INTRODUCTION

Frontal sinus fractures (FSFs) account for 5-15% of all maxillofacial injuries and are associated with 32% of panfacial and maxillary injuries.[1-3] Rodriguez et al.,[1] reported concomitant facial fractures in over 75% of patients with FSFs. FSFs usually result from high energy impact/high-velocity blunt force, and are usually associated with intracranial and bodily injuries.[1,2] The integrity of the frontal bone contributes to the morphological appearance of the face. Therefore, fractures of the frontal bone and sinus require accurate assessment and adequate management in order to preserve and/or restore the esthetic facial appearance of the patient.[2] Although frequency of occurrence is relatively low, but FSFs have a large potential of complication and may involve not only the frontal sinuses but more importantly the brain and the eyes. Unlike most facial fractures, mismanagement of FSFs leads to devastating and potentially fatal complications.[4] In addition, complications of such fractures should be prevented if possible, and if not, complications should be identified early and be given the adequate treatment to avoid grave neurological consequences.[1] Morbidity and mortality associated with these fractures are often dependent on the anatomic characteristics of the fracture, concomitant injuries, treatments rendered, age and gender of patients, and mechanism of injury.[1,3,5]

The management of FSFs presents a unique and challenging problem for the plastic surgeons, neurosurgeons and maxillofacial surgeons.[3] Management protocols have changed greatly over time since initial descriptions of this injury, with many surgeons presenting their management algorithms based on their experience.[1,6,7] Surgical

Management of frontal sinus fractures: A review of the literature

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Abstract

Aim: The aim of this paper is to conduct a literature review on the clinical anatomy of the frontal sinus as it relates to its implication in frontal sinus fractures (FSFs), as well as review the contemporary opinions on the management of these fractures. Materials and Methods: A computerized literature search of PubMed and Medline was conducted for publications on the clinical anatomy and management of FSFs. Search phrases were "frontal sinus" combined with "management", "treatment", and "anatomy". The Boolean operator 'AND' was used to narrow the searches. Result: FSFs account for 5-15% of all maxillofacial injuries and are associated with 32% of panfacial and maxillary injuries. The FSFs may result from high-velocity impacts, such as motor vehicle accidents and assaults; blunt or penetrating force. The potential for intracranial injuries, esthetic deformities, and late mucocele formation is high. The treatment goals of FSFs are an accurate diagnosis, avoidance of short- and long-term complications, return of normal sinus function, and re-establishment of the premorbid facial contour. Recently, several treatment protocol with greater emphasis on the nasofrontal outflow tract (NFOT) injury are described in the literature, however, controversies still abound on effectiveness of these protocols in reducing the attending complications. Conclusion: The management of FSFs presents a unique and challenging problem for the contemporary surgeons. A clear understanding of corrective techniques is essential when approaching these challenging injuries. Each treatment method has its advocates, and controversies still abound regarding indications, applications, and ultimate success in given situations.

Key words: Frontal sinus, fractures, management, review
management of FSFs and the modalities as well as treatment algorithms are still controversial.\cite{1,3,5} The major objectives of treatment are the prevention of intracranial infection and the restoration of facial contour.\cite{8} Management of FSFs is accomplished by following four basic principles: Reestablishment of the frontal bony contour to its premorbidity state, restoration of normal sinus mucosa with a patent drainage system if possible, eradication of the sinus cavity if the normal mucosa or drainage system cannot be reestablished, and creation of a permanent barrier between the intracranial and extracranial systems to prevent overwhelming infectious complications.\cite{8} Because of the location of the frontal sinus and its proximity to numerous intracranial structures, inadequate treatment may lead to life-threatening intracranial infectious complications.

The aim of this paper is to conduct a literature review on the clinical anatomy of the frontal sinus as it relates to its implication in FSFs, as well as review the contemporary opinions on the management of these fractures.

