Correlation between Orbital Computed Tomography Scan Measurements and Clinical Enophthalmos in Acute Isolated Orbital Floor Fractures

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Abstract

Purpose: To analyze the correlation between orbital computed tomography (CT) scan measurements including the fracture area (FA), the fracture location, the soft-tissue herniation volume (HV), the fractured orbital volume ratio (OVR) to the normal orbit, and the clinical enophthalmos in acute isolated orbital floor fractures.

Methods: We enrolled 100 patients with acute isolated unilateral orbital floor fractures from May 2017 to January 2021. Based on the CT scan findings, we measured the FA, HV, OVR, and fracture site. We assessed enophthalmos using both clinical (CE) and radiographic (RE) measurements. Additionally, we investigated the correlation between CE and the measured parameters, along with the relationship between the pattern of diplopia and the fracture site.

Results: We identified enophthalmos in 81% and diplopia in 78% of the patients with an acute blowout orbital floor fracture. CE was moderately correlated with the FA ($R^2 = 0.4341$, $P < 0.001$). CE was weakly correlated with the HV ($R^2 = 0.2861$, $P = 0.04$). Anterior fractures caused diplopia in both vertical gazes, but posterior fractures were mostly associated with diplopia in the up gaze. OVR was strongly associated with RE ($R^2 = 0.663$, $P < 0.0001$) and moderately associated with CE ($R^2 = 0.4378$, $P < 0.0001$). The univariate regression analysis also showed that OVR could significantly predict CE and RE.

Conclusions: OVR surpasses other CT scan measurements such as FA and HV in the prediction of clinical enophthalmos. Thus, OVR could be utilized to estimate clinical enophthalmos at the time of presentation, especially when the acute clinical setting prohibits the proper clinical evaluation.

Keywords: Blowout fracture, Computed tomography scan, Diplopia, Enophthalmos, Orbital fracture

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Introduction

An increasing number of patients have suffered from blowout orbital fractures (BOFs), mainly caused by blunt periorbital trauma due to more occurring car accidents and social violence.[1] Inferior orbital wall is one of the most vulnerable structures, involved in more than two-thirds of orbital fractures.[2] Affected patients commonly experience diplopia, dystopia, enophthalmos, and ocular motility disturbances. Among these complications, diplopia and enophthalmos are the most significant. In contrast with diplopia which may be transient in acute stages of orbital fractures and resolve by subsiding periorbital edema, enophthalmos may be obscure in early stages and worsen by edema resolution.[3] The accepted criteria to consider surgical treatment are mainly based on clinical and radiological findings including diplopia, muscle entrapment, significant fracture size, and enophthalmos. Early diagnosis and proper management of these cases are crucial,

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as missed instances regardless of early or late orbitotomy, may lead to persistent cosmetic and functional problems.[4,5] Indeed, radiographic findings are accessible clues at the time of presentation to predict the[6] ongoing clinical signs and symptoms as early as possible to save time for probable surgical intervention and to achieve better results.[7,8] Clinical experts usually utilize radiographic measurements in challenging cases of periorbital edema, zygomatic fractures, severe enophthalmos or exophthalmos, and uncooperative patients. However, it is unclear how much clinical enophthalmos is correlated with orbital computed tomography (CT) scan measurements in acute settings.

Many studies analyzed radiographic correlations with clinical signs and symptoms and reported different variables to predict future clinical pictures to facilitate on-time management. Choi *et al*. found that enophthalmos was closely correlated with orbital volume expansion, and a 107% increase in orbital volume would result in 1.25 mm enophthalmos.[9] Fracture area (FA), fracture site, and herniation volume (HV) were other predictor variables. However, according to the latest systematic review about posttraumatic enophthalmos prediction, most studies included patients with late enophthalmos, several months after trauma onset, and investigated the predictor variables retrospectively.[10] This may lead to biased conclusions, as patients with late enophthalmos who underwent surgical treatment likely had more severe fractures, larger FAs, and greater herniation of orbital tissue, compared to those managed with conservative, nonsurgical methods. Another limitation in previous studies related to enophthalmos measurement which was either clinically or radiographically measured; hence, the comparison between these studies is impossible.[7,8]

We decided to perform this study to measure the correlation between clinical enophthalmos and certain radiographic predictor parameters, namely, fracture site, FA, HV, and orbital volume ratio (OVR). Moreover, we investigated the diplopia pattern in our patients in correlation with the fracture site.

