Three-Dimensional Computer-Aided Analysis of 293 Isolated Blowout Fractures – Which Radiological Findings Guide Treatment Decision?

Krista Pyötsiä, DDS, Valtteri Lehtinen, DDS,† Miika Toivari, DDS, MD, PhD,‡ Tero Puolakkainen, DDS, PhD,§ Michael Lowery Wilson, PhD,‖ and Johanna Snäll, DDS, MD, PhD¶*

Purpose: Our study purpose was to clarify the extent of isolated unilateral orbital blowout fracture in relation to surgical treatment and other factors behind the treatment decision. The specific aim was to determine which computer-aided measurements based on radiological images associate with treatment choice.

Methods: A retrospective cohort study was implemented on patients with an isolated unilateral orbital blowout fracture. Computer-aided measurement of fracture extent was performed. The study variables included treatment as primary outcome (surgical vs nonsurgical), post-traumatic orbital volume difference (mL) compared to contralateral orbit, fracture area (mm^2), fracture depth (mm) as predictor variables, and age, sex, injury mechanism, side and site of orbital fracture and positions of recti muscles as explanatory variables. Postoperative outcomes were reported. Logistic regression analysis was used to determine the risk factors for surgery. The statistical significance level was set at $P < .05$.

Results: Of 293 patients, 28.0% received surgical and 72.0% nonsurgical treatment. Volume difference, fracture area and fracture depth predicted surgical outcome ($P < .001$). In adjusted univariate regression analyses, fractures with moderate and severe displacement of recti muscles were more likely to receive surgical treatment than fractures with mild or no displacement (OR 6.15 and 30.75, respectively, $P <$

*Researcher, Department of Oral and Maxillofacial Diseases, University of Helsinki and Helsinki University Hospital, Helsinki, Finland.

†Researcher, Department of Oral and Maxillofacial Diseases, University of Helsinki and Helsinki University Hospital, Helsinki, Finland.

‡Consultant, Department of Oral and Maxillofacial Diseases, University of Helsinki and Helsinki University Hospital, Helsinki, Finland.

§Resident, Department of Oral and Maxillofacial Diseases, University of Helsinki and Helsinki University Hospital, Helsinki, Finland.

‖Researcher, Heidelberg Institute of Global Health (HIGH), Faculty of Medicine and University Hospital, Heidelberg University, Heidelberg, Germany.

¶Head of Department, Department of Oral and Maxillofacial Diseases, University of Helsinki and Helsinki University Hospital, Helsinki, Finland.

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Address correspondence and reprint requests to Dr Pyötsiä: Department of Oral and Maxillofacial Diseases, University of Helsinki and Helsinki University Hospital, Haartmaninkatu 4E, PL 220, 00029 HUS, Helsinki, Finland; e-mail: krista.pyotsia@gmail.com

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.001). Isolated medial wall fractures were significantly less often (OR 0.05, P = .006) and patients with older age (OR 0.97, P = .013) slightly less often treated with surgery. Patients with preoperative symptoms had more often persisting postoperative symptoms than patients without preoperative symptoms.

Conclusions: Positions of the recti muscles are an independent radiological factor guiding orbital blowout fracture treatment decision. The bony fracture extent is a combination of volume difference, fracture area and fracture depth which are strongly correlated to each other. A computer-aided method significantly facilitates the systematic evaluation of bone fragments, and the extent of orbital fractures.

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Orbital blowout fractures are isolated fractures of the fragile internal orbital walls, most frequently orbital floor and medial wall, without the involvement of the orbital rim(s) and other facial bones.[1-3] Despite the location or type of isolated orbital fracture, the goal of surgical treatment is to restore normal vision and globe function,[3] the latter being much more dependent on the extent and the location of the fracture and deviations in orbital volume.

