SURGICAL REPAIR OF FRONTAL SINUS FRACTURES

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INTRODUCTION
Fractures of the frontal sinus are relatively uncommon injuries that result from a higher energy impact than sinus fractures of the mandible or maxillary. This relative resistance to fracture is imparted by the thick bone of the sinus and by the configuration of that bone into anterior and posterior plates with an intervening air-containing space. The presence of a frontal sinus fracture must generate a high index of suspicion for associated intracranial and/or cervical spine injuries. The majority of these injuries occur as a consequence of motor vehicle accidents.

The importance of appropriate and timely repair of frontal sinus injuries arises not only from the possibility of the serious immediate complications that may result, but from the unique propensity of frontal sinus mucosa to form mucoceles when traumatized. Furthermore, the prominent location of the frontal bone results in noticeable cosmetic deficits even in the presence of minimally displaced fractures. In addition, the foramina of Breschet, within the posterior and superior walls of the frontal sinus, allow direct communication between vessels supplying the sinus mucosa and the subarachnoid space. Frontal sinus mucosa is tethered within these foramina and can become retained if meticulous removal of all mucosa with a rotating burr is not carried out. Resulting mucoceles can develop for up to 20 years following the original injury. Such mucoceles may give rise to a number of complications, compromising cosmesis and threatening the orbit. In addition, they may become infected and result in the development of a mucopecele, which can result in osteomyelitis and life-threatening infections.

PATIENT EVALUATION
Frontal sinus injuries are often associated with other injuries for which prompt attention is required. After the patient is stabilized and evaluated with respect to neurological and ophthalmological injury, clinical examination of the frontal bone or laceration of the skin overlying the region often leads the surgeon to suspect the presence of an underlying frontal sinus injury. It should be noted that edema or hematoma overlying the frontal bone might obscure any depression associated with the fracture. At times, the fracture may be clinically occult, particularly if it does not involve the anterior table.

The presence of a cerebrospinal fluid (CSF) leak is a critical finding in frontal sinus injuries and should be considered in every patient. Where available, the use of beta-2 transferrin levels has a high specificity for CSF; less accurate methods for evaluating rhinorrhea or otorrhea for CSF include chloride or glucose concentration and the “halo sign.” If a CSF leak is difficult to localize, the use of iohexol intrathecal computed tomography (CT) may be useful.

CT is the imaging tool of choice in the evaluation of frontal sinus fractures. Imaging in the axial and coronal planes is quite helpful in delineating the severity of these injuries. A 6-foot Caldwell plain
sinus x-ray is necessary when surgical exploration of the sinus via an osteoplastic flap is planned (see below). Magnetic resonance imaging does not show bony definition and is not useful unless for further assessment of a concomitant brain injury.

Fractures of the anterior wall of the frontal sinus are classified as simple or compound, linear or comminuted, and displaced or nondisplaced. Fractures of the posterior wall may be classified as linear or displaced, although displaced fractures are much more common. Any frontal sinus injury has the potential for damage to the frontonasal duct. Injury in this area may be difficult to confirm radiologically. The nasofrontal duct area is the most poorly visualized area of the frontal sinus and may be missed even with a coronal fine-cut CT. A through-and-through frontal sinus injury involves fractures of both anterior and posterior tables. These severe injuries are often associated with dural or cerebral injury.

**TREATMENT PRINCIPLES**

CSF leaks need to be considered and localized in every patient. As mentioned, beta-2 transferrin levels may be used to evaluate the presence of suspected CSF leaks. The presence of glucose or elevated chloride levels in a patient with persistent rhinorrhea, or the "halo sign," can be valuable to note. CSF leaks should be treated at the time of surgical repair of frontal sinus fractures. If surgery is otherwise not indicated, CSF leaks may be treated expectantly with the following caveat: continued CSF leak beyond 2 weeks or evidence of impending or existing complications requires prompt surgical repair. In greater than 90% of cases, traumatic CSF leaks seal on their own with conservative nonoperative treatment. Various graft options exist for repair of CSF leaks; temporalis fascia is readily available. Tensor fascia lata may be the best option; it can be harvested via a limited incision over the lateral thigh.

Isolated linear nondisplaced fractures of the anterior frontal sinus wall typically do not require treatment. Patients with more complex fractures of the anterior frontal sinus should undergo treatment as even minimally displaced fractures may result in significant subsequent cosmetic deformity or the secondary development of a mucocele.

Fractures of the posterior wall of the frontal sinus warrant exploration in the vast majority of cases. Even minimal displacement of the posterior wall may result in a mucocele. In addition, occult dural tears may be associated with nondisplaced posterior wall fractures. The treatment of posterior wall fractures depends upon their severity. Simple nondisplaced posterior wall fractures with intact frontonasal ducts and healthy mucosa can be treated without obliteration. The more conservative (and safer) approach is to obliterate the sinus with abdominal fat as described before. On the other hand, significant comminution (>25% of the dimension of the posterior wall) of the posterior sinus wall mandates cranialization of the sinus.