Methods

We performed this cross-sectional case series study with 100 patients with isolated orbital floor fractures from May 2017 to January 2021 in the Farabi Eye Hospital. The research protocol was approved by the Ethical Committee of Tehran University of Medical Sciences (ethical approval code: (TUMS.REC.1401.028)), and it was conducted following the Declaration of Helsinki principles. A written consent form was obtained from all patients.

We included patients with acute isolated unilateral inferior orbital wall fractures without rim involvement. The exclusion criteria included patients younger than 13 years, the presence of severe periorbital edema hindering reliable clinical examination and diplopia evaluation, concomitant zygomatic or other facial bone fractures, combined orbital fractures, delayed presentation more than a month after the initial injury, preexisting enophthalmos or globe injuries, previous orbital surgery or injury history, and other orbital deformities or abnormalities such as thyroid ophthalmopathy and proptosis.

We recorded demographic data and physical examination findings at the first visit. All patients had undergone a complete ophthalmologic examination. Diplopia was assessed in all patients subjectively and objectively in the primary position and 30° up-and-down gaze. Binocular diplopia was confirmed if it was eliminated after closing one eye. Diagnosis of orbital fracture was made based on clinical assessments and orbital CT scan findings. Spiral axial, sagittal, and coronal orbital CT scans with 3 mm section intervals were performed for all patients as a routine part of their applied diagnosis and treatment schedule. The CT scan data of the initial visit were imported to AW VolumeShare 2 software (GE Healthcare Life Sciences) for further analysis.

We assumed the fracture site as an oval bone defect. We measured FA by multiplying the fracture's most extended length on sagittal scans by the fracture's greatest width on coronal cuts of the orbital CT scan. We used the ellipse area formula as π AB\4 to calculate the bony defect area measurement. A and B were the so-called diameters of the oval.[11]

We outlined herniated fibrofatty tissue in coronal view, level by level manually, from posterior to anterior, in AW VolumeShare 2 software (GE Healthcare Life Sciences). The HV was measured by the automatic summation of marked displaced tissue in each CT scan slice. The formula that the software calculated the outlined volume in a 3-mm thickness orbital CT scan was:[11]

$$\text{Volume} = \sum (\text{area of slice}_n + \text{area of slice}_{n+1}) \div 2 \times \text{thickness}$$

To measure orbital volume, first, we confined the surrounding boundaries of the bony orbit with delicate outlines in coronal scans. The anterior landmark was the orbital rim, and the posterior border was the anterior opening of the optic canal. We similarly outlined the orbital area by tracing the surrounding bony structures as fine as possible in each slice from posterior to anterior. Finally, the software automatically regenerated the final reconstructed 3D orbital image and calculated the orbital volume with the same formula mentioned above [Figure 1a-c]. HV was also measured as part of the fractured orbital content volume. The contralateral normal orbital volume was also calculated as a control measurement, and we calculated the OVR as:[12,13]

$$\text{OVR} = \frac{\text{fractured orbital volume}}{\text{normal orbital volume}} \times 100$$

We measured clinical enophthalmos with a Hertel exophthalmometer (Oculus, Germany) by fixing its base on lateral canthi, and lateral orbital rim, and measured the distance of corneal apex protrusion to the base, bilaterally. The differences between the two eyes revealed "clinical enophthalmos".

To measure radiographic enophthalmos (RE), an axial orbital CT scan was reconstructed to be symmetric bilaterally. We found the slice with the most corneal protrusion (corneal apex) and connected the most anterior part of two zygomatic bones with a line within the software, then, the vertical distance from the corneal apex to this line was measured, and the differences between the two eyes revealed RE [Figure 1d]. If the patient suffered from hypoglobus, first, the interzygomatic connection was lined in the slice with the corneal apex of the fellow eye; then, the line was kept while shifting through the lower slices to reach the corneal apex of the injured eye and the discrepancy of measurements between the two sides revealed RE.

