Neurosurgery: Skull Base Craniofacial Trauma

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J Neurol Surg B 2016;77:412–418.

Abstract

Keywords

- frontal sinus
- craniofacial trauma
- dural tear
- CSF leak
- cranialization

Much of craniofacial trauma involves the frontal sinuses. Because of its response to injury, the frontal sinus mucosa has an innate ability to develop mucocoeles, and if infected, mucopyoceles. This article presents a therapeutic algorithm for all forms of craniofacial trauma with concentration on the most severe injury—the through and through fracture and its surgical remediation.

Introduction

The frontal sinus is a part of the paranasal sinus system comprised of aerated bones of the central face. The superior walls of these sinuses, with the exception of the maxillary sinus, make up a significant part of the anterior and the central skull base, especially the floor of the anterior cranial fossa. The roof of the sphenoid sinus contributes to the floor of the central skull base in the middle fossa as well as providing the medial boundaries of the cavernous sinuses.

The frontal sinus is an aeration of the frontal bone that at birth is nothing more than a small dimple in the anterior aspect of the middle meatus of the nose leading toward the nasal vault. This is the forerunner of the nasofrontal duct. It is the last sinus to become pneumatized. Pea-sized at 3 to 4 years of age, it extends just above the brows at 12 to 14 years of age and achieves its full size at about the age of 19 years.¹

The sinus has several components, each of which needs special consideration. The skeletal aspects of the frontal sinus are designed for protection of the brain. The anterior wall is made of heavy, thick bone in an arch configuration. On the other hand, the posterior wall is comprised of paper thin bone. The air contained within the cavity acts like a shock absorber. There are several vertically arranged thin partial septations subtended from the sinus roof that are incomplete that in turn act as baffles to an oncoming force. There is usually only one complete vertically oriented septation, usually in the midline, which separates the sinus into two cavities. The cavities of the frontal sinus are rarely symmetrical and can extend for a long way over the orbital roofs. The

posterior sinus wall forms part of the anterior wall of the anterior cranial fossa as well as a portion of its anterior floor.

The sinus cavity varies in size considerably. Its periphery has a series of scalloped edges where it becomes extremely narrow. It is at the narrow edges that it becomes difficult to remove all the mucosa when debriding the sinus. This narrow configuration can be a somewhat vexing problem when there is an extension of the sinus cavity over the orbital roof. In exceptional cases this may extend all the way to the lesser wing of the sphenoid.

The sinus cavity ends in a funnel-shaped egress, the frontonasal duct, which is located in the anterior sinus floor adjacent to the intersinus septum. The duct continues to exit into the middle meatus of the nose at the hiatus semilunaris. The exit of the sinus may be apparent as either a duct or a foramen. In Lang's series of dissections, he found that the egress from the sinus was a duct in 77% of the cases and a foramen in 23% of the cases.² Because of its narrow, circular, configuration, and delicate mucosal lining; the frontonasal duct is highly susceptible to stenosis if injured.

The mucosal lining of the frontal sinus is a pseudostratified columnar epithelium with fewer goblet cells than those that line the nasal cavity.³ One of the unique qualities of this lining is its tendency to grow into the vascular pits of the bone facing the sinus cavity.⁴ Frontal sinus mucocoeles may form if the frontonasal duct is damaged to the extent that mucus is unable to drain through it. There is then the danger of infection and the creation of a mucopyocoele. Both of these conditions cause erosion of the frontal bone by stimulating osteoclastic action.^{5,6}

Small veins located under the basement membrane of the mucosa are valve less, penetrate the posterior wall of the sinus through vascular foramina, and gain access to the subdural space underlying the frontal lobes. This provides a clear avenue for the intracranial spread of infection to the subdural space.^{7,8}

The frontal sinus has extremely important anatomical relations that are well-known to both neurosurgeons and otolaryngologists alike. Along with the ethmoid sinuses, the floor of the frontal sinus comprises the superior wall of the orbit. The inferior aspect of the posterior wall of the frontal sinus is related to the crista galli to which the falx cerebri is attached and immediately behind that is the cribriform plate. Just anterior to the crista is the dorsal nasal vein which is the origin of the superior sagittal sinus. This venous sinus extends superiorly on a crest of bone that lies on the posterior wall of the frontal sinus as the sinus continues superiorly to the vertex of the skull. Most important is the fact that it is immediately adjacent to the frontal lobes over a very large area.

