Clinical Features and Treatment of Pediatric Orbit Fractures

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Purpose: To describe a series of orbital fractures and associated ophthalmic and craniofacial injuries in the pediatric population.

Methods: A retrospective case series of 312 pediatric patients over a 9-year period (2002–2011) with orbit fractures diagnosed by CT.

Results: Five hundred ninety-one fractures in 312 patients were evaluated. There were 192 boys (62%) and 120 girls (38%) with an average age of 7.3 years (range 4 months to 16 years). Orbit fractures associated with other craniofacial fractures were more common (62%) than isolated orbit fractures (internal fractures and fractures involving the orbital rim but without extension beyond the orbit) (38%). Roof and medial wall fractures were most common (30% and 28%, respectively), followed by orbital floor (24%) and lateral wall (18%) fractures. Orbital roof fractures are the most common fracture in patients <8 years old, whereas orbital floor fractures are the most common fracture in patients older than 8 years. Eighty-seven patients (28%) underwent surgical repair. There is an increasing incidence of surgery in older patients ($p = 0.02$). Associated neurologic injuries were more common (23%) than associated ophthalmic injuries (20%).

Conclusions: Pediatric orbit fracture patterns are dictated by the age of the patient with respect to their craniofacial morphology and mechanism of injury. Orbital roof fractures are more likely to occur in younger patients and not require surgery, whereas orbital floor fractures are more common in older patients and are more likely to require surgery.

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Orbital fractures in children represent a diverse group of injuries and therapeutic challenges.[1,2] Trauma is the leading cause of morbidity and mortality in children, causing 15,000 deaths, leaving 100,000 children permanently disabled, and costing 15 billion dollars annually.[2] In the United States, an estimated 850,000 pediatric emergency room visits per year are the result of craniofacial injuries.[3]In comparison with adults, there is a paucity of literature describing craniofacial and orbital trauma in children and less consensus regarding optimal management.[1–4] Certain types of orbit fractures tend to occur in specific age groups, depending on children's activities and stage of craniofacial skeletal development.[1] Orbit fractures may be associated with ophthalmic, neurologic, and craniofacial injuries that may require intervention. The result is that pediatric facial trauma is often managed by a diverse group of specialists, and each service may have their own bias as to the ideal management plan.[4] In addition, children's skeletal morphology and physiology are quite different from adults, and the benefits of surgery must be weighed against the possibility of detrimental changes to facial skeletal growth and development. The purpose of this study was to describe a series of pediatric orbital fractures; associated ophthalmic, neurologic, and craniofacial injuries; and fracture management and outcomes.

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METHODS

This study was performed under institutional review board approval (COMIRB 11–1006). The medical records of all pediatric patients with orbit fractures diagnosed by CT from 2002 to 2011 at University of Colorado Hospital and Children's Hospital Colorado (a level 1 pediatric trauma hospital) were reviewed by billing records for ICD-9 diagnosis codes 802.6, 802.7, and 802.8. Patients were included if they had an orbital fracture and were <18 years old. CT scans were analyzed by 1 investigator (E.M.H.) for fracture location and involvement of the orbital rim. Patient demographics, mechanism of injury, presenting and final visual acuity, associated ophthalmic, neurologic, and craniofacial injuries, utilization of consult services, length of hospital stay, surgical interventions, and final outcomes were analyzed.

Data were de-identified and recorded in a Microsoft Excel (2008; Microsoft Corporation, Redmond, WA) spreadsheet for statistical analysis using Mann-Whitney and Fisher exact test and linear regression analysis.

RESULTS

Five hundred ninety-one orbital fractures in 312 patients were evaluated. There were 192 boys and 120 girls with an average age of 7.3 years (range 4 months to 16 years). The most common mechanism of injury was sports (37%), followed by falls (23%), and motor vehicle accidents (15%) (Table 1). Mechanisms of injury were influenced by patient age with falls being more prevalent in younger patients (average age = 3.9 years), and sports injuries more common in older patients (average age = 9.0 years, $p < 0.001$).

General Characteristics. There were 178 orbital roof fractures, 162 medial wall fractures, 146 floor fractures, and 105 lateral wall fractures. Roof fractures occurred in 157 patients (50%), floor fractures in 134 patients (43%), medial wall fractures in 125 patients (40%), and lateral wall fractures in 97 patients (31%) (Table 2). One hundred twenty patients (38%) had isolated orbit fractures (internal fractures and fractures involving the orbital rim but without extension beyond the orbit), and 192 patients (62%) had orbit fractures associated with other craniofacial fractures (excluding nasal fractures). One hundred twenty-six patients had associated skull fractures (40%), and 88 patients (28%) had associated midface fractures. Additional skull fractures included frontal bone fractures involving the squama frontalis (100), temporal

TABLE 1. Causes of pediatric orbit fractures

Sports	114	37%
Falls	86	28%
Motor vehicle accident	48	15%
Scooter/ATV/motorbike	19	6%
Automobile versus pedestrian	14	4%
Assault	11	4%
Horseplay	12	4%
Dog bite	5	2%
Unwitnessed/unknown	3	1%

ATV indicates all-terrain vehicle.

bone fractures (34), cribriform fractures (32), parietal fractures (23), and occipital fractures (8). Additional facial fractures included maxillary fractures (53), nasal fractures (35), zygomaticomaxillary complex (ZMC) fractures (39), naso-orbital-ethmoid fractures (23), Le Fort fractures (18), and mandible fractures (15). Thirty-seven patients (12%) had open fractures.

