

Evaluation of Computer-Based Area and Volume Measurement From Coronal Computed Tomography Scans in Isolated Blowout Fractures of the Orbital Floor

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Purpose: In this retrospective study, we evaluated isolated blowout fractures of the orbital floor by region-of-interest measurements from coronal computed tomography (CT) scans and their relationship to ophthalmologic findings.

Patients and Methods: Fracture area and volume of displaced tissue of blowout fractures in 38 patients were measured from coronal CT scans. Measurement was performed by identifying distances (for area calculation) of the fracture and identifying areas (for volume calculation) of the displaced tissue in each CT slice. The calculated data were then compared with the amount of enophthalmos, presence of diplopia, and limitation of ocular motility.

Results: Orbital floor area (mean \pm SD) was 5.72 ± 1.07 cm²; fracture area, 2.63 ± 1.20 cm²; and the volume of displaced tissue, 1.15 ± 0.91 mL. The average proportion of the fracture within the orbital floor was $45.3 \pm 17.6\%$. Fracture area and volume of displaced tissue were significantly positively correlated with enophthalmos and diplopia and not correlated with the limitation of ocular motility. For enophthalmos of 2 mm or greater, mean fracture area (mean \pm SD) was 4.08 ± 1.09 cm² and volume of displaced tissue was 1.89 ± 1.19 mL; for less than 2-mm enophthalmos, 1.98 ± 0.83 cm² and 0.83 ± 0.58 mL, respectively. Enophthalmos of 2 mm can be expected with 3.38 cm² of fracture area and 1.62 mL of displaced tissue.

Conclusions: Region-of-interest measurement from coronal CT scan has an application in the assessment of patients with pure blowout fractures of the orbital floor and adds useful information in posttraumatic evaluation of orbital fractures.

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Fracture of the orbital floor is a common injury secondary to blunt trauma of the ocular globe. Treatment

of blowout fractures of the orbital floor depends on clinical symptoms and on findings from the computed tomography (CT) scan.¹⁻⁴ In the initial period after injury, selection of patients for surgical repair is influenced by a combination of clinical symptoms including acute enophthalmos, diplopia, and limitation of ocular motility. Surgical intervention is recommended if fracture size portends late enophthalmos or if diplopia and limitation of gaze have not resolved within 2 weeks of injury.^{2,4,5}

CT is recognized to be the best imaging technique to evaluate orbital fractures.² Coronal CT scans in particular offer excellent diagnostic information for assessing blowout fractures of the orbital floor. The extent and location of a blowout fracture in the CT scan were noted to have an effect on the clinical outcome.¹ Specifically, a relationship between type of the fracture ("trap-door" and "punched-out") and re-

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gression of the motility disturbance of the globe has been described.⁶ Whitehouse et al⁷ presented evidence for a correlation between increase in orbital volume after orbital trauma and enophthalmos, suggesting that posttraumatic enophthalmos is caused by the dislocation of the bony fragments rather than fat atrophy or fibrosis.

With the use of 3-dimensional CT scanning, visualization and measurement of orbital fractures were obtained and allowed evaluation of the extent and location of the fracture.⁸⁻¹⁰ Due to longer processing time and threshold errors, the ability of this method is limited to posttraumatic reconstruction of enophthalmos.¹¹

For evaluation of acute orbital fractures, coronal CT scans remain the most commonly used examination method. However, there is no study available of reliable measurement of blowout fractures from 2-dimensional CT scans. A recently developed computer-based method enables for the first time assessment of orbital fractures by region-of-interest measurements using 2-dimensional CT scans.¹² Evaluation of the extent and the location of the fracture within the orbital floor area and the volume of the displaced orbital tissue allows objective assessment of orbital fractures.

The aim of our retrospective study was to evaluate patients with isolated blowout fractures of the orbital floor using a computer-based calculation from coronal CT scans. The measured data were also compared with the findings of the ophthalmologic examinations.

Patients and Methods

The CT examinations and charts of 38 patients (11 women and 27 men) who were treated with isolated blowout fractures of the orbital floor between 1997 and 2000 at the Clinic of Cranio and Maxillofacial Surgery were reviewed retrospectively. Mean patient age (\pm SD) was 38.50 ± 19.1 years (range, 11 to 81 years). The time interval to the CT examination after injury was 2.7 days (range, 1 to 10 days). The CT examinations (Philips Secura, Best, The Netherlands) of all patients were performed in the coronal plane. In addition, 3 patients had an axial CT examination. The imaging parameters were 120 kV; 150 milliampereseconds (mAs); field of vision, 25 cm; and 3-mm section thickness in 31 patients and 2-mm thickness in 7 patients. The images loaded onto an optical disc were transferred to a workstation (Philips Easy Vision, Best, The Netherlands) for further evaluation.