Classification of Frontal Sinus Fractures

Fractures can best be classified by their site as follows:

1. Anterior wall
2. Posterior wall
3. Orbital roof
4. Nasofrontal duct
5. Corner
6. Through and through

They may then be subclassified as:

1. Linear
2. Displaced
3. Compound
4. Comminuted
5. With or without missing bone

The utility of a classification system is that each fracture in isolation invokes a repair algorithm. When a combination of injuries is sustained, the contingencies of each site and type of fracture must be considered together before performing the definitive repair.

Clinical Presentation

Patients with frontal sinus fractures are usually the victims of severe trauma. At one time, the commonest cause of this injury was automobile accidents, but since the advent and use of shoulder seat belt restraints the numbers of frontal sinus fractures has diminished. Industrial accidents, violent crime, and rarely contact sports are the commonest etiological factors now.

A period of loss of consciousness is not uncommon on presentation. Headache is universal and numbness over the forehead secondary to supraorbital nerve damage is usual. Epistaxis may be present and a check for a cerebrospinal fluid (CSF) leak by testing for B transferrin may be warranted. Checking the nasal drainage for the presence of CSF can be done with a drop of effluvium from the nose on a surgical

towel and looking for the width of the halo around the blood drop. As a clinical guideline, if the width of the halo is wider than twice the width of the central clot, then there is probably a CSF leak. The patient may have a deformity of his forehead or brow if there is a depressed fracture.

A solitary frontal sinus injury is uncommon. Many patients will have multiple injuries, especially if they have been involved in road traffic accident. Most often these injuries take precedence in the treatment algorithm and sometimes the frontal sinus fracture is overlooked.

On examination there will be a depression of the forehead or brow if the anterior wall has been displaced. An isolated posterior wall fracture or fracture of the frontonasal duct may have no external signs of damage.

The so-called "through and through" fracture is the most serious of all (►Fig. 1). This injury is caused by a penetrating force or blast and the forehead skin or scalp is lacerated. The anterior frontal sinus wall is usually comminuted and displaced along with the posterior wall. The dura is torn and the underlying brain lacerated and contused (►Fig. 2). Patients then present with blood, brain, and CSF emanating from the forehead wound (►Fig. 3). Approximately 50% of the patients with this injury die at the scene of the accident or in the first 24 hours following it. These victims are usually the victims of polytrauma and die of these wounds as well as their frontal injury.

Investigation

After a general physical examination the most important diagnostic tool is a computed tomography (CT) scan. If the lesion is a through-and-through fracture, the patient is usually in a desperate condition so that a magnetic resonance imaging (MRI), while giving additional valuable information, is often not acquired. MRI tends to give little useful information in injuries that do not have central penetration. CT gives

Fig. 1 Extensive frontal sinus fracture. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 34, page 390.)

Fig. 2 Through and through fracture. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 15, page 378.)

information regarding the displacement of either the anterior and posterior walls of the sinus. Minor displacement of the posterior wall can be difficult to discern accurately and fine cuts may be required. Sagittal CT cuts will often display fractures of the frontal nasal duct. A high index of suspicion of this is anticipated when a Le Fort II or III fracture of the midface is also present.

Surgical Repair

Anterior Wall

Linear fractures with minimal or no displacement requires no surgical intervention. The clinical presentation of a depressed anterior wall fracture may be quite obvious if seen very soon after the injury. A little later the displacement may be obscured by an overlying hematoma. Conversely, a palpable deformity at the site of injury may represent the edges of a

Fig. 3 Through and through fracture of frontal sinus, penetrating injury to frontal skin, both frontal sinus walls, dura, and brain. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 33A, page 389.)

Fig. 4 Obvious deformity following nonintervention in a depressed frontal sinus fracture. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 17, page 379.)

subgaleal hematoma and not a depressed fracture. The distinction can be easily resolved by sagittal section of a reformatted CT scan.

Displaced fractures must be treated by open reduction and internal fixation with miniplates or square plates. In this way, any external deformity will be prevented (►Fig. 4) and the possibility of subsequent mucocoele formation from entrapped remnants of mucosa reduced.

The easiest access to the injury is through a coronal scalp flap. The fracture fragments are reduced using a bone hook. It is advisable to remove the mucosa from around the edges of the fracture to avoid possible entrapment and later mucocoele development that may take 15 or more years to form.

Some compound fractures may be accessed and reduced through the forehead laceration. Better exposure can be achieved by extension along a natural crease line in the forehead.

Corner Fractures

A fracture through a corner of the sinus is usually part of a larger fracture of the frontal bone. It is usually linear and undisplaced, requiring no treatment other than close follow-up.