The generally accepted indications for corrective surgery in orbital trauma include muscle entrapment, persistent diplopia, large defects (eg, fractures 2 cm^2 or larger), and globe malposition (GMP).[4-6] Regarding GMP, particularly enophthalmos correlates with increased orbital volume[7-9]; a volume change of even as low as 5% has been reported to cause clinically significant post-traumatic enophthalmos.[6]

Un-operated orbital fractures can result in offending enophthalmos,[10] concealed during primary evaluation by the post-traumatic soft tissue swelling and hematoma.[4] Due to the challenges of primary evaluating of enophthalmos, in addition to clinical symptoms the selection for surgical treatment is also dependent on radiological findings.[3] Previous studies have determined the threshold values of trauma-induced change in orbital volume for surgical treatment. However, measurement methods and fracture types vary and studies have focused mainly on volume changes. Only a few studies have evaluated how the position of inferior rectus muscle (IRM) is associated with the choice of surgical treatment.[11,12]

The purpose of this study was to clarify the extent of isolated unilateral orbital blowout fracture in relation to surgical treatment and other factors behind the treatment decision. The secondary objective was to introduce a computer-aided method for measuring fracture dimensions of orbital fracture. The specific aim was to determine which computer-aided measurements based on radiological images associate with treatment choice. The hypothesis was that bony fracture shape and fracture extent, particularly the volume change, are leading factors in guiding the choice of surgical treatment.

Patients and Methods

STUDY DESIGN

To address the research aim, a retrospective cohort study was designed and implemented. Patient records of all facial fracture patients admitted to a tertiary trauma center (Trauma Unit of Helsinki University Hospital, Helsinki, Finland) in a 6-year time period from January 1, 2013 to December 31, 2018 were retrospectively reviewed. Patient data and computed tomography scans of fractures extending to orbit were analyzed further.

INCLUSION AND EXCLUSION CRITERIA

All patients with recent diagnosis (ie, within 30 days) of isolated, unilateral orbital blowout fracture (ie, isolated fracture of orbital floor, medial wall, or combination thereof) were included in the study. Patients with orbital roof fractures, fractures of the lateral wall, bilateral orbital fractures, any other concomitant facial fracture, orbital fractures extending to orbital rim(s), earlier facial fractures in the orbital region, or insufficient computed tomography data (slice thickness > 2 mm, absence of axial images, or both) were excluded from the analysis.

STUDY VARIABLES

The primary outcome variable was choice of treatment (surgical vs nonsurgical). The predictor variables were post-traumatic orbital volume difference (mL) compared with the contralateral nonfractured orbit, post-traumatic orbital fracture area (mm^2), and maximal fracture depth (mm). The explanatory variables were: age, sex, injury mechanism (classified as one of the following: fall on the ground, assault, sports, fall from height, bicycle, motor vehicle accident [MVA], hit by a blunt object, and unknown), side of fracture (ie, left or right), site of fracture (classified as isolated orbital floor, isolated medial wall, or combined orbital floor and medial wall), and the positions of recti muscles classified as; Grade 1, 2, or 3 with respect to the fracture (see below).

'Indications for surgical treatment were classified into 3 categories: surgical treatment without symptoms (ie, indication for surgery was based solely on the extent of the fracture, globe malposition, or both), surgical treatment with mild symptoms (ie, diplopia or pain in extreme gaze directions), and severe symptoms/findings (ie, restricted eye movement, significant diplopia in nonextreme gaze directions, or both).

Additionally, clinical outcomes of surgically treated patients at 1, 3, and 5 months were reported.

COMPUTED TOMOGRAPHY AND ORBITAL VOLUME MEASUREMENTS

Orbit volume segmentation was performed using a Disior Bonelogic CMF Orbita version 1.32 (Disior Inc, Helsinki, Finland). Primary axial series with a slice thickness of less than or equal to 2.0 mm and reconstructed using soft tissue or bone algorithm was used for analysis. The Bonelogic software segments orbital volume with an algorithm that expands the segment until it comes into contact with tissue whose Hounsfield unit (HU) value exceeds the values for bony walls of orbit or the air inside skull sinuses or with the anterior closing of each orbit. The default upper limit for segmentation was 230 HU (bone) and lower limit was -800 HU. However, due to varying soft tissue contrast in images reconstructed with different algorithms, the limits were modified when needed after visual review of the segmentation results. Anterior closing is automatically detected in the software by mathematically defining a concave surface that is as flat as possible while maintaining contact with the orbital rim. Anterior closing and the resulting orbital volume segments are shown in Figure 1. Volume expansion or shrinkage caused by orbital fracture is then analyzed by mirroring the intact, contralateral orbit, registering it on top of the fractured orbit and by finding the continuous parts of both segments where the volumes do not overlap. Fracture area was defined as the area where the expanded or contracted volume segment is in contact with the simulated preinjury orbit wall based on the shape of intact orbit, whereas the maximal fracture depth was defined as the maximum linear distance between fractured orbit wall, surface and simulated preinjury orbit wall. The validity of the automatic segmentation was reviewed by K.P. and V.L.