A manufacturer's measuring tool provided with the software of the workstation was used for measurement of distances and areas in each CT slice. With the slice thickness of the CT scans known, areas (from

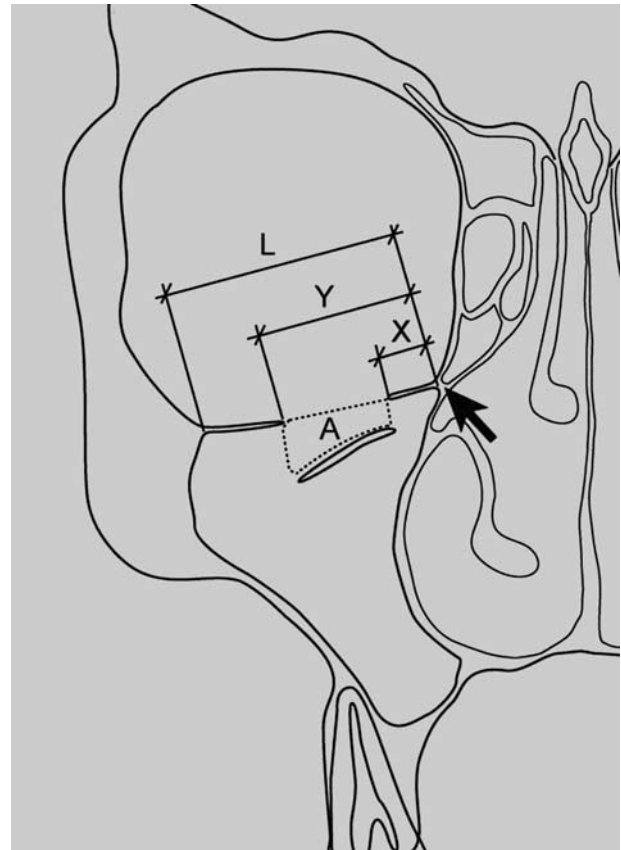


FIGURE 1. Schematic drawing of right orbit with measured distances for area and volumetric measurements. The distances from the ethmoidomaxillary suture (arrow) to the medial (X) and lateral boundary (Y) of the fracture and to the lateral border of the orbital floor (L) are shown. Area of displaced tissue (A) is outlined.

distances) and volumes (from areas) can be calculated.

One investigator (O.P.) performed radiographic tracings at predetermined bone (window width, 3,000; window center, 600) and soft-tissue window levels and width settings (window width, 350; window center, 50) and was blinded to the patient's charts. The ethmoidomaxillary suture was defined as the medial anatomic landmark for measurement in each CT slice (Fig 1). The anterior border of the orbital floor was determined as the first CT slice with a visible maxillary sinus and the posterior border as the apex of the orbit. Measurement of the area of the orbital floor was performed by measuring the distance (L) between the defined medial anatomic landmark and the lateral aspect of the orbital floor in each CT slice (Figs 1, 2). In cases of a concave configuration of the orbital floor ($n = 2$), the maximum extent of the curve was implemented in the calculation. Where fractures involved the medial anatomic landmark ($n = 3$), the fracture area was calculated without relating the fracture to the orbital floor.

