Frontal sinus fracture classifications: a review of literature and presenting a new classification
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Introduction
Several classifications have been published for the frontal sinus (FS) fractures.

Objectives
To review the literature regarding different classifications of the FS fractures to collect and analyze the most commonly used classification and to present a new easily applicable and therapeutically helpful classification that avoids the disadvantages of the previous classifications.

Data synthesis
Repeated searches were performed in the PubMed, LILACS, MEDLINE, SciELO, databases, and Cochrane Library, and the key words used in the search were FS fractures, FS outflow tract, classification, and frontal bone. Collected studies were read and analyzed, and different FS fractures classifications were described and assessed for advantages, disadvantages, missed data, and pitfalls.

Conclusion
This review would be helpful for surgeons to be familiar with different classifications of the FS fractures. A new classification for the FS fractures was presented and described here to overcome the pitfalls of the already described classification and to update the categorization data to the currently used treatment philosophy and tools to be more applicable and treatment based. Moreover, we precisely provide the supposed appropriate treatment for each FS type.

Keywords:
classification, frontal sinus fractures, frontal sinus outflow tract, internal fixation, nasofrontal, open reduction, orbit

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Original article

Introduction
The frontal sinus (FS) aeration and development are radiologically obvious at the age of 5–6 years, and they reach their complete development at the age of 10–12 years. The FSs are absent in ~4% of population and presented as small upper air cells in additional 4–5% of population. FSs are divided into left and right sinuses by complete septum, and these can be further divided in subcompartments or recesses by incomplete or complete bony septum(s) [1].

The frontal bone represents the most frequently fractured bone in cranial trauma, accounting for 37% of cranial fractures [2]. However, it accounts for ~8% of all facial fractures [3].

FS fracture could be accompanied with several injuries, including skull base, intracranial, maxillofacial, and ophthalmologic [4].

High-resolution computed tomography (CT) scanning assists surgeons to recognize the fracture pattern and extensions and the involvement of the FS drainage system, but there is nothing as perfect as direct visualization of the nasofrontal ostia [5–7]. Sagittal reformatted CT images added a very useful and dependable preoperative radiologic estimation for the frontal sinus outflow tract (FSOT) particularly in FS fractures [8].

To reach successful management of FS fractures, surgeon should make accurate diagnosis of structural pathology [5,9,10].

There are numerous approaches and surgical techniques to manage the FS fractures. The choice of management technique depends on the types of FS fracture classification that assists to standardize severity, diagnosis, and treatment protocols in relation to the different fractures types. After reviewing and analyzing the related studies published from 1992, the used FS fracture classifications between the maxillofacial surgeons in the literatures were focused, including the following classifications (ordered form the older to the more recent): (a) Raveh classification (1992) [11], (b) the classification system
by Ioannides and Freihofer [12], (c) the classification by Gonty et al. [13], (d) metric classification by Torre et al. [14], (e) the classification by Vora and Gala [15], and (f) the classification by Garg et al. [16].

These FS fracture classifications had many pitfalls and defects that could affect the diagnosis and the regimes of treatment of FS fractures. Thus, the aim of the current study was to review the literature regarding different classifications of the FS fractures to collect and analyze the most commonly used classification and to present a new easily applicable and therapeutically helpful classification that avoids the disadvantages of previous classifications.

**Methods**

Repeated searches were performed in the PubMed, LILACS, MEDLINE, SciELO, databases, and Cochrane Library in March 2018, and the key words used in the search were FS, FS fractures, FSOT, classification, and frontal bone. Collected studies were read and analyzed and then different FS fracture classifications were described, and each classification was assessed for advantages, disadvantages, missed data, and pitfalls. Then, we created a new classification to overcome these disadvantages.

**Results**

After reviewing and analyzing related published studies published from 1992, the used FS fracture classifications among the maxillofacial surgeons in the literatures were focused including the following classifications (ordered form the older to the more recent) (used by later study after initial describing study):

1. Raveh classification (1992) [11]: it presented two broad categories: type I, which consists of fronto-naso-ethmoidal and medial orbital wall fractures without skull base involvement, and type II, which consists of combined skull base, fronto-naso-ethmoidal, and medial orbital wall fractures with common optic nerve compression [11]. Even though this classification was graded according to associated nearby injuries, it did not detail the FS fracture itself, so has limited effect on repair options.

2. The classification system by Ioannides and Freihofer [12]: it depends on a detailed description of the FS fracture, suggesting treatment for each type
   
   (a) Type IA: FS fracture without displacement with intact nasofrontal duct that needs observation.
   
   (b) Type IB: displaced FS fracture limited to the superior part of the anterior wall without FSOT injury. The fracture fragments need to be explored, reduced, and fixed.
   
   (c) Type IC: FS fracture with bone loss with intact FSOT. Exploration followed by debridement, reduction of fragments, and reconstruction of the lasting defects (bone grafts) is necessary.
   
   (d) Type ID: the inferior portion of the FS anterior wall is fractured with fragment displacement and/or bone loss and injured nasofrontal duct. Fragments are reduced when possible, defects are reconstructed when required, and the nasofrontal duct needs to be managed.
   
