Muscle Shape as a Predictor of Traumatic Enophthalmos

Genevieve Chiasson, D.M.D.,[1] and Damir B. Matic, M.D., M.Sc., F.R.C.S.C.[1,2,3]

ABSTRACT

The literature on enophthalmos is reviewed to understand its etiology and its prevention following orbital fractures. Specifically, the importance of muscle shape changes in predicting enophthalmos is discussed. The indications for surgical repair of orbital blowout fractures are well established. However, 7 to 10% of patients still develop enophthalmos despite these criteria. Because late repair of enophthalmos is associated with poor esthetic and functional results, the sensitivity and specificity of the current indications need to be further improved. Increased orbital volumes after fracture together with soft tissue displacement and herniation are the two most important factors causing enophthalmos. The loss of both bone and periorbita as supporting structures is seen on coronal computed tomography scan as changes in shape of the extraocular muscles. In floor fractures, the inferior rectus changes from an ellipse to a more rounded shape. The same is true for the medial rectus in medial wall fractures. It is the degree of rounding measured as a ratio of height to width that has been shown to be predictive of enophthalmos. Therefore, because rounding signifies loss of bone and soft tissue support, it may be a more important indication for surgical intervention than fracture size alone.

KEYWORDS: Orbital floor fracture, enophthalmos, inferior rectus muscle, medial rectus muscle, blowout fracture, muscle rounding

Smith and Regan first coined the term *orbital blowout fracture* in 1957 to describe isolated fractures of the orbital floor after an impact to the globe and orbit.[1] Common symptoms of blowout fractures include pain, swelling, and diplopia. Some patients also develop enophthalmos in which the globe is retropositioned within the orbit. Clinical signs include deepening of the supratarsal fold, a decrease in interfissural distance, pseudoptosis, and retropositioning of the globe with a component of vertical dystopia (Figs. 1A and B). Enophthalmos can occur either acutely after fracture or late, several months following injury. Biesman et al[2] showed that the frequency of late enophthalmos doubled when the fracture involved both the orbital floor and medial wall versus the orbital floor alone. This related the development of enophthalmos to fracture size and displacement. They also suggested that a greater force was needed to create this type of fracture resulting in more significant periorbital tissue injury and soft tissue displacement.[2] Prior to this, Manson et al found that orbital fractures alone did not predispose to enophthalmos. Only when floor fractures resulted in orbital soft tissue shape change, displacement, or herniation did the incidence of enophthalmos rise.[3,4]

[1]Division of Plastic and Reconstructive Surgery; [2]Division of Paediatric Surgery; [3]Department of Paediatrics, University of Western Ontario, London, Canada.

Address for correspondence and reprint requests: Damir B. Matic, M.D., M.Sc., F.R.C.S.C., London Health Sciences Center–Westminster Campus, Room E1-332, 800 Commissioner's Road E, London, ON, Canada N6A 5W9 (e-mail: damir.matic@lhsc.on.ca).

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Figure 1 (A) Close-up frontal view of eyes of patient with left-sided posttraumatic enophthalmos. Clinical signs include deepening of the supratarsal fold, a decrease in interfissural distance, pseudoptosis, and retropositioning of the globe with vertical dystopia. (B) Close-up worm's-eye view of patient with left-sided posttraumatic enophthalmos showing significant retrodisplacement of left globe.

ENOPHTHALMOS

Several theories have been proposed to describe the pathophysiology of enophthalmos. They include an increase in orbital volume, herniation of periorbita into the maxillary/ethmoid sinuses, loss of periorbital ligamentous support, orbital fat atrophy, and scar contracture.[3–5] In reality, more than one, if not all, of these factors likely contribute to the development of enophthalmos.

