Traumatic Orbital Roof Fractures: Interdisciplinary Evaluation and Management

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Background: The orbital roof forms part of the anterior skull base and is positioned for potential concomitant ophthalmologic and neurologic injury. Despite potential morbidity and mortality, orbital roof fractures have garnered little attention compared with orbital floor fractures. The authors' purpose is to review and describe key points when treating these fractures.

Methods: The authors reviewed 1171 consecutive patient at a trauma center with orbital or skull base fractures from 2009 to 2011. Patient demographics, mechanism of injury, associated injuries, treatment, outcomes, and complications were recorded.

Results: Among the 1171 patients, the authors identified 60 with an orbital roof fracture (5 percent). All were evaluated by plastic surgery, neurosurgery, and ophthalmology. Average age was 38.1 years, and the male-to-female ratio was 4:1. Frequent mechanisms of injury were fall (33 percent), followed by assault (25 percent). Concomitant craniofacial skeletal fractures were common (87 percent), as were ophthalmologic injuries (47 percent), and traumatic brain injury with intracranial hemorrhage (65 percent). Six patients (10 percent) required operative repair of the orbital roof, all of whom had a dural laceration and cerebrospinal fluid leak. Most patients (90 percent) had minimal displacement and no clinically evident cerebrospinal fluid leak and were treated with observation without complications.

Conclusions: Orbital roof fractures are a less common but potentially serious craniofacial injury. Most can be safely observed; however, intracranial or intraorbital injury may warrant surgical intervention to remove impinging bony fragments, repair dura, or reconstruct the orbital roof. An interdisciplinary approach with plastic surgery, ophthalmology, and neurosurgery is crucial to providing comprehensive care. (*Plast. Reconstr. Surg.* 133: 335e, 2014.)

CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, IV.

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THERAPEUTIC

The orbital roofs constitute the lateral aspects of the anterior skull base. Each orbital roof is formed by the frontal bone and the lesser wing of the sphenoid bone and is precariously positioned for concomitant craniofacial, ophthalmologic, and neurologic injury.[1,2] Although orbital roof fractures are less common than orbital floor fractures in both adults and children, with an estimated involvement in only 1 to 9 percent of all facial fractures,[3–5] the significant potential for morbidity and mortality justifies careful evaluation and interdisciplinary management.[1,6,7]

Orbital roof fractures in adults are typically described after high-energy impact, because the pneumatized frontal and paranasal sinuses can effectively dissipate low-energy forces.[8] Although an orbital roof fracture may occur in isolation, the high-energy force commonly incurs fractures of the orbit, frontal sinus, skull bones, nasal bones, zygomaticomaxillary complex, maxilla, or mandible.[7] Notable ophthalmologic injuries may include retrobulbar hematoma, globe rupture, optic neuropathy, ptosis and lagophthalmos, dystopia, perforating eye injuries and intraorbital foreign bodies, cranial

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Received for publication May 21, 2013; accepted October 3, 2013.
Presented at the 19th Annual Brown University and Rhode Island Hospital Research Celebration, October 27, 2011, Providence, Rhode Island; and the 54th Annual Meeting of the New England Society of Plastic and Reconstructive Surgeons, in Newport, Rhode Island, May 31 through June 2, 2013.

DOI: 10.1097/01.prs.0000438051.36881.e0

Disclosure: *The authors have no financial interest to declare in relation to the content of this article.*

nerve palsies, and orbital encephalocele.[9–12] Associated intracranial injuries include dural laceration with cerebrospinal fluid leak, pneumocephalus, and traumatic brain injury.[5,13,14] Unlike adults, children, particularly those younger than 7 years, are more likely to suffer isolated orbital roof fractures because of immature or incomplete sinus development and a more prominent forehead.[5,8,10,15,16] The potential for a growing skull fracture and long-term effects on orbit and zygoma position lower the threshold for intervention in children.[6,17,18] Our purpose is to review our institutional experience with these potentially morbid fractures, highlighting diagnosis of concomitant injuries, indications for surgery, and results of operative and nonoperative management.