Suspected isolated frontonasal duct injuries are not predictably visualized on CT. If a frontonasal duct injury is suspected, but surgery is not otherwise mandated, it may be prudent to perform a follow-up CT in 3 months. If the frontal sinus is clear, it is probably safe to assume that adequate sinus drainage is taking place via one or both frontonasal ducts. If the sinus is fluid filled, it should be electively obliterated.

The optimal time for treatment of frontal sinus injuries is within 10 days of the original injury. Often, associated injuries assume precedence or the patient may be unstable in the first days after a severe injury. Delays longer than 10 days may result in difficulty elevating or manipulating bone fragments. Conversely, immediate evaluation may result in the overestimation of frontonasal duct injury, in that apparent obstruction may be caused by temporary edema that will resolve in time, even if untreated. Regardless of surgical timing, any CSF leaks present at the time of surgery should be repaired.

**SURGICAL TECHNIQUE**

The patient is brought to the operating room and general anesthesia is administered. The patient is positioned supine on a Mayfield horseshoe-shaped headrest (Figure 1). There are several options for exposure of the frontal sinus: existing forehead laceration, coronal incision, mid-forehead incision, or "butterfly" incision (bilateral supraborbincisions connected by an incision a: the nasion). Only signifi-

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**Figure 1.** Patient’s head positioned on a Mayfield headrest. Access incisions used from frontal sinus fractures are demonstrated.

**Figure 2.** Cross section through temporal fascia layers. FrONTAL sinus fracture is accessed following coronal flap elevation.

**Figure 3A and B.** Release of the supraorbital nerve from the foramen to allow for increased traction to be exerted on coronal flap.
cant lacerations are suitable as a route of exposure; occasionally, an existing smaller laceration may be extended by incision into one of the forehead rhytids. The choice of incision otherwise depends on the state of hair loss. For most patients, a coronal incision is best; if the patient has significant frontotemporal hair loss, a forehead incision may offer a better outcome. The “butterfly” incision is quite noticeable in the majority of patients and may not allow access to the superior portion of well-acclimated frontal sinuses.

The chosen incision site is infiltrated with 1% lidocaine with 1:100,000 epinephrine. Preparation of the hair adjacent to the incision without head shave is facilitated by isolating the incision using a comb with Bactracin ointment. Sterile towels are then stapled immediately anterior and posterior to the incision to prevent hair from falling back into the incision during the case. The coronal incision is made 2 to 3 cm posterior to the anterior hairline, through scalp, subcutaneous tissue, and galea. The mid-forehead incision is made within existing forehead rhytids; it is preferable to start in one rhytid and subsequently pass into another rhytid in order to avoid having a solid unbroken line across the forehead. Raney clips are used on the skin edge to minimize bleeding. Subsequent dissection is carried out in the subgaleal plane roughly 2 cm superior to the supraorbital rim, at which point an incision is made through the pericranium. Inferior to this point, subpericranial dissection is continued to the orbital rim where the supraorbital and supra trochlear nerve bundles are preserved (Figure 2). A completely subpericranial approach is also feasible unless an osteoplastic flap is planned. When the anterior table is significantly comminuted, it may be preferable to dissect in a superpericranial plane all the way to the orbital rim to preserve vascularity to the small fragments.

If it is necessary to gain additional exposure, the supranasal nerves may be released from their foramina using a 3-mm osteotome and Freer elevator (Figure 2). This may be particularly useful if there is an associated naso-orbital-ethmoid complex fracture and exposure of the nasal dorsum is required. Laterally, dissection should be undertaken superficial to the superficial layer of the deep temporal fascia down to the temporal line of fusion between the superficial and deep layers of the deep temporal fascia (Figure 3). If further inferior dissection is required, one may incise the superficial layer of the deep temporal fascia and continue just superior to the superficial temporal fat pad inferiorly, to the level of the zygomatic arch. It is important to avoid traumatizing or using electrocautery within the temporals muscle or the temporal fat pad, as these actions may result in long-term sequelae such as atrophy and temporal wasting. Any harvesting of the temporals fascia or muscle should be done in a cosmetically silent area, beginning at the most posterosuperior aspect of the muscle.

Following the specific surgical treatment as outlined below, the temporal fascia should be resuspended with 3-0 Vicryl to maintain a temporal fossa contour. The scalp wound is closed using interrupted subcutaneous 2-0 Vicryl and skin staples, while the preauricular portions of the incision are closed with 4-0 Vicryl and 5-0 Prolene sutures. The wound is drained with a #10 Jackson-Pratt suction drain. A head wrap of gauze and Keflex may be useful in decreasing forehead edema.

