



# Breach of Posterior Wall of Frontal Sinus: Management with Preservation of the Sinus

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## Key words

- Breach of frontal sinus
- Complications
- Cranialization of frontal sinus
- Frontal sinus fracture
- Management of frontal sinus fracture
- Posterior wall of frontal sinus
- Rhinorrhea

## Abbreviations and Acronyms

CSF: Cerebrospinal fluid

NF: Nasofrontal

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## INTRODUCTION

Breaches of the posterior wall of the frontal sinus can result from trauma, infection, neoplasia, or erosion from pressure. In addition, the frontal sinus may be breached iatrogenically or by intention in the course of gaining intracranial surgical exposure. Aggressive surgical methods commonly are used to manage breaches of the posterior wall that are moderately or severely displaced, comminuted, associated with cerebrospinal fluid (CSF) rhinorrhea, have nasofrontal (NF) duct compromise, or are filled with purulence (2, 5, 9, 10, 14, 29, 31, 32). Neurosurgeons deal with many categories of breach of the posterior wall of the frontal sinus, yet most publications on this subject are in the otolaryngological, plastic surgical, and oral maxillofacial literature, with relatively few found in neurosurgical journals (1, 2, 4-8, 10, 12-16, 21, 22, 24-27, 29-34, 36, 39-43, 48).

For decades, cranialization and/or obliteration has been used commonly for most significant breaches of the posterior

■ **OBJECTIVE:** To analyze outcomes after the management of mild (<1 mm) and moderately severe (>1 mm and <5 mm) breaches of the posterior wall of the frontal sinus with a goal of maintaining or restoring the functional status of the sinus.

■ **METHODS:** A retrospective analysis of prospectively accrued data was performed on patients with mild and moderately severe breaches of the posterior wall of their frontal sinus who were managed with the intent to preserve the frontal sinus. Data on presenting features, pathology, details on breaches of the posterior wall, management, outcome, and complications were collected from medical records and neuroimaging.

■ **RESULTS:** Forty-two cases met inclusion criteria. Diagnostic categories included trauma in 34 cases, infection in 3, and other categories in another 5 cases. Five presented with cerebrospinal fluid rhinorrhea, and 26 had radiographic evidence of obstruction of a nasofrontal duct at time of presentation. Fifteen patients were managed without surgical intervention, and 27 underwent surgery. No complications occurred in the patients managed without surgery and 4 postoperative cerebrospinal leaks that were managed successfully with a period of drainage occurred in the surgical group. No patient developed meningitis or mucocele.

■ **CONCLUSIONS:** Many patients with mild to moderately severe breaches of the posterior wall of the frontal sinus can be managed safely and effectively by techniques that preserve the anatomy and function of the frontal sinus.

wall of the frontal sinus (9, 13-15, 22, 24, 26). Several authors have stressed the nearly mandatory requirement for cranialization and/or obliteration in patients with CSF rhinorrhea, NF duct compromise, or fractures of the posterior wall that are appreciably comminuted or displaced (13, 15, 31, 32). Most surgeons are uncomfortable with nonsurgical management for all except the most minor breaches because of fear of persistent CSF rhinorrhea, meningitis, brain abscess, mucocele, or combinations thereof. Although many surgeons agree on the need for aggressive surgical management, usually cranialization or obliteration for severely disrupted or shattered frontal sinuses, there remains a large group of patients with mild to moderately severe posterior wall disruptions, from multiple etiologies, that is often, but inconsistently, grouped managerially in published reports with those having severe breaches, particularly if there is fracture displacement greater than one wall

thickness, posterior wall comminution, CSF rhinorrhea, or compromise of the NF ducts (2, 5, 13, 29).

This report reviews the outcomes and complication rates in a consecutively encountered series of patients with mild to moderately severe frontal sinus breaches, all of whom were managed with a consistent goal of maintaining or restoring the functional status of the frontal sinus with satisfactory cosmetic outcome and without compromising safety. Multiple etiologies for breaches of the posterior wall of the frontal sinus that come to neurosurgical attention are included in this report because of their similarities in therapeutic decision-making and management.