PATIENTS AND METHODS

We obtained institutional review board approval and performed a retrospective review of a 2-year period (2009 to 2011) for patients treated at a Level I trauma center. We reviewed the charts and radiographs of patients with *International Classification of Diseases, Ninth Revision* codes for orbital fractures and skull base fractures. We collected data concerning patient demographics (age and sex), mechanism of injury, associated craniofacial and extracranial fractures, intracranial and ophthalmologic injuries, treatment, and complications.

Concomitant injuries were classified as skeletal, ophthalmologic, or neurologic. Skeletal fractures were further categorized by type (i.e., orbital floor, medial orbital wall, lateral orbital wall, frontal sinus, zygomaticomaxillary complex, nasal, nasoorbitoethmoid, mandibular, maxillary, cervical spine, or other skull) and ipsilateral or contralateral in relation to the orbital roof fracture. This study was conducted in accordance with the tenets of the Declaration of Helsinki.

Statistical Analysis

Patient characteristics and descriptive statistics were summarized. Continuous data were compared using the Wilcoxon rank sum test and proportions were analyzed using Fisher's exact test. All calculated p values were two-tailed and considered significant for values of $p < 0.05$. Statistical analyses were performed using Stata/SE version 12.1 (StataCorp, College Station, Texas).

RESULTS

We identified 1171 patients with traumatic orbital or skull base fractures. Of these, 60 patients had an orbital roof fracture. Patient demographics are summarized in Table 1. We found no significant difference in median age of injury between male patients and female patients (36.0 versus 29.5 years, respectively; $p = 0.48$). There was no significant relationship between sex and mechanism of injury ($p = 0.93$). Concomitant skeletal, ophthalmologic, and neurologic injuries are also summarized (Table 2). Radiographic evaluation of the cervical spine was performed in all patients, two of whom (3 percent) were found to have cervical spine injury: one with C1 arch and dens fractures with cervical-cranial junction dislocation, and one with a C2 odontoid fracture. Computed tomographic angiography of the neck was performed in 22 patients (37 percent), and no vascular injuries or thromboemboli were identified. Additional craniofacial fractures were common [$n = 52$ (87 percent)] (Fig. 1). The most commonly associated craniofacial fractures involved the ipsilateral zygomaticomaxillary complex [$n = 24$ (40 percent)]; the least common were mandibular fractures [$n = 2$ (3 percent)]. An isolated orbital roof fracture was uncommon but occurred in eight patients (13 percent), who had a median age of 33 years (range, 14 to 93 years) (Table 3). Bilateral orbital roof fractures occurred in six patients (10 percent). There were three patients younger than 7 years, one of whom started frontal sinus development and had an associated but minimally displaced nonoperative anterior table fracture. Of the two children without frontal sinus development, one had a minimally displaced nonoperative frontal skull fracture.

Ophthalmologic injury was noted in 28 patients (47 percent), seven (12 percent) of whom required an operation performed by the ophthalmology specialty. Three patients (5 percent) required urgent lateral canthotomy and cantholysis because of retrobulbar hematoma and orbital compartment syndrome. Two patients required

Table 1. Patient Demographics and Mechanisms of Injury

Characteristic	Value
No. of patients	60
Male-to-female ratio	48:12
Age, yr	
Mean ± SD	38.1 ± 21.2
Range	3–93
Mechanism of injury	
Fall	20
Assault	15
Motor vehicle collision	10
Bicycle collision	6
Motorcycle collision	6
Pedestrian struck	3