**Anterior Table Fractures**

Once the anterior frontal sinus wall is visualized, it can be repaired using a variety of techniques. Bone hooks may be used to elevate any depressed fragments (Figure 4A). Mucosa entrapped by these fragments must be removed with a cutting burr drill. Care must be taken to remove any mucosal granulations on the undersurface of the anterior table fragments (Figure 4B). Evaluation of the frontonasal duct is most effectively performed intraoperatively by direct visual inspection utilizing a 30-degree endoscope. The fractured fragments are typically stabilized with 1.2-mm Leibinger miniplates utilizing 4- to 6-mm screws, or alternatively, with wires (Figure 4C). All bone fragments should be soaked in saline prior to reinsertion. Any significant osseous defects (>1.5 cm) should be filled in with autogenous bone; split calvarial bone grafts are easily harvested via the coronal flap, with or without a posterior vertical extension. Iliac crest is another option for obtaining autogenous bone grafts.

**Posterior Table Fractures**

The approach to the posterior table is typically achieved via an osteoplastic sinus flap. The osteoplastic flap requires that a 5-foot Caldwell sinus film be obtained preoperatively. A coin or other recognizable metal object can be placed on the patient to assure that the film was taken without enlargement or shrinking of sinus size. The film is soaked in Betadine or equivalent for 30 minutes, then rinsed with saline and transferred to the operative field. Under sterile technique, the image of the frontal sinus is cut out to the superior orbital rims to form a template. This will minimize the risk of accidental dural injury during osteoplastic flap elevation. If Caldwell films are not available, the size of the sinus may be estimated by transillumination into the frontal sinus with an endoscope placed within the nose.

After exposure of the frontal bone is achieved by the approaches detailed above, the template is used to determine the limits of the sinus. A 0.5-cm Stryker drill with a 703 cutting burr is used to enter the sinus in a 45-degree beveled fashion superiorly.
Figure 4. Anterior table fractures. A, elevation of impacted anterior table fragments. B, stripping of mucosal remnants from the frontal sinus. C, precise fracture reduction has been achieved. It is maintained with Leibinger miniplates (1.2 mm). Hydroxyapatite cement may be utilized between osseous fragments to maintain continuity.
and laterally (Figure 5A). Osteotomes are then used to complete the osseous cuts (Figure 5B). The bone flap composed of anterior sinus wall is left pedicled inferiorly on intact pericranium. It is prudent to make the saw cuts inside the apparent sinus edge as shown on the template, as the 6-foot Caldwell film overestimates the size of the sinus by 5%. The frontal sinus mucosa is then meticulously removed with small and medium-sized mastoid-type cutting burrs at low speed, with copious irrigation to prevent thermal bone injury. It is critical to remove mucosa from the undersurface of the osteoplastic flap as well. The mucosa should be removed in a reproducible segmental pattern to ensure complete exenteration. At this point, the frontonasal duct is obliterated by inverting the frontonasal duct mucosa and plugging the duct with temporalis muscle or fascia. Posterior wall fragments are reduced and any devitalized tissue or bone is removed.

Most often, the sinus is obliterated using fat. Typically, this is harvested from the abdomen via a transverse left-lower quadrant incision to avoid possible confusion with an appendectomy scar. In thin individuals, fat may be harvested from any site with significant stock, such as the buttock. It is important to section the fat into small pieces as these are more readily able to obliterate the sinus and, theoretically, smaller pieces are more easily vascularized than a single large piece (Figure 5C). The osteoplastic flap is then returned into position and fixed with microplates. BoneSource (Leibinger Corp.) is used within the drill groove to maintain a smooth contour, although cosmetic problems with the osteoplastic flap are uncommon (Figure 5D). If used, 5 to 10 gm of BoneSource is mixed with a sodium phosphate solution in a dry bowl with sterile instruments free of contamination with blood. The BoneSource is applied in a dry field and should be left for 10-20 minutes to set before the flap is reapplied. To achieve obliteration of the sinus, BoneSource or bone graft may also be used as an alternative to adipose tissue. These materials are effective. However, in the event that mucocoele develops later, it may be extremely difficult to safely discern the boundaries of the sinus.

Another option is a pedicled pericranial flap, which may be elevated and rotated into the sinus if needed for vascular covering or obliteration.

