# Association Between Ocular Injuries and Internal Orbital Fractures

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**Purpose:** The physical mechanism of orbital blowout fractures has been debated for years by surgeons. Three main theories have been promulgated, including the hydraulic theory, the contact of globe-to-orbital wall theory, and the bone buckling theory. One might anticipate a strong association of blowout fractures and traumatically induced ocular injuries with the hydraulic and globe-to-wall theories because in both, the force is delivered directly to the ocular globe. This study was performed to assess the association between orbital blowout fractures and ocular injuries.

**Patients and Methods:** Records of patients with orbital blowout fractures were collected from a single hospital. Those with complete records that included a thorough ophthalmologic examination were collected, and information about the nature of the injury to the bone and the ocular globe was tabulated.

**Results:** A total of 225 patients ranging in age from 13 to 98 years (mean, 34.9 yr) who had sustained 240 blowout fractures (15 were bilateral) met the inclusion criteria. In all, 53 fractures (22%) involved ocular injuries that were thought to be directly associated with ocular trauma. The most common positive ocular finding was commotio retinae, which was present in 21 of 60 globes with significant traumatic ocular findings. This was followed in frequency by traumatic mydriasis (19 globes) and traumatic iritis (15 globes). Most ocular injuries were minor.

**Conclusions:** The low incidence of significant ocular injury may indicate that direct contact of the globe with the traumatic force is not common. This finding gives credence to the buckling theory of blowout fracture, which seems more likely in most cases.

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Orbital blowout fractures are fractures that occur within the bony orbit, usually along the floor and/or medial walls of the orbit, where the orbital rims are intact.[1] According to the literature, blowout fractures account for approximately 11% of fractures involving the orbit.[2]

Regarding the cause of blowout fractures, in one of the earliest descriptions of this injury in 1944, King mentioned, " . . . there is a downward displacement of part of the orbital floor, unassociated with any damage to the margin of the orbit surrounding the facial bones. The cause of such a fracture is difficult to visualize."[3] The physical mechanism of orbital blowout fracture has been debated for years by ophthalmologists, otolaryngologists, plastic surgeons, and maxillofacial surgeons. Because it occurs behind the rim of the orbit, direct contact of the bony walls with an object does not occur. Blowout fractures therefore occur indirectly. Most opinions about the mechanism of blowout fractures fall under 3 main theories: the "hydraulic" theory, the globe-to-wall contact theory, and the bone conduction theory.

The hydraulic theory was first proposed by King (1944) when he wrote, "The most ready explanation [for orbital blowout fractures] is trauma transmitted through the eye to the orbital floor."[3] Smith and Regan in 1957[1] were advocates of this theory, stating that blowout fractures were caused by a generalized increase in orbital soft tissue pressure, which results when the globe is pushed posteriorly as the result of contact with an object. Posterior displacement of the globe increases pressure within the orbit, resulting in fracture of the thin-walled orbital floor and/or medial wall. This theory is based on an experiment in which

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a ball placed over the cadaver's closed eyelids (and globe) was sharply struck by a hammer. This produced a depressed comminuted fracture of the orbital floor and a comminuted nondisplaced fracture involving the lamina of the ethmoid bone. But when the same force was applied to the orbit after the orbital soft tissues had been removed, no fracture occurred until the striking force was sufficient to fracture both the orbital rim and the floor. This led investigators to believe that blowout fractures are caused by increased intraorbital pressure, rather than by transmission of force through the bony rim. The hydraulic mechanism for blowout fractures is supported by many others.[4-8]

The globe-to-wall contact theory proposed by Raymond Pfeiffer in 1943[4] states that a force is delivered to the globe, pushing it backward into the orbit and causing it to strike and fracture the bony walls. It is based on common sense and practical deduction from radiologic analysis but lacks experimental evidence. Recently however, Erling et al[9] found that the size of the orbital wall defect exactly fits the size of the globe in many cases of blowout fracture analyzed on computed tomographic (CT) scan. They believe it is the displacement of the globe that directly causes many orbital wall fractures.