The average age of patients with an associated skull fracture (5.5 years) was less than the average age of patients with an associated midface fracture (8.5 years, $p < 0.0001$). The average age of patients with an orbital roof fracture (5.5 years) was less than the average age of patients with floor fractures (8.9 years, $p < 0.0001$), medial wall fractures (7.6 years, $p < 0.0001$), and lateral wall fractures (7.5 years, $p = 0.0004$). Orbital roof fractures were more common than other orbital fractures in patients <8 years, whereas orbital floor fractures were more common than other orbital fractures in patients older than 8 years. Additional skull fractures were more likely to occur in patients who sustained an orbital roof fracture (70%) versus patients with medial wall fractures (46%, $p < 0.0001$), floor fractures (21%, $p < 0.0001$), or lateral wall fractures (42%, $p < 0.0001$). Midface fractures were more likely to occur in patients with orbital floor fractures (52%) and lateral wall fractures (57%) than in patients with roof fractures (17%, $p < 0.0001$) and medial wall fractures (26%, $p < 0.0001$).

Surgical Intervention. Eighty-seven patients (28%) underwent surgical treatment to repair orbital fractures (Tables 2 and 3). The average time to surgery was 7.3 days (range 0–210 days). Patients with orbital floor fractures were more likely to require surgery (42%) than patients with orbital roof fractures (18%, $p < 0.0001$) or medial wall fractures (15%, $p < 0.0001$). Patients with isolated orbit fractures were less likely to require surgery (21%) than patients with extensive fractures (32%, $p = 0.04$). There was an increasing incidence of surgical repair with increasing patient age ($p = 0.02$).

Entrapped Trapdoor Fractures. There were 59 patients with indirect orbital floor fractures (i.e., not involving the rim) with a mean age of 9.3 years and 76 patients with direct orbital floor fractures (i.e., involving the orbital rim) with an average age of 8.7 years. Entrapped trap door fractures, where orbital soft tissue including intraorbital fat or an extraocular muscle (EOM) becomes "trapped" by a closed hinged fracture, accounted for 11% (16/146) of orbital floor fractures and 2% (3/162) of medial wall fractures. The average age of patients with an entrapped floor fracture was 10.4 years, and entrapped medial wall fracture was 11 years. Entrapped trapdoor fractures were more likely to occur in indirect orbital floor fractures (22%) than direct orbital floor fractures (3%, $p = 0.0008$, OR 7.6 [2.1–28.2]). Sixty-three percent of patients had nausea and vomiting associated with an entrapped trapdoor floor fracture. Extraocular motility was limited in 17 of 19 patients (89%) with entrapment, and 2 patients had full motility on presentation, but both had pain with eye movement, vomiting, and a chin-up position. Two patients (11%) had severe bradycardia, 1 with new onset bigeminy.

Fifty percent of formal radiology reports in patients with entrapped orbit fractures commented on suspected or likely soft tissue or muscle entrapment associated with the orbit fracture. Three reports identified an orbital floor fracture but did not comment on suspicion of entrapment. Three reports failed to identify any orbit fracture (Fig. A–C).

Eighteen patients had surgery for an entrapped trapdoor orbit fracture (1 patient with an entrapped trapdoor fracture was transferred to another institution before surgery secondary to insurance, and no additional information is available). All surgeries were performed by the oculofacial plastics service and involved placement of porous polyethylene implants. Ninety-three percent of patients with acute presentations had surgery within 24 hours. Sixteen patients followed up after surgery, and 10 of 16 patients (63%) had full motility at last follow up (Average time to follow up 7.1 months). Four of 6 patients with EOM limitation at last follow up did not follow -up past their 1-month postoperative visit and may have experienced further improvement in motility beyond their last visit. Two patients had persistent EOM deficits (50% supraduction deficits) with longer follow up (3 and 7 months). One of the patients with late EOM deficits presented 6 weeks after the initial trauma.

Consulting Services and Follow Up. Two hundred sixty-six patients (85%) had a formal ophthalmology consult and examination. Neurosurgery was consulted in 151 patients (48%), otolaryngology in 123 patients (39%), and plastic surgery in 13 patients (4%). Of the 46 patients not evaluated by ophthalmology, only 4 had formal visual acuity testing.