## MATERIALS AND METHODS

All patients encountered by the senior author (K.R.W.) between August 1, 1998, and January 1, 2014, who had breach of the posterior wall of the frontal sinus of 5 mm

or less, regardless of cause, are the basis for this investigation. Fractures were divided into 4 groups: nondisplaced, displaced less than 1 mm (mild), displaced 1–5 mm with or without comminution (moderate), and displaced greater than 5 mm with or without comminution (severe). Severe, comminuted fractures were treated surgically with a cranialization operation that does not preserve the function of the sinus. These patients were therefore excluded from the study. Additional exclusion criteria included breach of the frontal sinus that did not involve the posterior wall and death within 7 days of presentation. Patients with surgical osteotomies crossing the frontal sinus were included, as were patients having sinus breaches related to sinusitis, subdural, or epidural empyema, and Pott puffy tumor. The radiographic appearance of the NF duct did not affect the categorization of these fractures in the current study. Hospital records and neuroimaging were reviewed. This study was done with approval of the Colorado Multi-Institutional Review Board.

### Description of Technique

Fractures of the posterior wall of the frontal sinus with no displacement or with displacement of less than 1 wall thickness, including those with suspicious or definite CSF rhinorrhea, were managed nonoperatively. Minimally displaced posterior wall fractures, with or without comminution, in patients who required surgical intervention for other cranial or intracranial pathologies such as depressed fractures of the cranial vault or intracranial hematomas were surgically ignored. Persistent CSF rhinorrhea lasting more than approximately 24 hours, if not controlled by bed tilt, was managed with lumbar or ventricular drainage, and antibiotics were administered during the course of drainage.

Moderately depressed and comminuted fractures of the posterior wall with displacement of bony fragments greater than one wall thickness, including patients with definite or presumed disruption of dura, as evidenced by subdural air or by CSF rhinorrhea, were managed through a bicoronal scalp incision and bifrontal craniotomy. Mucosa that was disrupted, loose, or folded was removed. Loose bony fragments of the posterior wall were

repositioned and aligned to reestablish normal sinus anatomy. When possible the fragments were wedged in place but some required metal plates and screws.

The NF duct was explored with a probe for patency in all patients undergoing surgery in whom there was radiographic evidence of compromise and in all patients with sinusitis. If found to be compromised, the duct was expanded with a small osteotome, bone impactor, or both to reestablish a functional drainage pathway.

The dura was inspected in all surgical cases, and lacerations and durotomies were repaired with running 4-0 polyglycolate suture when the dural edges could be identified and brought together. In patients with tenuous dural approximation, a free strip of periosteum was harvested and either sewn snugly over the damaged dura with 4-0 polyglycolate suture or simply placed over the area of attenuated dura and tacked in place with sutures to prevent displacement during irrigation, and the frontal bone flap was replaced. Free periosteal flaps were placed along the floor of the frontal fossa when secure, watertight closure was not possible. All patients with purulence within a frontal sinus underwent surgery to drain and irrigate the sinus and to remove any associated infection in epidural, subdural, or intracerebral locations. All contaminated bone, including free flaps, were scrubbed with either a bacitracin or providone iodine solution and returned to their normal anatomical locations (49).

In patients in whom both anterior and posterior walls of the frontal sinus were surgically breached, typically by an osteotomy crossing the upper or mid-portion of the frontal sinuses during elective craniotomy to address intracranial pathology, the disrupted mucosa was removed from the sinus within the free bone flap, the sinuses irrigated, and the NF ducts were ignored. At time of closure, all frontal bone flaps were seated snugly to obliterate the kerf crossing the sinus.

A subgaleal drain was inserted in each patient and removed 1–2 days later. Intravenous antibiotics were administered preoperatively in nonemergent cases for 24–48 hours after surgery in clean and clean-contaminated cases. Longer courses of antibiotics were administered in patients

with persistent CSF rhinorrhea, frontal sinusitis, or epidural or subdural abscess.

### RESULTS

Forty-two patients, 33 male and 9 female, with breaches of the posterior wall of the frontal sinus met criteria for inclusion. The diagnostic categories and associated intracranial pathologies are summarized in [Table 1](#). The age range was 6–79 years with a median of 27 years; 15 patients were younger than 18 years of age. More males were affected than females (77%), and the great majority of posterior wall breaches (81%) were traumatic in origin. The mechanism of posterior wall breaches was attributable to trauma in 34 patients, iatrogenic breach during craniotomy to address cranial, or intracranial pathology in 7 and posterior wall erosion from arteriovenous malformation in 1 ([Table 2](#)). Twenty-three patients, including those cases with infection and neoplasia, had disruptions of dura, but only 5 of these presented with CSF rhinorrhea ([Table 3](#)).

