Patterns of Frontobasal and Frontosinal Fractures in Children and Teenagers Relative to Developmental Stage of the Facial Skeleton

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Objectives: To clarify the patterns of frontobasal and frontosinal fractures in children and teenagers and to analyze whether the patterns relate to developmental stage of the facial skeleton.

Design: Retrospective study.

Setting: Level I trauma center in Bern, Switzerland.

Patients: Forty-three consecutive patients aged 18 years or younger with fracture of the frontal skull base.

Main Outcome Measures: Age at the time of injury and site, type, and degree of displacement among frontobasal and frontosinal fractures.

Results: The orbital roof was the most common frontobasal fracture site (86.0% [37 of 43]), and a combined lateral and central frontobasal fracture was the most common fracture type (55.8% [24 of 43]). Frontosinal fractures were observed in 46.5% of patients (20 of 43). Displacement or comminution of frontobasal fractures occurred in 46.5% of patients (20 of 43) and of frontosinal fractures in 70.0% (14 of 20). Isolated central frontobasal fractures were significantly more frequent in teenagers than in children aged 6 years or younger, but isolated lateral frontobasal fractures were significantly more frequent in children aged 6 years or younger than in teenagers (P = .02 for both). Dislocation or comminution of frontosinal fractures was significantly more frequent in teenagers than in children aged 6 years or younger (P = .04).

Conclusion: Frontobasal fracture patterns are related to age, reflecting their correlation with the developmental phase of the facial skeleton, particularly size and degree of pneumatization of the paranasal sinuses.


DENTAL AND SOFT-TISSUE injuries are the most common facial injuries in children,1 but facial bone fractures are infrequent. Many reasons for this finding exist, including the significant elasticity of bones and the fact that the youngest children in particular live in a protected environment and are not as exposed to accidents as adults. Several investigations have addressed the characteristics of facial fracture patterns in pediatric patients; the most extensive is the study published in 2008 by Imahara et al.2 The authors surveyed the US National Trauma Data Bank and identified 277,008 pediatric trauma patients, 12,739 of whom (4.6%) had facial bone fractures. They observed that fracture patterns varied with age. Cranial and centrofacial injuries were more common among toddlers and infants, but mandibular injuries were more common among teenagers. The results reflect the assertion that fracture patterns are influenced by the developmental stage of the facial skeleton. The prominence of the skull in the youngest patients predisposes them to fractures in the upper third of the face; as the mandible grows downward and forward, the risk for mandibular fractures increases. Obviously, the force of impact also affects facial fracture patterns.3,4

The term frontobasal fracture describes a fracture of the anterocranial base (ie, the orbital roofs and apexes, the posterior wall of the frontal sinus, the roof of the ethmoid sinus, and the walls of the sphenoid sinus). These injuries are rare in the youngest individuals. A study by Eggersperger Wymann et al3 performed at a level I trauma center responsible for treatment of these injuries revealed that annually, only approximately 5 children were diagnosed as having these fractures.
It can be assumed that the patterns of frontobasal and frontosinal fractures are related to age at the time of injury because of age-related variations in size and degree of pneumatization of the paranasal sinuses. The literature contains no study that has focused on these issues, to our knowledge. Therefore, the primary objectives of our investigation were to clarify the patterns of frontobasal and frontosinal fractures in children and teenagers and to analyze whether the patterns relate to the developmental stage of the facial skeleton.

METHODS

We reviewed medical records and radiographic images from 43 consecutive patients aged 18 years or younger who had been diagnosed as having fracture of the frontal skull base at the Department of Cranio-Maxillofacial Surgery, Bern University Hospital and University of Bern, Switzerland. Inclusion criteria were fractures of the orbital roof, the posterior wall of the frontal sinus, the roof of the ethmoid sinus, or the roof or wall of the sphenoid sinus.

Sex, age, and cause of injury were recorded from the medical records of the emergency department. Also, the cause of injury was classified as high force vs non–high force. All available images, including conventional radiographic and computed tomographic images, were reviewed. Fine-section computed tomographic images were available for all 43 patients. Based on radiographic findings, the presence of frontobasal fractures, frontosinal fractures, and associated fractures of the skull and facial bones was recorded. Frontobasal fractures and frontosinal fractures were further classified, as detailed herein.