An alternate theory for the cause of blowout fractures was proposed by Le Fort in 1901[10] and Lagrange in 1917.[11] The bone conduction hypothesis states that a force is delivered to the orbital rim that temporarily deforms, or "buckles," without grossly fracturing. Posterior movement of the orbital rim during that split second causes fracture along the orbital floor and/or medial wall. The orbital rim then springs back into position without any evidence of a complete fracture. This possibility was explored by Fujino.[12-14] In his experiments, he used a 420-g silicone-tipped brass cylinder dropped from 15 or 20 cm onto the infraorbital rim. A linear blowout fracture of the orbital floor was produced in the orbit struck from the lower height, and the orbit struck from the higher height sustained a typical blowout fracture with a defect at the posteromedial bulge of the orbital floor. In further research with the use of high-speed photography and tolerance limit curves to show actual movement of the infraorbital rim and orbital floor during a fracture, Fujino demonstrated various fracture patterns based on the location of impact: globe alone, infraorbital rim alone, or a combination. He concluded that it was the orbital rim component that resulted in most clinical fractures. Further, he believes that contacting only the globe in practice is rare.[15] In his experiments, it took less than one third of the force to produce a blowout fracture when the bone was directly impacted compared with when force was delivered to the globe.[15] This mechanism is also supported by several others.[16-19] People who disagree with this theory point out that if it were true, the complication of extraocular muscle entrapment would be much less common.[20-22] This theory would not explain all floor fractures and would certainly not play a large role in the commonly observed medial wall fracture.[20,22]

Both hydraulic and "globe-to-wall" mechanisms are based on the theory that the globe and not the orbital rim receives the force. That blowout fractures can occur through direct contact of the globe with a traumatic force has been shown in several experiments. Jones and Evans[7] impacted the globes of cadavers with a 1-inch-diameter metal cylinder. Twenty-seven fractures of the floor of the orbit occurred in the 33 orbits tested. In 4 of these, the medial wall was also involved. Six additional orbits had only medial wall fractures. Thus, investigators were able to consistently produce blowout fractures by direct force to the globe in 82% of orbits. Green et al,[8] by using an apparatus that delivered a quantifiable force directly to the globe of monkeys, confirmed that this mechanism is capable of causing blowout fractures. It could not be determined whether it was the hydraulic force or the posteriorly displaced globe that caused the blowout fracture in these studies, but findings clearly indicated that 1 or both of these mechanisms are possible causes. However, Wolfe[23] thought that if the fracture was caused by direct contact with the globe, a greater number of globe ruptures should result from such a posterior displacement.

Because of the large variety of blowout fractures that are seen, it is presumptuous to believe that a single theory may explain completely all types of fractures. However, one would expect that a strong association should be noted between blowout fractures and traumatically induced ocular injuries with the hydraulic and globe-to-wall theories because in both, force is delivered directly to the ocular globe. This study was performed to evaluate the association between orbital blowout fractures and ocular injuries.

## Materials and Methods

Records of patients who were given a diagnosis of orbital wall fracture in the Parkland Hospital Emergency Room from 1995 to 2005 were reviewed. Inclusion criteria for the study sample consisted of the following: *1*) patients with pure blowout fracture(s), *2*) available results of CT findings, and *3*) available results of pretreatment ophthalmologic examination (by an ophthalmologist or ophthalmology resident). Patient charts were reviewed for the following information: age, gender, race, method of injury, date of injury, date of presentation to the hospital, date of ophthalmologic examination, side of fracture (right, left, bilateral), and associated facial fractures. On the basis of pretreatment CT scan results, locations of fractures within the orbit were categorized into those that involved the floor, those that affected the medial wall, and those that involved both. Findings of the pretreatment ophthalmologic examination were assessed by an ophthalmologist (PHB) for ocular injuries thought to be the result of direct globe contact trauma. Injuries that were tabulated included traumatic iritis, traumatic mydriasis, hyphema, choroidal rupture, globe rupture, and commotio retinae. Cases of traumatic optic neuropathy were also recorded, although these could not be directly related to direct ocular trauma. The results of this assessment were tabulated for analysis.

## Results

A total of 1,570 patients with orbital fractures were identified within the 10-year period. In all, 1,177 of these patients' charts were located and reviewed. It was found that 894 patients had sustained impure orbital fracture (zygomatic, maxillary, naso-orbito-ethmoid) and could not be included. Of 283 patients with pure blowout fractures, 225 patients ranging in age from 13 to 98 years (mean, 34.9 yr) with 240 blowout fractures (15 were bilateral) met the inclusion criteria. A male preponderance (181 male, 44 female) was observed, and fractures were reported to have occurred in 80 non-Hispanic Caucasians, 76 Hispanics, 61 African Americans, and 8 Asians. The most common cause of fracture was assault (117 cases); this was followed in frequency by motor vehicle–related accidents (78), falls (15), sports injuries (5), and other (10). Of 210 unilateral blowout fractures, 108 occurred on the left and 102 on the right. Fractures of the orbital floor were most common (n = 114), followed by medial wall fractures (n = 72) and those categorized as combination floor/medial wall (n = 54). Of 15 bilateral fractures, 9 were bilateral fractures of the floor of the orbit, 3 were bilateral fractures of the medial wall, 2 were bilateral fractures of the floor/medial wall, and 1 involved a medial wall fracture on one side and a floor fracture on the other.