MATERIALS AND METHODS

A computerized literature search of PubMed and Medline was conducted for publications on the clinical anatomy and management of FSFs. Search phrases were “frontal sinus” combined with “management”, “treatment”, and “anatomy”. The Boolean operator ‘AND’ was used to narrow the searches. The computerized literature search spanned a period between 1976 and 2013. A total of 44 relevant articles were included in the review. All the articles were descriptive and comparative in nature, and were either prospective, retrospective, or cross-sectional in design.

Anatomy of the Frontal Sinus

The frontal sinus is the only paranasal sinus not present at birth though its development begins in utero.\cite{9} The frontal sinus originates from the frontal recess, the development of which starts about the 4th or 5th month of intrauterine life.\cite{9} It either develops from the entire frontal recess or one of its pits. The pattern of development varies in individuals; the spectrum ranges from the poorly developed to the markedly pneumatized, with involvement of adjacent bone.\cite{10} In about 4% of population there is bilateral agenesis of the frontal sinus.\cite{11} Pneumatization of the two frontal sinuses begins after the 2nd year of life. The sinus becomes radiological evidence at 8 years and continue to develop until puberty when it attains appreciable size, assuming an adult size at the age of 15 years and reaching full development at the age of 19 years.\cite{11,12}

The frontal sinuses are arch-shaped or curvilinear in outline. The two sinuses are situated posterior to the superciliary arches, bounded by a thick anterior wall about 2-12 mm thick and a thin posterior wall which is about 0.1-4.8 mm thick.\cite{13} The floor of the sinus is thin and fragile and forms part of the roof of the orbital cavity.\cite{9} The posterior wall provides attachment for the superior sagittal sinus near its origin at the foramen caecum. This makes the superior sagittal sinus vulnerable in penetrating injuries and fractures of the posterior wall. Fortunately, rupture is uncommon because the dura is tough and unyielding, and the sinus is often atretic for some distance from its origin, close to the frontal sinus. When rupture occurs, however, the outcome is often fatal.\cite{9,10}

The sinuses are rarely symmetrical. There is a vertical septum close to the midline often deviated from the mid-sagittal plane and several septa may be present, dividing the sinus into separate cavities.\cite{9} The position of some septa may impair drainage in some individuals.\cite{10,11} On an average, the sinus in adult measures about 3.2 cm in height, 2.6 cm wide, and about 1.8 cm in depth giving about 720 mm² in total surface area.\cite{10,11} The outlets of the frontal sinus are the nasofrontal ducts located on either side of the septum.\cite{9} The nasofrontal duct is a funnel-shaped constriction which transvers the cancellous part of the anterior wall between the glabella and the anterior ethmoidal cells.\cite{9,13} The opening of the nasofrontal duct is not constant and it may drain into the frontal recess or above the infundibulum in most individuals. In other individuals it is continuous with the ethmoid infundibulum, and rarely opens above the ethmoid bulla.\cite{11}

The mucosal lining of the frontal sinus is made of ciliated pseudostratified columnar epithelium which makes vascular depressions or pits in the bone.\cite{11} These depressions are the exit points of the diploic veins of Breschet, which form major connections between the capillaries and the narrow cavities of the frontal bone, and ultimately lead to the dural veins.\cite{10,11} The frontal sinus is supplied mainly by the supraorbital artery by its diploic branch as it passes from the orbit to the forehead.\cite{10} Additional blood supply comes from the branches of the anterior ethmoidal artery.\cite{11} The superficial venous drainage occurs via the anterior facial and the angular veins, while the deep venous drainage occurs through the foramina of Breschet on the posterior wall of the sinus. The foramen of Breschet communicates directly with the subdural venous system.\cite{11}

Etiology of Frontal Sinus Fracture

FSFs commonly result from high-velocity impact, blunt, or penetrating force.\cite{1}