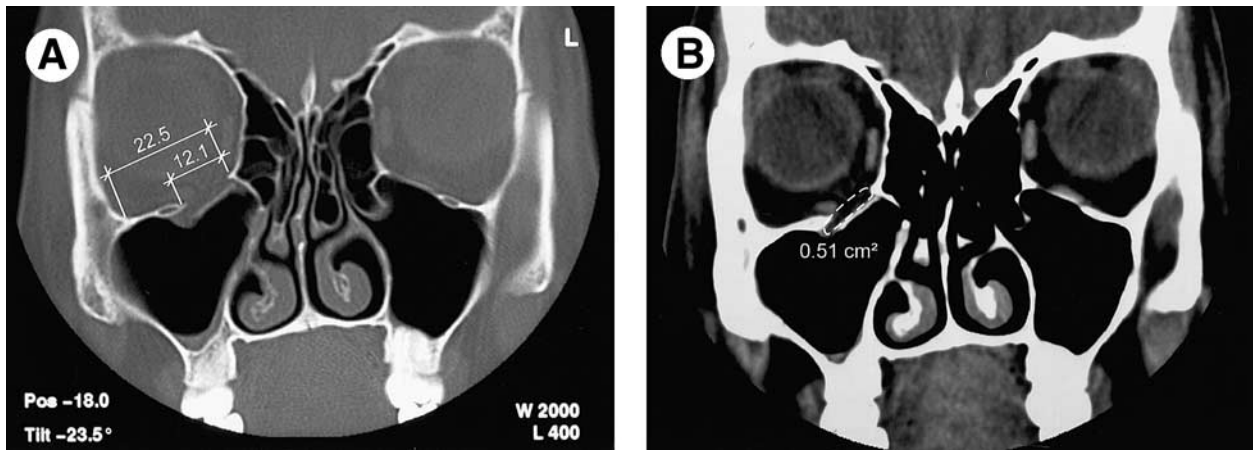


FIGURE 2. A, Coronal CT scan (bone window setting) of patient 23 showing blowout fracture in the middle third of the orbital floor. Measured distances (in mm) of orbital floor and fracture in slice 12 are shown as described in Figure 1. B, Corresponding CT slice (soft tissue setting) with outlined area of displaced orbital tissue.

The area and localization of the fracture were determined by measuring the distance between the medial anatomic landmark and the medial (X) and lateral (Y) boundaries of the fracture in each CT slice displaying the fracture (Figs 1 to 3). By performing these measurements, the localization of the fracture in relation to the medial and the lateral aspect of the orbital floor could be obtained. The anteroposterior extension of the fracture was determined by relating the CT slices that displayed the fracture to those with the orbital floor. The measurement data of each CT slice were transferred to a personal computer for calculation of orbital floor and fracture areas (Table 1). The data for fracture and orbital floor area were printed as a 2-dimensional diagram using standard software (Microsoft Excel 2000; Microsoft Corporation, Redmond, WA) (Fig 4). The mathematical method for area calculation from coronal CT scans was previously described.¹²

For measurement of displaced orbital tissue, the area of the displaced tissue was outlined with a cursor and calculated with the workstation's software for each CT slice (Fig 1). The total volume, V, of the displaced soft tissue was calculated by summing partial volumes, V_n, which were calculated from the measured areas, A_n;

$$V_n = \frac{S}{3} \times (A_n + \sqrt{A_n \times A_{n+1}} + A_{n+1}), \quad V = \sum_{n=1}^{N-1} V_n$$

where n is the slice index, N is the total number of slices, and S is the thickness of the CT slice.

The amount of enophthalmos determined by Hertel exophthalmometer, the presence of diplopia, and the presence of a limitation of ocular motility were evaluated by an ophthalmologist after a time interval of 4.6 days, with a range from 2 to 9 days. Hertel's measurement was not performed in 17 patients before surgical

