Similarity in Bilateral Isolated Internal Orbital Fractures

Hung-Chang Chen, M.D., Jacob T. Cox, M.Phil.†, Abanti Sanyal, M.S.‡, Nicholas R. Mahoney, M.D.§*

**Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, College of Medicine, Chang Gung University, Taipei, Taiwan; †School of Medicine, Johns Hopkins University, Baltimore, Maryland, U.S.A.; ‡Department of Biostatistics, Johns Hopkins School of Public Health, Johns Hopkins University, Baltimore, Maryland, U.S.A.; §Department of Ophthalmology, Wilmer Eye Institute, Johns Hopkins University, Baltimore, Maryland, U.S.A.*

Purpose: In evaluating patients sustaining bilateral isolated internal orbital fractures, the authors have observed both similar fracture locations and also similar expansion of orbital volumes. In this study, we aim to investigate if there is a propensity for the 2 orbits to fracture in symmetrically similar patterns when sustaining similar trauma.

Methods: A retrospective chart review was performed studying all cases at our institution of bilateral isolated internal orbital fractures involving the medial wall and/or the floor at the time of presentation. The similarity of the bilateral fracture locations was evaluated using the Fisher's exact test. The bilateral expanded orbital volumes were analyzed using the Wilcoxon signed-rank test to assess for orbital volume similarity.

Results: Twenty-four patients with bilateral internal orbital fractures were analyzed for fracture location similarity. Seventeen patients (70.8%) had 100% concordance in the orbital subregion fractured, and the association between the right and the left orbital fracture subregion locations was statistically significant ($P < 0.0001$). Fifteen patients were analyzed for orbital volume similarity. The average orbital cavity volume was $31.2 \pm 3.8\,cm^3$ on the right and $32.0 \pm 3.7\,cm^3$ on the left. There was a statistically significant difference between right and left orbital cavity volumes ($P = 0.0026$).

Conclusions: The data from this study suggest that an individual who suffers isolated bilateral internal orbital fractures has a statistically significant similarity in the location of their orbital fractures. However, there does not appear to be statistically significant similarity in the expansion of the orbital volumes in these patients.

(*Ophthal Plast Reconstr Surg* XXX;XX:00–00)

The orbits, like many other paired structures in the human body, develop with significant bilateral symmetry.[1] Unilateral blunt orbital trauma can fracture the orbital bones and create asymmetry as the fractures of the thin bones of the orbital floor and the medial wall are displaced into the adjacent sinus cavities.[2]

While caring for cases of bilateral orbital bony trauma at our institution, we noted an apparent symmetry in the location of the left and right orbital fractures, and apparent bilateral similarity in the postinjury orbital volumes (Fig. 1). Our primary aim is to systematically evaluate the propensity of bilateral orbits to fracture in similar patterns when sustaining similar trauma. Our secondary outcome was to assess for bilateral similarity in the postinjury orbital volumes in such cases.

Accepted for publication February 14, 2018.

Presented at the 2017 ASOPRS Fall Symposium as a poster on November 10, 2017 in New Orleans, LA.

The authors have no financial or conflicts of interest to disclose.

Address correspondence and reprint requests to Nicholas R. Mahoney, M.D., Wilmer Eye Institute, Johns Hopkins University, 600 N Wolfe St, Maumenee 505, Baltimore, MD 21287. E-mail: nick.mahoney@jhmi.edu

DOI: 10.1097/IOP.0000000000001117

MATERIALS AND METHODS

The study was compliant with the Health Insurance Portability and Accountability Act of 1996 approved by the Johns Hopkins Hospital Institutional Review Board. A retrospective chart review was performed studying all cases with a diagnosis of orbital fracture seen by the Department of Ophthalmology at the Johns Hopkins Hospital from April 2013 to May 2017. Patients were included for review if they had radiologically confirmed bilateral isolated internal orbital fractures involving the medial wall and/or the floor at the time of presentation. The selected cases had either simultaneous bilateral or sequential unilateral blunt orbital trauma. We intended to study the location and morphology of the fractures occurring with classic "blow-out,"that is, injuries with fractures from isolated blunt orbital trauma and expansion of the volume from displacement of the pressurized internal orbital contents. High-velocity injuries with asymmetrical mechanisms of bilateral panfacial damage were thus excluded—such as those of the rim, zygomaticomaxillary complex, or naso-orbitoethmoidal fractures. Given the goal of studying displaced fracture segment morphology, we excluded fractures if both fractures were nondisplaced.