Most series in the literature report motor vehicle collisions as the primary injury mechanism.\cite{1,4,14} The next most common mechanisms are assault and accidental injuries, confirming high-energy trauma as the common denominator.\cite{1} Rodriguez et al.,\cite{1} in the largest series (857 cases) of FSFs reported motor vehicle collision as the most common cause of FSFs, constituting 42% of the series, followed by assaults (14%), motorcycle collisions (10%), and pedestrian crossing the road (8%). Seven percent of cases in their series were due
to ballistic injuries.\(^1\) Rodríguez et al.\(^1\) also noted that about 60% of cases involved in motor vehicle collision were unrestrained (not wearing seat-belt). All the mechanisms highlighted previously confirm high energy trauma associated with FSFs. According to Rodríguez et al.,\(^1\) the rarity with lower energy trauma reflects the structural ability of the skull and face to absorb and distribute forces along the stress-bearing framework, reducing the incidence of skull and brain damage despite extensive facial fractures.

Clinical Presentation and Diagnosis
The physical examination of patients with FSFs is difficult because swelling from the soft tissue injury often obscures the physical findings.\(^3\) Clinical presentation of trauma to the frontal sinus, whether blunt or penetrating type, may range from focal mucosal contusion to significant fracture of the sinus with involvement of the intracranial contents.\(^6\) Clinical assessment may be hindered by facial and scalp edema. Clinical features include bruises, skin lacerations, hematoma, anesthesia of the supraorbital nerves, subconjunctival ecchymosis, and cerebrospinal fluid (CSF) rhinorrhea. There may also be depression of the frontal bone with obvious facial deformity, and in some cases bony fragments may be visible through the lacerations.\(^1,6\) The most important part of the preoperative surgical examination is the detection of CSF rhinorrhea, indicating a posterior table injury with a dural tear;\(^3\) A thorough and careful inspection of the nostrils should be done and CSF leak looked for. Clear fluids should be sent to the laboratory for analysis for glucose and beta-2 transferrin.\(^8\) A positive finding greatly influences the choice of treatment for the injury.\(^5\) Dural tears may however not present with CSF rhinorrhea if the nasofrontal duct is obstructed.\(^1,3\)

Abnormal vision and limitation of movement of extraocular muscles may occur as a result of neuro-ophthalmic injury.\(^1\) Though clinical features of the fracture are important, they are unable to fully characterize the frontal injury and define its extent especially in blunt trauma with masking facial edema. Imaging of the frontal sinus therefore becomes expedient.\(^1,15\)

Conventional plain skull radiographs used to be the basic diagnostic tool for head and neck injuries.\(^1\) Standard sinus series included the Water’s lateral and submentovertex views, and the Caldwell’s view.\(^3\) These views were able to demonstrate fracture lines and opacification of the sinus if there is fluid in the sinus. Even if a fracture line is not visualized, sinus pathology is strongly suspected when the roentgenogram demonstrates air-fluid levels, a diffusely cloudy sinus, or pneumocephalus.\(^3\) The current imaging modality widely used for the assessment of craniofacial injuries is computed tomography (CT) scan.\(^16\) CT scan demonstrates the soft tissue, bony elements as well as the nasofrontal ducts and gives a panoramic view of the intracranial contents.\(^16\) Current high resolution CT scanners are able to provide axial and coronal direct cuts with demonstration of bony architecture in great detail.\(^16\) Stanwix et al.,\(^16\) in a study on 857 patients with FSFs demonstrated that specific computed tomographic data play a pivotal role in classification and surgical management of potentially fatal frontal sinus injuries. It is well-recognized that radiologic diagnosis of nasofrontal outflow tract (NFOT) in FSFs, particularly obstruction, plays a decisive role in surgical planning; therefore, the level of fracture, degree of disruption of the sinus floor, or presence of fluid in the sinus as shown by CT scan imaging will suggest if the nasofrontal duct is disrupted or obstructed.\(^15,17\)

Plain radiographs do not adequately characterize FSFs and therefore have been largely supplanted by CT.\(^1,18,19\) Importantly, one cannot assess NFOT involvement from plain films alone. NFOT involvement can be defined by CT: Obstruction, associated anterior ethmoid complex fracture, and frontal sinus floor fracture.\(^1,18,21\) CT scan also improve assessment of posterior wall of the frontal sinus.\(^1\) Therefore, CT scan has been made mandatory for adequately assessing FSF and NFOT function and for planning surgery.\(^1,18,19,21\)

Classification of Frontal Sinus Fractures
Many classification schemes have been proposed for FSFs.\(^3\) However, the most common classifications in the literature are:\(^22,23\)

- Anterior wall fractures
- Posterior wall fractures (PWFs)
- Anterior and PWFs
- “Through and through” fractures
- Fractures involving the nasofrontal duct.