Thirty-four patients sustained breaches of their anterior and posterior walls, and 8 had isolated posterior wall breaches. The posterior wall breaches were not displaced in 22 patients, displaced less than one posterior wall thickness in 11, and between one wall thickness and 5 mm in another 9. The NF duct appeared on computed tomography imaging to be patent in 16 patients and was possibly compromised or indeterminate in 26. Five patients had CSF rhinorrhea on presentation, and 1 patient sustained a complex fracture extending from the posterior wall of the frontal sinus, across the middle fossa, and into the petrous temporal bone resulting in CSF otorrhea. This patient's CSF leak was managed successfully with lumbar drainage. Twenty-nine of the 34 patients with trauma sustained concomitant intracranial injuries as evidenced by pneumocephalus, intracranial hemorrhage, bullet tract, large intracerebral hemorrhage, and cerebral contusion.

Twenty-seven patients underwent surgical intervention, and the remaining 15 were managed without surgery. Five of these operations were done solely to address issues confined to the frontal sinus and underlying dura (11), and the remaining 22

**Table 1.** Intracranial Pathologies of Patients with Breach of the Posterior Wall of the Frontal Sinus

Diagnostic Category	Intracranial Pathology on Presentation*
Infection, n = 3	1 Potts puffy tumor and epidural abscess† 1 Frontal sinus tract into frontal lobe 1 Frontal sinusitis with intracerebral abscess
Neoplasia, n = 3	1 Meningioma† 1 Esthesioneuroblastoma† 1 Eosinophilic granuloma†
Trauma, n = 34	12 Cerebral contusion† 2 Epidural hematoma† 5 Intraparenchymal blood 1 Intraventricular blood 6 Pneumocephalus 7 Subarachnoid blood 6 Subdural hematoma
Vascular, n = 1	Arteriovenous malformation Meningitis
Fibrous dysplasia, n = 1	None†

\*Some patients had more than one category of intracranial pathology.  
†Iatrogenic breach of the anterior and posterior walls of frontal sinus.

were performed to also address other cranial or intracranial pathologies. None of the patients underwent cranialization or obliteration of the frontal sinus. Sixteen of 23 patients with dural disruption underwent craniotomy and dural repair. Nine patients had posterior wall displacements of greater than one wall thickness, and 5 of these underwent craniotomy with realignment of wall fragments and repair of dural disruptions.

Sinus mucosa was subtotally removed in 6 patients and not removed in the remaining 21. Eleven patients underwent evacuation of the frontal sinus (6 hematomas, 2 neoplasms, and 3 with purulence). None of the patients, including those with possible NF duct injury or obstruction, underwent cranialization, sinus obliteration, or placement of a temporary drainage tube through the NF duct.

Forty-one of the 42 patients were alive at the time of last entry in their medical record. The family elected to withdraw care

**Table 2.** Mechanisms of Disruption of Frontal Sinus That Included Breach of the Posterior Wall

Age, Years	Number	Sex, Female/Male	Mechanism of Sinus Injury
5–10	4	3/1	1 Craniotomy for Pott’s puffy tumor* 1 Motor vehicle accident
11–15	6	0/6	1 Craniotomy for fibrous dysplasia* 1 Craniotomy for eosinophilic granuloma* 2 Motor vehicle accident
16–20	6	2/4	1 Vascular erosion (AVM) 2 Gunshot wound 1 Sinusitis
21–30	8	3/5	2 Motor vehicle accident 2 Auto — pedestrian 1 Motor scooter — brick wall; EDH required craniotomy* 1 Fist fight
31–40	4	1/3	1 Bicycle accident 1 Auto—pedestrian; TBI required craniotomy*
41–50	4	0/4	2 Motor vehicle accident 1 Fall down escalator
51–60	9	0/9	1 Motor vehicle accident 1 Fall down stairs 1 Glass plate fell on head 1 Craniotomy for esthesioneuroblastoma* 1 Intoxicated fall from standing
Older than 60	1	0/1	1 Bicycle accident
Total	42	9/33	

AVM, arteriovenous malformation; EDH, extradural hematoma; TBI, traumatic brain injury.  
\*Iatrogenic entry into frontal sinus.

**Table 3.** Presenting Characteristics of Patients with Breach of Posterior Wall of Frontal Sinus

Frontal Sinus Injuries That Included Breach In Posterior Wall, N = 42						
Diagnostic Category	Iatrogenic Breach	Breach In Anterior Wall	Breach in Floor	Dural Disruption	CSF Leak on Presentation	Complications
Trauma n = 34	2	31	24	18	5	CSF leak 3
Neoplasia n = 3	3	2	1	1*	0	CSF leak 1
Infection n = 3	1	0	0	2	0	0
Vascular n = 1	0	0	0	1*	1	0
Fibrous dysplasia n = 1	1	1	1	0	0	0
Totals N = 42	7	34	26	22	6	4

CSF, cerebrospinal fluid.