POSITIONS OF RECTI MUSCLES

The position of the inferior rectus muscle (IRM) and the medial rectus muscle (MRM) was evaluated by K.P. and J.S. from coronal, sagittal and axial series of CT images. The position of the IRM and the MRM was classified as Grade 1 (IRM and MRM within the orbit), Grade 2 (IRM partly within the maxillary sinus or MRM partly within the ethmoid sinus) and Grade 3 (IRM completely within the maxillary sinus at any point or MRM completely within the ethmoid sinus at any point) (Fig 2). In combined fractures of orbital floor and medial wall the grading was set according to the higher category.

STATISTICAL ANALYSES

Descriptive statistics are reported. Pearson's chi-square or Fisher's exact tests were performed for categorical variables. Categorical variables (ie, injury mechanism) were reported as absolute numbers and percentages, while continuous variables (ie, age) were reported as the median and interquartile range. Median differences for the volume difference in mL and the fractured area in mm^2 were reported and Wilcoxon rank-sum or Pearson's or Fisher's exact tests were performed. Univariate logistic and multivariable logistic regression were used to estimate associations between the odds of surgical treatment and the predictor or explanatory variables. Multivariable logistic regression analysis was performed using the backward stepwise method using a threshold of 0.2. The backward stepwise method, is a model building strategy in logistic regression that begins with a full model which runs in a stepwise manner by gradually removing the less significant variables until the set threshold. The 3 predictor variables were highly correlated, and the predictor variable which achieved the highest statistical significance was retained in the final model. Estimates were reported as odds ratios (OR) and reported along with 95% confidence intervals (CI). Statistical significance was set at .05 for P values. The fit of the final model was tested using the Hosmer-Lemeshow test and found to have a good fit (P = 0.659). The Hosmer-Lemeshow test is used to test the fit of the model, and a significant value less than 0.05 would indicate a poor fit. The variance inflation factor (VIF) was used to test for multicollinearity. A value greater than 5 for any variable would imply high multicollinearity. Values ranging between 1 and 4 were found for the VIF for each of the variables in the final model, indicating minimal multicollinearity. The data analysis was conducted using Stata version 16 (StataCorp, TX, USA).

ETHICAL CONSIDERATIONS

The Internal Review Board of the Head and Neck Center, Helsinki University Hospital (HUS/356/2017) approved the study protocol. Patient consent was not required because of the retrospective nature of the