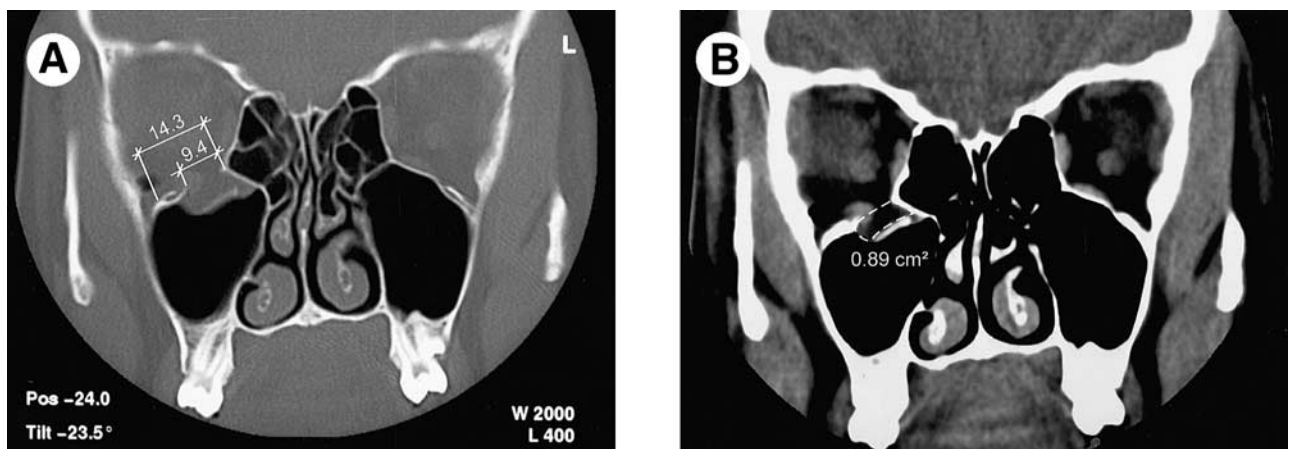


FIGURE 3. A, Coronal CT scan (bone window setting) of patient 23 showing blowout fracture in the posterior third of the orbital floor. Measured distances (in mm) of orbital floor and fracture in slice 14 are shown as described in Figure 1. B, Corresponding CT slice (soft tissue setting) with outlined area of displaced orbital tissue.

Table 1. MEASUREMENT OF CORONAL CT SCAN (PATIENT 23) WITH A BLOWOUT FRACTURE OF THE RIGHT ORBITAL FLOOR

CT Slice (3 mm)	Orbital Floor L (mm)	Fracture		Displaced Tissue A (cm ²)
		X (mm)	Y (mm)	
6	7.8	—	—	—
7	8.6	—	—	—
8	16.3	—	—	—
9	20.3	—	—	—
10	21.7	—	—	—
11	23.1	0.0	11.9	0.36
12	22.5	0.0	12.1	0.51
13	21.0	0.0	10.7	0.74
14	14.3	0.0	9.4	0.89
15	8.3	0.0	7.0	0.85
16	7.5	0.0	7.5	0.74
17	6.5	—	—	—
Totals	Orbital floor area 5.22 cm ²	Fracture area 1.65 cm ²		Vol of displaced tissue 1.17 mL

Abbreviations: L, X, Y, and A are described in legend to Figure 1.

treatment due to swelling or incomppliance of the patient.

STATISTICAL ANALYSIS

Linear relationships between 2 variables were assessed with Pearson’s correlation coefficient (*r*). Mean differences of a continuous variable between 2 groups were tested with Student’s unpaired *t* test. The location preference (left/right) of the orbit was tested with the binomial test, along with the exact *P* value. Owing to the directional hypotheses, all reported *P* values are 1-tailed. The statistical significance level was set on $\alpha = .05$; a statistical trend level

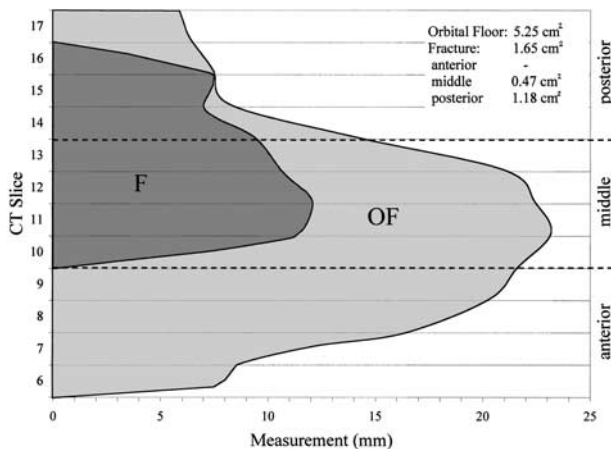


FIGURE 4. Two-dimensional diagram of the right orbital floor and the calculated areas (tabulated) of patient 23 (F, fracture area; OF, orbital floor area). For each measurement (x axis), the ethmoidomaxillary suture represents the reference point (y axis). The orbital floor is separated into thirds (interrupted line), and the actual size of fracture area is listed for each third.

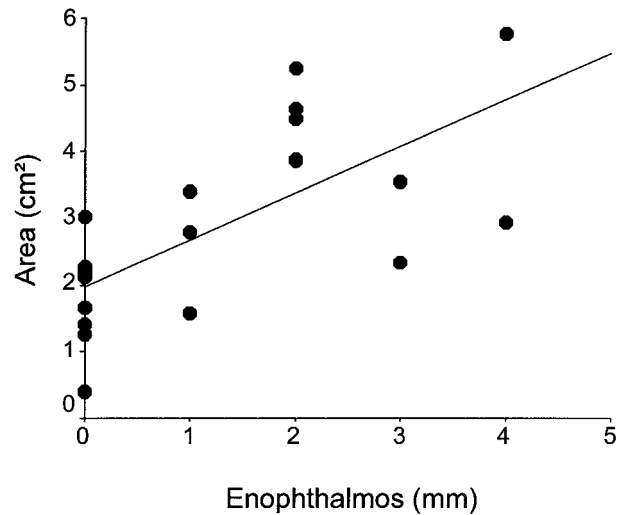


FIGURE 5. Relationship between fracture area (A) and enophthalmos ($A = 1.980 + 0.698 * \text{enophthalmos}$).

was set on .10. All statistical analyses were performed with the SPSS for Windows, version 10, software.