Evaluation of Bilateral Similarity in Fracture Location. Computed tomography images of these patients were collected, and the subregional locations of the fractures were recorded according to the AOCMF classification system - Level 3: Orbital Fractures (Fig. 2).[3] The subregions of the medial orbital wall and orbital floor were defined as follows:

1. Anterior orbit: from the orbital rim to the anterior loop of the inferior orbital fissure (IOF).
2. Midorbit: between the anterior loop of the IOF to the confluence of the IOF and the superior orbital fissure.
3. Apex: from the confluence of the IOF and superior orbital fissure to the optic canal.

The subregional locations of the orbital fractures were examined independently by a plastic surgeon (H.C.C.) and an oculoplastic surgeon (N.R.M.), and then a consensus discussion was held. Bilateral similarity in fracture location was evaluated using the Fisher's exact test.

Evaluation of Bilateral Similarity in Postinjury Orbital Volume. If CT images were obtained with a slice thickness of 0.5 mm or less, the images were included in orbital volume analysis. Most pediatric cases had slice thickness exceeding this threshold, and because a fracture might alter the growth pattern of the orbit if it was still growing, we opted to exclude the few remaining.[4,5] We used the iPlan software package (ver. ENT 3.0, Brainlab, Feldkirchen, Germany) to generate the 3D reconstruction of the bilateral orbital volumes.

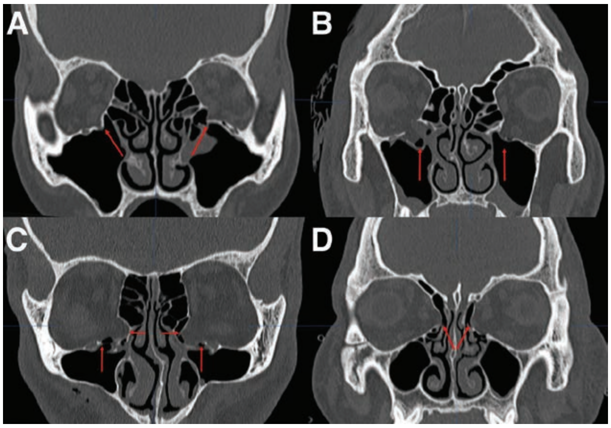

FIG. 1. Four cases demonstrating similarity of bilateral isolated internal orbital fractures. **A** and **B**, Bilateral orbital floor fractures. **C**, Bilateral orbital floor and medial wall fractures. **D**, bilateral medial wall fractures.

Atlas-based automatic segmentation was performed first using the iPlan software to generate the internal orbital cavity.[6] This automatic segmentation is easy and fast, but it usually includes a portion of the surrounding bone, sinuses, and internal orbital fissure, which overestimates the volume. Therefore, a manual adjustment was performed after automatic segmentation by using the "smart shaper" tool and eraser.[7] The "smart shaper" tool recontours the segmented orbital volume in 3D by working on a 2D slice to facilitate volume adjustment. The eraser can remove residual volume outside the orbit carefully after smart shaper adjustment. The resultant expanded orbital volumes were analyzed using the Wilcoxon signed-rank test to evaluate for bilateral symmetry.

RESULTS

A total of 949 cases of orbital fractures with available CT scans were evaluated. Of these, 24 cases demonstrated bilateral isolated internal fractures and were reviewed in detail. Fifteen patients (62.5%) suffered simultaneous bilateral fractures, while 9 patients (37.5%) suffered sequential fractures. Four patients underwent orbital fracture repair.