The approach to each patient must be individualized, but in general is based on three clinical factors:\(^7,15,24-28\)

- Fracture location and displacement
- Dural and cerebral involvement
- Damage to the frontal sinus drainage system.

Anterior Wall Fractures
Isolated fracture of the anterior wall is the most common type of frontal sinus injury.\(^3,25\) Anterior wall fractures constituted 38.3% of cases of FSFs reported by Rodríguez et al.\(^1\) However, only about 17% of these fractures were displaced anterior wall fractures.\(^1\) The expected sequelae from failure to treat these injuries is a contour deformity of the forehead and potential involvement of the nasofrontal drainage system.\(^3\) Anterior wall fractures involving the nasal-orbital-ethmoidal area or supraorbital rim have a 25-50% incidence of nasofrontal duct involvement.\(^3,23\)

Gossman et al.,\(^27\) in their series reported anterior wall fractures as the most common FSFs constituting 50% of all cases. Isolated anterior wall fractures were also found in 72.5% of cases of FSFs in a series reported by El Khatib et al.\(^28\)
Posterior Wall Fractures
This usually results from extremely high velocity injury and is associated with comminution of the posterior table with significant dural tearing.\[3\] PWF places the intracranial contents in direct communication with nasal mucosa with possible intracranial complications.\[3\] Fortunately, PWFs are not as common as anterior wall fractures.\[1,3\] Most cases of PWF are associated with fractures of the anterior wall.\[1,27,28\] Rodriguez et al.\[1\] reported 6.9% cases of isolated PWF in their series. Posterior wall involvement is an indication of severity of the injury. It has also been observed that associated injuries are more common when the fractures involved the posterior wall.\[29\]

Antero-Posterior Wall Fractures
Severe injury to the frontal sinus region commonly results in a combined fracture of the anterior and posterior walls.\[1,27,28\] A combined anterior/PWFs constituted 54.9% of cases of FSFs reported by Rodriguez et al.,\[1\] while Gossman et al.,\[27\] El Khatib et al.,\[28\] reported 50 and 27.5%, respectively. Figure 1 shows a CT revealing anteroposterior FSFs.

Nasofrontal Duct Injuries (NFOT Injuries)
The floor of the frontal sinus constitutes part of the orbital roof. The drainage to the frontal sinus is provided by ostia which are located bilaterally in the medial, posterior aspect of the frontal sinus floor. These ostia drain caudally into the nasal cavity by means of the frontal recess or nasofrontal duct and empty into the middle meatus.\[30\] A true duct may be identified in only 15% of humans,\[3\] and for this reason, the term “NFOT” was defined.\[3\] NFOT injuries are commonly associated with frontal sinus wall fractures (anterior and posterior walls and floor).\[1,3,22-29\] In addition, injury to nasofrontal duct with NFOT obstruction is one of the major factors that determines the treatment protocol in FSFs. The relationship between NFOT and severity of injury and complications is well-established.\[1,3-4\]

Treatment Algorithms
Management of FSFs is so controversial that the indications, timing, method of repair, and surveillance remain disputable among several surgical specialties. However, the most important tenet of FSF management remains the same: Create a safe sinus.\[8\] Rohrich and Hollier\[6,7\] were the first to present a diagnostic and therapeutic algorithm and established a major emphasis on NFOT anatomy and drainage. Since then, several other authors have reported other therapeutic algorithms considered to be effective in the management of FSFs.\[1,3,27-29\]