We divided the orbital space to localize the fracture site into two parts. In coronal and sagittal scans, we determined the section with the globe equator. If the main part of the fracture was located anterior to this section, we considered it as an "anterior fracture." If it was mostly located posterior to the determining section, we considered it as a "posterior fracture." If the location was challenging to assign to either group easily, we excluded the case for data analysis in this part. Less than 10% of fractures were excluded from this analysis. The mean FA in each group was also calculated.[11,14]

Data analysis was performed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). Qualitative data were reported as frequency (%) and quantitative data as mean with standard deviation (mean ± SD). The correlation between the variables was assessed by Pearson's (r) and Spearman's correlation coefficient. We calculated univariate regression analysis for the assessment of the correlation between CT scan measurements and enophthalmos. The level of significance with a confidence interval of 95% was set as $P < 0.05$.

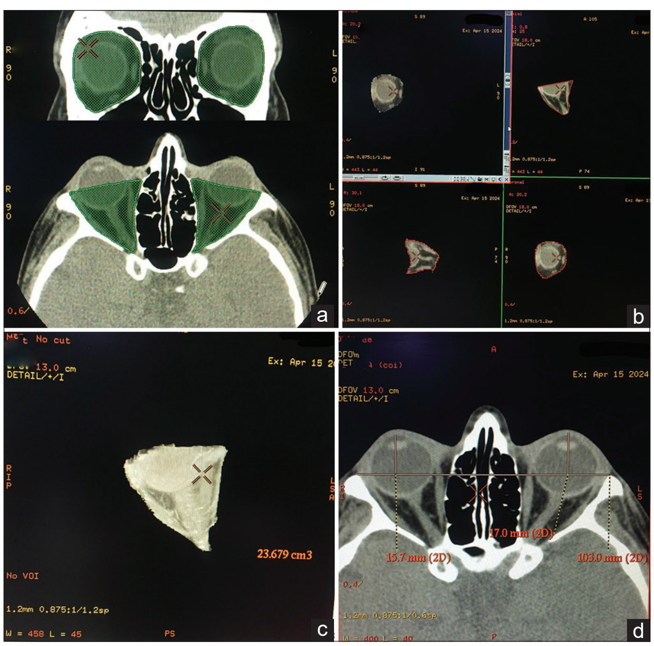

Figure 1: Orbital volume and radiographic enophthalmos (RE) measurement (a) we identified orbital boundaries and outlined the enclosed orbital area in each slice, in AW VolumeShare 2 software (b) the software calculated the orbital volume by summation of all outlined sections (c) the software regenerated the final reconstructed 3D orbital image and showed the orbital volume (d) RE measurement was performed by lining the anterior parts of two zygomatic bones in the section containing corneal apex. The vertical line from the corneal apex to this line was drawn, and the difference between the two sides reveals RE

Results

One hundred patients with inferior orbital blowout fractures were included, and their demographic data are shown in Table 1. Seventy-four percentage were males. The patient's average age was 30.3 ± 7.3 years. Table 1 also shows common trauma mechanisms, and motor vehicle accidents were the leading cause of traumatic orbital fracture. The clinically measured enophthalmos (CE) was recorded in 81% of the patients (mean CE was 1.6 ± 0.3 mm).

The mean FA was 144 ± 122.7 (0.7–522) mm^2 in all patients. CE was moderately correlated with the FA (univariate regression model; $R^2 = 0.4341$, $P < 0.001$) [Figure 2]. Univariate regression analysis showed that FA could significantly predict CE with the following equation:

FA = 66.963 × CEs + 35.226 ($P < 0.001$).

Fifty-five percentage of cases had soft-tissue herniation, and the mean volume of herniated tissue into the maxillary sinus was 2940 ± 1121 (0.5337) mm^3. CE was weakly correlated with the HV (univariate regression; $R^2 = 0.2861$, $P = 0.04$) [Figure 2].