Many have noted that the incidence of longstanding diplopia and enophthalmos could be prevented with surgical exploration and repair of the bone defect.[3,6–15] As a result, indications for early orbital floor surgery were determined and are currently well established. These indications include persistent diplopia (>2 weeks) with indices of entropy of perimuscular structure or significant sagging of the muscle, cosmetically acceptable enophthalmos of >2 mm, clinical or radiographic signs of muscle entrapment, size of fracture greater than 2 cm^2 on computed tomography (CT) scan or measuring more than half of the floor, and persistent oculocardiac reflex.[4–9,11,16–18]

Despite these indications, however, 7 to 10% of patients who are not operated on because they do not meet these criteria develop enophthalmos.[5–7,9] This is significant as the correction of late enophthalmos is associated with inferior functional and esthetic results as well as an increased incidence of complications such as blindness or worsening diplopia. Alternatively, the number of patients who have early surgery based on the established criteria but who actually would not have needed surgery is currently unknown. Further indications for early surgery therefore need to be identified to reduce both these risks.

Several authors have focused on the degree of periorbital tissue herniation and increased orbital volumes as possible criteria.[3,4,17,19,20] Harris et al looked at the severity of soft tissue herniation in proportion with the width of the defect. They suggested that when the periorbita was displaced greater than the displacement of the fracture segment or when the floor defect was greater than half of the orbital floor, surgery should be performed. Surgery in these cases would avoid intrinsic fibrosis and contraction of the periorbita, which could lead to enophthalmos.[19]

ROUNDING OF THE INFERIOR RECTUS MUSCLE

Disruption of orbital periosteum and subsequent soft tissue herniation can cause a change in the position and resting shape of the extraocular muscles. These changes can be seen as shape changes in the muscles on coronal CT scans.[5,8,9,13,19,21] Few authors have studied the change in shape of the extraocular muscles after orbital floor fracture. Gilbard et al evaluated the position of the inferior rectus muscle as it related to the fracture site on coronal CT. They found that when both muscle edges were in contact with bone, the shape of the muscle would change. Surgery was indicated in these cases to decrease the risk of diplopia. These muscle shape changes, however, were not found to correlate with the development of enophthalmos.[22] Most likely this is because the shape changes were related to direct muscle impingement or entrapment by the underlying bony fractures and not a result of fracture size or soft tissue herniation.

Levine et al proposed that soft tissue edema alone or together with intramuscular and perimuscular hemorrhage could cause the shape of the inferior rectus muscle to change from elliptical to round on coronal CT.[21] Alternatively, others have hypothesized that rounding occurs because of disruption of orbital periosteum, which subsequently leads to periorbital herniation into the maxillary sinus.[5,8,9] These opposing theories were tested by Banerjee et al in a cadaveric study.[8] They showed that progressively larger orbital floor defects resulted in ptosis of orbital soft tissue into the maxillary sinus. The inferior rectus muscle was seen to progressively round on coronal CT as the size of the floor defect increased. Interestingly, this rounding increased further when the orbital periosteum was disrupted in addition to the floor fracture. They concluded that inferior rectus rounding on coronal CT scan reflects both orbital floor fracture size and loss of orbital soft tissue support.[8]

These cadaveric findings confirm that rounding of the inferior rectus muscle on CT scan can occur without edema or hemorrhage and be purely due to loss of both bone and soft tissue support. This is further supported clinically on postoperative CT scans taken after floor repair. The shape of the inferior rectus muscle can be seen to normalize even 1 day postoperatively (Figs. 2A and 2B).

