OPEN ACCESS ATLAS OF OTOLARYNGOLOGY, HEAD & NECK OPERATIVE SURGERY

SURGICAL MANAGEMENT OF FRONTAL SINUS FRACTURES

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The frontal sinus is a centrally located structure of functional and aesthetic importance. Fractures of the frontal sinus may occur by either blunt or penetrating trauma. The fronto-cranial bones have a greater thickness than their neighbouring parietal and temporal bones, as they are often subject to more forceful mechanisms of injury[1]. For this reason frontal sinus injuries account for only 5-15% of maxillofacial injuries, and are predominantly caused by highspeed motor vehicle accidents, assaults or direct contact sports [2–4]. Settings with road traffic safety laws, seatbelts, airbags, and helmet laws have significantly reduced rates of high-impact injuries. In regions with few traffic safety measures (e.g. helmet laws, seatbelt laws) frontal sinus fractures are frequently seen [5–7]. Without proper treatment, frontal sinus fractures may lead to a wide array of complications including facial deformity, CSF leak, mucocoele and death. For these reasons, proper diagnosis and treatment of acute frontal sinus injuries remains an important part of treating head and neck trauma.

Frontal Sinus Anatomy

Unlike other sinuses, the frontal sinus is not present at birth. Beginning around age 2yrs, aeration of the ethmoid cells extends into the frontal bone until approximately age 15yrs. There is heterogeneity in the size and shape of the adult frontal sinus. A unilateral frontal sinus is found in 11% of people, and 4% have no frontal sinus at all.

The intersinus septum divides the frontal sinus in two, each side draining mucus through its respective outflow tract. The outflow tract is shaped like an hourglass. The nasofrontal recess is the outflow tract of the frontal sinus and the ostia is the narrowest point of the hourglass configuration *(Figure 1)*. Fractures that disturb outflow can lead to acute and chronic sinusitis and eventually mucocoele formation. Thus, the outflow tract is a critical anatomical structure of the frontal sinus.

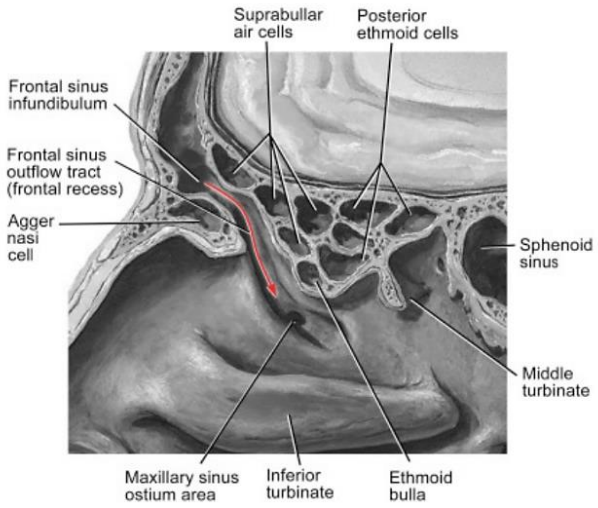

Figure 1: Frontal sinus outflow tract

The frontal sinus may have offered an evolutionary advantage as a "crumple zone" to absorb high impact energy and protect the brain. The anterior table of the sinus is known to be thicker than the posterior table, providing most of the protection to the cranial vault. The 4mm thickness of anterior table takes significant force to fracture. As a result, frontal sinus fractures are often associated with other maxillofacial or bodily injuries. One-third of frontal sinus injuries are isolated anterior table fractures; two-thirds involve some combination of the anterior and posterior tables as well as the nasofrontal recess; while isolated posterior table fractures remain quite rare (<2%) [8,9].

History & Physical Exam

It is important to take a thorough history for any trauma patient. Time and date of the fracture should be ascertained to gauge the age of the injury. If the injury was due to a mode of transportation, this information

should be elicited, including the use of seatbelts or airbag deployment, or helmets in the case of bicycles or motorbikes. Details of the mechanism of injury such as the speed, airbag deployment, and presence of shattered glass will help surgeons assess the severity of the injury and detect associated injuries. It is also important to elicit whether there was involvement of a metallic object, such as a knife, nail or farming tool, which may necessitate a tetanus booster.

Examining a patient with frontal sinus fractures includes attention to facial deformity, bony step-offs, ophthalmologic and neurologic exams. Soft tissue lacerations are examined for depth and injured structures, then copiously irrigated prior to layered closure.

Cerebrospinal fluid (CSF) rhinorrhoea or CSF within a wound indicates an injury that breached dura. The most common clinical presentation of CSF rhinorrhoea is intermittent bloodstained, or clear watery anterior nasal discharge, salty postnasal drainage, and headache. If rhinorrhoea is present, it can be evaluated with a "halo test," whereby fluid is dropped onto fabric or filter paper. If CSF is present, it will diffuse faster than blood and result in a clear halo around the blood *(Figure 2)*.