To determine the correlation between enophthalmos and HV in the maxillary sinus, we performed regression analysis. The univariate regression analysis revealed the following correlation between HV and CE:

HV = 531.31 × CE-67.235 ($P < 0.001$)

The mean orbital volume on the affected side was 28.73 ± 6.23 cm^3 and in the unaffected orbit was 25.43 ± 4.12 cm^3, and the mean OVR was 112.96% ± 8.4 (94.1–140). The mean CE

Table 1: Patient's demographic data and trauma mechanisms

Variables	Descriptive statistics
Sample size (n)	100
Male (%)	74
Age (year)	
Mean±SD	30.3±7.3
Range	16–45
Laterality (right, %)	43
Time interval from trauma to the first visit (day)	
Mean	9
Range	1–27
Trauma mechanism (%)	
Motor accidents	40
Sport injuries	21
Falling	20
Physical assault	17
Others	2

SD: Standard deviation

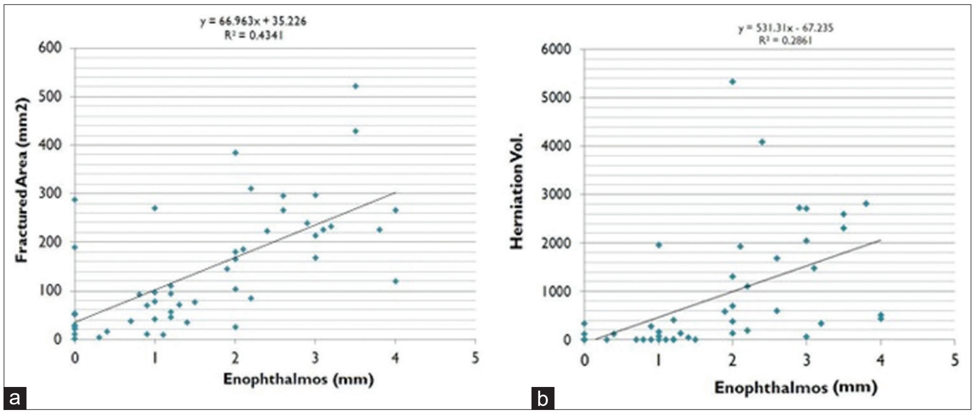

Figure 2: The correlation between the fractured area (a) and the herniated tissue volume (b) with clinical enophthalmos has been illustrated

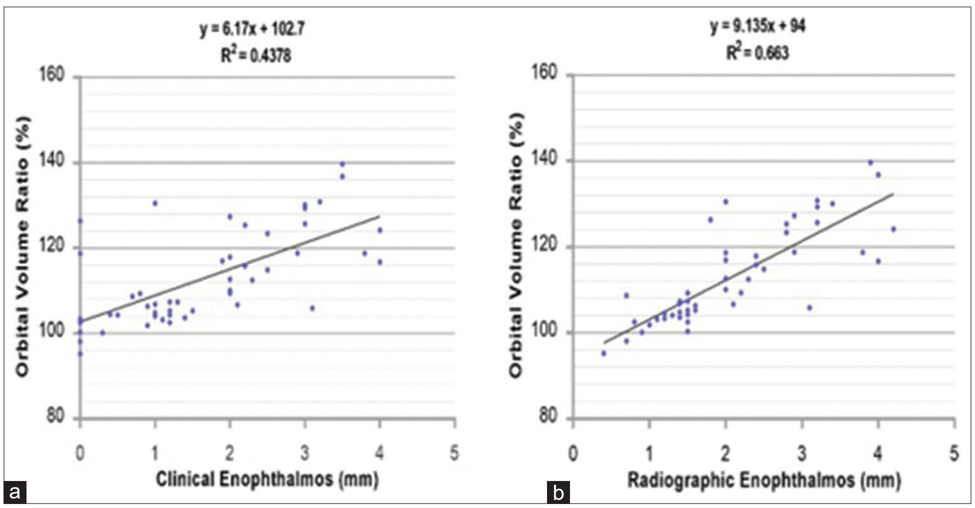

Figure 3: The correlation between the orbital volume ratio and enophthalmos has been shown (a) clinical enophthalmos (b) radiographic enophthalmos

