Titanium mesh was used to reconstruct the superior orbital rim and orbital roof, and the frontal sinus was obliterated with abdominal fat (Figure 23-6). Complex facial lacerations were then closed

Figure 23-4. Penetrating left facial injury from an improvised explosive device with a comminuted left frontal sinus fracture and a left globe injury.

primarily. The patient was intubated, transferred to the intensive care unit, and his closed-head injury managed accordingly.

Lessons Learned

This case is typical of most frontal sinus fractures encountered in host nation patients in combat. Although the patient now has a large dead space in place of his left globe, he has an intact skin covering, a safe left frontal sinus, and his intracranial contents are isolated.

Case Study 23-2

Presentation

An Iraqi male was dropped at the Balad Air Base gate after sustaining an isolated gunshot wound through both eyes, a common torture technique used by insurgents. There were no other injuries. The patient was disoriented and was intubated in the Air Force Theater Hospital emergency department. On examination, there was extensive soft-tissue loss involving the globes, the ocular adnexa, and the upper nose (Figure 23-7). A CT demonstrated complete loss of the anterior globes, the nasal bones, and the ascending process of the maxilla. The anterior and posterior tables of the frontal sinuses and the ethmoid sinuses sustained comminuted fractures. There were intracranial bone fragments in the frontal lobes.

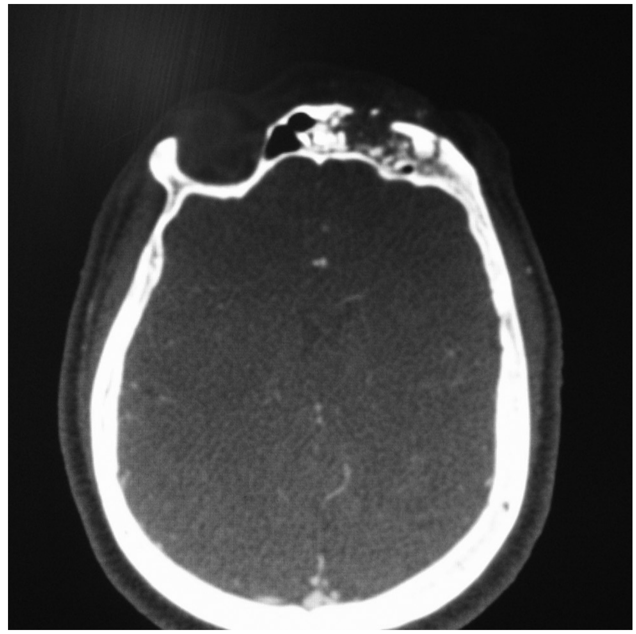

Figure 23-5. CT (computed tomography) maxillofacial demonstrating a comminuted left frontal sinus fracture with an intrasinus foreign body.

Operation

The neurosurgeon performed an anterior craniotomy and exploration of the frontal lobes, and the ophthalmologist then followed with a bilateral enucleation. There was no pericranium or dura remaining from the injury. A collagen matrix dura substitute was

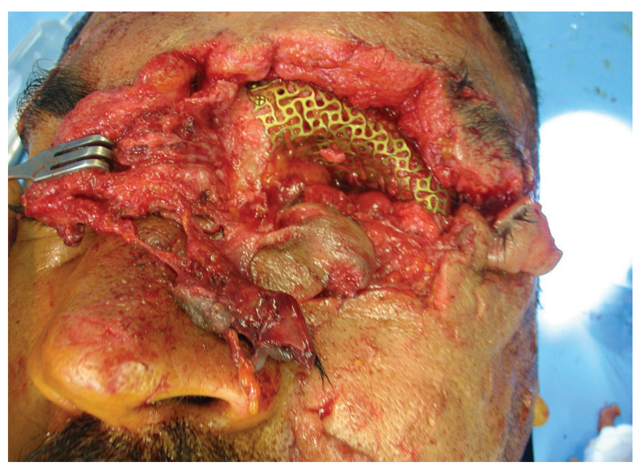

Figure 23-6. Titanium mesh reconstruction of superior orbital rim and frontal sinus.

Figure 23-7. Anterior skull base, nose, and globe injury from gunshot wound.

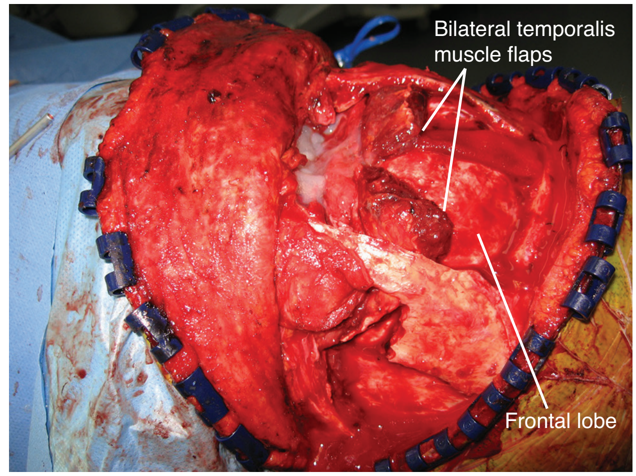

Figure 23-8. Right lateral view of exposed brain and bilateral temporalis muscle flaps.

placed over both frontal lobes and bilateral temporalis muscle flaps. They were rotated anteriorly to separate the dura from the nasal cavity and to provide bulk to the orbits (Figure 23-8). The frontal sinuses were cranialized. The anterior skull base was reconstructed with titanium mesh (Figure 23-9). Large, bilateral melolabial advancement flaps were used to cover the orbits and were sutured to the forehead skin. The patient was then then transferred to the intensive care unit for further management.

Lessons Learned

Reconstruction of the skull base to separate the intracranial and extracranial contents is critical. A multilayered closure (to include fascia) is necessary to support the frontal lobes, prevent a spinal fluid leak, and protect the brain from outside pathogens. Although there are multiple reconstruction options for this case, the time and resource limitations inherent in a deployed environment generally mandate single-stage, expeditious surgical care. Although this reconstruction is not ideal from a cosmetic standpoint, the brain is supported and protected, there is an adequate skin barrier, and the remaining paranasal sinuses can drain into the nasal cavity. Division of the melolabial flaps at the reconstructed frontal bar and rotation onto the orbital floor would allow reconstruction of the orbits at a later date.

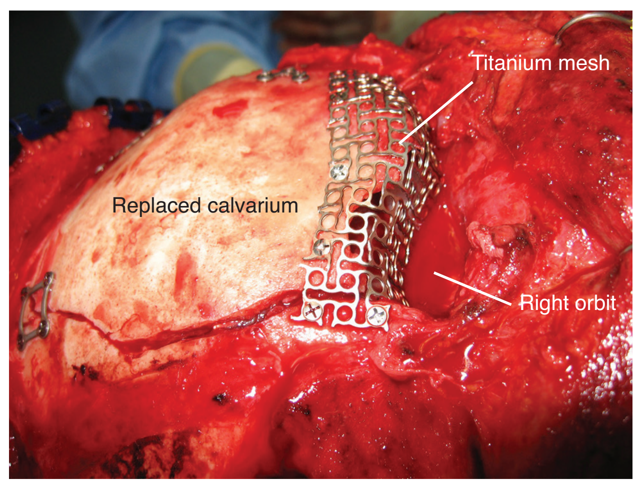

Figure 23-9. Titanium mesh reconstruction of anterior skull base.

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