Nasofrontal Duct Fractures

Fractures of the nasofrontal duct are the hardest of all to diagnose. They are often discovered some days to weeks after the initial injury. Often the clinician is alerted to the presence of this fracture by the serendipitous finding of a persistent fluid level in the frontal sinus. These fluid levels usually resolve within 2 weeks. Sagittal CT cuts of the sinus usually reveal the fractured duct. If there is a displaced anterior wall fracture, an endoscope placed through the opening in the anterior wall of the sinus at the time of the repair will reveal the fracture. Alternatively, a trephine hole in the anterior frontal sinus floor using a small skin incision will allow the introduction of a sinus endoscope with a 45 or 70-degrees angled lens to visualize the duct for evidence of injury. A more definitive test is first to drain and irrigate the trephined sinus with a mixture of saline and cocaine or epinephrine. Then, introduce radiocontrast material into the sinus and observe the presence or absence of radiocontrast in the

duct and nasal cavity fluoroscopically. Methylene blue can be used instead of contrast fluid and the passage of dye viewed using an endoscope placed in the middle meatus of the nose. Lack of contrast or methylene blue in the nose indicates a frontonasal duct fracture.

There are three basic methods of addressing the isolated frontonasal duct fracture. The traditional method of dealing with this fracture is through an osteoplastic flap and fat obliteration of the frontal sinus. A coronal scalp flap is raised and the area of the sinus outlined using a template made from an X-ray cutout of a 5 foot P-A Caldwell view of the paranasal sinuses. A coin of suitable size is used as a reference guide. Once marked, the anterior wall of the sinus is cut through with either a craniotome or a bone-cutting needle. The flap is pedicled on the periosteum of the bone of the brow.⁹ After down-fracture, all the mucosa is removed from the sinus cavity. It is important to drill down 1 to 2 mms of the inner table of bone of the sinus to avoid leaving any remnant of mucosa in the vascular pits of the sinus walls. The nasofrontal duct mucosa is inverted on itself and the cavity filled with fat harvested from the subcutaneous aspect of the abdomen.¹⁰

The second method which is becoming more popular is the use of the Draf III sinusotomy.¹¹ This is essentially an endoscopic Lothrop operation but appears to be more effective than the open Lothrop of bygone times.¹² It is in essence a complete ethmoidectomy with removal of the frontal sinus floor, the frontonasal duct and the superior portion of the nasal septum. In this operation it is essential to remove the so-called "beak" of the anterior frontal sinus floor. The worthiness of this procedure in these fractures has yet to withstand the test of time.

The third type of procedure is done through an osteoplastic flap and is an attempt at preserving the function of the frontal sinus by removal of the intersinus septum. This procedure is only useful when just one duct is fractured and the opposing duct is functional. The intersinus septum is excised so that the damaged sinus can drain into the normal side.

Posterior Wall Fractures

The difficulty of the differentiation of a displaced versus a nondisplaced fracture has already been discussed. Long-term follow-up is often difficult in this cohort of patients. The patient's frontal sinus should be explored if there is any doubt about displacement.

The best approach to these injuries is through an osteoplastic flap. With no disruption of the dura, the displaced fragments are removed. The bone of the sinus cavity drilled down to ensure complete mucosal removal.¹⁵ It is essential to resist the placement of either of the frontal sinus "poisons," namely, bone wax or acrylic (W. H. Montgomery, MD, oral, June, 1988). The author has seen numerous mucoceles, and especially mucopyoceles, secondary to these agents placed in the frontal sinus to obliterate the sinus cavity after trauma. Obliteration with an abdominal fat graft or cancellous bone is much safer. If more than 15 or 20% of the posterior wall is removed, the sinus cavity should be obliterated by cranialization.

In severely displaced fractures there is not uncommonly a dural tear. Once the bone flap has been turned and the mucosa

Fig. 5 Confusing appearance of injury, anterior frontal sinus wall (open arrow), and posterior frontal sinus wall (closed arrow), and brain frontal sinus wall (large arrow). (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 22B, page 389.)

completely removed, attention is directed to the CSF leak. Shattered bone fragments are removed around the leak with a margin of bone peripheral to the leak so that a complete water tight seal can be obtained. It is a wise precaution to place a fascia graft over the suture line tucking the edges under the bone at the periphery. The sinus is then obliterated keeping in mind the admonitions of the previous paragraph.

Orbital Roof Fractures

These fractures are not uncommonly seen accompanying fractures of the posterior wall as well as in through and through fractures. The only real problem is if displaced fragments are impacting the periorbital or have ripped it and are impinging on the levator palpebrae superioris muscle. If the fragments can be replaced then this is done, especially if they are large. But if these fragments are removed, especially if the periorbital is torn, this process will result in increased orbital volume and resulting enophthalmos.