measurement was 1.6 ± 0.3 (0–4) mm, while the average of RE was 2 ± 0.2 (0–4.2) mm. The difference between CE and RE measurements was not significant (*t*-test, $P = 0.1$). Figure 3 illustrates the correlation between RE, CE, and OVR. OVR was strongly associated with RE (univariate regression, $R^2 = 0.663$, $P < 0.0001$) and moderately associated with CE (univariate regression, $R^2 = 0.4378$, $P < 0.0001$). The univariate regression analysis showed that OVR could significantly predict CE and RE with the following coefficients:

OVR (%) = 6.17 × CE + 102.7 ($P < 0.0001$)

OVR (%) = 9.135 × RE + 94 ($P < 0.0001$)

We analyzed anterior and posterior fracture sites' correlation with CE. The mean distance of the fracture line from the inferior orbital rim was 12.9 ± 5.37 (3–24) mm. The mean FA in each group (anterior vs. posterior fractures) did not have significant differences (*t*-test, $P = 0.06$). In univariate regression analysis, the fracture site was not significantly correlated with CE ($P = 0.095$).

We also analyzed anterior and posterior fracture sites' correlation with diplopia. Diplopia occurred in 78% of BOF, 30% only in upward gaze, 29.7% in primary gaze, and 38% in upward and downward gazes. Patients with anterior BOF complained equally about diplopia in upward (35.5%) or both the gazes (41.9%) (Chi-square, $P > 0.05$). In posterior BOF, reported diplopia in upward gaze was more (48.4% vs. 35.4%, Chi-square, $P = 0.04$).

Discussion

In this study, we tried to clarify the relationship between enophthalmos and objective radiographic clues. Previous studies were mainly retrospective and determined late enophthalmos correlations with a small sample size. Furthermore, they investigated fewer predictor variables and limited correlations.[11,12,15-18] Diplopia was also reported to be significantly related to fracture sites in literature.[19,20] We evaluated these correlations from another viewpoint.

Previous studies reported the correlation of FA and HV with enophthalmos.[12,16,21] We showed that FA was associated with clinical enophthalmos. We also showed that HV in the maxillary sinus was significantly associated with the amount of enophthalmos. Other studies supported this association.[12,19,22]

Although significant, the CE was weakly correlated with HV which limits its usage in clinical practice ($R^2 = 0.28$). Previous studies considered herniated tissue as a semielliptical configuration and found its volume with relevant equations, but we measured it through manual planimetry to improve its accuracy. Figure 2 revealed the relationship between HV and enophthalmos, and the correlation seemed to be linear when the HV reached the minimum threshold of 600 mm^3. It means that there was not a linear relationship starting from the tiniest volumes of herniation. Overall, this correlation demonstrated a significant association between HV and enophthalmos ($P < 0.05$). The probable explanation of the weak correlation between HV and CE is the threshold of linear relationship; a minimal amount of HV did not affect the intraorbital structures as much as to be clinically reflected as enophthalmos. In these cases, other parameters, especially orbital volume expansion, are better predictors of CE. This variability reflected the importance of the measurement method. Simulation techniques gave less reliable data and volumetric analysis through planimetry was less biased and more reliable.[11,23]

The correlation between OVR and enophthalmos was also reported in the literature. Jin *et al*. proposed that the prediction of enophthalmos from the area of the BOF without considering the volume of transposed tissue has been often misleading. They emphasized more on the predictive value of orbital volume change rather than the area of the fracture.[16] We similarly found that OVR and relative orbital expansion following orbital fracture were the best predictive index to the subsequent induced enophthalmos. Our results showed that an OVR of 113% induced 1.6 and 2 mm CE and RE, respectively, which is significant to considering surgical treatment. In this regard, Kolk *et al*. revealed a strong correlation between the degree of enophthalmos and orbital volume change. They suggested each 1 cm^3 increase in orbital volume resulted in an average of 0.93 mm enophthalmos.[17,24] We preferred to report OVR instead of definite orbital volume due to physiologic variability between right and left orbital volume as high as 7%, individually.[25] Indeed, reporting the net volume in the presence of such variability reduces the accuracy of the results.