Oculofacial plastics performed/participated in 60 surgeries (69%), otolaryngology in 30 surgeries (34%), neurosurgery in 22 surgeries (25%), and plastic surgery in 4 cases (5%). Twenty-one percent of surgeries involved at least 2 subspecialties. Two hundred forty-eight patients (79%) had follow up with an average of 6.4 months (range 1–96 months).

Associated Injuries. Serious ophthalmic injuries occurred in 20% of patients (Table 3). Ophthalmic injury occurred in equal frequency in patients with orbital roof fractures (18%), medial orbital wall fractures (28%), orbital floor fractures (24%), and lateral orbital wall fractures (26%). Patients with isolated orbit fractures and extensive fractures were equally likely to sustain an ophthalmic injury as were patients with associated skull fractures and associated midface fractures. There were no open globes. Nine patients (3%) had permanent visual acuity deficits, and there were 9 cases (3%) of traumatic optic neuropathy with final best-corrected visual acuities ranging from 20/20 to light perception. There was a nonsignificant increasing trend for an associated ophthalmic injury with increasing patient age ($p = 0.32$). Overall, serious ophthalmic injuries and complications typically associated with orbit fractures, including diplopia, strabismus, and enophthalmos, were relatively rare (Table 4).

TABLE 2. Pediatric patients with orbit fractures by location

	Patients	Average age	Isolated fracture, (%)	With associated skull fracture, (%)	With associated midface fracture, (%)	Surgical repair, (%)
Roof fracture	157	5.5	27	70	17	18
Medial wall fracture	125	7.6	39	46	26	15
Floor fracture	134	8.9	39	21	52	42
Lateral wall fracture	97	7.5	20	42	57	28

TABLE 3. Indications for surgical repair of pediatric orbit fractures

Patient with orbit fracture	312	100%
Patient with surgical repair of orbit fracture	87	28%
Orbital floor fracture	31	10%
Nonentrapped orbital floor fracture	16	5%
Entrapped orbital floor fracture	15	5%
Zygomaticomaxillary complex fracture	24	8%
Superior orbital rim/frontal fracture	22	7%
Growing orbital roof fracture	3	1%
Naso-orbital-ethmoid fracture	8	3%
Medial orbital wall fracture	7	2%
Nonentrapped medial wall fracture	4	1%
Entrapped medial wall fracture	3	1%
Le Fort fracture	3	1%
Orbital bone fragment causing dysmotility	2	1%

*Several patients had multiple indications for surgery.

TABLE 4. Ophthalmic injuries associated with pediatric orbit fractures

Patients with orbit fracture	312	100%
Ophthalmic injury	63	20%
Retrobulbar hemorrhage	19	6%
Commotio	14	4%
Hyphema	11	4%
Permanent visual acuity deficit	9	3%
Traumatic optic neuropathy*	9	3%
Diplopia or strabismus	8	3%
Optic canal fracture†	7	2%
Ptosis at last follow up	7	2%
Orbital compartment syndrome‡	6	2%
Iridodialysis	6	2%
Enophthalmos at last follow up	6	2%
Telecanthus at last follow up	6	2%
Nasolacrimal duct obstruction§	5	2%
Cranial nerve 6 palsy	5	2%
Cranial nerve 3 palsy	4	1%
Retinal hemorrhage	3	1%
Traumatic cataract	1	<1%
Vitreous hemorrhage	1	<1%
Dislocated lens	1	<1%

*With best corrected visual acuity from 20/20 to light perception.
†Only 1 of 7 had associated optic neuropathy.
‡Requiring canthotomy/cantholysis.
§Requiring dacryocystorhinostomy.

TABLE 5. Neurologic injuries associated with pediatric orbit fractures

Patients with orbit fracture	312	100%
Neurologic injury	72	23%
Traumatic brain injury	35	11%
Subdural hematoma	28	9%
Cerebral edema	20	6%
Craniotomy	20	6%
Intraparenchymal hemorrhage	17	5%
Subarachnoid hemorrhage	16	5%
Carotid artery occlusion/CVA	14	4%
Epidural hematoma	12	4%
Death	4	1%
Orbital encephalocele	2	<1%

CVA, Cerebral vascular accident.

Neurologically, 72 patients (23%) had significant intracranial trauma including 4 patients who died from neurologic injuries (Table 5). Thirty-five patients (11%) experienced prolonged traumatic brain injury, which was diagnosed by the neurology or neurosurgical service. Patients with orbital floor fractures were less likely to have an associated neurologic injury (16%) than patients with an orbital roof fracture (31%, $p = 0.0024$), medial orbital wall fracture (29%, $p = 0.011$), or lateral orbital wall fracture (30%, $p = 0.003$). Patients with extensive fractures beyond the orbit were far more likely to sustain a neurologic injury (34%) than patients with isolated orbit fractures (6%, $p < 0.0001$, OR 8.4 [3.7–19.0]). Similarly, patients with associated skull fractures were more likely to have neurologic injuries (45%) than patients with associated midface fractures (27%, $p = 0.0325$). There was a nonsignificant decreasing trend for an associated neurologic injury with increasing patient age ($p = 0.18$).