SITE AND TYPE OF FRONTOBASAL FRACTURE

The site of frontobasal fracture was noted. It was classified as the orbital roof, the posterior wall of the frontal sinus, the roof of the ethmoid sinus, or the roof or wall of the sphenoid sinus. Based on frontobasal fracture site distribution, each patient was assigned to 1 of the following fracture type groups: isolated lateral frontobasal fracture (ie, fracture of the orbital roof) (Figure 1), isolated central frontobasal fracture (ie, fracture of the posterior wall of the frontal sinus, the roof of the ethmoid sinus, or the roof or wall of the sphenoid sinus [or a combination of these]) (Figure 2), or combined lateral and central frontobasal fracture (Figure 3). The presence of intracranial air also was recorded (Figures 2 and 3). In addition, based on the most severe dislocation, each fracture type was classified as nondisplaced (Figure 4), displaced (ie, a step in the fracture line) (Figure 5), or comminuted (Figure 6).

FRONTOSINAL FRACTURES

Frontosinal fractures were identified and classified as fracture of the anterior wall of the frontal sinus, fracture of the posterior wall of the frontal sinus, or fracture of the anterior and posterior walls of the frontal sinus. Frontosinal fractures were further classified as nondisplaced or displaced (ie, a step in the fracture line or comminution).

STATISTICAL ANALYSIS

In the data analysis, associations were analyzed between age, site and type of frontobasal fracture, degree of displacement among frontobasal fractures, and involvement and displacement of the frontal sinus. Patients were divided into the following age groups: 0 to 6 years, 7 to 12 years, and 13 to 18 years. Statistical significance of the associations was evaluated using the \( \chi^2 \) test.

RESULTS

SEX AND AGE

Table 1 gives sex and age distributions. Twenty-nine patients (67.4%) were male, for an approximately 2:1 ratio of boys to girls. The age range was 0.4 to 18.9 years (mean age, 10.7 years). The largest age group comprised patients aged 13 to 18 years (n = 19 patients [44.2%]), followed by those aged 0 to 6 years (n = 13 patients [30.2%]) and those aged 7 to 12 years (n = 11 patients [25.5%]).
CAUSE OF INJURY

Thirty-nine patients (90.7%) had sustained their injury due to a high-velocity force. Table 2 lists the causes of injury and how they differed among age groups. The leading causes were falls from a high place (range, 1-11 m) (17 patients [39.5%]) and motor vehicle crashes (14 patients [32.5%]). Most patients in the youngest group (10 of 13 [76.9%]) sustained their injury due to a fall from a high place. The occurrence of falls from high
places decreased with older age to 3 of 19 patients (15.8%) in the oldest group. In contrast, the occurrence of motor vehicle crashes increased with older age, from 1 of 13 patients (7.7%) in the youngest group to 10 of 19 patients (52.6%) in the oldest group. The frequency of falls associated with bicycle riding also tended to increase with older age, from 0 of 13 patients in the youngest group to 3 of 19 patients (15.8%) in the oldest group.

Table 3 lists sites of frontobasal fracture by age group. The most common fracture site was the orbital roof (37 patients [86.0%]), followed by the roof of the ethmoid sinus (23 patients [53.5%]), the roof or wall of the sphenoid sinus (16 patients [37.2%]), and the posterior wall of the frontal sinus (13 patients [30.2%]). Fractures in the posterior wall of the frontal sinus occurred significantly more frequently in patients aged 13 to 18 years (10 of 19 [52.6%]) than in patients aged 0 to 6 years (1 of 13 [7.7%]) (P = .01).

Figure 3. Radiographic images of a combined lateral and central frontobasal fracture (ie, fracture of the orbital roof and the ethmoid sinus roof on the right side) with intracranial air. A, View from above. B, Close-up of fracture site, view from above.

Figure 4. Radiographic image of a nondisplaced fracture of the ethmoid sinus roof on the right (close-up of fracture site, front view).

Figure 5. Radiographic image of the displaced fracture of the ethmoid sinus roof on the left (view from above).
No statistically significant differences were observed among age groups in the occurrence of fractures in the orbital roof, the roof of the ethmoid sinus, or the roof or wall of the sphenoid sinus.