Based on extensive report in the literature, treatment decisions depend on the following: Fracture type, comminution, degree of posterior table fracture, nasofrontal duct injury, neurologic status, and CSF leak.\[1,3,22,25-30\] Existing treatment options based on the above factors are: Observation, reconstruction of the sinus walls, obliteration of the sinus, osteoneogenesis, ablation/exenteration, and cranialization.\[32,22-30\] The aims of these treatment include:\[31\]
- Elimination of predisposing conditions to early or delayed complications including CSF leak and foreign bodies.
- Restoration of normal sinus function.
- Restoration of premorbid facial esthetics.

Anterior Sinus Wall Fractures
Anterior wall fractures may be either undisplaced or displaced. Undisplaced or minimally displaced fractures of the anterior wall do not usually require surgical treatment, and therefore affected patients are placed under observation.\[1,32,33\] If it is an open fracture with overlying skin laceration, the laceration is usually sutured and patients may be followed with serial imaging.

Anterior wall fractures with significant displacement ultimately require surgical reduction.\[1,3\] This helps correct the resultant facial deformity that may result from such injuries. The fact that damaged mucosa may predispose the patient to mucocele formation as a late complication, makes surgical correction imperative.\[32,33\] Repair of simple depressed fractures is carried out by elevation of the fragments and this could be achieved using a bicoronal incision, a transverse forehead crease incision, or a brow or trephine incision.\[1,32,33\] The height of the sinus and position of patient’s hairline influences the choice of incision.\[32,33\] The bilateral brow glabella or butterfly incision results in division of the supraorbital neurovascular bundle with resultant facial numbness and the scar is usually ugly and unacceptable from cosmetic point of view.\[32,33\] The transverse forehead crease incision also produces similar cosmetic results.\[32,33\] The coronal incision is more esthetically acceptable, but this becomes difficult in bald patients or those whose hairlines are actively receding.\[32,33\]

Reduction of simple fractures usually produces good results since the fracture segments can be maintained in position...
with minimal support. The facial muscles are easily apposed over the fracture site without tension. However, the placement of gelfoam sponge in the sinus as a temporary support has been documented.

In compound or open fractures, exploration is usually possible through the overlying laceration or just by extending it at the edges. This usually results in paresthesia or hyperesthesia of the part superior to the scar. It is widely accepted that the pericranium over and between the bone fragments should be preserved through gentle elevation of the fragments. Access to the sinus is often possible by the removal of one or more loose fragments, through which the bone elevator can be inserted. This obviates the need for bone drilling.

The need for bone fixation is determined by the degree of comminution of the fracture. Minimally comminuted fractures remain stable after reduction. Approximation of the pericranium over the reduced fragments may provide additional support, but intraosseous wiring and the use of microplates become necessary in severely comminuted fractures. Some authors advocate excision of all devitalized mucosa in severely comminuted fracture of the frontal sinus. Intrasinus support can be achieved with gelfoam sponge or gauze packing which can be removed through the nostrils. There is however a risk of damage to the sinus mucosa by this maneuver.

Treatment modality in the presence of bone loss varies. If the gap appears less than 2.0 cm it can be closed without grafting and the deformity is usually minimal. Larger defects require grafting and the options include split calvarial grafts, ribs, iliac grafts, and methylmethacrylate.

Treatment of anterior wall fractures with nasofrontal duct involvement requires complete mucosal exenteration with light burring of the bony wall followed by occlusion of the nasofrontal duct. Burring stimulates osteogenesis but if the sinus is large, additional bone chips may be harvested to fill the space.

Endoscopic Treatment
The place of endoscopic surgery is presently limited to anterior wall fractures and this is often done as an elective procedure after the facial swelling must have subsided. Fractures amenable to endoscopic surgery are minimally displaced fractures. Extensive or comminuted fractures require open reduction and fixation in order to achieve better esthetic features postoperatively. Endoscopic repair can be carried out either through a single incision or via two separate incisions.