Three patients underwent delayed repair of growing orbital roof fractures. Other associated body injuries included orthopedic fractures (27 patients) and severe abdominal trauma (13 patients).

DISCUSSION

An understanding of craniofacial and orbital trauma in children requires an understanding of the changing craniofacial morphology from birth to adulthood and the mechanisms of trauma in children.[1–3,5,6] The incidence of orbital fractures in children is not well-defined, and estimates of craniofacial trauma incidence, causes, fracture patterns, and associated injuries vary widely in the literature.[3,4] There are several reasons for this variability, including the methods of analysis and definitions of fracture location.

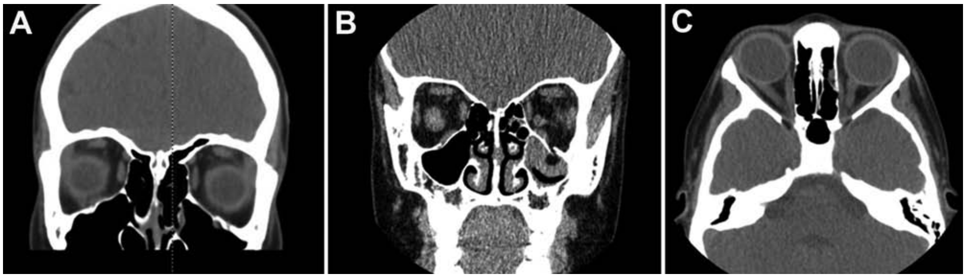
Many studies that examine the epidemiology of fractures in children have grouped orbital roof fractures in a larger subset of “skull fractures,” whereas medial orbital wall, orbital floor, and lateral orbital wall fractures have been grouped in the larger subset of “facial fractures.” This makes the true incidence of orbit fractures difficult to elucidate.

In children, skull fractures are much more common than facial fractures, whereas in adults, facial fractures are more common than skull fractures. Pediatric facial fractures may account for only 1.5% to 15% of facial fractures in all ages.[1–3,5,7–11] Facial fractures are more rare in the very young, with facial fractures in children younger than 5 years accounting for only 0.6% to 1.4% of facial fractures in all age groups.[2,4] Orbit fractures represent a portion of all facial fractures in children, from 3% to 45%, depending on the series.[1,2,4–6,8,9] It is recognized that orbital roof fractures occur more commonly in children than adults, whereas medial orbital wall, orbital floor, and lateral orbital are more common in older children and adults.[1,2,4,6,10]

Two peaks in pediatric facial fracture incidence have been observed previously, at 6 to 7 years and at 12 to 14 years.[1,5] The first appears to be associated with starting elementary school and the second with an increased participation in organized sports.[1,5] The authors’ series corroborates these findings and shows a third peak at 2 to 3 years, with patients sustaining primarily orbital roof fractures around this time.

Worldwide, facial and orbit fractures appear more prevalent in boys, with a ratio ranging from 1.1:1 to 8.5:1, although in very young children, there are no gender differences.[1,5–8,12–18] The ratio of boy to girls in this study was 1.6:1 overall and 1.1:1 in patients <4 years old. Authors have postulated that the more aggressive activity level in boys is more hazardous.[1,5] Furthermore, authors have shown an increasing trend of severity of injuries and the need for surgical repair,[1,2,5–7] in agreement with this study.

Pediatric Facial Skeletal Development. Understanding the changing pediatric facial skeletal anatomy and physiology including growth of the cranium, face, and paranasal sinuses



A, Patient with entrapped right orbital floor fracture that had a delay in diagnosis and treatment because the image was reversed in error; note the missing inferior rectus muscle (on the left); **B**, patient with entrapped left orbital floor fracture. The opacity in the left maxillary sinus was read as a polyretention cyst by the radiologist; **C**, patient with entrapped left medial orbital wall fracture. This was read as ethmoid sinus opacification.

is critical to understanding the patterns of pediatric orbit fractures. Newborns and infants have very large craniums about their face. The cranium to face ratio is 8:1 in infants and 2:1 in adults.[1,2,4–6,8,9,15,19] During the first few years, the cranium grows disproportionately faster than the face, whereas after 2 years of age, the face begins to grow faster than the cranium.[9] The orbit and brain approach completion of growth around 7 years of age, but the lower face continues to grow in the early 20s.[2] Ultimately, from birth to adulthood, the cranium undergoes a 4-fold increase in size, whereas the face undergoes a 12-fold increase in size.[1] The prominence of the brow in infancy makes it more vulnerable to injury and serves to shelter the face, and the thick layer of adipose in the midface in young children may also serve to dissipate traumatic forces to the midface skeleton.[1,2,5,8,12,19,20] With age, the midface and mandible become more prominent and are more likely to sustain injury.[1,2,5,8,19] These anatomical changes make the brow and cranium more likely to sustain injury in infancy, whereas older children are more likely to receive trauma to the face.[1,2,5,6,9,12] These patterns of injury are mirrored in the orbit. Orbital roof fractures are more common in younger patients, and orbital floor, medial, and lateral wall fractures are more common in older patients.[1,2,4–6,9,10,18] Koltai et al.[6] reviewed orbit fractures in 40 children and calculated the age at which the probability of floor and medial wall fractures exceeds the probability of an orbital roof fracture to be 7.1 years old. These results support Koltai's study, demonstrating a significant difference in the average age of patients with orbital roof fractures (5.5 years old) vs. medial (7.6 years old), lateral (7.5 years), and orbital floor fractures (8.9 years).