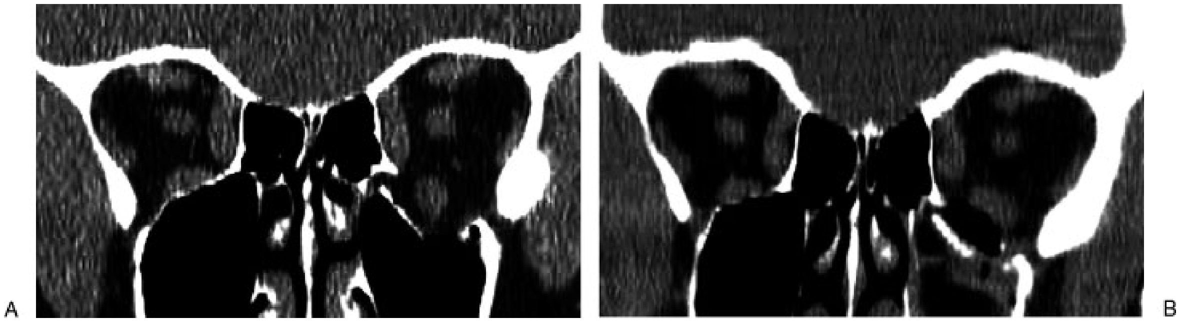

Figure 2 (A) Coronal computed tomography (CT) scan of acute left-sided orbital floor fracture showing significant rounding of inferior rectus muscle as compared with the uninjured right side. (B) Coronal CT scan 1 day postoperatively after left-sided orbital floor fracture repair with 1-mm polyethylene sheet. A return of the elliptical shape of the inferior rectus muscle can be seen as compared with the right uninjured side and as compared with its preoperative shape seen in Fig. 2A. This suggests that muscle rounding after injury is not just due to muscle swelling or hemorrhage.

Recently our center published a study evaluating the long-term outcomes of patients with orbital floor fractures that were treated by observation and no surgery.[9] The purpose was to determine whether rounding of the inferior rectus muscle on initial coronal CT scan is predictive of the development of late enophthalmos. In a blinded experiment, radiologists independently evaluated all CT scans for fracture size, location, and presence of inferior rectus rounding. Seventy-eight patients were identified with rounding of the rectus and 18 were available for clinical evaluation at least 6 months postinjury. None of the patients had surgical intervention. Clinical evaluations documented the presence of primary gaze diplopia and/or enophthalmos greater than 2 mm.[9]

We found that all patients with enophthalmos had rounding of the inferior rectus muscle in which the cross-sectional height of the muscle was greater than or equal to its width. The muscle was seen therefore to be either perfectly round or a vertical ellipse. Cross-sectional rounding was measured posterior to the globe on the coronal CT slice in which the largest diameter of the fracture was seen. An example is seen in Figs. 3A to 3C in which the patient presents with late enophthalmos and has a height-to-width ratio of 1.38. Most patients in this study also had rounding but not to this degree. It is interesting to note that in these cases, there was little periorbital soft tissue herniation within the maxillary sinus (Fig. 4). The rounding seen in cases without enophthalmos was likely due to edema or hemorrhage. Furthermore, the incidence of diplopia in this study was unrelated to either the degree of muscle rounding or the presence of enophthalmos.[9]

Using the same data set with the same sample of 18 patients, we measured surface area of all the orbital floor fractures using coronal CT slices in an attempt to