We performed both CE and RE measurements, as the clinical measurement with the Hertel exophthalmometer might be imprecise due to preorbital swelling, concomitant zygomatic, or other facial bone fractures.[10,13] Furthermore, according to Ebrahimi *et al*., intraobserver and interobserver variability in RE measurement was lower than in CE measurement.[13] We concluded that clinical measurement slightly underestimated the degree of enophthalmos, and radiographic measurement showed a better correlation with OVR. Furthermore, we found that OVR was highly correlated with RE and moderately correlated with CE. Clinical experts usually utilize radiographic measurements in challenging cases of periorbital edema, zygomatic fractures, severe enophthalmos or exophthalmos, and uncooperative patients. Although there was no significant difference between CE and RE in this study, the result of this study showed that OVR is a better predictor of RE than CE. Therefore, it seems that OVR can be regarded as a useful radiographic measurement to help in treatment planning. Further prospective studies are required to demonstrate the effect of decision-making based on radiographic findings such as OVR and compare patients' outcomes with the current practice.

Diplopia is another common complication following trauma to the periorbital region. Early diplopia is mostly attributed to periorbital swelling and ecchymosis, but persistent diplopia can be caused by extraocular muscles and soft-tissue entrapment within the fracture site, muscles or related nerve injury, or vertical deviation of the globe. Usually, the cause of diplopia in down gaze is paresis of the inferior rectus muscle. Paresis of the inferior rectus muscle can have several reasons. A possible reason is the damage to the motor nerve related to this muscle as neuropraxia, which restricts the downward movement of the eye and causes diplopia in the down gaze. Another reason can be due to the creation of hematoma and inflammation in the bulk of the inferior rectus muscle and the temporary decrease in the function of muscle fibers, which can cause temporary paralysis and diplopia when looking down.[26] In this study, diplopia occurrence was more than previously estimated in the acute setting of orbital fractures.[26,27] Recent studies showed that anterior and medially located orbital floor fractures were more correlated with diplopia.[14,27,28] We also found that in the acute setting, anterior fractures caused diplopia in both vertical gazes, but posterior fractures were mostly associated with diplopia in the up gaze. We speculated that in posterior fractures adjacent to the bulk of the inferior rectus muscle, the probability of muscle entrapment and restriction effect was higher than the anterior fractures, which led to the limitation in elevation and diplopia in the up gaze. On the other hand, anterior fractures were mainly located adjacent to the inferior rectus insertion, far from the bulky muscle. Hence, it looked as if the main cause of induced diplopia in anterior fractures was related to perimuscular connective tissue edema, inflammation, and subsequent fibrosis, which characterized restriction while elevation and depression. Thus, the inflammation, nonspecifically, induced diplopia in both vertical gazes. It was also why permanent nonresolving diplopia was mostly accompanied by more posteriorly located fractures.[14,20,26,28] However, in the literature, contrasting results were also reported. Some studies of posteriorly located fractures reported more prevalent diplopia in down gaze due to inferior rectus nerve trauma.[29,30] This difference could be explained by different sizes of fractures in previous studies. Further computer modeling of fracture forces is required to evaluate the possible mechanism.

This study has several limitations. First, we considered the fracture site as an elliptical bony defect and measured its area with related mathematics. It made bias to our measurement and gave an approximate FA; furthermore, to localize the fracture site, we considered anterior and posterior fractures based on the globe equator location. Both tiny and large fractures might be located anterior to the equator; however, these fractures may have various effects on the diplopia pattern. In other words, we did not analyze the fracture site and FA at the same time. Although the mean FA in both groups was approximately the same, we suggest that multivariate analysis considering both variables gave more accurate results. Second, we evaluated enophthalmos in the acute setting which could be affected by the orbital edema. Although the decision for the treatment based on enophthalmos is usually made after the resolution of orbital emphysema, recent studies use posttraumatic enophthalmos as a factor for the prognosis of surgery.[31] The third limitation was the single assessment of enophthalmos and the lack of serial evaluation which could affect the predictive power of the results. Finally, although the current work validates OVR as the best CT scan-based variable to predict clinical enophthalmos, we did not study its clinical usage. We recommend further studies to assess the usefulness of early posttraumatic OVR as a prognostic factor of late cosmetic and visual outcome.