When greater than 25% of the posterior table is missing, the sinus should be cranialized. All steps are the same as for obliteration, including the meticulous removal of all frontal sinus mucosa and obstruction of the frontonasal duct. The frontonasal duct may be inspected directly or with a 30-degree rigid endoscope, which significantly improves visualization (Figure 5E). The entire posterior sinus wall is then removed, allowing anterior expansion of the intracranial contents to fill the sinus. A large pericranial flap is usually placed to further separate the intracranial and extracranial spaces. It is easily harvested by dissecting the pericranial layer from the coronal flap.

Significant posterior table fractures are often associated with injuries to the dura and, less commonly, the brain parenchyma. Linear dural tears should be repaired with 4-0 Nuron sutures following elevation of the dura from the undersurface of the adjacent posterior table fragments using an angled elevator (Figure 6). Tears that are more complex may require duraplasty with fascial grafts using temporalis fascia, fascia lata, or lyophilized dura. Brain parenchymal injury may be approached via the posterior wall or may require a formal craniotomy for treatment. When there is significant bone loss in the anterior table of the frontal sinus, it may be possible to utilize fragments of the posterior sinus wall for anterior table reconstruction. Split calvarial bone grafts can be harvested, if required. In rare instances, cranialization is impossible due to significant frontal lobe resection, as there is not enough brain tissue to expand anteriorly and fill the sinus defect. These sinuses should be obliterated via the use of fat and a pericranial or other vascularized flap.

Isolated Frontonasal Duct Injury
Unilateral frontonasal duct injury, as demonstrated by a unilateral frontal sinus air-fluid level or by direct visualization, may be treated by removal of the intersinus septum to allow drainage of both sinuses through the one patent duct. This is usually done via an osteoplastic flap approach. Treatment of bilateral frontonasal duct injury with various forms of stenting has not been reliably successful. Thus, complete sinus obliteration is recommended in all but the most limited bilateral frontonasal duct injuries and is a safe option in unilateral disruption as well.

Figure 5. Posterior table fractures. A, Stryker drill with 701 or 703 burr directed into the sinus proper. Note angulation. B, osteotome utilized to complete osteotomy, releasing the osteoplastic flap. C, nasal endoscope utilized to critically examine nasofrontal duct. D, adipose tissue packed into the frontal sinus following mucosal exenteration. E, Leibinger miniplates (1.2 mm) applied and osteoplastic flap returned to the native position.
Figure 5.
Figure 6. A, elevation of dura beneath fractured posterior wall fragments. 
B, dural laceration closed.
Postoperative Care
The drain is removed and a pressure dressing is applied for the first postoperative day. In the absence of a CSF leak, dural repair, or significant associated injury, the patient is discharged home on postoperative Day 1. Oral antibiotics are continued for 1 week. Sutures and clips are removed on postoperative Day 10. Nasal blowing is contraindicated for 2 months postoperatively, and nasal saline irrigation is prescribed to prevent troublesome nasal crusting. The patient is prohibited from participating in contact sports for 6 months. If fascia lata is harvested, the patient is cautioned to avoid running for 1 month.

COMPICLATIONS
Possible wound complications include hematoma formation and infection. These may generally be avoided with the use of a suction drain and pressure dressing for the former and perioperative antibiotics for the latter. The coronal incision rarely results in alopecia; this is usually transient. Cosmetic complications vary with the incision site chosen. As a rule, the butterfly incision results in the most noticeable scar.

Significant trauma to the temporalis muscle may result in temporal wasting. Facial nerve injury and forehead anesthesia are possible complications of inattention to nerve preservation in flap elevation. As mentioned, mucocele and mucopyocele formation may result from incompletely exenterated obliterated sinus mucosa or from late stenosis of the frontonasal duct. Generally, mucoceles may be drained via transnasal functional endoscopic sinus surgery approaches, although large mucoceles and/or the sequelae of mucopyoceles may mandate the use of an open approach. Miniplates sometimes become noticeable in patients with thin forehead skin and may require removal. This is best done at 1 year postoperatively.

An extremely problematic complication is the loss of frontal sinus bone due to excessive comminution of the anterior table (or the use of the Reidel procedure, in which the anterior table is removed and the frontal skin is allowed to enter the sinus, creating a significant defect). Many options exist for cranioplasty repair of this defect, including titanium mesh, rib grafts, and bone grafts. All of these options can result in perceptible contour defects of the forehead. Again, BoneSource is a good option that generally allows for a smooth, curvable cranioplasty material with results pleasing to the patient.

CONCLUSIONS
Meticulous repair of frontal sinus injuries is critical to avoid undesirable complications including poor cosmesis and the development of a mucocele. The method of repair depends on the size of injury and the extent of comminution and bone loss. The coronal flap is the workhorse for repair of frontal sinus injuries, but other options exist depending on the extent of hair loss and pre-existing lacerations. The techniques described in this chapter are to be applied in an individualized fashion for the patient with a traumatic injury to the frontal sinus.