   (e) Type IE: the entire anterior wall is fractured with FSOT injury. A combination of the mentioned surgical steps is used for the treatment.
   
   (f) Type IIA: fractures of the FS posterior wall without dislocation or cerebrospinal fluid (CSF) leak are not treated surgically.
   
   (g) Type IIB: there is a posterior wall FS fracture with displacement of minor fragments and an intact dura without CSF leak. The displaced fragments could be removed.
   
   (h) Type IIC: the posterior wall is fractured with bone loss and injured dura. Minor fragments are removed; if there is brain tissue damage and herniation, it is cautiously debrided. Then, the dural tears are repaired by suturing or grafts according to the tear size. The sinus mucosa is then thoroughly removed, and the FS cavity and the nasofrontal duct are obliterated.
   
   (i) Type IID: there is extensive bone loss in a well-pneumatized sinus with severely injured dura. Herniating brain tissue is removed, the dura is repaired as in type IIC, the FS mucosa is removed, the duct is obliterated, and the FS is cranialized.
   
   (j) Type IIIA: all type I injuries + type IIA or type IIB fracture. Injuries are treated with a combination of previous measures.
   
   (k) Type IIIB: all type I injuries + type IIC or type IID fracture. Injuries are treated with obliteration or cranialization of the FS and the essential steps for restoration of the FS anterior wall.
   
   (l) Type IV: severe injuries involving anterior and posterior FS walls, the orbits, the nose, and the ethmoid bone are treated as previous type + fixation and reduction of the fragments and grafting of missed bones.

Even though it is a detailed classification, it appears difficult from multiple subcategories and combinations, so could not be easily popularized. Moreover, endoscopic assessment of FSOT was not shared in the classification.
The classification by Gonty et al. [13]: it depends mainly on the site of FS fracture
(a) Type 1 – fractures of the anterior wall
   (i) Isolated to anterior table
   (ii) Associated with supraorbital rim fractures
   (iii) Accompanied by naso-ethmoidal complex fractures.
(b) Type 2 – anterior and posterior walls fractures
   (i) Linear fractures: (a) transverse and (b) vertical
   (ii) Comminuted fractures: (a) comprising both tables and (b) accompanied by naso-ethmoidal complex fracture.
(c) Type 3 – posterior table fractures
(d) Type 4 – very severe comminuted fractures of the entire frontal area, involving the ethmoid bone, orbit, and nasal base.

Metric classification by Torre et al. [14]: it depends on the maximum metric dislocation of FS in all the three dimensions in combination with CSF rhinorrhea and FSOT injury
(a) Type A: FS fracture without displacement needs observation
(b) Type B: FS fracture with not more than 2 mm displacement
(c) Type C: FS fracture with 2–5 mm displacement
(d) Type D: FS fracture with displacement beyond 5 mm
Then each type (from B to D) was judged for simultaneous fractures, CSF leak, or nasofrontal injury.

Vora and Gala classification [15]: it separated FS fractures into five main categories:
(a) Type 1: anterior wall fracture with minimal comminution without concomitant orbital rim fractures or naso-orbito-ethmoidal
(b) Type 2: FS anterior wall comminuted fractures with probable extension to orbital rim and/or naso-orbito-ethmoidal
(c) Type 3: anterior and posterior wall FS fractures without significant posterior table displacement or dural injury
(d) Type 4: anterior and posterior wall FS fractures with dural injury and CSF leak
(e) Type 5: FS anterior and posterior wall fractures with dural injury, CSF leak, bone or soft tissue loss, and/or severe anterior cranial fossa disruption.

The classification by Garg et al. [16]: it tried to combine the direction of fracture, the kinds of fracture, the patient age, and the depth of the skull base extension. So, the FS fractures were divided as follows:
First: frontal bone fractures were principally distinguished as having a nonvertical or vertical trajectory:
(a) Type 1: FS comminuted fractures without a vertical trajectory
Other types have vertical trajectory:
(a) Type 2: fractures including the orbit but not the FS
(b) Type 3: fractures involving the frontal bone and FS and not the orbit
(c) Type 4: fractures involving both the FS and the ipsilateral orbit
(d) Type 5: fractures cross the midline of the face, to involve the FS and the bilateral or contralateral orbits.

In children without FS, the classification outline was slightly modified as follows:
(a) Type 1: nonvertical fracture through the frontal bone
(b) Type 2: vertical fracture through the orbit only
(c) Type 3: vertical fracture passes through the frontal bone and not the orbit
(d) Type 4: absent owing to there is no FS
(e) Type 5: vertical fracture passes through the frontal bone and involves the bilateral or contralateral orbits.

Second, the depth of skull base extension was also classified for all fractures
(a) Depth A: involvement of the frontal bone without extension into the skull base
(b) Depth B: fractures extend into the anterior cranial fossa (cribriform plate, fovea ethmoidalis, and orbital roof)
(c) Depth C: fractures extend into the middle cranial fossa (sphenoid body, sella, optic chiasm sulcus, and carotid canal)
(d) Depth D: fractures involve the posterior cranial fossa (clivus, petrosal segment of the carotid canal, and petromastoid temporal bone).