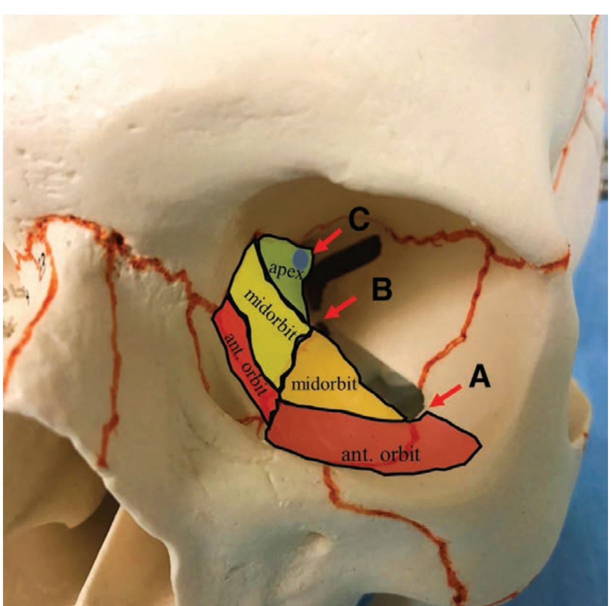

FIG. 2. The subregions of the medial orbital wall and orbital floor. **A**, Loop of the IOF. **B**, The confluence of the IOF and the SOF. **C**, The optic canal. IOF, inferior orbital fissure; SOF, superior orbital floor.

Evaluation of Bilateral Similarity in Fracture Location. Of the 24 patients included in fracture location analysis, 20 (83.3%) were male and 4 (16.7%) were female. The average age was 36 ± 15 years (range, 4–59). The timing of each injury was obtained by reviewing available patient history and with radiographic clues such as a lack of blood in the ethmoid/maxillary sinus and rounded edges of prolapsed orbital contents. Seventeen patients (70.8%) had 100% concordance in their subregions of orbital fracture (8 bilateral isolated orbital floor fractures, 7 bilateral isolated medial orbital wall fractures, and 2 combined orbital floor and medial orbital wall fractures). Fisher's exact testing indicated that there was a statistically significant association between the right and the left orbital fracture subregion locations ($P < 0.0001$; Table 1).

There were 15 patients who suffered bilateral internal orbital fractures due to physical assault without a weapon. Twelve (80%) of these cases had 100% concordance in the orbital fracture subregion (7 bilateral isolated orbital floor fractures, 4 bilateral isolated medial orbital wall fractures, and 1 combined orbital floor and medial orbital wall fracture).

Evaluation of Bilateral Similarity in Postinjury Orbital Volume. Fifteen patients (13 males and 2 females) were included in orbital volume evaluation. The average age was 36 ± 15 years (range, 20–59). The average orbital cavity volume was $31.2 \pm 3.8\,cm^3$ on the right and $32.0 \pm 3.7\,cm^3$ on the left. The Wilcoxon signed-rank test demonstrated a statistically significant difference between right and left orbital cavity volumes ($P = 0.0026$), with the left orbital cavity volume larger than the right orbital cavity volume (Table 2).

DISCUSSION

A number of human organs and tissues demonstrate symmetry across the midsagittal plane, such as the limbs, eyes, nares, and pinnae.[8] The orbits demonstrate such symmetry. They also have structurally weak points that are vulnerable to fracture, such as at the infraorbital canal or the lamina papyracea.[9] In this study, we sought to determine if there is a predilection for bilateral orbital fractures to occur not only at the same vulnerable points but also with similar expanded orbital volumes. We found that bilateral isolated internal fractures of the floor and/or medial wall have a statistically significant degree of symmetrical concordance in subregional location. However, quantitative assessment of postinjury orbital volumes demonstrated a statistically significant difference between sides, with left orbits generally having greater volumes than right orbits.