\*Dura opened intentionally in the course of a neurosurgical operation.

for one patient who developed sepsis and multiorgan failure. Mean follow-up time was 380 days. Six patients had CSF leaks on presentation, 5 with rhinorrhea and 1 with otorrhea. Three leaks ceased with temporary external CSF diversion, 2 stopped after a single operation, and 1 patient required 2 operations. Four patients

had new CSF leaks after cranial surgery, and all of these were successfully controlled with a period of CSF drainage. One patient with blunt head trauma and CSF rhinorrhea was managed initially with external CSF lumbar drainage. The leak abated and the drain was removed after 5 days, but 2 days later the patient underwent a

right frontotemporoparietal decompressive hinge craniectomy to address intracranial hypertension. Six days thereafter the bone flap with underlying epidural empyema and brain abscess, none of which were contiguous with or near the frontal sinus, were removed. Given that the infection was anatomically remote from the frontal sinus

**Table 4.** Surgical Management of Traumatic Frontal Sinus Injury That Included Breach of Posterior Wall of Sinus by the Amount of Wall Displacement

Breach of Posterior Wall of Frontal Sinus From Trauma					
Surgical Management, n = 27					
Displacement of Posterior Wall Fragment(s)	Posterior Wall Reconstructed	Dura Repaired	Mucosa Removed	Sinus Drained	Complications
>1 wall thickness, n = 8	5	Patched 4* Sutured 2 Not repaired 2	2 complete 1 partial	5	CSF leak 1
≤1 wall thickness, n = 6	1	Patched 1* Sutured 0 Not repaired 5	2 complete	3	CSF leak 2
No displacement, n = 13	1	Patched 5* Sutured 2 Not repaired 8	1 complete	2	CSF leak 1
Totals, n = 27	7	Patched 10* Sutured 4 Not repaired 15	6	10	4

CSF, cerebrospinal fluid.

\*patched or reinforced with pericranium.

and not related to the management of its breach, this was not considered a complication in this series. The 4 complications, all being postoperative CSF leaks, in this series that are reasonably attributable to the management of breaches of their frontal sinuses occurred in patients with trauma, and 1 occurred after surgery for tumor (Table 3). There were no complications of meningitis, osteomyelitis, or subdural or epidural hematoma, and no patient had developed a mucocele by the time of last contact.

Three patients presented with frontal sinusitis and intracranial purulence: 1 with erosion through the posterior wall resulting in cerebral abscess, 1 with a fibrous pus-filled fistula into the right frontal lobe, and 1 having Pott puffy tumor with erosion through the posterior wall of the sinus. All 3 underwent noncranialization surgery and a postoperative course of antibiotics. There has been no clinical or radiographic evidence of residual or recurrent infection.

## DISCUSSION

Distinctly different diagnostic categories of patients with breaches in the posterior wall of the frontal sinus have important commonalities which include many of the principles for management as well as types of complications and their causes. Trauma is the most common diagnostic category, but others include infection, bony disorders such as fibrous dysplasia, iatrogenic surgical entry, and erosion into the sinus by a destructive process such as a vascular malformation (Table 1). Breaches in the posterior wall of the frontal sinus occur in all groups old enough to have a frontal sinus. Frontal sinus fractures are a component of 2%–15% of craniomaxillofacial injuries, and approximately 5% of these involve disruption of the posterior wall (1, 2, 13, 15, 15, 26, 29, 30, 48). Blunt trauma is the most common mechanism (Table 2) and both the range of severity and presenting characteristics have a broad spectrum (Tables 1 and 3). Common abnormalities coexisting with breaches of the posterior wall of the frontal sinus include distant cranial fractures, intracranial hematoma, cerebral edema, neoplasia, cerebrovascular disease, purulence, and other intracranial entities. The age span in this series was 6–79 years, although the frontal sinus is usually radiographically absent or quite

small before 8 years of age (17, 50). Reflecting the large proportion of trauma patients in this series, the gender distribution was strongly skewed with 78.6% males. The severity of the pathologies in this series is reflected by the facts that 62% also had fracturing of the floor of the frontal fossa, 55% had dural violation from trauma or disease process, and all of the patients with infection within the sinus had extension of purulence far beyond the confines of the sinus (Table 3).