In adults, there is a clear relationship between the shape of the paranasal sinuses and orbit fracture patterns.[21] Similarly, the growth and changing shape of the sinuses in children are thought to influence the pattern of orbit fractures.[1,6] In particular, the lack of frontal sinus pneumatization until around 8 years of age leaves the orbital roof more prone to fracture from smaller impact forces.[1,6,8,9,22] It has been postulated that pneumatization may provide a crumple zone for dissipating impact forces and preventing more direct ophthalmic and neurologic injury.[4,9,10,23] With age and growth of the maxilla and maxillary sinus, the orbital floor becomes more susceptible to fracture.[4–6,10]

The unique bony physiology of children also influences orbital fracture patterns.[24] The newborn facial skeleton contains more elastic cancellous bone and cartilage, has low mineralization and underdeveloped cortex, and has more flexible suture lines.[1,9,20,24] This creates more elasticity and flexibility in the pediatric facial skeleton that leads to more greenstick fractures that are often minimally displaced.[1,5,9] This is a well-recognized cause of medial wall and orbital floor "trap door" fractures in children. In addition, the presence of tooth buds in the maxilla in children <12 years of age increases the stability and elasticity of the maxilla, further decreasing the incidence of midface fractures in this age group.[1,5,15]

Causes of Pediatric Orbit Fractures. The causes of pediatric orbit fractures vary with age and activity.[1–6,8] Overall, motor vehicle accidents, sports, and falls account for most pediatric facial and orbit fractures.[3–6,8,9,12–18,22,25,26] These results mirror these findings (Table 1). Younger children have a higher incidence of falls secondary to their limited motor development, and facial fractures in young children most commonly occur from falls at home.[5,12] Falls accounted for most injuries younger than 5 years, and sports accounted for most injuries in patients older than 5 years.

Pediatric Orbit Fracture Patterns in Other Studies. The distribution of pediatric orbit fractures in previous series has varied, depending on the methodology of review, age of patients, and referral patterns of different institutions.[4] Previous series that have included unhospitalized patients have shown a high incidence of isolated floor fractures (67%–71%) and low incidence of roof fractures (6%–13%).[4,27,28] Conversely, other reports have shown that roof fractures are the most common orbit fracture in pediatric patients admitted to the hospital.[6,10] This series captured all inpatients and outpatients seen at a level 1 pediatric hospital, a university hospital, and associated outpatient clinics with diagnosis of orbit fracture, regardless of service, and may be a more accurate representation of the entire spectrum of orbit fractures in the pediatric population. The study design and findings are similar to those of Chapman et al.[29] who reviewed all patients presenting to a pediatric hospital with nonpenetrating facial trauma who underwent CT of the face. They found orbital roof fractures to be the most common fracture (36%), followed by floor fractures (isolated and associated with a ZMC fracture) (35%), medial wall fractures (isolated and associated with a naso-orbito-ethmoid fracture) (25%), and lateral fractures associated with ZMC fractures (20%).[29]

Associated Ophthalmic Injuries. Serious ocular injuries occurring in conjunction with pediatric orbital fractures occurred in 20% of patients in this series (Table 4). Previous studies have found a 0% to 50% incidence of ophthalmic injuries associated with pediatric orbit and facial fractures.[4,11,18,25] However, some of these studies have included minor ophthalmic trauma (e.g., subconjunctival hemorrhage) in their analysis or only included patients requiring ophthalmologic consultations. The literature suggests that ophthalmic injuries may be more frequent in adult patients with facial fractures compared with children with facial fractures.[1,30] The largest series of ophthalmic injuries associated with facial fractures was performed in adults and demonstrated the highest incidence of serious ophthalmic injuries occurred with midface fractures (71%).[30] This series demonstrates lower incidence of serious ophthalmic injuries among children, and this agrees with other authors who have noted that pediatric patients are less likely to have ophthalmic injuries in association with facial fractures when compared with adults.[1] A nonsignificant increasing incidence of ophthalmic injury was shown with patient age, which would be expected as the morphology of the facial bones mature, and the incidence of ophthalmic injury becomes more similar to that seen in adults.