**TYPE OF FRONTOBASAL FRACTURE**

Table 3 lists types of frontobasal fracture by age group. The most common fracture type was a combined lateral and central frontobasal fracture, observed in 24 patients (55.8%). In 9 of these patients (37.5%), the fracture was extensively bilateral, involving the central frontobasal area and both orbital roofs. Isolated lateral frontobasal fractures (ie, all unilateral orbital roof fractures) were observed in 12 patients (27.9%). Isolated central frontobasal fractures occurred in 7 patients (16.3%), with 4 of these having fractures that crossed the midline. Intracranial air was observed on the radiographic images of 27 patients (62.8%).

As summarized in Table 3, type of frontobasal fracture correlated with age group ($P=.02$). Isolated lateral fractures were observed more frequently in patients aged 0 to 6 years (53.9%) than in patients aged 13 to 18 years (10.5%). However, isolated central fractures were observed more frequently in patients aged 13 to 18 years (6 of 19 [31.6%]) than in those aged 0 to 6 years (1 of 13 [7.7%]). Combined lateral and central fractures were observed significantly more frequently in the older groups than in the youngest group. No statistically significant association was observed between type of frontobasal fracture and cause of injury.

Frontobasal fractures were displaced in 13 patients (30.2%) (Table 3). Patients aged 13 to 18 years had displaced and comminuted fractures more frequently than patients in the younger groups, but the difference was not statistically significant.

**FRONTOSINAL FRACTURES**

Twenty of 43 patients (46.5%) had frontosinal fractures. In 10 of these (50.0%), the anterior and posterior walls of the frontal sinus were fractured. Seven other patients (35.0%) had anterior wall fractures and 3 other patients (15.0%) had posterior wall fractures. Fourteen of 20 patients (70.0%) had displacement of frontosinal fractures; 6 of 20 (30.0%) had no displacement. Table 4 summarizes the association between age group and involvement and displacement of the frontal sinus. Most patients with frontosinal fractures (13 of 20 [65.0%], $P=.02$) and with displaced frontosinal fractures (11 of 14 [78.6%], $P=.04$) belonged to the oldest group.

**ASSOCIATED FRACTURES OF THE SKULL AND FACIAL BONES**

Among 43 children and teenagers, 39 (90.7%) had 1 or more associated fractures of the skull or facial bones. As summarized in Table 5, most had skull (37 patients [86.0%]) or midfacial (16 patients [37.2%]) fractures, but mandibular fractures were infrequent (3 patients [7.0%]).

Few data have been published regarding fractures of the frontal skull base in children and teenagers. The English-language studies are essentially extended case reports in which the authors describe management and clinical course. Whatley et al analyzed fracture patterns in greater detail among 11 children and teenagers aged 6 to 14 years. However, the authors focused on frontosinal fractures and considered fractures of the ethmoid and sphenoid sinuses to be associated injuries. The lack of studies focusing on frontobasal fracture patterns in pediatric patients makes it difficult for us to compare results. Nevertheless, the aforementioned studies indicate that frontobasal fractures in children are complex injuries, a fact we could clearly prove. Thirty-nine of our patients (90.7%) sustained their injury owing to high-velocity trauma. Combined lateral and central frontobasal fractures occurred in 24 patients (55.8%), and the central frontobasal area and both sides of the orbital roof were involved in fractures among 9 patients (20.9%). Fracture displacement or comminution was frequent, noted in 20 of 43 patients (46.5%).

Development of the midface (particularly the maxillary sinuses) coincides with development and eruption of the dentition. Therefore, to link patient age to developmental stage of the facial skeleton, we grouped patients according to eruption sequence of dentition. Age
0 to 6 years is considered the period of deciduous dentition, age 7 to 12 years makes up the first and second eruption periods, and age 13 to 18 years represents the stage of permanent dentition. Some significant differences in fracture patterns were observed by age group. Isolated lateral fractures occurred significantly more frequently in patients aged 0 to 6 years than in patients aged 13 to 18 years, but isolated central fractures in general and fractures of the posterior wall of the frontal sinus in particular were observed significantly more frequently in patients aged 13 to 18 years than in those aged 0 to 6 years. The fact that frontobasal injuries shift from lateral to central location with older age reflects increased size and degree of pneumatization of the paranasal sinuses, supporting our hypothesis that frontobasal fracture patterns are related to the developmental stage of the facial skeleton.