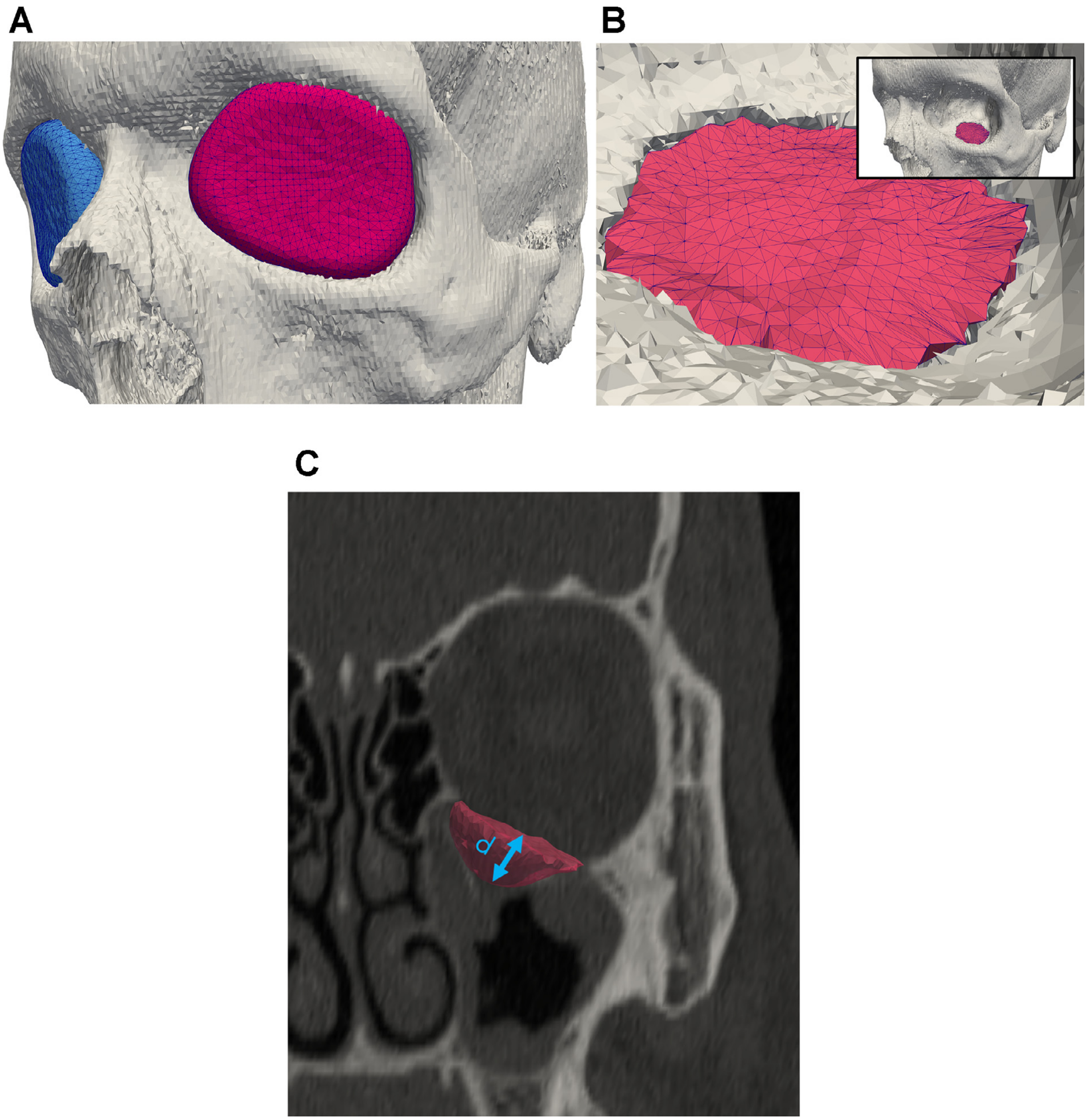

FIGURE 1. Examples of surface meshes of orbital volume segments from analysis software with *A*, automatically defined anterior closing of both orbits, *B*, segmented fracture surface area, and *C*, maximal fracture.

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study. The guidelines of the Declaration of Helsinki were followed in this study.

Results

A total of 293 patients with an isolated unilateral orbital fracture were identified and included in the present study (Fig 3). Median age was 45.8 years (range 6.8 to 98.0 years) and 58.0% of patients were male. Falling on the ground was the most common cause of fracture (35.5%). The most frequent site of fracture was an isolated fracture of the orbital floor (60.4%) and fractures were more common on the left (56.0%) side of midline.

Of the 293 patients, 82 (28.0%) required surgical treatment (Table 1). None of the nonsurgically treated patients required secondary surgery. The median age for patients who received surgical treatment was 43.11 (interquartile range 27.68, 62.44). Nearly one-third (32.8%) of all isolated orbital floor fractures were treated surgically, whereas medial wall fractures were generally treated nonsurgically (97.0%). Grade of recti muscles' displacement was significantly associated with surgical treatment ($P < .001$).

FIGURE 2. Visualization of inferior rectus muscle displacement. On the right side with no fracture, Grade 1† and Grade 3§ are shown. On the left side with orbital floor fracture, Grade 2* displacement of IRM is presented.