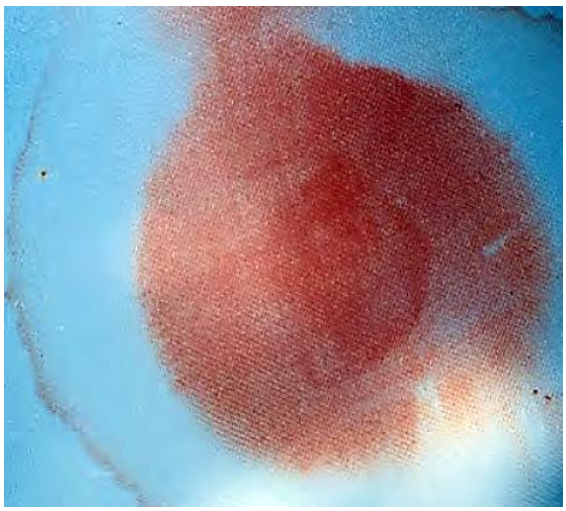

Figure 2: Halo sign of CSF mixed with blood

However this sign has been shown to have low sensitivity and specificity as blood mixed with tears or tap water also shows a similar pattern [10]. A more definitive diagnosis of CSF rhinorrhoea can be made using a beta-2 transferrin assay. It has a high sensitivity (99%) and specificity (97%) and is the gold standard for diagnosing CSF rhinorrhoea. However it is expensive, has a long waiting period (3-5 days minimum), and is not available in much of the world [11,12]. Therefore, initial diagnosis and management is based on clinical suspicion.

Considering the force required to cause a frontal sinus fracture, other craniomaxillofacial fractures should be ruled out. Naso-orbito-ethmoid (NOE) fractures frequently occur in conjunction with frontal sinus fractures. In NOE fractures, traumatic telecanthus indicates possible discontinuity of the medial canthal tendon. The integrity of the medial canthal tendon can be evaluated using the bowstring test [13]. One finger is used to pull laterally at the region of the lateral canthal tendon, while the other is gently placed on the medial canthal tendon to palpate for tension. Tension with lateral pull indicates a MCT that is attached to stable bone, while lack of tension indicates a MCT attached to a mobile fragment or avulsed altogether.

Radiology

Computed tomography (CT) is the gold standard to diagnose frontal sinus fractures. Standard imaging includes fine-cut, non-contrast CT of the CMF skeleton. Coronal, sagittal, and three-dimensional (3D) reconstructions offer additional insight into the fracture pattern *(Figures 3, 4)*. In the absence of CT imaging, plain film x-rays of the face may be obtained; however, plain films have a low sensitivity to identify frontal sinus fractures and cannot distinguish between the anterior and posterior tables.

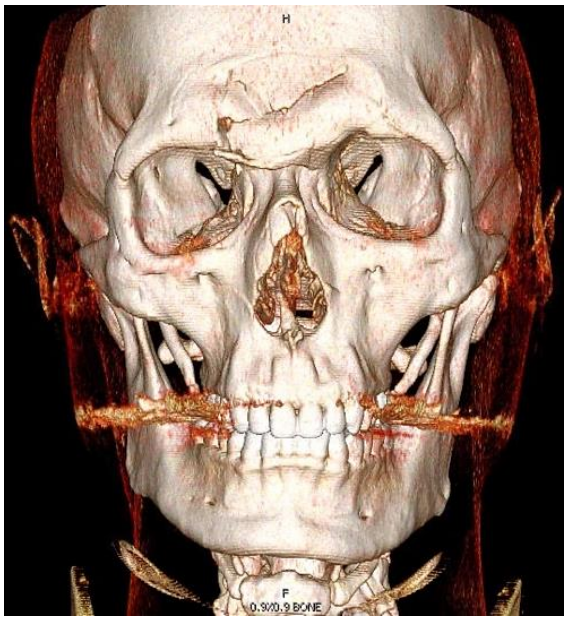

Figure 3: 3D CT: Frontal view of comminuted frontal sinus fracture

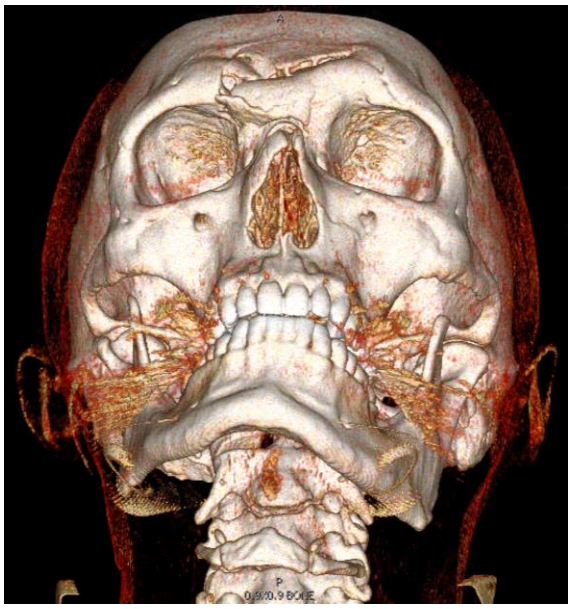

Figure 4: 3D CT Base view of a comminuted frontal sinus fracture

Certain CT cuts are helpful to evaluate anatomical aspects of the frontal sinus. Axial images highlight continuity of the anterior and posterior tables and the degree of fracture displacement *(Figure 5)*. Sagittal images are used to view the frontal sinus outflow tract and skull base *(Figure 6)*. Coronal images are used to view the orbital roof / frontal sinus floor. CT imaging can