Table 2. Spectrum of Concomitant Injuries among All 60 Patients

Injuries	No.
Craniofacial fractures	
Ipsilateral zygomaticomaxillary complex	24
Frontal sinus	22
Ipsilateral medial orbital wall	21
Nasal	21
Ipsilateral orbital floor	18
Maxilla	17
Skull (other)	17
Contralateral medial orbital wall	8
Isolated orbital roof	8
Bilateral orbital roof	6
Contralateral zygomaticomaxillary complex	6
Ipsilateral nasoorbitoethmoid	6
Contralateral orbital floor	5
Mandible	2
Cervical spine	2
Neurologic	
Multiple intracranial hemorrhages	26
Pneumocephalus	19
Cerebrospinal fluid leak	6
Frontal contusion	5
Acute subdural hematoma	4
Subarachnoid hemorrhage	4
Ophthalmologic	
Cranial nerve palsies (total)	8
Retrobulbar hematoma	6
Commotio retinae	2
Muscular entrapment	1
Ptosis	1
Ruptured globe	1

Fig. 1. In relation to an orbital roof fracture (*yellow* and *red stripes*), the frequencies of concomitant craniofacial fractures are depicted. The most frequently associated fracture involved the ipsilateral zygomaticomaxillary complex; the least frequently associated fracture involved the mandible.

secondary strabismus surgery to balance denervated or injured extraocular muscles. One patient required acute reduction of a lateral orbital wall fracture secondary to lateral rectus muscle entrapment, and one patient had a globe rupture leading to an enucleation. An acute cranial nerve palsy occurred in seven patients (12 percent), two with seventh cranial nerve (facial) palsy with lagophthalmos, two with third cranial nerve (oculomotor) palsy, one with mixed third cranial nerve and seventh cranial nerve palsies with lagophthalmos, one with sixth cranial nerve (abducens) palsy, and one with second cranial nerve (optic) injury.

Traumatic brain injury with intracranial hemorrhage was common [$n = 39$ (65 percent)], manifesting as frontal contusion [$n = 5$ (8 percent)], subarachnoid hemorrhage [$n = 4$ (7 percent)], acute subdural hematoma [$n = 4$ (7 percent)], or a combination thereof and including epidural hematoma [$n = 26$ (87 percent)]. Among those patients with traumatic brain injury, four patients (7 percent) were monitored clinically; 26 (87 percent) were monitored by serial computed tomographic imaging without surgical intervention; four patients (7 percent) were monitored with a transduced ventricular catheter, one of whom required a decompressive hemicraniectomy because of elevated intracranial pressure; and five patients (8 percent) underwent frontal craniotomy for repair of the orbital roof fracture, but not for neurologic indications. Three of these patients with operative orbital roof fractures also had subarachnoid hemorrhage. One patient required a lumbar drain for persistently elevated intracranial pressure.

The radiographic finding of pneumocephalus was frequent [$n = 19$ (32 percent)] (Fig. 2), suggesting dural laceration. Pneumocephalus was 100 percent sensitive for dural laceration with cerebrospinal fluid leak requiring operative repair of the orbital roof. However, whereas all operative fractures had pneumocephalus, the majority of patients with pneumocephalus were managed conservatively. A clinical cerebrospinal fluid leak was noted in three patients (5 percent), and a subclinical cerebrospinal fluid leak was suspected in three additional patients (5 percent) based on fracture displacement. A dural laceration with cerebrospinal fluid leak was confirmed at the time of operation for all six patients. Among these patients, four had "blow-out" type injuries with fracture displacement into the anterior cranial fossa (Fig. 3), one had a minimally displaced fracture (Fig. 4), and one had a "blow-in" type injury with fracture displacement into the orbit

Table 3. Characteristics of Patients with Isolated Orbital Roof Fractures and No Concurrent Craniofacial Fractures

Patient	Age (yr)	Mechanism of Injury	Operative Roof Repair	Multisystem Injuries
1	14	Bicycling accident	No	None
2	17	Fall	No	Subarachnoid hemorrhage, frontal lobe contusion
3	28	Motor vehicle collision	No	None
4	31	Motor vehicle collision	No	None
5	35	Fall	No	Frontal lobe contusion
6	53	Motorcycle collision	No	Subdural hematoma, clavicular fracture
7	76	Motor vehicle collision	No	None
8	93	Fall	No	None

(Fig. 5). Characteristics and management of the six operative patients are summarized in Table 4.