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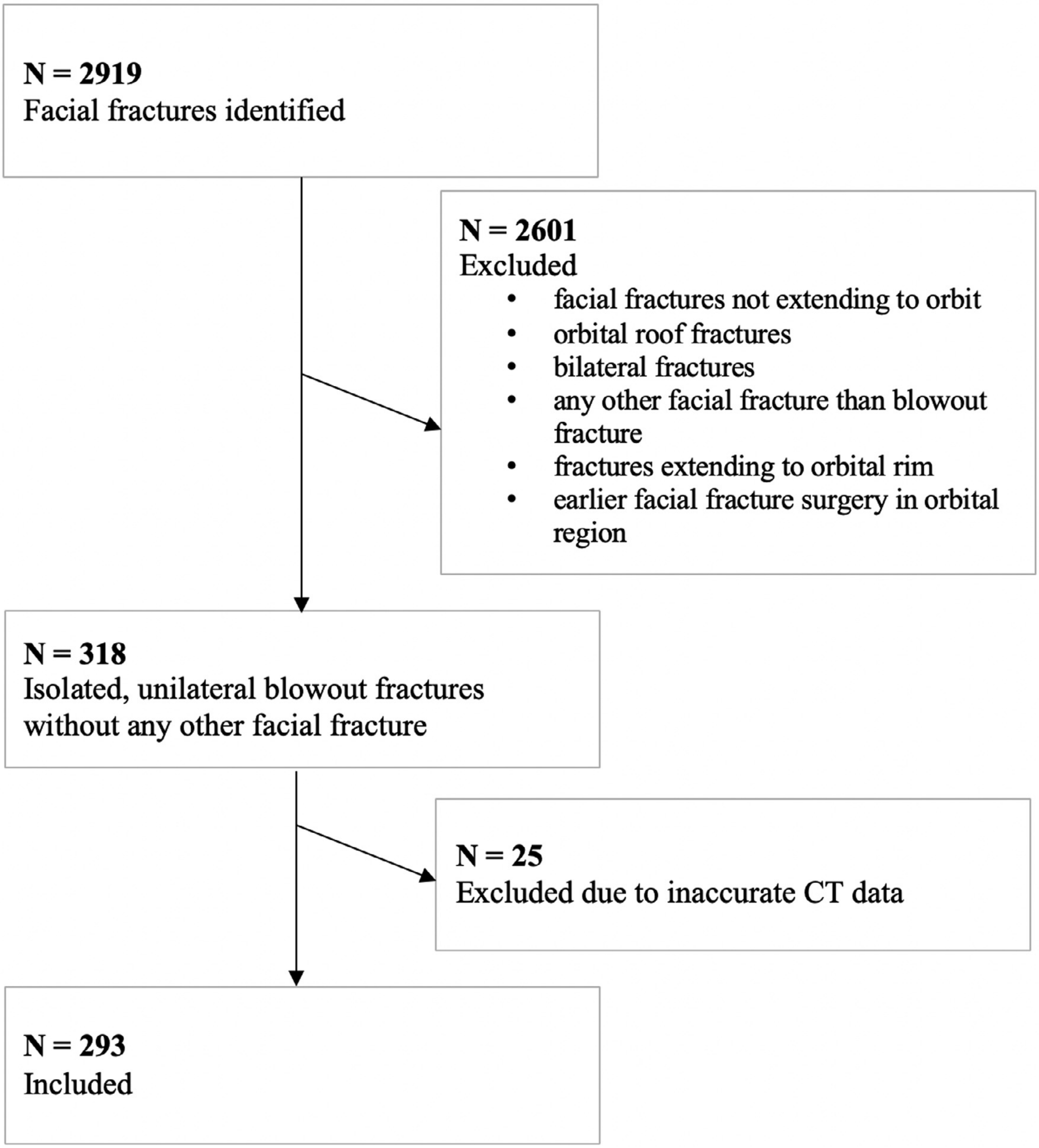

FIGURE 3. Study design.

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Table 1. ASSOCIATIONS BETWEEN EXPLANATORY VARIABLES AND TREATMENT IN 293 PATIENTS WITH AN ISOLATED AND UNILATERAL ORBITAL BLOWOUT FRACTURE.