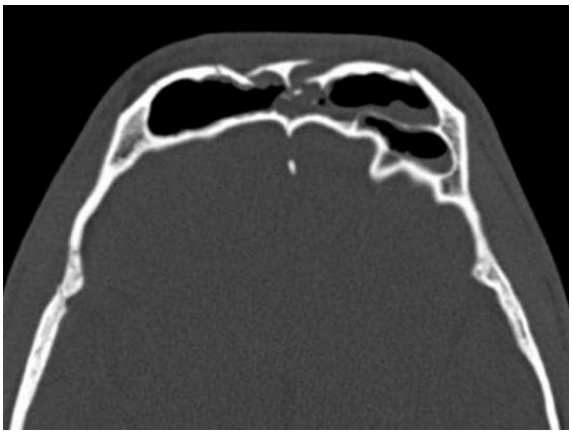

Figure 5: Axial CT of comminuted frontal sinus fracture

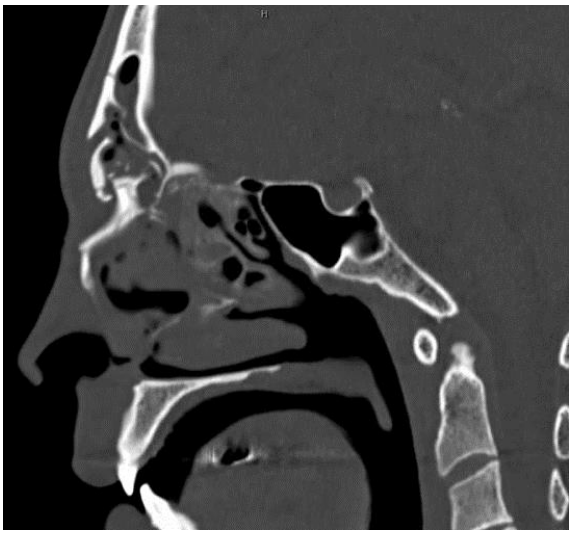

Figure 6: Sagittal CT of comminuted frontal sinus fracture

also detect pneumocephalus. It is imperative to review the radiologic imaging of the frontal sinus outflow tract, which often dictates management.

Surgical Approaches

Existing Laceration

Where a traumatic injury has left an open laceration over the frontal sinus, this may provide the most direct approach to the sinus. Refrain from extending the laceration and rather retract the tissues if needed. A combined open and endoscopic approach may also be useful in this setting.

Direct Transcutaneous/ Gullwing

In patients with deep rhytids (minor skin creases) a direct approach via an incision within a horizontal rhytid over the fracture may provide adequate access to anterior table fractures. A "gull-wing" incision is a direct suprabrow approach which extends bilaterally in deep rhytids. Direct transcutaneous incisions do carry a risk of long-term paraesthesia (though most resolve) as well as visible scarring [18].

Upper blepharoplasty

An upper blepharoplasty incision offers the advantage of a more camouflaged scar *(Figure 7)*. It provides good visualization of the orbital rim and floor of the sinus, but limited access to the medial and anterior wall of the sinus, unless the supraorbital and supratrochlear nerves are sacrificed, or an endoscope is used *(Figures 8, 9)*.

Figure 7: Upper blepharoplasty incision (Courtesy Darlene Lubbe)

Figure 8: Exposure of lateral orbital rim and supraorbital nerves (Courtesy Darlene Lubbe)

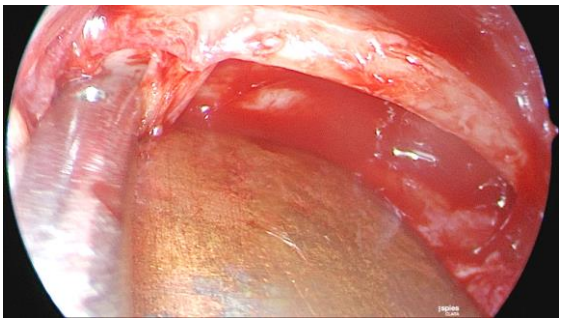

Figure 9: Endoscopic view of orbital rim and roof of orbit with preservation of supraorbital nerve (Courtesy Darlene Lubbe)

Transnasal endoscopic approach

Approach to the frontal sinuses in the setting of frontal sinus outflow tract obstruction is generally via a Draf IIb or Draf III approach. The authors recommend endoscopic approaches only if the surgeon has significant endoscopic sinus surgery experience and a complete set of instrumentation. Complications of endoscopic approaches to the frontal sinus include CSF leak, orbital injury, and postoperative stenosis resulting in outflow tract obstruction. Transnasal endoscopic approaches to an isolated anterior table injury should be carefully considered. The risk of frontal bone contour deformity must be weighed against potential for iatrogenic injury.

If simply observed, many patients will require no surgical intervention [15,19]. Other, more direct, approaches may also be considered with lower risk of iatrogenic injury to the skull base.

Coronal approach

A coronal approach provides wide exposure to the anterior cranial vault and is the gold standard approach for operative repair of frontal sinus fractures *(Figure 10)*. A good understanding of the anatomy of the scalp is critical to execute this approach without causing complications. Iatrogenic risks in-