All operations to repair bony fractures and dural lacerations were performed in collaboration with the neurosurgery and plastic surgery specialties. The orbital roof was repaired with a split calvarial bone graft ($n = 5$) (Fig. 6) or replacement of the bony fragment and absorbable mesh ($n = 1$), the latter in a pediatric patient. Three patients required simultaneous repair of other facial fractures, including frontal sinus cranialization and open reduction and internal fixation of zygomaticomaxillary complex, LeFort I/II pattern, nasoorbitoethmoid, and mandibular fractures. Six patients with nonoperative orbital roof fractures underwent repair of other facial fractures.

Fig. 2. Pneumocephalus is seen adjacent to an operative orbital roof fracture in a 3-year-old boy who was ejected during a motor vehicle accident. He sustained a right third cranial nerve palsy, resulting in ptosis and mydriasis, in addition to a seventh cranial nerve palsy and commotio retinae. He required ventriculostomy for elevated intracranial pressure; lumbar drainage for cerebrospinal fluid leak; repair of dural laceration; and reconstruction of numerous facial fractures, including the right orbital roof, using bony reduction and an absorbable plate.

There were no complications in either the orbital roof operative or nonoperative groups with mean follow-up periods of 23.5 ± 7.9 and 19.6 ± 7.8 months, respectively. Specifically, no patient developed meningitis, persistent or recurrent cerebrospinal fluid leak, surgical-site infection, or ocular entrapment. Although not needing repair of the orbital roof, two patients did require a delayed operation to correct residual strabismus. No patients developed clinically detectable enophthalmos requiring an operation. In addition, there were two patient deaths caused by withdrawal of care in the setting of multisystem trauma, neither of whom had an operative orbital roof fracture.

DISCUSSION

Orbital roof fractures are an uncommon but potentially morbid consequence of high-energy

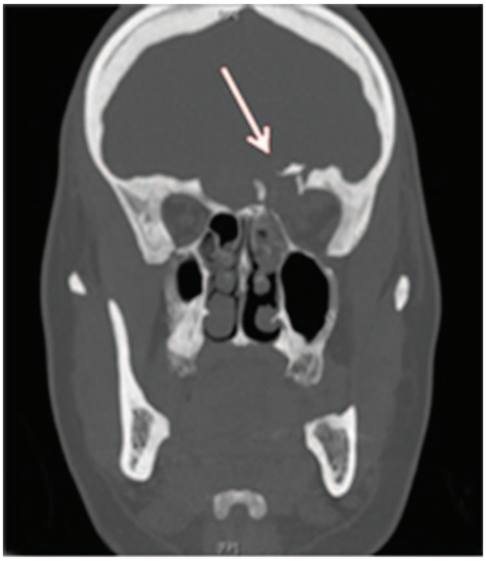

Fig. 3. A 27-year-old woman who was assaulted and stepped on with a stiletto high-heel shoe suffered an operative orbital roof blow-out fracture with displacement into the anterior cranial fossa and a frontal brain contusion, dural laceration, and injury to the superior rectus muscle.

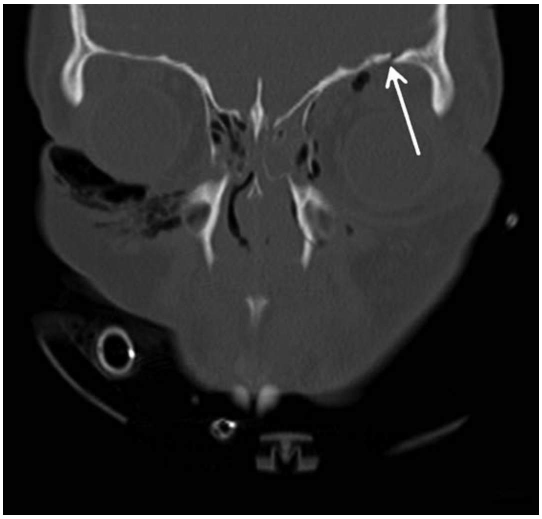

Fig. 4. A 12-year-old girl who was struck by a vehicle sustained a minimally displaced but operative orbital roof fracture with dural laceration and cerebrospinal fluid leak and other craniofacial fractures (see Table 4).