Sinus preservation may be accomplished either by nonsurgical management or by surgical interventions that protect or restore original anatomy (1, 2, 15, 22); however, the pathology and the severity of breach strongly influence the choice and details of management. This series differs from most published series by including multiple diagnostic categories and age groups that are customarily analyzed and published separately and by the extensive use of nonsurgical and less aggressive surgical management than commonly advocated (1, 2, 5, 14, 15, 24, 31, 32, 43).

Fear of serious complications such as meningitis, brain abscess, mucocele, and persistent CSF rhinorrhea has been the driving motivation for many surgeons to choose cranialization or obliteration for most cases of frontal sinus fracture. It is well established that complications occurring within 6 months of the posterior wall breach, for all diagnostic and age categories, include CSF leak, meningitis, and frontal sinusitis and later complications include persistent CSF leak, mucocele, mucopyocele, cerebral abscess, and osteomyelitis (5, 29, 31). It is important to recognize that comparison of complication rates for different therapeutic regimens has limited value because of varying criteria for surgical intervention such and inconsistent classification of postoperative CSF leaks and infections that do not require surgery as being complications. Our 42 cases, none of whom underwent cranialization, had an overall complication rate of 9.5% (4 CSF leaks). If CSF leaks that were successfully managed with a period of external CSF drainage are excluded, our overall complication rate was zero.

## Nonsurgical Management

No complications occurred in the 15 patients who were managed without surgery and these included 8 having no bony

displacement, 4 with displacements of less than one posterior table thickness, and 3 with bony displacements between one posterior wall thickness and 5 mm. None of these patients had CSF rhinorrhea on presentation; however, 8 of the 15 had radiographic evidence of unilateral or bilateral NF duct obstruction. There is sound evidence that nonsurgical management of non-comminuted, nondisplaced fractures without CSF leak is associated with low complication rates and therefore the low complication rate for our nonoperative patients is not surprising (1, 2, 5, 6, 13, 15); however, critical interpretation of these numbers requires recognition that at least 7 of our patients with posterior wall displacements would have met the threshold for surgical intervention (cranialization or obliteration) used in most other series (13, 14, 31, 32). The absence of postoperative leaks in patients managed without surgery likely reflects either the absence of dural tears or small tears that were sealed by brain tissue or bone fragments until healing occurred. Interestingly, in *ver* Bruggen's (46) experience, reported in 1952, CSF leaks consistently heal within "a few days" of keeping "the patient on his face with his head downward and forward, so that the brain comes forward and acts as a tampon on the crack in the posterior part of the frontal sinus." Nonsurgical management, when successful, has the advantage of avoiding all risks and morbidity associated with surgical management; however, delayed appearance or recognition of CSF rhinorrhea has been reported, even 10 years after head injury (11).

## Surgical Management

Four of our 27 surgically managed patients had complications related to the management of their frontal sinus fracture, all of which were postoperative CSF leaks (14.8%; Table 4). The complication rate in our surgical group compares favorably with published rates of 0%–27% for surgically managed frontal sinus fractures (Table 5). In a series of 149 patients who had surgery to address posttraumatic CSF rhinorrhea, not all of whom had identified fractures of their posterior sinus walls, the failure rate was 10%, and there were 2 cases of meningitis and 2 deaths (11). Many, if not all of our cases, particularly those with comminuted, displaced posterior walls, cases of sinusitis with intracranial

**Table 5.** Comparison of Complications Associated with Surgical and Nonsurgical Management of Breach of Posterior Wall of Frontal Sinus

Authors	Nonsurgical Management		Surgical Management		
	Cases (Complications)	Complications	Cranialization N (Complications)	Other Surgery N (Complications)	Complications
Current series	15 (0)	Not applicable	0 (not applicable)	27 (4)	CSF Leak 4
Wallis and Donald, 1998 (48)	0 (0)	Not applicable	30 (*)	42 (*)	“Major” 9 Meningitis 4 Mucocoele 4 Frontal pain 1 “Minor” 28 Wound infection 7 Frontal pain 1 Diplopia on upgaze 1 CSF leak 7 Contour deformity 6 Frontal numbness 6
Gerbino et al., 2000 (13)	39 (0)	Not applicable	46 (8)	73 (6)	Meningitis 3 Frontal Osteomyelitis 1 Contour deformity 10
Gossman et al., 2006 (15)	48 (3)	Chronic headache 1 Sinusitis 1 Forehead asymmetry 1 CSF leak 0 Wound infection 0	11 (4)	37 (9)	Chronic headache 6 Sinusitis 3 Forehead asymmetry CSF leak 2 Wound infection 1
Chen et al., 2006 (5)	6 (0)	Not applicable	14 (1)	46 (12)	Meningitis 1 CSF leak 6 Wound infection 4 Sinusitis 1 Pyomucocoele 1
Bell et al., 2007 (2)	66 (0)	Not applicable	16 (*)	34 (*)	Brain abscess 1 Meningitis 1 Frontal Osteomyelitis 1 Mucocoele 2 Contour Deformity 2 Hematoma 2 CSF leak 1
Rodriguez et al., 2008 (30)	353 (11)*	CSF leak Meningitis Abscess Sinusitis Mucocoele	209 (19)*	295 (42)*	CSF leak Meningitis Abscess Sinusitis Meningitis Mucocoele
Choi et al., 2011 (6)	46 (0)	“no major complications”	1 (0)	12 (0)	“No major complications”