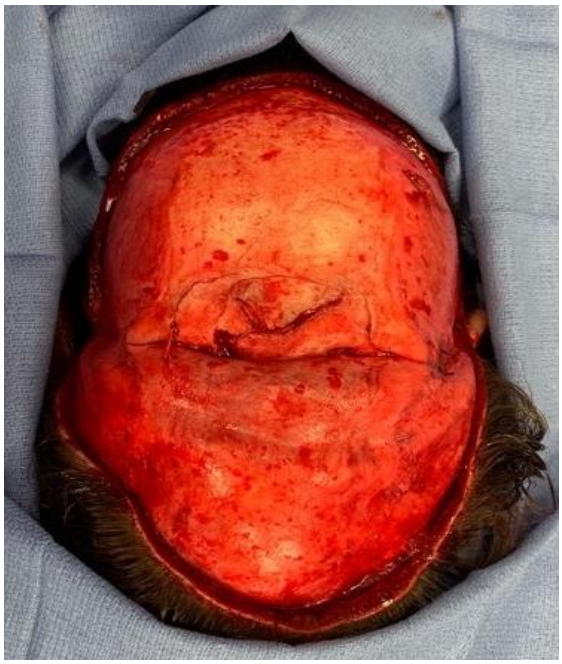

Figure 10: Coronal approach to expose frontal sinus fracture

clude alopecia, paraesthesia, facial nerve injury, and visible scarring. The surgeon should avoid injury to the supratrochlear and supraorbital neurovascular bundles. To avoid injury to these structures, as well as the frontal branch of the facial nerve, it is imperative to understand the layers of the scalp *(Figure 11).*

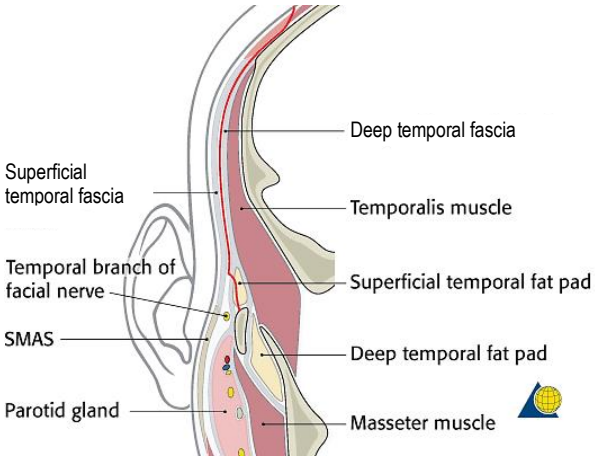

Figure 11: Temporal dissection layers of scalp: with coronal approach, temporal branch of facial nerve is protected by staying deep to superficial temporal fascia layer (AO Foundation)

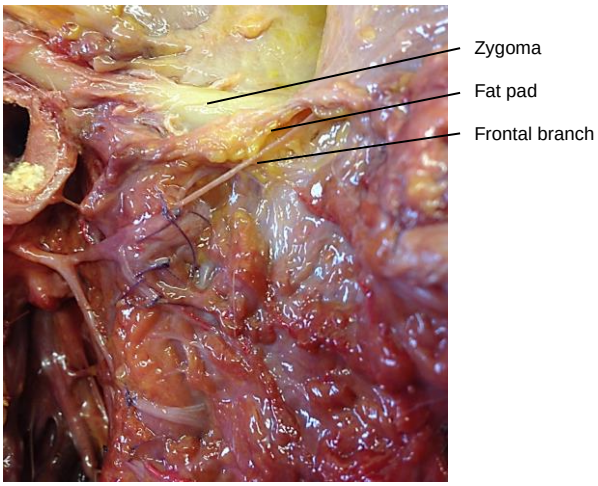

Figure 12: Frontal branch of facial nerve crossing zygoma at fat pad

Above the superior temporal line, the frontal branch of the facial nerve runs within the temporal-parietal fascia *(Figures 11, 12).*

- Make a coronal incision that extends from just superior to the root of the helix and is carried across the parietal bone posterior to the hairline, ending just superior to the contralateral helical root *(Figures 10, 13)*
- To minimize visible scarring, the incision can be made as a peaked line, a zigzag line, or a wavy line, some of which hides scar due to the irregular nature of the scar line *(Figure 13)*
- Alopecia in the incision-line is a complication that can be minimized by using cold steel rather than cautery to avoid injuring the hair follicles. The use of haemostatic clips to minimize bleeding, and bevelling the knife blade to avoid transecting the follicles are also helpful methods to avoid alopecia [20].
- Between the superior temporal lines, take the incision down to the calvarium
- Laterally, the dissection transitions to a plane between the superficial temporal fascia (STF) and the deep temporal fascia (DTF)

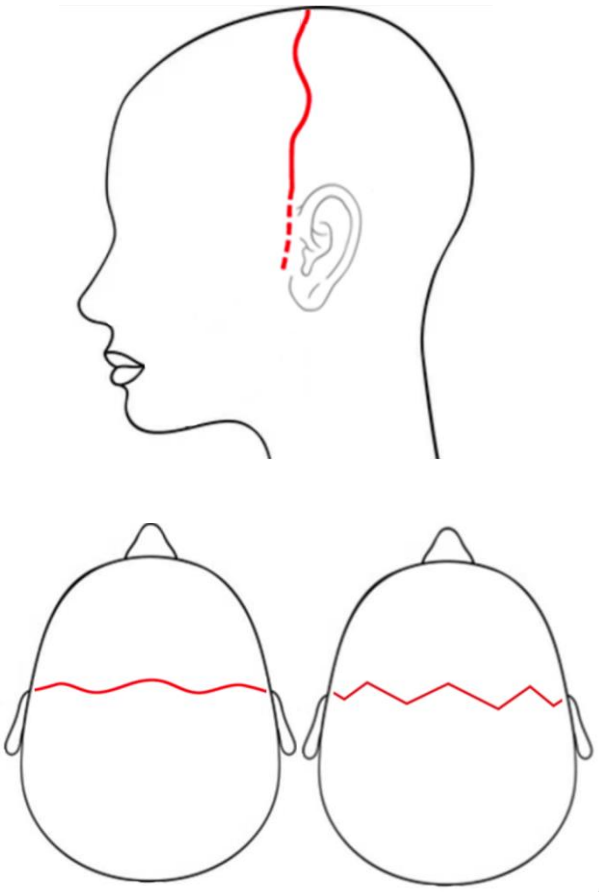

Figure 13: Coronal incision with wavy line to reduce risk of alopecia. Alternative zig-zag incision allows a more horizontal scar to be covered by overlying hair