craniofacial trauma, affecting patients of all ages. Using a combination of axial, sagittal, and coronal reformatted computed tomographic imaging and increased scan quality may contribute to improved detection of this sometimes subtle injury. The management algorithm for these fractures, however, has not been well-defined. We emphasize the importance of an interdisciplinary team to manage these injuries. The unique anatomical location provides the opportunity for the specialties of neurosurgery, ophthalmology, and plastic surgery to collaborate to provide safe and efficacious management and coordinated surgical care when indicated.

Fig. 5. A 22-year-old man who was assaulted with a baseball bat suffered an operative orbital roof blow-in fracture and fractures of the medial and lateral orbital walls, right frontal bone and sinus, and right temporal bone. He also sustained frontal brain parenchymal contusions in addition to a subdural hemorrhage and dural laceration. He sustained no ophthalmic injuries. He underwent orbital roof reconstruction with split calvarial bone graft, repair of dural laceration, obliteration of frontonasal ducts, and cranialization of frontal sinus.

Initial management should follow standard Advanced Trauma Life Support protocols.[19] Physical examination and mechanism of injury guide the use of imaging studies. Computed tomographic scans with thin (1-mm) axial cuts in addition to sagittal and coronal reformats may detect not only orbital roof fractures but also associated neurologic, ophthalmologic, and skeletal injuries to help guide management. Radiographic evaluation of neck vasculature may be warranted in patients with high-energy trauma, penetrating injuries to zones I and III of the neck, and symptoms suggestive of stroke. If present, vascular injuries are a priority and require acute intervention. Although no vascular injuries or thromboemboli were detected in our series, two patients (3 percent) were found to have cervical spine injuries. These findings provide a reminder that cervical spine imaging is indicated in this population, particularly because the consequence of missed injury may be devastating.[20–22]

In the event that an orbital roof fracture is identified, evaluation by the facial trauma team and the ophthalmology and neurosurgery specialties is prudent. Indications for emergent intervention for an orbital roof fracture are largely related to visual and neurologic compromise, including blow-in type injury, retrobulbar hematoma, extraocular muscle entrapment, globe rupture, or severe traumatic brain injury with clinical and radiographic signs of herniation.[9] Computed tomography and magnetic resonance imaging are preferred modalities for assessing neurologic injury and should be performed acutely in cases of head trauma when indicated. Indications for neurosurgical intervention depend on neurologic status, as evaluated by the Glasgow Coma Scale, findings of large hemorrhage or mass effect evidenced on imaging, or directly measured rising intracranial pressure. Epidural and subdural hematomas or intraparenchymal hemorrhage of concerning size or with mass effect may require evacuation by craniotomy or decompressive craniectomy.[23–26] The need for decompression was rare in our series of patients.

Table 4. Characteristics of Patients with Operative Orbital Roof Fractures

	Patients					
	1	2	3	4	5	6
Age, yr	3	12	16	22	27	33
Mechanism	Motor vehicle collision	Struck pedestrian	Bicycle collision	Assault	Assault	Fall
Orbital roof fracture type	Blow-out	Minimally displaced	Blow-out	Blow-in	Blow-out	Blow-out
CSF leak	Yes	Yes	Yes	Yes	Yes	Yes
Neurologic injury	SAH	SDH	Dural laceration	Dural laceration, SAH, frontal lobe contusion	Meningoencephalocele, frontal lobe contusion	EDH, SDH, SAH, temporal lobe contusion
Ophthalmologic injury	Third and seventh cranial nerve palsy, ptosis, lagophthalmos, commotio retinae	None	None	None	Ptosis	None
Other craniofacial fractures	Medial orbital wall, orbital floor, temporal bone, ZMC, mandible	Medial and lateral orbital walls, orbital floor, temporal bone, frontal bone	Frontal bone and sinus	Medial and lateral orbital walls, frontal bone and sinus, temporal bone	Medial orbital wall	NOE, frontal bone and sinus, ZMC, temporal bone
Orbital roof reconstruction	Bone reduction, absorbable mesh plate	Split calvaria	Split calvaria	Split calvaria	Split calvaria	Split calvaria
Complication	None	None	None	None	None	None