The time between injury and presentation to the hospital averaged 0.9 days, with a range of 0 to 20 days. The time between presentation and ophthalmologic examination averaged 1.4 days, with a range of 0 to 22 days.

A total of 52 patients sustained facial fractures in addition to the blowout fracture. The most common were nasal fractures (n = 39), followed by frontal sinus fractures (n = 7). Two patients sustained contralateral (to the blowout) zygomaticomaxillary complex fractures (ZMC), 1 patient sustained a combination of nasal and mandibular fractures, 1 sustained a nasal and a contralateral (to the blowout) ZMC fracture, 1 sustained a combination contralateral (to the blowout) naso-orbito-ethmoid and ZMC fracture, and 1 sustained a mandibular fracture. Six of 15 patients with bilateral blowout fractures had concomitant nasal fractures. All other concomitant fractures were associated with unilateral blowout fractures.

Ophthalmologic findings are presented in Table 1. Sixty of 240 blowout fractures (25%) showed positive findings of ocular or optic nerve injury, although 7 of these were isolated cases of traumatic optic neuropathy, which may or may not have been the result of ocular trauma. If these 7 patients are eliminated, 53 fractures (22%) were associated with ocular injuries thought to be directly associated with ocular trauma. The most common positive ocular finding was commotio retinae, which was present in 21 of 60 globes with significant traumatic ocular findings. This was followed in frequency by traumatic mydriasis (19 globes) and traumatic iritis (15 globes). Just over half of patients with positive ocular findings had only 1 finding. The others had combinations of findings.

## Discussion

Several investigators have examined the association between ocular findings and facial fractures.[24-36] A high incidence of ocular injury has been noted in several studies.[28,30,32,34,37,38] However, most of these studies included injuries to the ocular adnexa, such as eyelid lacerations, and/or included extremely common but expected and less important findings such as subconjunctival edema and hemorrhage, and diplopia. To be sure, our sample had associated adnexal injuries and diplopia, but we decided to tabulate only those ocular injuries that might be expected to be the result of direct injury to the globe.

Our study showed that blowout fractures were associated with traumatic optic neuropathy in 3% of cases. Traumatic optic neuropathy may be due to many causes, including fracture of the optic canal or direct nerve injury. It is often difficult to positively identify the cause, even when it is associated with other ocular findings. For purposes of this investigation, we decided to eliminate cases of traumatic optic neuropathy when this was the only significant ocular finding. When traumatic optic neuropathy was associated with other ocular findings, we included the case for purposes of discussing the potential causes of blowout fractures.

Results of this study show that 22% of blowout fractures are associated with a positive ocular finding that can usually be related to a force directly applied to the ocular globe. This incidence is similar to that reported by other studies in the literature that examined blowout fractures.[24,35-37,39] Fortunately, most of

**Table 1. POSITIVE OCULAR FINDINGS IN 60 (OF 225) PATIENTS WITH ORBITAL BLOWOUT FRACTURES**

| | No. of Patients | Traumatic Mydriasis | Traumatic Iritis | Hyphema | Lens Dislocation | Commotio Retinae | Subretinal Hemorrhage | Vitreous Hemorrhage | Retinal Detachment | Choroid Rupture | Globe Rupture | Traumatic Optic Neuropathy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | 9 | | | | | | | | | | |
| | 8 | | | | | 8 | | | | | | |
| | 7 | | 7 | | | | | | | | | |
| | 7 | | | | | | | | | | | 7 |
| | 5 | | | 5 | | | | | | | | |
| | 3 | | | | | 3 | 3 | | | | | |
| | 3 | 3 | 3 | | | 3 | | | | | | |
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| | 1 | | | 1 | | 1 | | | | | | 1 |
| | 1 | 1 | | | | 1 | | | | | | |
| Total | 60 | 19 | 15 | 9 | 1 | 21 | 5 | 1 | 2 | 2 | 2 | 9 |

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the ocular injuries found in our sample were not severe or damaging. Traumatic mydriasis, iritis, and commotio retinae usually recover without any permanent deficit. Globe rupture, choroidal rupture, retinal detachment, and lens dislocation are more severe. These, plus hyphema, may restrict the ability of the surgeon to reconstruct the orbit until some time after injury has occurred, to allow initial healing or monitoring of the health of the globe. However, the most common ocular findings, such as commotio retinae, traumatic mydriasis, and traumatic iritis, by themselves or in combination would not usually prohibit the repair of orbital fracture soon after injury.