CSF, cerebrospinal fluid.  
\*Incomplete list of type and number of complications for each different surgical technique however total number of complications is listed.

purulence, and some of the cases with CSF leaks, would almost certainly have been managed with cranialization or obliteration.

Postoperative complication rates as high as 50% are reported in series heavily populated with cases managed by surgically aggressive routines, most commonly cranialization (Table 5) (48). This finding is much greater than rates commonly recognized by neurosurgeons. In a report on 857 patients

with frontal sinus fractures, decisions for surgical intervention in 505 of these were strongly driven by concerns over patency of the NF duct, rather than extent of posterior wall comminution or CSF leak (29). In this subgroup, the 209 who were managed with cranialization had a complication rate of 10%. Those authors excluded postoperative “minor complications,” which included CSF leaks and infections not requiring

surgery, thereby resulting in an overall complication rate of 7.1% (29). If the same type complications are excluded from our surgical cases, the surgical complication rate becomes zero. Bell et al. (2) reported 116 cases in whom 16 who underwent cranializations were followed by one brain abscess and one case of frontal osteomyelitis (12.5%). Gerbino et al. (13) reviewed records of 158 patients with

frontal sinus fractures, 46 of whom underwent cranialization, and 8 of these subsequently developed either meningitis, frontal osteomyelitis or significant contour deformities; their post-operative infection rate following cranialization was 17%.

Surgical management that includes a goal of preservation of the frontal sinus tends to differ significantly from management that does not include this goal (1, 2, 12, 22, 40, 42). In this series each surgical procedure began with craniotomy, most often bifrontal, and any intracranial pathologies needing attention were dealt with before addressing the breaches in the frontal sinus. After dural openings were sutured or patched the NF duct was probed for patency and displaced bone fragments were realigned and secured with plates and screws, when necessary, to recreate the original sinus anatomy. Considerably less time is required in most cases as a result of not needing to remove all mucosa, burr the entire cavity, occlude the NF ducts, and then develop and reflect a large flap of pericranium.

Exeneration of the frontal sinus, a very disfiguring procedure, includes removal of the anterior and posterior walls of the sinus and the supraorbital rims (28). Osteoneogenesis of the frontal sinus involves removal of the all sinus mucosa followed by scoring of the inner walls to induce bony formation. This procedure carries with it a high risk of infection (23). Not surprisingly, both of these operations are now largely if not totally procedures of the past. Obliteration of the frontal sinus requires sufficient entry into the sinus to meticulously remove all mucosa, securely occlude the NF ducts, and completely fill the cavity with some avascular material such as fat, bone, galea, fascia, pericranium, lyophilized cartilage, hydroxyapatite, biocement, bioglass, or Teflon (2, 17, 18, 27, 29, 33, 34, 36). This latter procedure remains in use today, especially in cases of NF duct obstruction and has reported complication rates of 0%–22% (1, 2, 15, 30, 34).

Cranialization is a relatively complex surgical procedure that includes bifrontal craniotomy with removal of the entire posterior wall of the frontal sinus (9, 29, 50). All mucosa must be removed and many surgeons burr the entire bony surface to eliminate the chance that any

mucosal fragments remain. The NF ducts must be occluded with a material such as a bone autograft and a large flap of pericranium or galea, with or without intact vascularity, is reflected over the edge of the usually intact supraorbital rim to cover the sites of the now occluded NF ducts and any sites of dural repair. Cranialization, whether done as a subcomponent of a larger cranial intervention or done solely to deal with breach of the frontal sinus, has postoperative risks that include hematoma, infection, new or additional dural disruption, new or persistent CSF rhinorrhea, and mucocele (2, 15, 35, 48).