SDH, subdural hematoma; SAH, subarachnoid hemorrhage; EDH, epidural hematoma; NOE, nasoorbitoethmoid; ZMC, zygomaticomaxillary complex.

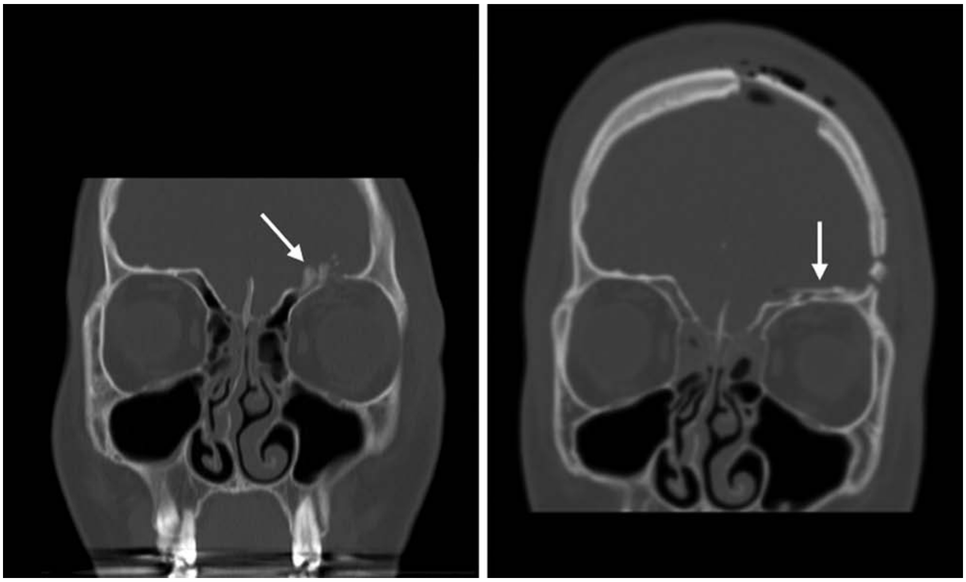

Fig. 6. A 16-year-old boy in a bicycle accident who suffered an operative orbital roof blow-out fracture (*left*), involving the left frontal bone and sinus with a corresponding dural laceration, in addition to a right nasal bone fracture, underwent reconstruction with a split calvarial bone graft (*right*).

Invasive intraparenchymal pressure monitoring or a transduced ventricular catheter can be used to monitor pressure, which may be maintained below 20 mmHg using hyperosmolar therapies, hyperventilation, or ventricular drainage.[27,28] Such monitoring has recently been challenged and not shown to be superior to care based on serial imaging and clinical examination.[27] In the absence of clinical changes, follow-up head computed tomography is commonly used to assess progression of intracranial processes.[29–32]

Aside from neurologic or ophthalmologic injury, nonemergent surgical indications include cerebrospinal fluid leak as determined by physical examination, blot test, or beta-2 transferrin assay; significant fracture displacement (often blow-out type injuries) causing concern for dural laceration and subclinical cerebrospinal fluid leak; or fracture displacement causing significant volume changes in the orbit that may cause enophthalmos (blow-out fractures) or exophthalmos (blow-in fractures).[13,33–35] Degree of fracture displacement alone does not predict the need for operative intervention, as one patient in our series with a minimally displaced orbital roof fracture developed a cerebrospinal fluid leak that required operative repair. We found pneumocephalus to be sensitive for cerebrospinal fluid leak, but pneumocephalus alone is also not an indication for repair of the orbital roof. In the absence of neurologic or visual compromise, clinical or subclinical cerebrospinal fluid leak, or significant bony displacement concerning for orbital volume changes, an orbital roof fracture may be managed nonoperatively.