- Elevate the STF in the coronal flap; it contains the superficial temporal artery (STA) and the frontal branch of the facial nerve
- The DTF is the white, glistening fascia that is fixed to the temporalis muscle itself and remains down *(Figure 14)*
- Take special care when approaching the zygoma to avoid injury to the frontal branch of the facial nerve which crosses the zygomatic arch within the STF by staying deep to the fat pad shown in *Figures 12 and 14.*
- For repair of isolated frontal sinus fractures, exposure of the zygomatic arch is not required

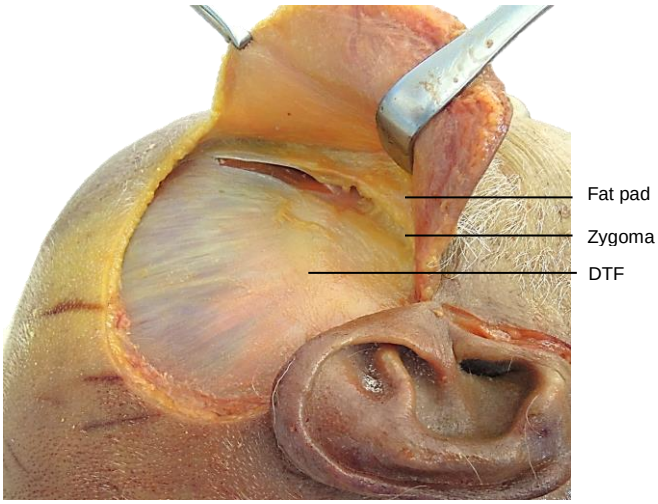

Figure 14: Hemicoronal incision to demonstrate deep temporalis fascia (DTF) and fat pad that is deep to the frontal branch of the facial nerve

- If exposure of the zygomatic arch is required e.g. with other midface fractures, great care is taken to stay deep to the STF and superficial fat pad to protect the facial nerve *(Figure 12).* For additional protection, some surgeons will incise the DTF 2cms superior to the zygomatic arch, which opens a dense plane between the fascia and superficial temporal fat pad prior to exposing the superior ridge of the zygomatic arch *(Figure 14)*
- Upon reaching the superior position of the zygomatic arch, the periosteum is incised and elevated with a Freer dissector to expose the bone for reduction

Pericranial Flap

The pericranial flap is a vascularized flap supplied by the supraorbital vessels. It may be used for frontal sinus obliteration and to reconstruct dura with injuries to the posterior table and dura.

- Make a coronal incision as previously described
- Elevate the scalp in a subgaleal plane leaving the pericranium on the bone

- Incise pericranium along both superior temporal lines and the coronal incision onto bone *(Figure 15a)*
- Elevate the pericranial flap off the skull as a separate flap using a wet gauze or elevator *(Figures 15b)*

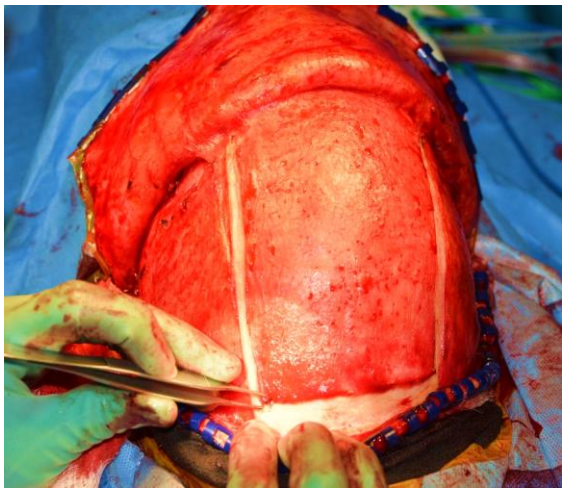

Figure 15a: Pericranium incised and mobilized off the skull, following temporal lines laterally and the coronal incision for the posterior cut. The posterior cut can be extended several centimeters further posteriorly, if additional length is required for reconstruction

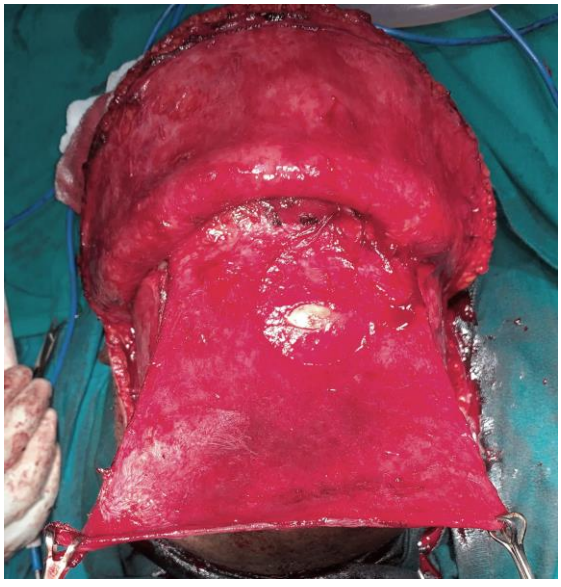

Figure 15b: Pericranial flap elevated separately from the coronal flap, which can be used for frontal sinus obliteration and dural repair