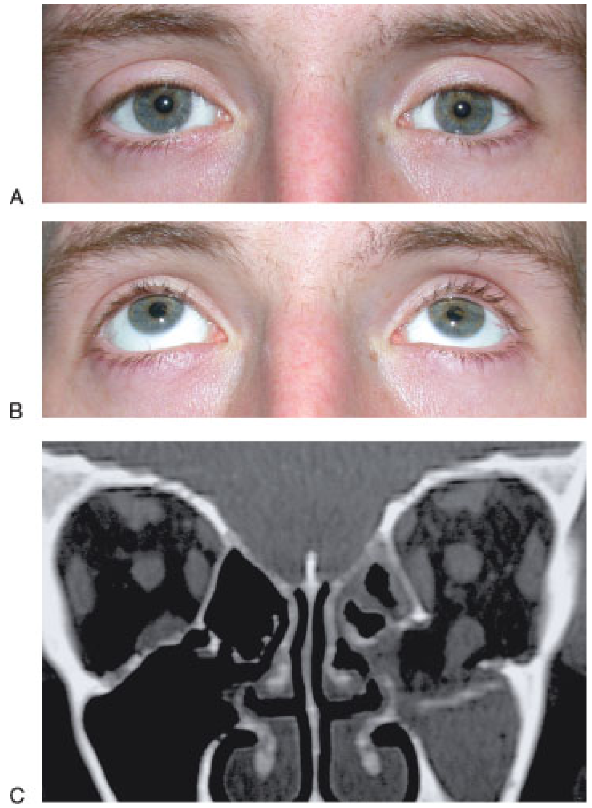

Figure 3 (A) Close-up frontal view of patient with post-traumatic enophthalmos following left-sided orbital floor fracture. Patient had no surgery. (B) Close-up worm's-eye view of same patient as in Fig. 3A with left-sided enophthalmos. (C) Coronal computed tomography scan of same patient as seen in Figs. 3A and 3B performed acutely after fracture showing rounding of the inferior rectus muscle with a height-to-width ratio of greater than 1 (1.38). A significant change in shape can be seen on the involved side as compared with the uninjured side in which the inferior rectus muscle retains its elliptical shape.

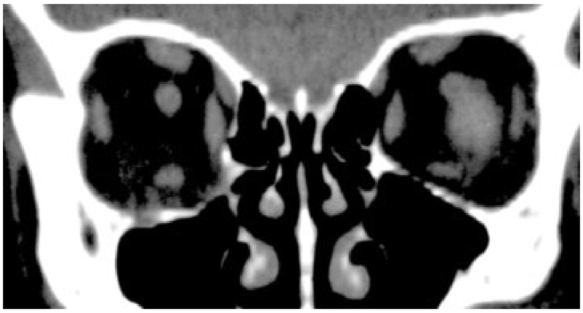

Figure 4 Coronal computed tomography scan of patient with right-sided orbital floor fracture showing some rounding of the inferior rectus muscle. Rounding in this case was not significant (height-to-width ratio <1). Minimal soft tissue herniation into the maxillary sinus is seen. This patient did not have surgery and did not develop enophthalmos.

correlate orbital floor fracture size to degree of inferior rectus muscle rounding (Table 1). Five of 18 patients had floor fractures greater than 2 cm^2, which would have led to early surgical correction based on established criteria. Three of these patients also had rounding of the inferior rectus muscle with a ratio greater than 1. However, only two of these three patients developed late enophthalmos. Therefore, if we only used the existing, established indications for surgery, three additional patients would have needlessly undergone surgical exploration to prevent enophthalmos compared with only one using a rounding ratio >1 as a criterion.

The patient with the largest defect (6.30 cm^2) did not have enophthalmos (Figs. 5A to 5C). This may have been either due to minimal soft tissue herniation or to an undisplaced medial orbital buttress (uncinate process of the maxilla), which remained in position, supporting the soft tissues (Fig. 5C). This finding of a large bony defect without significant enophthalmos further supports Manson and colleagues' assertion that fracture size alone does not predict the occurrence of enophthalmos.[3,4] Both soft tissue disruption and orbital fracture are necessary prerequisites for the development of enophthalmos as well as perhaps displacement of the medial orbital buttress. Therefore, significant rounding of the inferior rectus on coronal CT scan is a more sensitive indication for early surgical repair than the size of floor fracture alone.

No patient had significant muscle rounding with floor fractures less than 2 cm^2 in this study. When there is a small fracture with significant orbital tissue herniation, the risk of muscle or soft tissue entrapment increases, leading to significant diplopia necessitating exploration. If this is true, then these patients would have been operated on in our center and so did not meet the inclusion criteria of the study.

Jin et al reported on medial wall fractures.[17] They found that worsening enophthalmos was seen when both the size of the medial wall defect and the amount of orbital tissue herniation increased.[17] Further, Kim et al evaluated the shape of the medial rectus muscle in patients with medial orbital wall fractures. They showed that a height-to-width ratio of the medial rectus muscle greater than 0.7 was a predictor of enophthalmos.[5]

Table 1 Correlation of Orbital Fracture Size to Posttraumatic Enophthalmos and Inferior Rectus Muscle Height-to-Width Ratio