In summary, several radiographic parameters could be utilized to estimate acute clinical enophthalmos and diplopia of traumatized patients at the time of presentation, even if the clinical signs and symptoms were too confusing to be evaluated properly. Hence, timely identification of patients who benefit from surgical intervention might be possible. The best predictive index of enophthalmos in our study was OVR; however, it should be noted that no individual parameter provides adequate predictive power to be used alone. Further studies are required to take into account the impact of these predictor variables altogether to predict the final clinical features of fractures. OVR seems to be an ideal adjunctive method, besides Hertel measurement in challenging cases, and further studies are required to evaluate its significance in decision-making and visual prognosis in orbital wall fracture.

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Conflicts of interest

There are no conflicts of interest.

References

1. Smith B, Regan WF Jr. Blow-out fracture of the orbit; mechanism and correction of internal orbital fracture. Am J Ophthalmol 1957;44:733-9.
2. Goggin J, Jupiter DC, Czerwinski M. Simple computed tomography-based calculations of orbital floor fracture defect size are not sufficiently accurate for clinical use. J Oral Maxillofac Surg 2015;73:112-6.
3. Shin JW, Lim JS, Yoo G, Byeon JH. An analysis of pure blowout fractures and associated ocular symptoms. J Craniofac Surg 2013;24:703-7.
4. Tong L, Bauer RJ, Buchman SR. A current 10-year retrospective survey of 199 surgically treated orbital floor fractures in a nonurban tertiary care center. Plast Reconstr Surg 2001;108:612-21.
5. Pandya RP, Deng W, Hodgson NM. Current guidelines and opinions in the management of orbital floor fractures. Otolaryngol Clin North Am 2023;56:1101-12.
6. Murray-Douglass A, Peters MC, Johnson NR, Harris R. The impact of orbital volume on post-traumatic enophthalmos: A systematic review and meta-analysis. J Craniofac Surg 2023;34:1420-6.
7. Harris GJ, Garcia GH, Logani SC, Murphy ML. Correlation of preoperative computed tomography and postoperative ocular motility in orbital blowout fractures. Ophthalmic Plast Reconstr Surg 2000;16:179-87.
8. Shew M, Carlisle MP, Lu GN, Humphrey C, Kriet JD. Surgical treatment of orbital blowout fractures: Complications and postoperative care patterns. Craniomaxillofac Trauma Reconstr 2016;9:299-304.
9. Choi J, Park SW, Kim J, Park J, Kim JS. Predicting late enophthalmos: Differences between medial and inferior orbital wall fractures. J Plast Reconstr Aesthet Surg 2016;69:e238-44.
10. Schlund M, Lutz JC, Sentucq C, Bouet B, Ferri J, Nicot R. Prediction of post-traumatic enophthalmos based on orbital volume measurements: A systematic review. J Oral Maxillofac Surg 2020;78:2032-41.
11. Choi SH, Kang DH. Prediction of late enophthalmos using preoperative orbital volume and fracture area measurements in blowout fracture. J Craniofac Surg 2017;28:1717-20.
12. Zhang Z, Zhang Y, He Y, An J, Zwahlen RA. Correlation between volume of herniated orbital contents and the amount of enophthalmos in orbital floor and wall fractures. J Oral Maxillofac Surg 2012;70:68-73.
13. Ebrahimi A, Kalantar Motamedi MH, Rasouli HR, Naghdi N. Enophthalmos and orbital volume changes in zygomaticomaxillary complex fractures: Is there a correlation between them? J Oral Maxillofac Surg 2019;77:134.e1-9.
14. Hsu CK, Hsieh MW, Chang HC, Tai MC, Chien KH. Anatomic factors predicting postoperative strabismus in orbital wall fracture repair. Sci Rep 2019;9:14785.
15. Gilbard SM, Mafee MF, Lagouros PA, Langer BG. Orbital blowout fractures. The prognostic significance of computed tomography. Ophthalmology 1985;92:1523-8.
16. 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;58:617-20.
17. Kolk A, Pautke C, Schott V, Ventrella E, Wiener E, Ploder O, *et al.* Secondary post-traumatic enophthalmos: High-resolution magnetic resonance imaging compared with multislice computed tomography in postoperative orbital volume measurement. J Oral Maxillofac Surg 2007;65:1926-34.
18. Ploder O, Klug C, Voracek M, Burggasser G, Czerny C. Evaluation of computer-based area and volume measurement from coronal computed tomography scans in isolated blowout fractures of the orbital floor. J Oral Maxillofac Surg 2002;60:1267-72.
19. Shah HA, Shipchandler TZ, Sufyan AS, Nunery WR, Lee HB. Use of fracture size and soft tissue herniation on computed tomography to predict diplopia in isolated orbital floor fractures. Am J Otolaryngol 2013;34:695-8.
20. Cellina M, Floridi C, Panzeri M, Giancarlo O. The role of computed tomography (CT) in predicting diplopia in orbital blowout fractures (BOFs). Emerg Radiol 2018;25:13-9.
21. Ahmad Nasir S, Ramli R, Abd Jabar N. Predictors of enophthalmos among adult patients with pure orbital blowout fractures. PLoS One 2018;13:e0204946.
22. Safi AF, Richter MT, Rothamel D, Nickenig HJ, Scheer M, Zöller J, *et al.* Influence of the volume of soft tissue herniation on clinical symptoms of patients with orbital floor fractures. J Craniomaxillofac Surg 2016;44:1929-34.