The craniofacial principles of wide exposure and rigid fixation apply to these injuries.[36] In our experience, this involves using a zigzag coronal incision, elevation of a vascularized pericranial flap, frontal craniotomy, cranialization or obliteration of frontal sinus and frontonasal ducts as indicated, and repair of dura. The vascularized pericranial flap is used to repair dura and fill anatomical dead space as needed.[37] If significant bony comminution precludes anatomical reduction and fixation, a split calvarial bone graft, titanium mesh, or prosthetic (such as porous polyethylene) can be used to reconstruct the orbital roof. Other facial or skull fractures are repaired synchronously if indicated.

In adults, the high rate of concomitant facial fractures is likely related to high-energy mechanisms of injury, which were often focally directed at the middle and upper craniofacial regions. Associated fractures of the lower third of the face were less uncommon, with mandibular fractures present in only two patients. Our findings of concomitant fracture patterns corroborate results of previous studies.[36,38] Piotrowski and Beck-Mannagetta found similar findings in their series of patients.[36] Although their cohort had an overall higher incidence of multiple fractures, possibly attributable to a larger percentage of injuries caused by road accidents (49 percent, versus 17 percent in our series), they found a strong association with medial orbital wall fractures (90 percent, versus 35 percent in our series) and midface fractures (70 percent, versus 68 percent in our series). They also found the least commonly associated facial fracture to be mandibular (3.9 percent, versus 3 percent in our series).

Of special concern in pediatric patients is the risk of secondary growing skull fractures.[17,18] This process is potentiated by a skull fracture in conjunction with a dural tear which, if left untreated, can lead to progressive destruction of the cranium. Leptomeningeal cysts, fibrogliotic scars, cerebral herniation, hemiparesis, epilepsy, and recurrent meningitis caused by the pulsating brain or edema exerting force on the unrepaired area are also possible sequelae.[39] In addition, brain pulsations transmitted from the intracranial space to the orbit may result in significant growth disturbance of the midface with orbital dystopia.[6] Treatment involves early radiographic recognition of the injury followed by repair of the dural tear and anatomical reduction and fixation of the fracture.

It has been reported that pediatric patients younger than 7 years, compared with adult patients, are also more likely to suffer orbital roof fractures in isolation, as a consequence of anatomical differences.[5,8,15,16] However, the three patients younger than 7 years in our series also sustained other craniofacial injuries. There was no clear trend in mechanism of injury to account for our distinct findings suggesting that isolated orbital roof fractures in adult patients are less predictable by mechanism of injury or anatomy, consistent with previous assertions.[5] Moreover, patients with isolated orbital roof fractures may still incur some form of multisystem injury, particularly neurologic, which our series corroborates.[2,14]

We found no surgical complications in our cohort, which had a mean follow-up period of 23.5 ± 7.9 months. Complications of concern could include surgical-site infection, meningitis, persistent ophthalmologic injury, or recurrent cerebrospinal fluid leak. We saw no cases of meningitis or wound infection in either the operative or the nonoperative group.

CONCLUSIONS

Orbital roof fractures represent a unique class of craniofacial injury. Although definitive surgical intervention to repair the orbital roof fracture is required less commonly than orbital floor repairs, as shown by our retrospective review of patients diagnosed with orbital roof fractures, our data also show that almost two-thirds of orbital roof fractures are associated with traumatic brain injury. These circumstances confound early recognition of visual and neurologic complication, which is critical in determining the need for acute intervention.[40] Recognition of a cerebrospinal fluid leak and fracture displacement concerning for dural laceration with subclinical cerebrospinal fluid leak guide the timing of subacute surgical management. This underscores the importance of an interdisciplinary team of neurosurgeons, ophthalmologists, and plastic surgeons.

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