Associated Neurologic Injuries. Neurologic injuries were more common than ophthalmic injuries in our series and other series.[1,6,10,14–18,31,32] Neurologic injuries were associated with skull fractures, younger age, and extensive fracture patterns. They were inversely associated with orbital floor fractures. Given the close proximity of the orbital roof to the brain, orbital roof fractures are often associated with intracranial injuries.[6,10,25,31–34] In previous series, the incidence of intracranial injuries in children with orbital roof fractures ranged from 28% to 86%.[6,10,25,31,32]

This series demonstrated an 8-fold risk of neurologic injury in patients with extensive fractures compared with isolated orbit fractures. This finding concurs with the series of Greenwald et al.[32] that showed children with orbital roof fractures had a 7-fold increased risk of neurologic injury when associated with extensive skull fractures versus isolated orbital roof fractures.

Twenty patients (6%) had a craniotomy/cranioplasty in conjunction with repair of orbital roof and superior orbital rim fractures. Thirty-five patients (11%) were diagnosed with a traumatic brain injury, ranging from mild to severe, and there were 4 deaths from neurologic injuries.

Management and Surgery. Patients with suspected orbital fractures should undergo an ophthalmic, neurologic, and trauma examination and a dedicated CT of the face and/or orbits with multiplanar reformatting and 3-dimensional (3D) volume rendering, when available.[1,2,5,6,8,9,20,35]

To properly treat pediatric orbit fractures, it is first necessary to determine whether the orbit fracture is isolated or part of a larger fracture pattern. More extensive fracture patterns typically indicate a more forceful mechanism of injury and are more likely to require surgical intervention.[1,3,5] In this series, extensive fractures were twice as likely to require surgery compared with isolated orbit fractures.

Different subspecialties perform different evaluations on trauma patients, as demonstrated by the fact that in this series only 9% of patients not evaluated by the ophthalmology service had any evaluation of visual acuity. The authors advocate a multispecialty approach to more complex patients. Many cases in this series were co-managed with other services, including the pediatric, neurosurgical, plastic surgery, and otolaryngology departments. At this institution, it is routine for patients to be admitted to observation by the neurosurgery service and to monitor for mental status changes, if the fracture involves the orbital roof. Eighty-two percent of patients with orbital roof fractures in this series had a neurosurgical evaluation.

Twenty-eight percent of patients in this series underwent surgery to repair orbit fractures, and this finding supports the findings of Imahara et al.[3] who reviewed >12,000 inpatients with pediatric facial fractures from the National Trauma Database and found a 25% incidence of surgery. Other authors have demonstrated increased incidence in surgery with age, as does this study.[3,6,15].

Trapdoor Fractures. A well-recognized complication of pediatric orbital floor and medial wall fractures requiring urgent surgical repair is the entrapped "trapdoor" fracture.[1,9,26,35–41] Nausea, vomiting, and bradycardia via the oculocardiac reflex, in addition to limitations in ductions, are diagnostic clues to the possibility of EOM entrapment.[26–28,35–37,39,41] Sixty-three percent of patients in this series had nausea and vomiting associated with a trapdoor floor fracture, and 2 patients (11%) had severe bradycardia, 1 with new onset bigeminy. Radiographic evidence of a trapdoor fracture may be absent or easily missed,[1,9,35,42] and 50% of formal radiology reports in this series did not diagnose entrapment.

The true incidence of entrapped trapdoor orbital floor fractures varies in the literature (24–93%), but they are widely acknowledged to be much more common in the pediatric population.[1,8,9,26,32,35,39,40,43] A well-described pediatric phenomenon is the white-eyed blowout fracture, an entrapped fracture that occurs with almost no external evidence of trauma.[37,38,42,43] The authors observed an 11% incidence of trapdoor orbital floor fractures, finding them much less common than other case series. This discrepancy may be due to referral bias, where patients requiring urgent evaluation for entrapment are more likely to be referred to a specialist. However, by including all patients with a diagnosis of orbital fracture regardless of the consulting service, this series likely contains more patients with orbital floor fractures that did not require surgery or referral to specialists (i.e., nonentrapped fractures) and more direct fractures (i.e., associated with additional facial fractures), and therefore, a lower proportion of trapdoor fractures would be expected. Bansagi and Meyer[27] found that indirect (i.e., those not involving the orbital rim) orbital floor fractures were more likely to cause a trapdoor fracture than direct (i.e., those involving the orbital rim) orbital floor fractures, and these findings support this conclusion with indirect orbital floor fractures being 7 times more likely to cause entrapment compared with direct fractures.