One might assume that the magnitude of forces in the hydraulic and globe-to-wall theories would also be damaging to the ocular globe. In fact, if one examines the literature on ocular trauma, all ocular findings listed in Table 1 (with the possible exception of traumatic optic neuropathy) are thought to be caused by a force applied directly to the globe. This is perhaps best exemplified by traumatic hyphema. Hyphema is blood in the anterior chamber of the eye, and it is a common manifestation of blunt trauma to the globe. Blunt ocular trauma causes stretching of limbal tissues, equatorial scleral expansion, posterior displacement of the lens/iris diaphragm, and acute elevation of intraocular pressure, with consequent tearing of tissues near the anterior chamber angle. The site of impact determines the distribution of damage within the eye. In most patients, the impact is focused on the cornea or limbus, with resultant damage to underlying vascular tissue. This leads to bleeding into the anterior chamber, and a fluid level of blood is often formed.

If the hydraulic or globe-to-wall theory is viable, one would expect a strong association between traumatic hyphema and orbital blowout fracture. Results of this investigation show that this association is not common. Only 9 blowout fractures (3.75%) were associated with traumatic hyphema. Similarly small percentages were reported by Jayamanne and Gillie (6.7%)[33] and by Brown et al (5.6%)[35] in their series of blowout fractures.

The most common ocular finding in our sample was a contusion injury of the retina known as commotio retinae (Fig 1). Ophthalmoscopically, commotio retinae appears as whitening of the retina caused by damage to the outer retinal layers from shock waves that traverse the eye from the site of impact.[40] Commotio retinae is most commonly seen in the posterior pole, but it can occur anywhere in the retina. One would also expect a direct relationship between blowout fracture and commotio retinae, but even though this was the most common ocular finding in our sample, it was present in only 9% of blowout fractures. Brown et al[35] found a slightly higher incidence of commotio retinae (14.8%) in their sample of 54 blowout fractures, but Jayamanne and Gillie[33] had an even smaller incidence in their sample of 45 blowout fractures (6.7%).

**FIGURE 1.** Left eye fundus after blunt trauma. Note the sheenlike retinal whitening of the retina (commotio retinae). Intraretinal hemorrhage is present in the fovea.

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Choroidal rupture reflects an injury that results in considerable distortion of the globe. Stretching of posterior segment tissues around their fixed attachment to the optic nerve head ruptures the choroids and may disrupt the overlying retina. These ruptures are usually concentric with the optic disc and may be multiple. Small ruptures can be present without major hemorrhage. In more extensive ruptures, bleeding from the torn capillaries occurs, resulting in a hematoma underneath the retina (subretinal hemorrhage). We found only 2 patients in our sample who had visible choroidal rupture (0.8%); 5 had subretinal hemorrhage (2%). It is likely that these 5 patients also had choroidal rupture, but the rupture was obscured at initial examination by the overlying subretinal hemorrhage.

Although the relatively small percentage of ocular injuries with blowout fractures found in this and other studies[1,2,24,27,29,31,33,35,41-43] does not refute the possibility that blowout fractures are the result of a direct force applied to the globe, these findings cast doubt on the theory that this is the main mechanism in most cases. Unfortunately, studies are not available that have determined how much force it takes to produce hyphema, commotio retinae, choroidal rupture, traumatic mydriasis or iritis, lens dislocation, and so forth. Some experimental evidence is available on the amount of energy necessary to rupture the globe, but it is difficult to relate these forces to the pressure necessary to cause blowout fractures.[44,45] It is likely, however, that a force sufficient to cause a blowout fracture by a hydraulic or globe-to-wall mechanism would be sufficient to cause significant intraocular injury. Green et al[8] found that rupture of the globe occurred in 23% of blowout fractures created by a force delivered to the globe of monkeys. This should not be surprising when one considers that the force was delivered directly to the globe. However, because globe rupture was seen in only 2 of our patients (0.83%), and because ocular injuries were present in only 22% of our cases, and most of these injuries were minor, one might suspect that another mechanism of blowout fracture occurs more commonly.