When blunt force is applied to the globe and orbit, a displaced internal orbital fracture can occur. In our series, this was exclusively in the anterior and/or middle orbit with all the orbital fractures involving the anterior orbit to some extent and none involving the apex. There are 2 proposed mechanisms for the occurrence of the displaced internal orbital fracture, also called a "blow-out fracture": the hydraulic theory and the buckling theory.[10,11] The buckling theory suggests that the direct trauma to the orbital rim transmits force posteriorly and creates a compression fracture of the orbital floor or wall. The hydraulic theory suggests that the globe is retropulsed by a force, which elevating the intraorbital pressure and transmitting the force to the orbital floor or walls, leading to fracture. It is likely that both the buckling theory and the hydraulic theory happen to some extent in the formation of a blow-out fracture, with the hydraulic element being responsible for the degree of bone displacement. The orbital rim aperture and the relative globe position may

TABLE 1. Bilateral Orbital Fracture According to Subregions Involved

Case	Age	Gender	Right Orbital Floor	Left Orbital Floor	Right Medial Orbital Wall	Left Medial Orbital Wall
1	40	Female			ant., mid.	ant., mid.
2	23	Male			ant., mid.	ant., mid.
3	20	Female	ant.	ant.		ant.
4	45	Male	ant., mid.	ant., mid.		
5	16	Male		ant., mid.	ant., mid.	ant., mid.
6	20	Male			ant.	ant.
7	4	Female			ant., mid.	ant., mid.
8	31	Male			ant., mid.	ant., mid.
9	59	Male	ant., mid.	ant., mid.		ant.
10	59	Male			ant., mid.	ant.
11	51	Male	ant., mid.	ant., mid.		
12	31	Male	ant., mid.	ant., mid.	ant., mid.	ant., mid.
13	34	Male	ant., mid.	ant., mid.		
14	39	Male	ant., mid.	ant.	ant.	ant., mid.
15	24	Male	ant., mid.	ant.		ant., mid.
16	59	Male			ant., mid.	ant., mid.
17	56	Male	ant., mid.	ant., mid.		ant., mid.
18	35	Male	ant., mid.	ant., mid.		
19	35	Male	ant., mid.	ant., mid.		
20	50	Male	ant., mid.	ant., mid.		
21	33	Male	ant., mid.	ant., mid.	ant.	ant.
22	39	Female	ant., mid.	ant., mid.		
23	39	Male	ant.,	ant.		
24	32	Male			ant., mid.	ant., mid.
Average	36.4					
SD	14.5					

Shading indicates 100% same bilateral subregions of orbital fractures. Association between right and left orbital fracture subregions using Fisher's exact test ($P < 0.0001$).

Ant., anterior orbit; mid., midorbit; SD, standard deviation.

TABLE 2. Bilateral Postinjury Orbital Volumes and Width of CT Slices

Case	Age	Gender	Right Orbital Cavity Volume (cm^3)	Left Orbital Cavity Volume (cm^3)	CT Slice Distance (mm)
1	40	Female	22.43	24.69	0.500
2	23	Male	32.40	31.87	0.500
3	20	Female	25.06	26.33	0.500
4	45	Male	31.15	32.08	0.500
5	16	Male	33.77	34.76	0.500
6	20	Male	28.92	28.68	0.499
7	31	Male	31.17	31.93	0.500
8	59	Male	28.64	29.06	0.499
9	59	Male	29.48	29.88	0.499
10	51	Male	32.87	33.18	0.208
11	31	Male	34.95	37.02	0.500
12	34	Male	33.12	33.50	0.500
13	39	Male	36.63	37.25	0.500
14	24	Male	34.46	35.65	0.233
15	59	Male	33.47	34.58	0.499
Average	36.7		31.23	32.03	0.462
SD	15.1		3.81	3.72	0.098

Difference between right and left postinjury orbital volumes using Wilcoxon signed-rank test ($P = 0.0026$; left > right).