Results

CT MEASUREMENTS

Isolated blowout fractures (*n* = 38) occurred on the right orbit in 13 patients and on the left orbit in 25 patients (this location preference is statistically significant, exact *P* = .04). Orbital floor area obtained by computer-based measurement (mean \pm SD) was $5.72 \pm 1.07 \text{ cm}^2$ (range, 3.43 to 7.69 cm²), and the fracture area was $2.63 \pm 1.20 \text{ cm}^2$ (range, 0.40 to 5.77 cm²). When comparing both measurements, there were no significant left/right differences. The average proportion of the fracture within the orbital floor area was $45.3 \pm 17.6\%$. The overall volume of displaced tissue was $1.15 \pm 0.91 \text{ mL}$ (range, 0.14 to 4.56 mL).

In anteroposterior dimension, 28 fractures involved the anterior third (mean fracture area, $0.43 \pm 0.44 \text{ cm}^2$), 36 involved the middle third ($1.64 \pm 0.69 \text{ cm}^2$), and 33 involved the posterior third ($0.62 \pm 0.43 \text{ cm}^2$) of the orbital floor. Mean fracture proportion for the anterior, middle, and posterior thirds were, in order, $14.4 \pm 10.8\%$, $62.7 \pm 12.1\%$, and $22.9 \pm 13.3\%$, respectively.

Ophthalmologic Evaluation

Fracture area and the extent of enophthalmos were significantly correlated ($r = 0.69, P < .001$) (Fig 5). Mean fracture area associated with 2-mm or greater enophthalmos (*n* = 9) was $4.08 \pm 1.09 \text{ cm}^2$; with less than 2-mm enophthalmos (*n* = 12), $1.98 \pm 0.83 \text{ cm}^2$. The expected area of fracture associated with 2-mm enophthalmos was 3.38 cm^2 , as estimated from linear

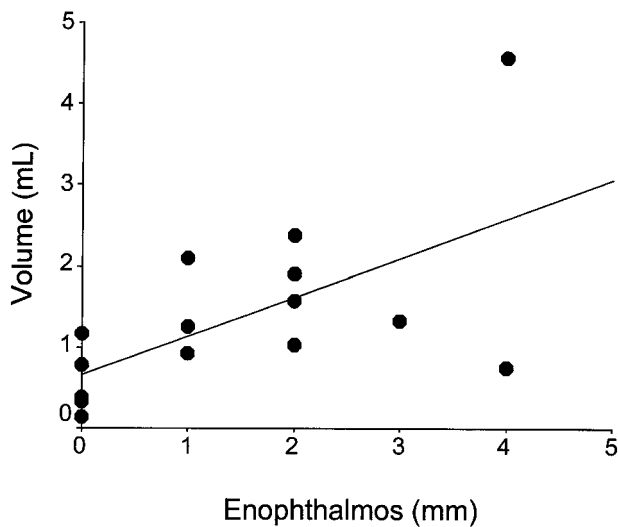


FIGURE 6. Relationship between volume of displaced orbital tissue (V) and enophthalmos ($V = 0.660 + 0.478 * \text{enophthalmos}$).

regression. Area and volume measurements of patients with missing Hertel examination ($n = 17$) did not differ from those of patients with present Hertel examination. Fracture area was significantly larger in the presence of diplopia ($n = 21$) ($P = .04$); however, there was no difference with regard to the presence of a limitation of ocular motility ($n = 17$). Furthermore, these ophthalmologic findings did not show differences when separating the orbital floor in thirds.

Volume of displaced tissue and the extent of enophthalmos were significantly correlated ($r = 0.64$, $P = .002$) (Fig 6). Mean volume of displaced tissue associated with 2-mm or greater enophthalmos was 1.89 ± 1.19 mL; with less than 2-mm enophthalmos, 0.83 ± 0.58 mL. The volume of displaced tissue associated with 2-mm enophthalmos was 1.62 mL. There was a statistical trend for a larger volume of displaced tissue in the presence of diplopia ($P = .07$); however, there was no difference with regard to the presence of a limitation of ocular motility.