- As the dissection is carried inferiorly it is important to identify and preserve the supratrochlear and supraorbital neurovascular bundles as they exit the skull from the supraorbital notch (2/3 of patients) or a foramen (1/3 of patients) *(Figure 16)*
- For additional exposure, the supraorbital foramen may be outfractured with a small osteotome and the neurovascular bundle coaxed out of the bone
- If a pericranial flap was not initially raised but is required, the pericranial flap may be carefully dissected off the elevated coronal flap

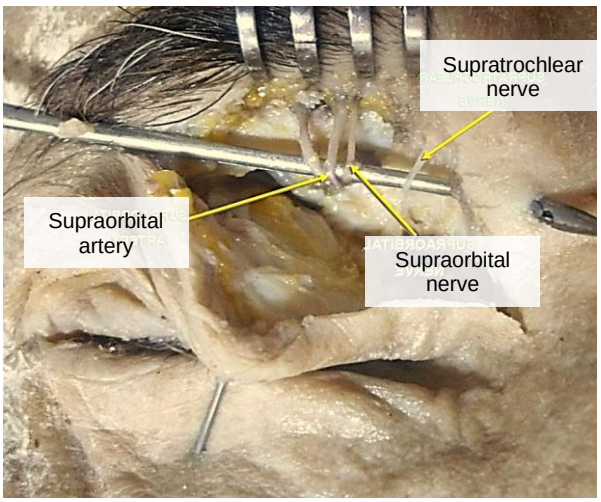

Figure 16: Supraorbital and supratrochlear nerves (Right eye)
(http://commons.wikimedia.org/wiki/File%3ASlide1h.JPG)

Management of frontal sinus fractures

Observation

Management of frontal sinus fractures has undergone a shift towards a more conservative approach [14–16]. Observation may be a first line of treatment when a fracture does not cause significant cosmetic deformity, or when there is no long-term functional concern about the sinus.

When determining treatment, it is important to consider the surgical approach to expose the frontal sinus. In many cases, an open

approach to the frontal sinus requires a coronal incision that carries risks of alopecia and/or scarring that may outweigh risks of nonoperative management. A patient's hairstyle is an important consideration in relation to morbidity of a coronal incision as short hair results in a much more visible scar.

The functional prognosis of the frontal sinus can be predicted by the location and severity of fracture displacement as viewed on CT. Observation is warranted for mildly displaced anterior table fractures without aesthetic or functional concerns. Serial CT scans can be performed at intervals to evaluate the ability of the frontal sinus to effectively drain, e.g. at 3, 6 and 12-monthly intervals in the first year. If radiographic evidence demonstrates frontal sinus opacification, endoscopic sinus surgery to improve drainage may be considered.

Open Reduction Internal Fixation (ORIF) of the Frontal Sinus

Indications for ORIF include fractures that will result in a significant cosmetic deformity, and fractures which pose a high risk for frontal sinus outflow obstruction and subsequently, a mucocoele.

- Expose and enter the frontal sinus *(Figure 17)*
- Remove obstructing fragments to assess frontonasal duct outflow obstruction and to facilitate fracture reduction
- Irrigate the sinus to determine patency of the frontonasal duct
- Instil a coloured liquid into the sinus intraoperatively such as methylene blue dye, fluoresceine or propofol (only for its white colour) and see if it drains into the nose to confirm patency of the frontonasal duct [17]
- Once patency of the frontonasal duct tract is confirmed, reduce and fixate the bony fragments

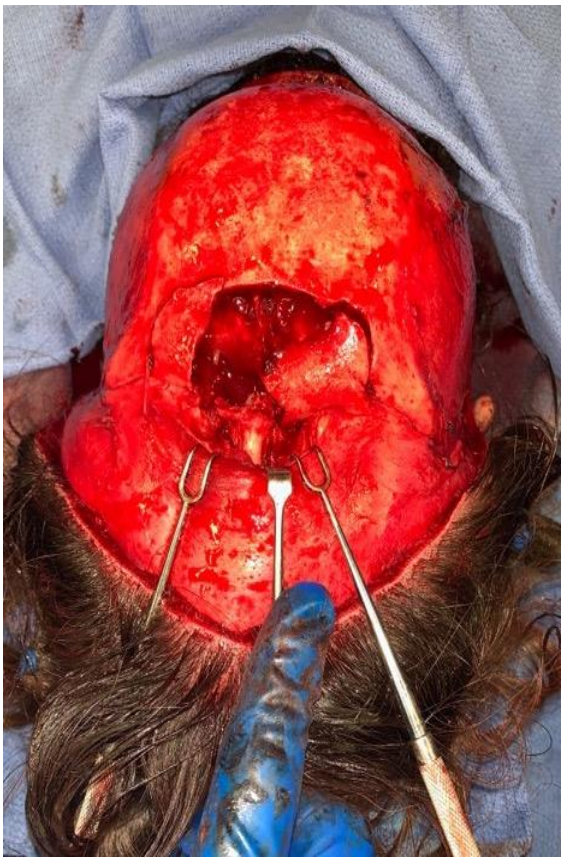

Figure 17: Comminuted frontal sinus fracture exposed via coronal approach

- Manual reduction of bony fragments may be achieved using instrumentation e.g. a small bone hook to elevate and reduce individual fragments of a comminuted fracture
- Accurate repair relies on the remaining bony fragments; therefore, the majority of fragments should be left in place
- Fixation can be achieved with 1.0-1.33mm microplates *(Figures 18, 19)*
- If plates are not available, large sutures or wires can provide semirigid fixation for larger bone segments
- Micromesh can be used to cover bony defects and to achieve a smooth facial contour