Cranialization gained broad popularity in the early 1990s because of improved morbidities in management of posterior wall fractures (14, 32, 48), and many surgeons continue to rely on this and other relatively aggressive routines for patients with posterior wall breaches having bony displacement greater than one wall thickness, particularly if there is comminution, and in most patients in whom there is CSF rhinorrhea or suspicion of NF duct compromise (1, 13, 29, 30, 32, 44, 50). A recent review, highlighting Class II and III evidence, recommended cranialization for CSF leakage and obliteration to deal with NF duct obstruction (3). Cranialization and obliteration continue in common use by many surgeons, including neurosurgeons, for dealing with a high percentage of breaches of the posterior wall of the frontal sinus (1, 2, 15, 24, 29, 30, 50). However, some recent authors have advocated less frequent use of these techniques for the less severe breaches of the posterior wall (2, 5, 6, 50).

A sinus-preserving option for primary management in selected less severe fractures of the posterior wall involves a transnasal endoscopic approach (4, 45, 47). This less-invasive technique is a relatively safe and well-tolerated alternative for elimination of many persistent and recurrent CSF leaks and for reopening of obstructed NF ducts, thereby preserving both the anatomy of the frontal sinus and its mucociliary drainage (4, 8, 39, 41); however, mucocele has been reported following endoscopic repair in children (47). Endoscopic surgery has also been used successfully for rescue repair in select patients who have undergone failed surgical approaches, including sinus obliterations (21, 37, 38).

### Surgical Breach of Frontal Sinus

The frontal sinus was breached in the course of neurosurgical operations in 7 patients, spanning 4 diagnostic categories (Tables 2 and 3). There are 2 scenarios in which surgical breach of the frontal sinus are encountered in neurosurgical practice: iatrogenic, in the original sense of unintentional entry, and intentional or non-avoidance entry. Commonly neurosurgeons manage these with cranialization or obliteration. Iatrogenic breach typically occurs from a low transverse frontal osteotomy executed as part of a craniotomy to deal with intracranial pathology. Typically these breaches traverse the upper portion of both anterior and posterior walls. Complications following iatrogenic breaches of the frontal sinus are reported to occur in up to 12% of cases (2, 7). No patient with surgical breach of the frontal sinus in this series, whether from iatrogenic or intentional entry, underwent cranialization or obliteration. All 7 of iatrogenic breaches were managed by positioning the elective durotomy sites to not align with the trans-sinus osteotomies.

Intentional neurosurgical breach of the frontal sinus occurs in 2 settings: in the course of providing exposure to deal with intracranial pathology and to address pathology within the frontal sinus. Cases of the first type can be managed in the same way as iatrogenic breaches. Our 5 cases in the second category included one in which a cerebral arteriovenous malformation eroded through the posterior sinus wall, one in which a portion of the posterior wall was removed in the course of treatment of fibrous dysplasia, and three cases in which there was pus within the sinus and intracranial spaces.

### Frontal Sinusitis

Frontal sinusitis with extension into the subperiosteal space (Pott puffy tumor), epidural space, subdural space, or brain parenchyma typically has been managed by neurosurgical intervention that includes cranialization of the frontal sinus; however, our patients with frontal sinusitis, all of whom had purulence beyond the sinus itself, were successfully managed with sinus preservation. Each underwent bifrontal craniotomy with a transverse osteotomy that intentionally crossed the mid-portion of the sinus, evacuation of pus and irrigation of the sinus and all other

pus-containing spaces, followed by provision of a path for drainage of the frontal sinus via probing and opening of NF ducts. Both the walls of the frontal sinus and the free frontal bone flaps in these cases were definitely bacteriologically contaminated. The rationale for less aggressive surgical management is identical to that published for the successful management of other bacteriologically contaminated free bone flaps (49). All of these patients received several weeks of postoperative intravenous antibiotics, as would have been administered following cranialization. Drainage of purulence, irrigation with antibiotic-infused saline, and establishment or maintenance of patency of the NF duct is essential in these patients. No patient with frontal sinusitis and extension of purulence beyond underwent cranialization. No postoperative complications occurred in this group.

### CSF Rhinorrhea

Five patients had CSF rhinorrhea on presentation, and all were related to trauma. Two ceased with a period of CSF drainage, and 3 required surgical interventions. Postoperative CSF rhinorrhea occurred in 4 of our 27 surgical cases and the rhinorrhea had been present before surgery in one of these. The incidence of postoperative CSF rhinorrhea in the current series is lower than that in published series in which more aggressive surgical managements were used.