Patient ($n = 18$)	Maximum Defect Width (mm)	Maximum Defect Length (mm)	Surface Area of Defect (cm^2)	Presence of Enophthalmos (>2 mm)	Inferior Rectus Muscle Ratio (Height:Width) of Affected Orbit
G.M.	18	14.5	2.61	No	1.00
K.H.	15	11.6	1.74	No	0.50
K.M.	14	9.3	1.30	No	0.50
R.S.	12	11.6	1.39	No	0.73
S.T.	20	7.2	1.44	No	0.89
B.F.	35	18	6.30	No	0.67
J.D.	5	8.7	0.44	No	0.69
G.S.	17	8.7	1.48	No	0.58
A.H.	20	9	1.80	No	0.90
D.M.	15	10	1.50	No	0.64
A.L.	10	5.9	0.59	No	0.44
P.G.P.	18	16.5	2.97	No	0.55
B.W.	5	9	0.45	No	0.62
M.B.	13	9	1.17	No	0.71
E.C.	22	8.4	1.84	No	0.80
M.K.	10	5.8	0.58	No	0.50
D.A.	20	29	5.80	Yes	1.38
L.W.M.	12	24	2.88	Yes	1.00

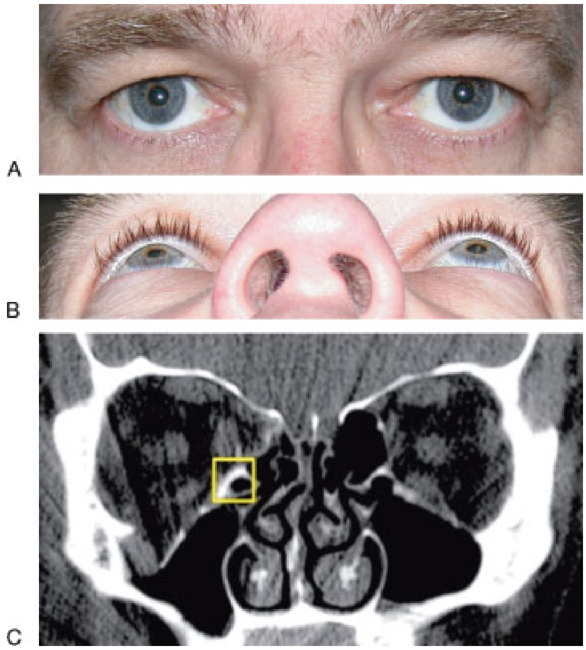

Figure 5 (A) Close-up frontal view of patient's eyes showing no signs of posttraumatic enophthalmos 6 months following the injury despite having a large right-sided orbital floor and medial wall fracture (Fig. 5C). The patient had no surgery. (B) Close-up worm's-eye view of same patient as seen in Fig. 5A showing no evidence of posttraumatic enophthalmos following large orbital fracture on right side. The patient had no surgery. (C) Coronal computed tomography scan of same patient as seen in Figs. 5A and 5B performed acutely after right-sided orbital floor and medial wall fractures. Total fracture area measures 6.30 cm^2. There is minimal rounding seen in the inferior rectus muscle possibly due to either minimal soft tissue herniation or an intact medial orbital buttress (uncinate process of maxilla), which is outlined in the yellow square. Despite having a large fracture, this patient did not develop posttraumatic enophthalmos.

CONCLUSIONS

In conclusion, orbital floor/wall fractures together with orbital soft tissue herniation are necessary factors contributing to the development of late enophthalmos. The shapes of the inferior rectus and the medial rectus muscles on coronal CT scan slices reflect both orbital bone and soft tissue support. Loss of these supporting structures leads to a rounding of these muscles. The degree of rounding reflects the severity of the injury to these supporting structures. Rounding may therefore be a more important criteria for early surgery than fracture size alone.

A height-to-width ratio of greater than or equal to 1 for the inferior rectus and a ratio greater than 0.7 for the medial rectus reliably predict enophthalmos and should be added to the established criteria for early surgery on orbital floor/wall fractures. Clinicians can perform these simple ratio measurements using a regular ruler placed on a representative coronal CT slice as an additional clinical tool to identify patients at risk for enophthalmos post orbital trauma.