The most attractive alternate theory is the bone conduction theory, or "buckling" of the infraorbital rim that occurs when a force is applied directly onto it. Convincing evidence for this mechanism has been presented by Fujino[12] in experiments in which both skulls and models were used and consistent force was applied during monitoring with high-speed photography.[15,46] Fujino has shown that the force necessary to produce a blowout fracture by pressure exerted on the globe is 10 times greater than the pressure exerted on the infraorbital rim. He argues that this amount of force applied to the globe would cause a high incidence of ocular injury, but in his review of 101 blowout fractures, only 8 patients had iridocyclitis.[47]

However, one of the main criticisms of this theory is that it does not explain fractures of the medial wall.[20-22] One has to wonder whether a force delivered to the nose could produce fracture of the medial wall through the bone conduction mechanism. Given the thickness of the bone along the medial orbital rim, this would seem unlikely. Only 10 of 65 unilateral medial wall fractures were associated with nasal fractures (15.4%) in our study.

An interesting finding in our sample, however, is the presence of 15 bilateral blowout fractures. One has to wonder how one would receive 2 blowout fractures if one subscribes to the belief that they result from a direct force applied to the globe. In such cases, the unfortunate individual would have to have had something strike both globes at once, such as an automobile airbag, or perhaps each globe at different times, such as from multiple blows in an altercation. Seven of the bilateral fractures were caused by motor vehicle accidents, 7 were the result of assaults, and 1 was caused by a sporting accident. Unfortunately, details on the mechanisms of injury, such as airbag deployment, were not available.

It is interesting to note that 6 of 15 patients in our study with bilateral blowout fractures had associated nasal fractures, and 4 of these sustained fractures of the medial wall on at least 1 side. Two of them had bilateral fractures of the medial wall, 1 had a medial wall fracture on one side and a floor fracture on the other, and another had bilateral fractures of the floor/medial wall. Two fractures were caused by motor vehicle accidents and 2 by assaults.

So, although unilateral medial wall fractures were associated with nasal fractures only 15.4% of the time, bilateral blowout fractures that involved the medial wall on at least 1 side were associated with nasal fractures 66.7% of the time. Of 3 bilateral medial wall fractures, 2 had an associated nasal fracture (66.7%), and the cause in all 3 was a motor vehicle accident. CT scans showed that the nasal fractures were not naso-orbito-ethmoid fractures, and that the orbits had nonfractured medial orbital rims. This raises the question about the possibility of a bone conduction mechanism causing bilateral medial wall fractures. However, just as plausible is the possibility that a force was delivered across the entire midface, striking the nose and both globes at the same time, as may occur with the steering wheel of a car.

Another criticism that has been launched at the bone conduction theory is that it cannot easily explain how orbital soft tissues become displaced out of the orbit or entrapped within the fractured walls of the orbit.[20-22] In the hydraulic theory, it is clear how orbital soft tissues could become displaced and/or trapped within fractured bone fragments of the orbital walls by simple herniation from the increase in orbital pressure. Clinical evidence that supports the hydraulic theory for soft tissue entrapment is also offered by the proposed mechanism of "trapdoor" orbital fractures often seen in children.[48-51] In such cases, intraorbital pressure is thought to increase to the point that a linear or trapdoor fracture is created, and the orbital soft tissues are forced through. The elastic recoil of the bone is faster than that of the herniated soft tissue, so the soft tissue becomes trapped by the rapidly reapproximating bone edges (Fig 2). Fujino[15,47] has offered some support for the possibility of soft tissue entrapment with the bone conduction theory, using the same logic. With the use of high-speed photography, it was shown that when a sudden force is applied to the infraorbital rim of an epoxy model of the orbit, a linear fracture of the orbital floor occurs through buckling of the posteriorly displaced infraorbital rim. It was hypothesized that this tears the periorbita, and the orbital soft tissues are forced into the maxillary sinus by their attachment to the displaced orbital rim and floor, anterior to the linear fracture. Once the force is relieved, the bone springs back to the normal position, but the soft tissue does not return as quickly, causing entrapment within the fracture.