Those FS fracture classifications had many pitfalls and defects that could affect the diagnosis and the regimes of treatment of FS fractures. So, in the current study, we add, describe, and discuss a new classification to standardize the diagnosis and the regimes of treatment related to different types of the fractures. Moreover, we precisely provide the supposed appropriate treatment for each type.

Discussion
FS fractures are relatively uncommon but serious. Thin-slice high-resolution CT scans, taken in axial, coronal, and recently sagittal planes (8), help to precisely define the fracture details [17]. In our attempts to overcome the fallacies and pitfalls that appeared on application of previously described classifications, we
suggest the following new classification (El-Anwar and El-Aassar classification) with our suggested management plan for each type.

Type 1: nondisplaced or asymptomatic displaced FS fractures (anterior and/or posterior table) with patent FSOT (radiologically and operatively) need conservative management

Type 2: isolated displaced anterior table fracture with symptomatic external depression and patent FSOT (radiologically and operatively) that could need repair for cosmetic reason

Type 3: displaced anterior table fractures (with or without bone gap) with intact or asymptomatic displaced posterior table fractures and with obstructed FSOT

(a) FSOT could be cleaned operatively (could resume its patency operatively ± endoscopy) (needs repair without FS obliteration)
(b) FSOT could not be cleaned operatively and needs FS obliteration with anterior table repair.

Type 4 (a): symptomatic displaced posterior table fractures with dural injury (needs cranialization and repair of the dura with repair of the anterior table fracture) or without dural injury (needs repair of fracture)
(c) Displaced anterior table fractures with symptomatic displaced posterior table fractures (operatively detected, persistent CSF leak or significant neurological sequels). With obstruction of FSOT (needs FS obliteration and repair of anterior table fracture) or without obstructed FSOT (needs only repair of the anterior table).

Despite FS fractures been described extensively [18–23], the used classifications have many fallacies and pitfalls. Therefore, classification of the FS fractures is still a challenge to describe the fracture in clinically and surgical applied details.

The defects in Gonty classification [13] (the most commonly used classification) include the following: (a) it ignores vital data in the algorithm for repair of FS fractures [24] such as the data of FSOT, bone loss, and dural injury, and significant brain injury/dural embarrassment; (b) also, it is not sequential regarding management, as isolated frontal table fracture is type 3 that may be treated conservatively, whereas some of type 2 could need surgical intervention; and (c) it is not helpful with endoscopic management.

The defects in the classification by Ioannides and Freihofer [12] (the second commonly used classification) include the following: (a) it is not sequential (like Gonty classification), (b) it is too long with many subclassification, so it is difficult to be interpreted and popularized, and (c) it gives fixed ideas for management, so it is less malleable and unchangeable with operative findings.

Although the classification which is mentioned by Vora and Gala [15] is very helpful in endoscopic management of fractures of the anterior table of the FS, it ignores vital data for repair of FS fractures [24] such as the data of FSOT and bone loss.

Raveh classification [11] is just a classification of the craniofacial fractures not for FS fracture. So, it is not helpful for surgical management.

Defects in Ravi classification [16] include that it depends mainly on the direction of the fracture (Trajectory classification) and ignores the FSOT. It is a classification of craniofacial fractures not for FS fracture.

The treatment philosophies of the FS fractures are based mainly on the amount of displacement or comminution of the anterior and/or posterior table, the integrity of the FSOT, and the neurologic status of the patient as determined by clinical and radiographic examination [24]. Thus, the previously published classifications are not sufficient because proper description and classification of the FS fractures should be a guide for treatment planning. Additionally, associated fracture study within the classification of the frontal fractures is misleading, as the effect of associated fracture on FS fracture repair is directed to the effect of associated fracture on FSOT. So it mandatorily involves FSOT fractures in the FS fracture classification, while classifying combined associated fractures in its specific separate classification.

The advent of endoscopic and endoscopic assisted approaches [25–27] has changed the approaches and algorithms used in the management of these challenging fractures with proposed new algorithms [27]. However, these new algorithms were not associated with new classifications to fit with them.

Our newly described classification covers all types of FS fractures including FSOT. It is applicable and can present one understandable language between the maxillofacial surgeons and the radiologists. It is a sequential categorization in an order from FS fractures that need less invasive and simpler management to more invasive and difficult ways of interference. Thus, it gives clear steps of FS fracture management and fits with Bell’s algorithm of FS management [24]. With the recent shift to preserve the form and functions of the FS and FSOT [28] and with the advancement of endoscopic procedures and new technologies, less aggressive surgeries become available [28–30]. This
the first classification that applies the endoscopic evaluation and clearance of the FSOT from above to the FS fracture classification because now endoscopy adds an easy detailed and magnified diagnostic and therapeutic tool that was not considered in the previous classification. However, this classification needs to be investigated on a large number of cases and many centers.

**Conclusion**

El-Anwar and El-Aassar classification – a new classification for the FS fractures – was presented and described here in the way to fill the gaps of the already described classifications and to update the categorization data to the currently used treatment philosophy and tools.

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**Conflicts of interest**

There are no conflicts of interest.

**References**