REFERENCES

1. 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
2. Biesman BS, Hornblass A, Lisman R, Kazlas M, Hawes MJ. Diplopia after surgical repair of orbital floor fractures. Ophthal Plast Reconstr Surg 1996;12:9–16; discussion 17
3. Manson PN, Clifford CM, Su CT, Iliff NT, Morgan R. Mechanisms of global support and posttraumatic enophthalmos: I. The anatomy of the ligament sling and its relation to intramuscular cone orbital fat. Plast Reconstr Surg 1986; 77:193–202
4. Manson PN, Grivas A, Rosenbaum A, Vannier M, Zinreich J, Iliff N. Studies on enophthalmos: II. The measurement of orbital injuries and their treatment by quantitative computed tomography. Plast Reconstr Surg 1986;77:203–214
5. Kim YK, Park CS, Kim HK, Lew DH, Tark KC. Correlation between changes of medial rectus muscle section and enophthalmos in patients with medial orbital wall fracture. J Plast Reconstr Aesthet Surg 2009;62:1379–1383
6. Hoal BM, Beatty RL. Diplopia and enophthalmos after surgical repair of blowout fracture. Orbit 2002;21:27–33
7. Catone GA, Morrissette MP, Carlson ER. A retrospective study of untreated orbital blow-out fractures. J Oral Maxillofac Surg 1988;46:1033–1038
8. Banerjee A, Moore CC, Tse R, Matic D. Rounding of the inferior rectus muscle as an indication of orbital floor fracture with periorbital disruption. J Otolaryngol 2007;36: 175–180
9. Matic DB, Tse R, Banerjee A, Moore CC. Rounding of the inferior rectus muscle as a predictor of enophthalmos in orbital floor fractures. J Craniofac Surg 2007;18:127–132
10. Roth A, Desmangles P, Rossillion D. Early treatment of secondary muscle restriction due to orbital blow-out fractures. J Fr Ophtalmol 1999;22:645–650
11. Burnstine MA. Clinical recommendations for repair of orbital facial fractures. Curr Opin Ophthalmol 2003;14:236–240
12. Yano H, Minagawa T, Masuda K, Hirano A. Urgent rescue of "missing rectus" in blowout fracture. J Plast Reconstr Aesthet Surg 2009;62:e301–e304
13. Furuta M, Yago K, Iida T. Correlation between ocular motility and evaluation of computed tomography in orbital blowout fracture. Am J Ophthalmol 2006;142:1019–1025
14. Yano H, Nakano M, Anraku K, et al. A consecutive case review of orbital blowout fractures and recommendations for comprehensive management. Plast Reconstr Surg 2009;124: 602–611
15. Hawes MJ, Dortzbach RK. Surgery on orbital floor fractures. Influence of time of repair and fracture size. Ophthalmology 1983;90:1066–1070
16. Burnstine MA. Clinical recommendations for repair of isolated orbital floor fractures: an evidence-based analysis. Ophthalmology 2002;109:1207–1210; discussion 1210–1211; quiz 1212–1213
17. Jin HR, Shin SO, Choo MJ, Choi YS. Relationship between the extent of fracture and the degree of enophthalmos in isolated blowout fractures of the medial orbital wall. J Oral Maxillofac Surg 2000;58:617–620; discussion 620–621

18. Parbhu KC, Galler KE, Li C, Mawn LA. Underestimation of soft tissue entrapment by computed tomography in orbital floor fractures in the pediatric population. Ophthalmology 2008;115:1620–1625
19. Harris GJ, Garcia GH, Logani SC, Murphy ML. Correlation of preoperative computed tomography and postoperative ocular motility in orbital blowout fractures. Ophthal Plast Reconstr Surg 2000;16:179–187
20. Harris GJ. Orbital blow-out fractures: surgical timing and technique. Eye (Lond) 2006;20:1207–1212
21. Levine LM, Sires BS, Gentry LR, Dortzbach RK. Rounding of the inferior rectus muscle: a helpful radiologic findings in the management of orbital floor fractures. Ophthal Plast Reconstr Surg 1998;14:141–143
22. Gilbard SM, Mafee MF, Lagouros PA, Langer BG. Orbital blowout fractures. The prognostic significance of computed tomography. Ophthalmology 1985;92:1523–1528