Although this "buckling" theory seems plausible, it is less clear how the bone conduction theory can result in the large displacement of orbital soft tissues that accompanies many orbital fractures. Most orbital fractures are comminuted, and multiple bone frag-

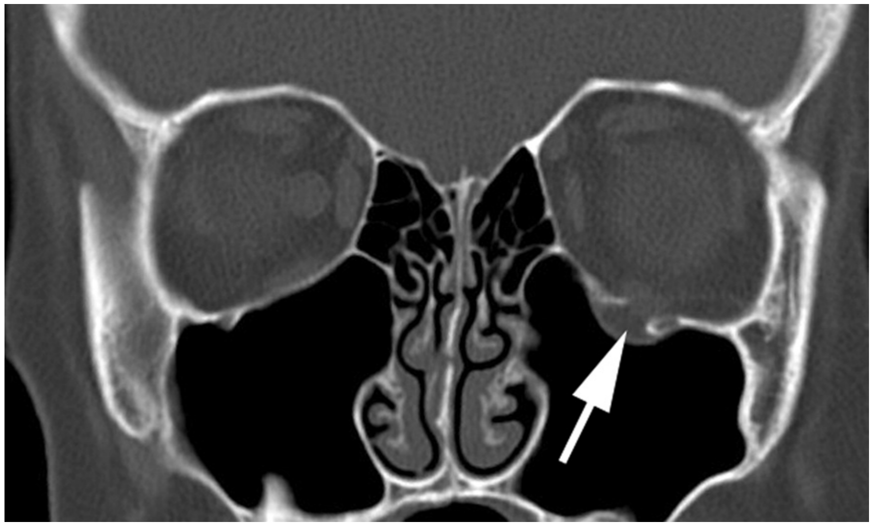

**FIGURE 2.** Coronal computed tomographic (CT) scan of a case where the inferior rectus muscle *(arrow)* is entrapped within the nondisplaced orbital floor fracture. This is an example of a trapdoor fracture with a positive forced duction test.

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ments are displaced, along with the orbital soft tissues, into the adjacent sinuses. For instance, the image in Figure 3 shows a large amount of orbital soft tissue displacement into adjacent sinuses. Although the bone conduction theory may explain the comminuted fracture, it is less clear how it can explain such a large amount of soft tissue displacement. Using his model, Fujino[15,47] demonstrated that when a larger force is applied to the infraorbital rim, a comminuted fracture of the orbital floor may result. He hypothesized that the orbital soft tissues that were displaced by posterior displacement of the infraorbital rim and anterior floor never return completely back into position once the force is relieved and the infraorbital rim and anterior floor spring back into position. He further hypothesized that periorbital edema that develops after injury causes an increase in hydraulic pressure within the orbit, and that this pressure, coupled with gravity, causes further displacement of orbital soft tissues into the sinuses.

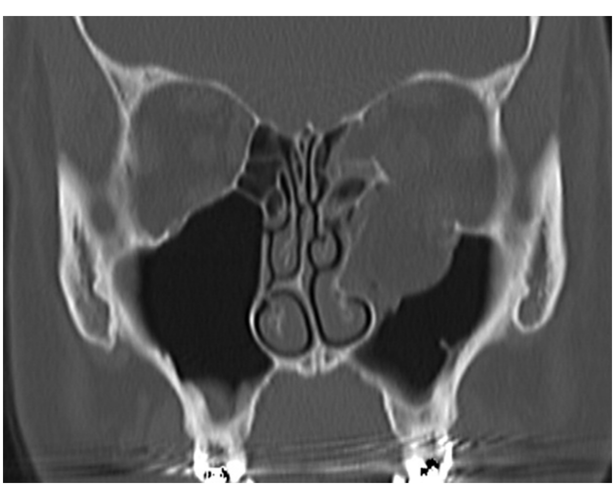

**FIGURE 3.** Coronal computed tomographic (CT) scan of a case of orbital floor (and partial medial wall) fracture(s) with a gross amount of orbital soft tissue herniation into the maxillary sinus.

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It is likely that all of the hypothesized mechanisms of orbital fractures occur in patients. Bullock et al[44] presented 2 cases of blowout fracture. One was clearly the result of a force applied directly to the globe, and the other was clearly the result of the force being applied to the orbital rim.[19] It is even more likely now that most blowout fractures that occur clinically result from a force that is delivered to both the globe and the bony orbital rims. This supposition is supported by the fact that the size of the striking force, such as a tennis ball, is almost always larger than the circumference of the orbital rim, necessitating that the object contact both the bony rim and the globe. It would therefore be extremely unlikely that a blow from a fist or contact with a dashboard would result in isolated contact with the globe. Contact with both the globe and the infraorbital rim would also more readily explain the extensive soft tissue herniation that often accompanies blowout fractures.

In summary, major ocular injuries are uncommon with orbital blowout fractures, but minor ocular injuries occur more frequently. "Sparing" of severe trauma to the globe makes the bone conduction theory, perhaps in combination with the hydraulic and globe-to-wall theories of the blowout fracture mechanism, more attractive.

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