Chen et al. described the use of an endoscope in the repair of anterior table fractures in selected patients with intact nasofrontal duct. They described a procedure that allows for minimal incision with less scarring and paresthesia and also adaptable in bald patients. Though they discussed the adaptability of this procedure to assess frontonasal duct injuries, they agreed that this method is not suitable for extensive or severely comminuted skull base fractures, orbital roof injuries and PWFs with dural tears.

Obliteration of the Sinus
This entails complete removal of sinus mucosa; burring the sinus walls to eliminate mucosal invaginations; plugging the nasal frontals ducts; and filling the sinus cavity of the sinus with an autogenous or alloplastic obliteration material. Obliteration is indicated in severe frontal sinus injury and chronic frontal sinus disease in which the outflow tract of the sinus is compromised. Autogenous tissue grafts such as fat, muscle, and bone have been used for decades. These autogenous material have been demonstrated to provide scaffold for new bone formation by osteoconduction and osteoinduction with the new bone formed providing solid bony buttress against further trauma. The main drawback is the need for a separate donor site, which can be a source of postoperative morbidity.

Fattahi et al. compared two methods for frontal sinus obliteration. One group was treated using autogenous abdominal fat for obliteration purposes, while the other group underwent frontal sinus obliteration using a hydroxyapatite cement. They concluded that frontal sinus obliteration using autogenous abdominal fat appears to be more cost effective compared with hydroxyapatite cement.

Other alloplastic biomaterials in use include bioactive glass, methyl methacrylate, calcium phosphate bone cement, and oxidized regenerated cellulose. Proponents of these materials note their possible antibacterial properties, lack of donor morbidity and unending supply. However, the use of autogenous material has been reported to be of superior advantage.

Posterior Sinus Wall Fractures
Successful management of PWFs involves complete isolation of the brain from potential communication with the exterior (nasal cavity), via the nasofrontal duct or possibly fractured ethmoid. A bifrontal craniotomy is performed (preferably), and the posterior wall is removed, with the mucous lining of the sinus. This is the concept of “cranialization” of the frontal sinus.

If there are displaced bony fragments, they are carefully removed, the dura is inspected for tears which are repaired under magnification. The base of the anterior cranial fossa and the nasofrontal ducts are then obliterated with the aid of a pedicled pericranial flap, split-thickness calvarial bone, or lyophilized dura. The integrity of the anterior wall of the frontal sinus can now be restored as earlier described. The brain is allowed to “expand” into the space created by the removal of the posterior wall. Gel foam or any autologous
material may be used to obliterate any dead space that may be left between the dura and the anterior sinus wall.[32-43]

The open procedure for the posterior sinus wall fractures enables the surgeon to take care of other associated injuries of the brain and the skull base comfortably. This is not possible by the very limited endoscopic approach.[38-44] This highlights one of the limits of the “minimally invasive” procedures earlier described for isolated, simple anterior wall fractures.

Complications

Because of the location of the frontal sinus and its proximity to numerous intracranial structures, inadequate treatment may lead to life-threatening intracranial infectious complications. Meningitis, encephalitis, and brain abscess are the most commonly reported intracranial complications.[38-40] Other complications include persistent cerebrospinal leakage, mucopyoceles, frontal osteomyelitis, esthetic deformity, forehead paresthesia or anesthesia, chronic sinusitis, mucopyoceple, temporal nerve paresis frontal bone irregularity, meningoencephalocele, and nonunion of the frontal bone.[38-40] Orbital involvement may result in ophthalmoplegia, orbital abscess, diplopia, enophthalmos, proptosis, preseptal cellulitis, and partial or complete loss of vision.[8]

CONCLUSIONS

The management of FSFs presents a unique and challenging problem for the contemporary surgeons. A clear understanding of corrective techniques is essential when approaching these challenging injuries. Each treatment method has its advocates, and controversies still abound regarding indications, applications, and ultimate success in given situations.

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