Ant., the anterior orbit; mid, the midorbit; SD, standard deviation.

affect the degree of contact with the globe itself, thus affecting the degree of increased orbital pressurization. We hypothesize that the similar amounts of bone displacement in our study was related to this phenomenon.

Only 4 patients received surgical repair in this study. In our opinion, cases with bilateral injuries that are highly symmetric are not likely to develop relative enophthalmos, but we do not have long-term follow up with exophthalmometry to draw this conclusion with strong evidence. In our practice, patients with naturally prominent globes or shallow midfaces are treated with observation if extraocular motility is full. Conversely, 2 of the 4 operative cases had naturally deep-set globes at baseline, so bilateral repair was recommended in the setting of bilateral acute injuries. When performing repair bilaterally, bilateral preformed anatomic plates can aid in choosing a target orbital contour (Fig. 3). The other 2 cases underwent unilateral repairs

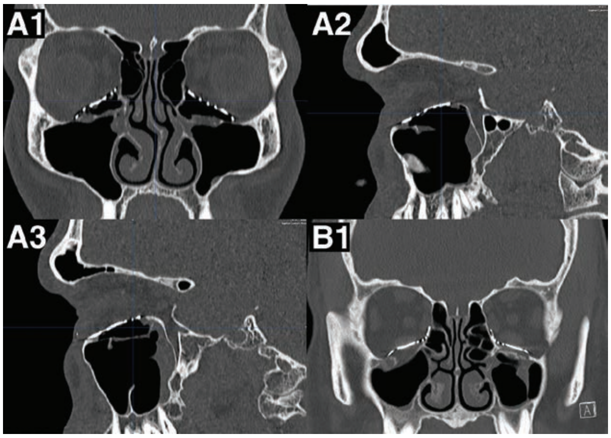

FIG. 3. Two patients demonstrating bilateral orbital floor and medial wall fractures repaired using preformed anatomic plates. A1, A2, A3: coronal view and bilateral sagittal view of 1 patient; B1: coronal view of another patient.

in the setting of sequential injuries, with the surgical indication being strabismus. Of the 20 nonoperative cases, 2 had motility restriction at presentation; 1 was lost to follow up, whereas the other refused surgery, demonstrated partial motility improvement, and then was also lost to follow up.

In a study published earlier this year, Patel et al.[12] measured 87 orbital floors to establish the mean orbital floor thickness and generate an orbital floor thickness map. The medial portion of the anterior orbit has the thinnest mean orbital floor thickness and may thus be more vulnerable to fracture during orbital trauma. Our study also demonstrates consistent involvement of this location in the anterior orbit any cases of isolated midorbit fractures. The bony structure around the apex is generally thicker than the orbital floor and the medial orbital wall. Apex fractures usually occur in association with or as extension of complicated facial fractures, skull base fractures, or cranial fractures. These complicated fractures were excluded in this study as detailed above.

Although prior studies have not demonstrated a statistically significant difference in normal left and right orbital volumes, some publications suggest a contralateral orbital volume discrepancy of up to 8%.[13–17] We expected that after bilateral isolated internal orbital fractures, there might be bilateral orbital volumes expansions of similar magnitude. The results in this study did not support this, and we found a significant difference between the bilateral orbital volumes after bilateral isolated internal orbital fractures. Given preexisting volume asymmetry, we speculate that bilateral orbital volume expansion after injury might actually increase the discrepancy through an amplification effect though we did not have preinjury volume assessments to make this conclusion. In addition, bilateral orbits might suffer from different impact forces during trauma. Though different impact forces cause similar fracture locations over bilateral orbits, differences in hydraulic pressure would also lead to volume expansion differences after bilateral orbital fractures.

This study is limited by its retrospective nature. As an accurate history and long term follow up are often lacking in trauma cases, the retrospective series limits are ability to draw conclusions on outcomes. Although our sample size was modest, to measure the volume accurately, we had to narrow the volume assessment cohort size to exclude 9 patients who had images obtained with CT slice thickness > 0.5 mm. Because many of the patients with larger slice thickness were pediatric cases, we have limited volume conclusions in the pediatric population. Finally, we have no way of measuring the preinjury volumes of the patients studied to determine if a degree of volume asymmetry was preexisting.