Most authors advocate repair of entrapped fractures within 24 to 48 hours, given the better outcomes associated with early intervention.[9,27,35,36,38,41–44] Of the 16 patients with entrapped orbital floor fractures and 3 patients with entrapped medial wall fractures in this series, 1 was transferred to another institution for repair, and 4 had late presentations and nonemergent repair. Ninety-three percent of patients with acute presentation of their entrapped orbital floor fractures underwent repair within 24 hours. Sixteen patients followed up after surgery, and 10 of 16 patients (63%) had full motility at last follow up (average time to follow up 7.1 months). Of the patients with EOM deficits (6), only 2 had longer follow up than 1 month, and some of the patients with persistent motility deficits and short-term follow up may have experience further improvement. One of the patients with late EOM deficits had presented 6 weeks after the initial trauma. This finding once again supports the conclusion that early diagnosis and treatment of orbital entrapment are critical to improved patient outcomes.

Nonentrapped Orbital Wall Fractures. Surgical indications for nonentrapped isolated orbital wall fractures include orbital volume expansion with possible globe malposition and enophthalmos, diplopia, or intraorbital bone fragments causing compression or diplopia.[4,36] The current well-described indications was typically followed for repair of orbital floor fractures, including evidence of entrapment, early enophthalmos, or orbital floor defect >50%.[4,9,27,35,37] There is a debate regarding ideal timing of surgical repair, with some authors waiting 2 weeks to allow swelling to abate, and others finding improved outcomes for patients repaired within 2 weeks.[4,9,27,36,40] Patients in this series typically had relatively early intervention and, excluding 1 patient who underwent a very delayed repair with a calvarial bone graft, the average time to surgery for repair of an orbital floor fracture was 4.3 days.

Some authors avoid alloplastic implants in the pediatric population,[5,44] while others have used alloplastic implants without complication,[27,28,37,39,42,45–47] and this has been their experience. Forty-three patients (94%) underwent orbit fracture repair with a porous polyethylene implant (Porex Surgical Inc., Fairburn, GA; Styker Inc., Kalamazo, MI; Synthes Inc., West Chester, PA). 2 patients (4%) had placement of a resorbable implant (Biomet Inc., Warsaw, IN), and 1 patient (2%) received a calvarial bone graft to the orbital floor. No complications, including infection, exposure, or migration, related to the choice of implant were observed.

Midface Fractures. Surgical indications for complex midfacial fractures including naso-orbital-ethmoidal fractures, orbito-zygomaticomalar fractures, and Le Fort fractures include significant displacement and/or communition that are likely to lead to functional or aesthetic impairment including abnormal orbital volume, globe dystopia, and telecanthus among others.[1,5] The benefit of any surgical intervention should be weighted against the possible impact on future facial bone growth and development.[1,2,5,8]

In general, the pediatric facial skeleton has more osteogenic potential, remodeling capacity, undergoes faster healing, and is at less risk for nonunion of fractures.[1,2,5,48] Therefore, surgeons are typically more conservative in the surgical repair of pediatric facial fracture when compared with adults. In addition, surgery may have a detrimental impact on the pediatric facial skeleton. Periosteal elevation during surgery may influence later facial skeletal growth, and studies performed on infant animals have demonstrated impaired bony growth across midface suture lines when rigid metallic fixation is applied, although this has not been demonstrated in humans.[1,2,5,45] There is further concern that implanted metallic plates in children may drift with continued skeletal facial growth, as has been observed in cranial metallic fixation, leading to displacement of implanted hardware and possible complications.[2,5,9,49] However, this has not been observed in pediatric facial or orbital fracture repair. Given these concerns, some support early plate removal,[5,19,45,49] but others believe this is unnecessary.[8]

Given the concern over metallic fixation and more robust osteogenic remodeling potential in children, most authors believe that the indications for facial fracture repair in the pediatric population should be more conservative than adults.[1–3,5,8,15,20] The use of resorbable plating systems for osteosynthesis in children is promising but currently has limitations, and there is no consensus on the appropriate use.[1,2,5,8,9,19,20,45,48,49] In older children, whose facial skeletons are closer to adult size, their remodeling capacity is diminished, and the drawbacks of metallic fixation become less important.

In this series, 32 patients, with an average age of 8.9 years, underwent orbit fracture repair using titanium mini-plates (Stryker Inc. and Synthes Inc.), and 12 patients, with an average age of 6.6 years, underwent repair using resorbable plating systems (Stryker Inc., Synthes Inc., and Biomet Inc.). The difference in age between patients receiving titanium plates versus patients receiving resorbable plates was not statistically significant. Indications for internal fixation included ZMC fracture (24 patients), naso-orbito-ethmoid fracture (9 patients), Le Fort fracture (3 patients), superior orbital rim fracture with or without cranioplasty (15 patients), lateral wall fracture (1 patient), and inferior orbital rim fracture (3 patients). Resorbable plates were used in 13% (3) of ZMC fracture repairs, and 47% (7) of superior orbital rim/cranioplasty repairs requiring fixation. Three patients underwent removal of the titanium hardware at a later date, including 1 patient who developed infected hardware. No other complications related to the use of titanium hardware was observed.