23. Yang JH, Hwang SB, Shin JY, Roh SG, Chang SC, Lee NH. 3-dimensional volumetric analysis of relationship between the orbital volume ratio and enophthalmos in unoperated blowout fractures. J Oral Maxillofac Surg 2019;77:1847-54.
24. Charteris DG, Chan CH, Whitehouse RW, Noble JL. Orbital volume measurement in the management of pure blowout fractures of the orbital floor. Br J Ophthalmol 1993;77:100-2.
25. Forbes G, Gehring DG, Gorman CA, Brennan MD, Jackson IT. Volume measurements of normal orbital structures by computed tomographic analysis. AJR Am J Roentgenol 1985;145:149-54.
26. Boffano P, Roccia F, Gallesio C, Karagozoglu KH, Forouzanfar T. Diplopia and orbital wall fractures. J Craniofac Surg 2014;25:e183-5.
27. Higashino T, Hirabayashi S, Eguchi T, Kato Y. Straightforward factors for predicting the prognosis of blow-out fractures. J Craniofac Surg 2011;22:1210-4.
28. Schönegg D, Wagner M, Schumann P, Essig H, Seifert B, Rücker M, *et al.* Correlation between increased orbital volume and enophthalmos and diplopia in patients with fractures of the orbital floor or the medial orbital wall. J Craniomaxillofac Surg 2018;46:1544-9.
29. Bruneau S, De Haller R, Courvoisier DS, Scolozzi P. Can a specific computed tomography-based assessment predict the ophthalmological outcome in pure orbital floor blowout fractures? J Craniofac Surg 2016;27:2092-7.
30. Burm JS, Chung CH, Oh SJ. Pure orbital blowout fracture: New concepts and importance of medial orbital blowout fracture. Plast Reconstr Surg 1999;103:1839-49.
31. Koryczan P, Zapała J, Gontarz M, Wyszyńska-Pawelec G. Enophthalmos as a prognostic factor in blow-out fracture of the orbit. Retrospective study of over 700 cases. Folia Med Cracov 2020;60:53-63.