Discussion

This study evaluated the ability to use a region-of-interest measurement method from coronal CT scans that quantifies blowout fractures of the orbital floor by fracture area and volume of displaced tissue. In addition, the surgeon may gain insight as to the extent and translocation of the fracture, degree of enophthalmos, presence and severity of diplopia and/or restricted ocular motility, and entrapment and displacement of the fibrofatty-muscle complex. All of these factors affect the decision for conservative versus surgical treatment.^{1,2,4,13} Acute enophthalmos, severe limitation of gaze, and entrapment of any of the com-

ponents are seen as absolute indications for surgical intervention.⁴ CT scanning of the orbit has provided a means of assessing of the extent of fracture and the associated change in orbital volume.^{8-11,14,15} These factors are seen to have an impact in the evaluation of patients without severe clinical symptoms. Area and volumetric measurements of orbital fractures from CT scans can be performed with 2- and 3-dimensional CT scanning.^{3,8-10} Measurement from 3-dimensional CT scanning for evaluation of orbital fractures has 2 major limitations: first, volume averaging and threshold artifacts reduce the ability of 3-dimensional images when showing small bony structures.¹⁵ Second, the contralateral orbit was used as a control when volume changes of the injured orbit were compared. The volume difference between the 2 orbits is normally between 7% and 8%, and therefore the validity of this method is questionable.^{14,16} Measurement from 2-dimensional CT scanning is a further attempt to objectify orbital fractures. In general, the reliability of CT linear measurement is limited due to partial volume effects, beam hardening, and patient motion. Calibration of the CT scanner has to be done frequently to ensure spatial uniformity. Including these factors, the accuracy of linear measurements from CT scans is within acceptable limits and ranges from 0.4 to 0.9 mm.¹⁷

In a recent study, fracture area and volume of displaced tissue of medial wall fractures were measured from coronal and axial CT scans.³ The authors assumed that a fracture of the orbital wall is elliptically shaped and the tissue displacement depicts a hemielipsoid. The maximum distance from one representative CT slice displaying the fracture was used to calculate the extent of fracture and the volume of displaced periorbital tissue. These values showed a linear relationship to the degree of enophthalmos. A disadvantage of this method was the inability to calculate the actual size from the CT scan, because the shape of a defect is not necessarily elliptical and a herniation does not necessarily display a hemielipsoid.

To consider the individual shape of a fracture, we used a region-of-interest measurement from 2-dimensional CT scanning for quantitative assessment of orbital floor fractures. In an previous experimental study on human skulls, interobserver and intraobserver discrepancies of this computer-based measurement method were low and measurements were highly reproducible.¹²

In this study, both the defect size and the volume of displaced tissue were significantly related to enophthalmos and diplopia. These results are comparable to previous studies that noted an effect of defect size and displacement of orbital tissue to the clinical outcome.^{1,2,6,7,15,18} Results of a study about the measure-

ment of medial orbital wall fractures supported the view that prediction of the degree of enophthalmos was more related to the displaced volume than to the area of the fracture.³ However, in our study the extent of fracture ($r = 0.69$) and volume of displaced orbital tissue ($r = 0.64$) were equally correlated with enophthalmos.

Interestingly, the presence of impaired ocular motility was not significantly associated with the CT measurement data. This confirms the findings of a study that the limitation of ocular motility results more from muscle traction of the connective tissue septa or direct muscle injury than from defect size and herniation volume.¹⁹ Furthermore, the location of the fracture in anteroposterior dimension showed no difference when relating the ophthalmologic findings to the thirds of the orbital floor. This may be due to the fact that mean proportion of the fractures involved almost half of the orbital floor and therefore most of the fractures transverse into all thirds of the orbital floor.

A general limitation of volume measurement is found when displaced orbital tissue is identified in the CT scan several days after trauma. Post-traumatic damage, edema, hematoma, or emphysema of the soft tissue can substantially affect the actual results. Furthermore, different times of examination by the ophthalmologist after the injury can impair the validity of the findings. However, the measured volume data of displaced orbital tissue were significantly positive correlated to enophthalmos and diplopia in our study.

These results suggest that region-of-interest measurement from coronal CT scans has an application in the assessment of patients with isolated blowout fractures of the orbital floor. Quantitative measurement of the extent of fracture and volume of displaced orbital tissue adds helpful parameters in the diagnosis and treatment of posttraumatic orbital fractures.

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