Fig. 6 Through and through injury with cerebrospinal fluid and brain oozing through the fracture. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 36A, page 391.)

Fig. 7 Anterior craniotomy done. Anterior wall fragments are cleansed and stored. Fracture of both sinus walls, dural rent, and damaged brain exposed. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 36B, page 392.)

Through and Through Fractures

These are the most serious of all the frontal sinus fractures (→Figs. 5 and 6) and require the cooperation of the skull base team for the best result. In our early series of these fractures this injury was the commonest.

Historically, the neurosurgical dictates of management of depressed compound skull fractures was to remove all depressed skull fragments and either discard them or store them for later use in reconstruction. If a craniotomy flap needed to be constructed because of the need for improved exposure, it was often discarded as well due to worries about

Fig. 8 Brain debrided, dura patched, and posterior wall remnants removed with double action rongeur. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 36C, page 392.)

Fig. 9 Removal of remaining posterior wall of frontal sinus procedures cranialization. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 36D, page 392.)

potential contamination and the need of eliminating restriction of brain secondary to posttraumatic edema. When such fractures involved the frontal sinus the tradition of the otolaryngological community was to ablate the sinus to avoid infection from contamination of the intracranial space with damaged sinus mucosa. Ablation involved removal of the entire frontal sinus wall, much of the sinus floor and the bone of the supraorbital rim as originally described by Reidel.¹³

In 1974 Nadell and Kline, two neurosurgeons from the University of North Carolina, published their seminal work on the preservation of the bone flap in compound skull fractures.¹⁴ After management of the central injury and dural repair, they carefully cleansed the bone flap and restored it

Fig. 10 The Mucosa of the sinus is removed from the sinus lumen and the nasofrontal duct mucosa is inverted on itself and the frontonasal ducts are plugged with temporalis muscle. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 36E, page 393.)

Fig. 11 Craniotomy returned with wire and fragments of frontal sinus fixed with plates. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 36G, page 393.)

per primum. The author was made aware of this work by a Sacramento Neurosurgeon, Dr. Paul Forest, as they attended a through and through injury involving the frontal sinus.¹⁵ They agreed to apply this principle to the frontal sinus fracture, thus avoiding secondary infection by completely excising the frontal sinus, then returning the bone flap excised for exposure, as well as carefully cleansed bone fragments from the anterior wall of the frontal sinus. The operation is quite simple to perform and has become part of the regimen of managing severe frontal sinus fractures in many centers of the world.

The first step, once all life-threatening injuries have been controlled, is neurosurgical. All fragments of bone involved in the injury are carefully cleansed and soaked in Betadine

(Purdue Products L.P., Stamford, Connecticut, United States). The area of brain injury is exposed, necrotic brain excised, hemostasis effected, and a watertight dural repair undertaken (→Fig. 7). Commonly the injury to the frontal lobe dura is so considerable that dural grafts are need to effect closure.

The cranialization procedure begins with a complete removal of what is left of the posterior wall of the frontal sinus (→Fig. 8). The extremities of the sinus are burred down flush with bone of the anterior cranial fossa. The floor of the sinus is superficially burred down until all the narrow extensions of the sinus over the orbital roof are completed (→Fig. 9). Narrow extensions can be widened with a diamond bur to enable removal of all vestiges of mucosa. If there is loose bone in the fractured ethmoid sinuses it is removed. The bone of the remaining anterior wall of the sinus is similarly burred away as is the mucosa on the saved fragments of the anterior wall. Meticulous mucosal removal is an essential part of this operation. If any mucosa remains then infection is almost inevitable. However, with the wide exposure available by virtue of the anterior craniotomy which is undertaken to manage the brain injury and torn dura, this is not difficult to accomplish.

Attention is now turned to the nasofrontal duct. Any remaining mucosa in the duct is elevated and imbricated on itself toward the nasal cavity. The bone of the duct is now lightly burred and plugs of temporalis muscle placed therein to seal off the nasal cavity to the now expanded anterior cranial fossa (→Fig. 10). All the bone fragments are then returned. Split calvarial bone grafts can be placed if small fragments have been lost (→Fig. 11).

Postoperatively the brain expands (→Fig. 12) into the newly enlarged anterior cranial fossa and the rest of the dead space is filled with blood. There may also be some residual air which absorbs over a period of 3 months.

In a relatively small series of 21 patients who had cranialization with follow-ups of up to 8 years, there was preservation of a normal frontal contour in all but one patient, with no CSF leaks or meningitis and no mucocele formation.¹⁶

Fig. 12 Brain migrates forward to fill defect. (Reprinted with permission from Donald¹⁶ Chap. 26, Fig. 36F, page 393.)

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