None developed intracranial infection. One of our 7 patients in whom the frontal sinus was intentionally breached during craniotomy developed postoperative CSF rhinorrhea that resolved with lumbar drainage. Although inconsistently reported as being a complication, or at least as a major one, postoperative CSF rhinorrhea, is said to occur at a rate of 3%–10% after cranialization or obliteration (5, 15, 24, 31, 32, 37).

Considering that at least half of all CSF leaks recognized on presentation resolve spontaneously (32) and the great majority identified postoperatively cease with either observation or a period of lumbar or ventricular drainage, an argument for immediate surgical intervention, particularly cranialization, solely on the basis of CSF rhinorrhea, is unconvincing in the opinion of these authors. If leaking continues after an attempted trial of CSF drainage, surgical intervention will be

required to address a rent in the dura using some combination of suturing, patching, or biological adhesive. These authors agree with Tosun et al. (45) that “Intracranial approaches should be reserved for more complicated CSF rhinorrhea which results from extensive comminuted fractures ....”

### Mucocele

Mucocele development after fracture of the frontal sinus is an uncommon but well-known and often discussed complication that can follow either nonsurgical or surgical management of breaches of the frontal sinus and has been reported to come to attention as late as 35 years after frontal bone fracture (16, 20, 24, 31). In a report by Chen et al. (5) on 78 patients with frontal sinus fractures, there was one mucocele among the 6 patients who did not have surgery (1.3% of their total group). Mucocele is caused by the continuing production of mucous by mucosa that is loculated in a frontal sinus as a result of obstruction of the NF ducts by displaced bone fragments or by detached mucosal flaps. It can occur as a consequence of incomplete removal of mucosa during cranialization (5, 6, 16, 29, 50). The presence of a breach into the posterior wall of the frontal sinus is not, alone, known to predispose to subsequent mucocele development.

### NF Duct

Twenty-six of our cases had either definite or strong suspicion of NF duct obstruction, based on neuroimaging, and this reflects the severity of injury or presence of pathologies that caused the obstructions. Eight of the 26 were in the nonoperative group and the remaining 18 were in the operative group. None of our patients with radiographic evidence of NF duct compromise, including the 9 with blood or purulence within the sinus, underwent cranialization or sinus obliteration however each NF duct was probed to ensure patency. So far, no patient in this series has developed a mucocele. We cannot exclude the possibility that a few patients' neuroimages were over-read and therefore these patients did not have NF duct obstruction but this seems an improbable explanation for the low incidence of complications.

NF duct occlusion must be taken seriously and nothing in this report should be interpreted otherwise; if not addressed,

mucocele or mucopycocele is the expected result. NF duct obstruction or even its suspicion, has often been considered a stronger indication for cranialization or obliteration of the sinus than has CSF rhinorrhea or posterior wall displacement (6, 29). Many surgeons meticulously remove the mucosa, burr the entire cavity, and insert a filler material to obliterate the sinus in all cases in which the NF duct is thought to be compromised (1-3, 19, 24, 29, 30). The absence of complications in our patients with presenting evidence of NF duct compromise is consistent with the interpretation that NF duct occlusion associated with mild to moderately severe breaches of the posterior wall of the sinus can very often be safely managed with surgical techniques that achieve sinus preservation. In so doing the complications associated with the more radical procedures can be avoided.

### Deformity

Significant contour deformities have been reported following cranialization and some have required surgical attention (2, 13). A transverse depression low across the forehead marks the site at which the periosteal flap is folded inward. In patients with severe trauma or other cause for breach of the frontal sinus, a cosmetically permanent groove across the forehead is a small price to pay but oftentimes less aggressive management can safely achieve the same or better result with little or no cosmetic deformity. No significant deformity was noted in the surgically managed patients in this series of patients managed with sinus preservation.

### CONCLUSIONS

The data of this report are consistent with the position that mild and moderately severe breaches of the posterior wall of the frontal sinus can be safely managed with preservation of the frontal sinus and with comparable or lower risk of complications. The authors recognize that a larger series with a concurrent randomized control group for each subcategory would increase the confidence of conclusions drawn from these data. However, this would require a multi-institutional study spanning several years and, until this is done, clinicians must examine and interpret the available data in the most logically and compelling



way possible. It is important to not allow either tradition or the fear of relatively uncommon complications to lead to surgical interventions which have higher risks of equivalent or worse complications than those being possibly avoided.

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