Orbital Roof Fractures. The indications for surgical repair of orbit fractures are unique in comparison with other orbital wall fractures and include addressing the possibility of a dural tear with resultant cerebrospinal fluid (CSF) leak or dehiscence of the skull base. Most authors agree that conservative management of pediatric orbital roof fractures is preferred, given the generally good outcomes.[1,2,5,25,31,32] In this series, only 18% of patients required surgery to address the orbital roof fracture. Koltai et al.[6] likewise found the need for surgical repair of pediatric orbital roof fractures (7%) to be significantly less than pediatric orbit fractures involving the other orbital walls (65%).

The most common indication for surgical repair of pediatric orbital roof fracture is a significantly displaced bone fragment causing dysmotility or deformity to the superior orbital rim. Two patients did have surgery to remove an intraorbital bone fragment that was believed to be contributing to restriction of the extraocular muscles.

Three patients developed orbital meningoencephaloceles that required repair with biparietal split thickness bone grafts. These "growing orbital roof fractures" may occur when the roof fracture is associated with a subfrontal dural laceration, and the fracture enlarges over time with possible herniation of brain tissue in the orbit.[8,22,31,32,50–54] Continuous CSF pulsation and the growing brain in the absence of bony counter pressure are thought to be the mechanism.[18,51]

A fracture through the paranasal sinuses may establish a passageway from the sinuses to the brain, and patients are at risk for meningitis, brain abscess, CSF fistula, and penumocephalus.[10,25,31,33,55,56] The diagnosis of a dural tear and CSF leak may be difficult, and the necessity of surgical repair of the dura is controversial and outside the scope of this article.[33,57] Of greatest concern is the development of meningitis, as 2 patients developed in this series, but the use of prophylactic antibiotics in an acute traumatic CSF leak is controversial.[57]

Complications. Complications of pediatric orbital fractures include associated ocular and neurologic injuries, diplopia and/or strabismus, and aesthetic deformities. A low incidence of ocular complications including diplopia and strabismus (2%) and aesthetic deformities including enophthalmos (2%) and telecanthus (1%) was observed. These findings are limited by the relatively short-term follow up, and longer follow up would be necessary to know the true incidence of aesthetic deformities that may occur with further facial growth.

There were 4 patients (1%) who developed infections related to orbit fractures. Two patients experienced meningitis associated with orbital fractures. Both were 2-year-olds with cribriform plate fractures. One patient developed orbital cellulitis associated with a medial wall fracture. One patient developed infected hardware 2 months after repair of a zygomaticomaxillary fracture. One patient had severe epistaxis associated with a right medial wall fracture, requiring multiple interventions by multiple subspecialties.

Previous authors have estimated a 15% risk of significant growth disturbance in children secondary to all facial fractures.[1] These large series did not demonstrate any negative consequences attributed to the use of internal fixation or alloplastic materials used in pediatric orbital reconstruction. However, follow-up periods were variable, and many patients had not yet reached skeletal maturity at the conclusion of the study. It will be difficult, and well outside the scope of this article, to understand the possible negative effects that surgery, fixation, and alloplastic implants may have on facial growth. The patients with the most significant deformities need the most surgical intervention, and it may be very difficult to distinguish whether negative outcomes are secondary to trauma, surgery, or both.

CONCLUSIONS

This series describing pediatric orbital fractures is the largest series to date in Medline-indexed literature. Pediatric orbit fractures occur more commonly in boys, although in children <4 years of age there is an equal age distribution. The causes of pediatric orbit fractures vary with age, with falls being more common in patients <5 years and sports being more common in patients older than 5 years. Fractures occur in specific patterns dictated by the pattern of facial growth, growth of the paranasal sinuses, dentition, and bone physiology. Pediatric orbital roof fractures are more likely to occur in younger patients, and be associated with skull fractures and neurologic injuries, and are less likely to require repair. Floor fractures are more likely to occur in older patients, and be associated with midface fractures, and require surgical intervention. There is an increasing need for surgery with patient age. Associated neurologic injuries are more common than ophthalmic injuries. The need for surgical repair of pediatric orbit fractures must be balanced by the morbidity associated with surgery. No age-related complications related to the use of titanium mini-plate fixation or alloplastic orbital implants were observed in this series, but larger, prospective series are necessary to further elucidate the risks and benefits in the pediatric population.

This study has several limitations. The study was limited to 2 institutions, and therefore, like any institution, there is associated referral bias. This study is retrospective and has a lack of uniform follow up after presentation. These are problems that are inherent in most trauma series as patients are often evaluated, repaired and/or stabilized, and then followed up locally for less acute care.

Pediatric facial trauma can range from minor nonsurgical fractures to severe facial injury, requiring complex surgical reconstruction. As with any patient, the whole picture will dictate the level of monitoring and intervention. In general, it has been demonstrated that pediatric orbital fractures commonly require a multidisciplinary approach, often do not require surgical intervention, and have a higher risk of associated neurologic injury when compared with ophthalmic injury. Most patients can be managed conservatively, and those patients that require surgery typically have favorable outcomes.

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