Figure 18: Open reduction internal fixation of comminuted frontal sinus fracture using titanium plates

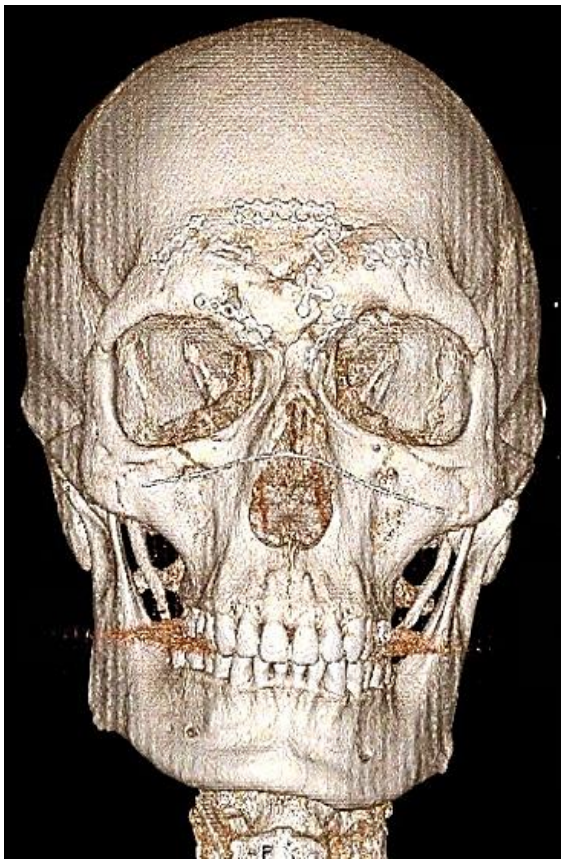

Figure 19: Postoperative CT following ORIF of frontal sinus fractures

Frontal Sinus Obliteration

Frontal sinus obliteration is performed when the frontal sinus outflow tract is badly obstructed. It involves converting a traumatised sinus to a non-functional, non-mucous producing space. This requires removal of all mucous-producing cells under direct vision, and filling the sinus with fascia, abdominal fat, pericranium etc.

- Expose the frontal sinus via a coronal approach
- Remove bone fragments of the anterior table, carefully noting their orientation by using a written map on a side table
- With the sinus opened, establish its exact borders using one of the following three methods:
    1. Transilluminate the sinus and pencil the outline of the sinus on the bone (authors preferred method) *(Figure 20)*
    2. Use a double-pronged instrument e.g. bipolar forceps with one prong inside the sinus and the other outside to determine and mark the boundaries of the frontal sinus *(Figure 21)*
    3. Intraoperative navigation

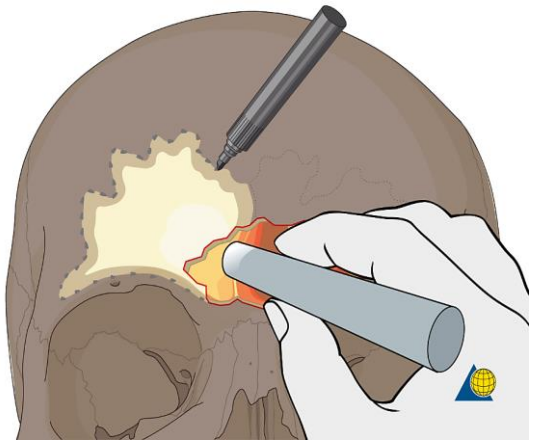

Figure 20: Transilluminating the frontal sinus to determine the outer periphery of the sinus (AO Foundation)

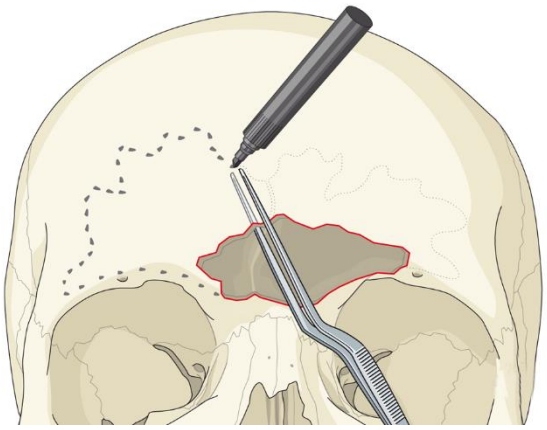

Figure 21: Bipolar or two-pronged instrument, with one prong in the sinus, and the other outside to assess and mark the boundaries of the sinus (AO Foundation)

- Preplate the anterior table along the outer borders of the sinus prior to removing the remaining bone of the anterior table
- Rotate the partially secured plates away from the bone to be removed
- Remove the remaining anterior table *en bloc* with a sharp osteotome or saw to provide wide exposure of the sinus
- Completely strip the sinus mucosa
- Burr the surface of the bone to ensure that no mucosal cells remain to avoid a future mucocoele
- Plug the frontonasal outflow tract with fascia or temporalis muscle and bone fragments
- Fill the frontal sinus space with abdominal fat harvested via a periumbilical incision to complete the obliteration
- Accurately replace the bony fragments of the anterior table and fixate them with miniplates or wires
- In the absence of hardware for fixation, larger segments of bone can be semi-rigidly secured with size 0 non-absorbable sutures through drill holes, placing the knots in countersunk holes to prevent them from being palpable through the skin

Cranialization

Cranialization refers to entirely removing the posterior table of the sinus, such that the brain now occupies that space. It is performed for severely comminuted anterior and posterior table fractures, a large disruption of the posterior table, or to gain access to a CSF leak for repair. It is less commonly performed as it has high rates of morbidity, requires skilled neurosurgical collaboration, and postoperative ICU admission. The procedure is done jointly with neurosurgery.