![Table 2. Cause of Injury by Age Group](image)

![Table 3. Site and Type of Frontobasal Fractures and Degree of Displacement by Age Group](image)

![Table 4. Involvement and Displacement of the Frontal Sinus by Age Group](image)

![Table 5. Associated Fractures of the Skull and Facial Bones in 43 Children and Teenagers With Frontobasal Fractures](image)
tions were based on computed tomographic images of children aged 12 years or younger who were investigated for various types of pathologic facial conditions. The authors observed that the ascending order of sinus size by type during the newborn period (age range, 0-3 months) was frontal, sphenoid, maxillary, and ethmoid sinuses. In particular, the frontal sinuses were minimally developed; immature frontal sinuses were observed in only 12% of children during this period. The authors noted that the frontal sinus is the least developed sinus type by the age of 12 years (the end point of their study). In a 1984 study, Brown et al demonstrated that development of the frontal sinus continues into puberty. Late development and pneumatization of the frontal sinus explain our finding that most patients with frontal sinus involvement were aged 13 years or older.

As demonstrated by Shah et al, the ethmoid sinus is the largest of the paranasal sinuses during the newborn period. Its pneumatization is most significant between age 3 and 8 years, and the ethmoid sinus reaches its maximum level of development by age 12 years. The authors showed that the sphenoid sinus undergoes significant development between age 1 and 3 years and is almost completely developed by age 12 years. Early development of these sinuses most likely explains why we found no significant differences between age groups in the occurrence of ethmoid and sphenoid fractures.

Whatley et al observed fractures in 3 of 11 children (27.3%) with frontonasal fractures. In our study, the frequency of displacement among frontonasal fractures was much higher, noted among 14 of 20 patients (70.0%), and displacement in frontonasal fractures occurred significantly more frequently in patients 13 years or older than in those younger than 13 years. Moreover, although the difference was not statistically significant, patients aged 13 to 18 years displayed displaced and comminuted frontobasal fractures more often than younger patients. Again, our findings reflect differences among age groups in developmental stages of the sinuses. The increase in size and degree of pneumatization of the paranasal sinuses decreases the resilience of bones in these areas, predisposing the sinuses to fracture and displacement.

Orbital roof fractures were frequent among our patients. However, of note, 4 patients had pure orbital roof fractures with no associated fractures of the skull or facial bones. Fractures of the orbital roof are usually extensions of frontal or temporal skull fractures and occur in isolation among 9.9% of children with different types of orbital fractures. Most pure orbital roof fractures observed in our study occurred in children aged 0 to 6 years. Because of a lack of communication skills and poor cooperation in the youngest patients, diagnosis of these fractures may be significantly impeded, but these injuries should not go undiagnosed. Amirjamshidi et al described 9 children who were seen with unilateral globe protrusion 2 to 12 months after head injury. Computed tomography and magnetic resonance imaging revealed a growing leptomeningeal cyst in the roof of the orbit among all of these children. The authors concluded, “Growing fractures of the anterior skull base may complicate the natural course of healing of any minor frontobasal injury, especially during childhood.”

The results by Amirjamshidi et al underline the importance of performing fine-section CT with coronal and sagittal reconstructions among children after a high-force blow to the skull has occurred and in whom a skull fracture is observed on conventional screening radiographic imaging. Only fine-section CT enables diagnosis of any microscopic fracture lines in the region of the anterior skull base. As shown in the present study, intracranial air is frequently observed in association with pediatric frontobasal fractures, indicating dural tear and predisposing the patient to nasal cerebrospinal fluid leak and meningitis. It is our experience that antibiotics are frequently prescribed to prevent bacterial meningitis in patients with basilar skull fractures. However, according to Ratilal et al, randomized controlled studies do not support prophylactic antibiotic use, regardless of evidence of cerebrospinal fluid leakage. However, prohibition of nose blowing for a period is indicated because of the communication between the paranasal sinuses and the intracranial space.

In conclusion, patterns of frontobasal and frontosinal fractures are age related and correlate with the developmental phase of the facial skeleton, particularly size and degree of pneumatization of the paranasal sinuses. Lateral frontobasal fractures (ie, orbital roof fractures) occur frequently in children aged 0 to 6 years, but combined lateral and central frontobasal fractures and dislocated frontonasal fractures are common in teenagers.

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