CONCLUSION

In this study, we assess for bilateral similarity in fracture location and postinjury orbital volume in cases of bilateral isolated internal orbital fractures. It appears that such fractures demonstrate a statistically significant similarity in fracture location, but not in postinjury expanded orbital volume. This phenomenon offers insight to treating physicians that new onset unilateral internal orbital fractures may have similar fracture locations to an old fracture in the contralateral orbit. In addition, we hypothesize that a given person's orbital configuration predisposes him or her to a particular pattern of injury from the combination of buckling and hydraulic forces that occur in the orbit as a result of injury. Further studies might be useful to understand what features of a given orbit predispose it to a given injury pattern. These features, in turn, may have implications for the selection of procedures in complex craniofacial reconstruction and orbital decompression surgery.

REFERENCES

1. Thiesen G, Gribel BF, Freitas MP. Facial asymmetry: a current review. *Dental Press J Orthod* 2015;20:110–125.
2. Smith B, Regan WF, Jr. Blow-out fracture of the orbit; mechanism and correction of internal orbital fracture. *Am J Ophthalmol* 1957;44:733–739.
3. Kunz C, Audigé L, Cornelius C, et al. The comprehensive AOCMF classification system: orbital fractures—level 3 tutorial. *Craniomaxillofac Trauma Reconstr* 2014;7(suppl 1):S92–S102.
4. Furuta M. Measurement of orbital volume by computed tomography: especially on the growth of the orbit. *Jpn J Ophthalmol* 2001;45:600–606.
5. Chau A, Fung K, Yip L, et al. Orbital development in Hong Kong Chinese subjects. *Ophthalmic Physiol Opt* 2004;24:436–439.
6. Simmat I, Georg P, Georg D, et al. Assessment of accuracy and efficiency of atlas-based autosegmentation for prostate radiotherapy in a variety of clinical conditions. *Strahlenther Onkol* 2012;188:807–815.
7. Jansen J, Schreurs R, Dubois L, et al. Orbital volume analysis: validation of a semi-automatic software segmentation method. *Int J Comput Assist Radiol Surg* 2016;11:11–18.
8. Tamir A. Quantitative analysis of face symmetry. *J Craniofac Surg* 2015;26:1268–1269.
9. Yen MT. *Surgery of the Eyelid, Lacrimal System, and Orbit*. 2nd ed. Oxford University Press, Inc., 2012 Chapter 16, page 206.
10. Pfeiffer RL. Traumatic enophthalmos. *Trans Am Ophthalmol Soc* 1943;41:293–306.
11. Tessier P. The classic reprint: experimental study of fractures of the upper jaw, I and II: Rene Le Fort, M.D. *Plast Reconstr Surg* 1972;50:497–506.
12. Patel S, Andrecovich C, Silverman M, et al. Biomechanic factors associated with orbital floor fractures. *JAMA Facial Plast Surg* 2017;19:298–302.
13. Forbes G, Gehring D, Gorman C, et al. Volume measurements of normal orbital structures by computed tomographic analysis. *Am J Neuroradiol* 1985;6:419–424.
14. Furuta M. Measurement of orbital volume by computed tomography: especially on the growth of the orbit. *Jpn J Ophthalmol* 2001;45:600–606.
15. Cooper WC. A method for volume determination of the orbit and its contents by high resolution axial tomography and quantitative digital image analysis. *Trans Am Ophthalmol Soc* 1985;83:546–609.
16. Shyu VB, Hsu CE, Chen CH, et al. 3D-assisted quantitative assessment of orbital volume using an open-source software platform in a Taiwanese population. *PLoS One* 2015;10:e0119589.
17. Parsons GS, Mathog RH. Orbital wall and volume relationships. *Arch Otolaryngol Head Neck Surg* 1988;114:743–747.