- A coronal approach with preservation of the pericranial flap is used for access
- Perform a frontal craniotomy, removing the entire anterior cranial vault, including the anterior and posterior tables of the frontal sinus
- On a back table, use a drill to remove the posterior table of the frontal sinus and the sinus mucosa
- Invert the mucosa around the frontal sinus outflow tracts into the frontonasal duct and pack it with fascia or bone dust
- Any dural injuries are repaired either primarily or using the pericranial flap.
- If a pericranial flap is used, create a space between the inferior cut of the craniotomy and the edge of the bone flap with a saw or burr to permit entry of the pericranial flap
- Replace and fixate the bone flap as described in the obliteration section
- Useful reference of alternate technique

CSF leaks

Fractures that breach the dura and cause a CSF leak require consultation with neurosurgery. A CSF leak as a complication of frontal sinus fractures is commonly associated with posterior table fractures. The majority of traumatic CSF leaks will resolve spontaneously without intervention [21]. Initial management is therefore close obser-

vation in hospital for 5-7 days, without antibiotics unless there is evidence of meningitis.

If the leak does not resolve, then surgical repair is warranted. If the fracture is not apparent on CT of the sinus, then a CT cisternogram may be used to identify the site of the leak.

CSF leaks associated wjth medial skull base defects are more amenable to endoscopic repair depending on surgical expertise, though both medial and lateral skull base defects may be repaired with an open approach.

Complications of frontal sinus fracture and repair

Early complications related to surgical repair include paraesthesia of the forehead, alopecia, wound infection, and facial nerve injury. Sensory changes of the forehead are often transient. The majority of paraesthesias improve over time, though may take up to a year to recover. Alopecia in the incision lines can be mitigated by avoiding monopolary cautery and only using bipolar cautery sparingly, as well as bevelling the knife blade. Injury to the frontal branch of the facial nerve is avoided by intimate knowledge of scalp anatomy. Wound infection can be reduced by perioperative antibiotics and local wound care.

Long-term complications can occur years after the initial injury or repair and include sinusitis and mucocoeles. Patients and families should be educated about signs and symptoms of these complications that include fever, periorbital or frontal swel-ing, mucopurulent nasal drainage, nasal obstruction, and headache. Routine surveillance with a CT scan of the sinus is recommended every 3-6 months for the first 1-2 years; however, patients should return earlier if symptomatic.

Mucocoele

Mucocoeles are cystic accumulations of trapped mucous which form when a sinus outflow tract is obstructed. Mucocoeles can be locally destructive, cause deformity, and erode the bone of the anterior and posterior tables *(Figures 22, 23).*

Figure 22: Mucocoele following old frontal sinus fracture. This illustrates the importance of proper, upfront treatment of frontal sinus fractures to reduce such long-term complications

By properly treating frontal sinus fractures the risk of mucocoeles which can become life threatening is reduced [22]. To monitor sinus function, serial CT scans can be performed e.g. at 3, 6 and 12 monthly intervals in the first year. Diagnosis is based on clinical signs and symptoms, supported by CT imaging. Surgery is warranted to stop progression and arrest local destruction. Normal sinus drainage pathways must be re-established. If this is not possible, the sinus may be obliterated. Surgical approaches may be endoscopic, open, or combined techniques.

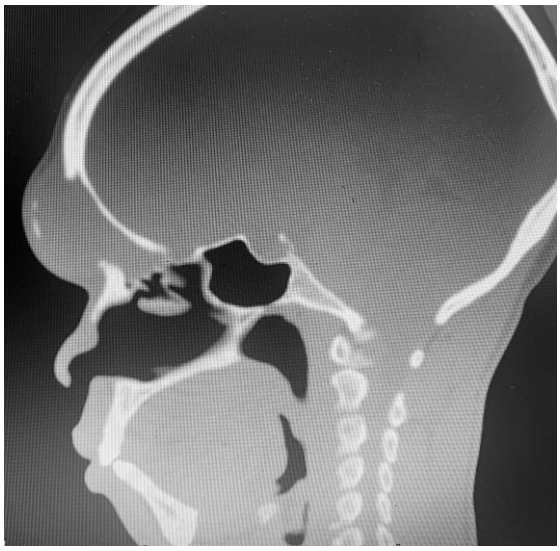

Figure 23: Mucocoele seen on sagittal cut of CT scan, with eroded anterior table and posterior table intact

Summary

Identifying and successfully managing frontal sinus fractures requires a sound knowledge of the regional anatomy and limits long-term functional and aesthetic complications. Where public health safety measures such as traffic safety, airbags, and seatbelt and helmet laws are in effect, frontal sinus fractures are decreasing [5–7].

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