Variables	Surgical n (%)	Nonsurgical n (%)	*P* value
All	82 (28.0)	211 (72.0)	
Age (yr) - Median (IQR)	43.11 (27.68, 62.44)	48.19 (29.68, 69.79)	.315
Mean	46.0	50.8	
Median	43.1	48.2	
Range	6.8-90.8	13.3-98.0	
Sex			
Male	50 (29.4)	120 (70.6)	.523
Female	32 (26.0)	91 (74.0)	
Mechanism of injury			
Assault	26 (26.8)	71 (73.2)	.751
Fall on the ground	30 (28.8)	74 (71.2)	.808
Bicycle	3 (18.8)	13 (81.2)	.569
Sports	11 (44.0)	14 (56.0)	.062
Hit by a blunt object	3 (50.0)	3 (50.0)	.354
Fall from height	5 (22.7)	17 (77.3)	.805
Motor vehicle accident	2 (12.5)	14 (87.5)	.251
Unknown	2 (28.6)	5 (71.4)	1.000
Fracture site			
Isolated orbital floor	58 (32.8)	119 (67.2)	.024
Isolated medial wall	1 (3.0)	32 (97.0)	<.001
Combined orbital floor and medial wall	23 (27.7)	60 (72.3)	.947
Fracture side			
Right	36 (27.9)	93 (72.1)	.979
Left	46 (28.0)	118 (72.0)	
Inferior or medial rectus muscle displacement			
Grade 1 Mild or no displacement	12 (7.2)	155 (92.8)	<.001
Grade 2 Moderate displacement	57 (51.4)	54 (48.6)	
Grade 3 Severe displacement	13 (86.7)	2 (13.3)	

Abbreviation: IQR, interquartile range.

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For the total population, the median post-traumatic volume difference was 0.74 mL, median fracture area was 198 mm^2, and median fracture depth was 3.52 mm (Table 2). In 96 patients (32.8%), the fracture was bent without significant borders or the fracture was nondislocated; therefore, the fracture area and depth were unmeasurable. The orbital fracture type associated significantly with extent of the fracture. Grade of recti muscles' displacement was significantly associated with volume, fracture area and fracture depth ($P < .001$).

All predictor variables were statistically significantly different between patients treated with corrective surgery and those who were not (Table 3). When surgical versus nonsurgical treatment was compared, the median volume difference was 1.08 versus 0.58 mL ($P = .008$), median fracture area was 302 versus 156 mm^2 ($P < .001$), and median maximum fracture depth was 5.69 versus 2.95 mm ($P < .001$), respectively.

In 28 of 82 patients (34.1%), the decision to treat surgically was based solely on fracture extent, whereas the remaining patients who underwent surgical treatment had either mild (37/82, 45.1%) or severe (17/82, 20.7%) symptoms (Table 4). Surgery was performed within 55 days of the injury (mean 8 days, median 7 days). Three patients required revision surgery due to suboptimal implant position with significant clinical symptoms. The fractures in patients presenting with severe symptoms were the least extensive compared to the fracture types of other, less symptomatic patients. Clinical data, including information of patients who were controlled for at least 1 month, were available for 72 patients. Eleven out of 54 patients (20.4%) with symptoms before surgery still had either mild or severe symptoms 5 months after surgery (Table 5). From preoperatively asymptomatic patients, 4 had mild symptoms postoperatively. In 1 patient, symptoms were still reported at 5 months.

Table 2. ASSOCIATIONS BETWEEN EXPLANATORY VARIABLES AND POST-TRAUMATIC ORBITAL VOLUME DIFFERENCE, AREA, AND DEPTH IN 293 PATIENTS WITH AN ISOLATED AND UNILATERAL ORBITAL BLOWOUT FRACTURE.

	Volume		Fracture Area		Fracture Depth	
	Median (IQR) Ml	*P* value	Median (IQR) mm2	*P* value	Median (IQR) mm	*P* value
All	0.74 (0.08-1.33)		198.0 (0.0-322.0)		3.52 (0.00-5.19)	
Age (yr)*		.381		.770		.682
Less than or equal to 45.5	0.68 (0.06-1.33)		205.0 (0.0-328.0)		3.49 (0.00-5.21)	
Greater than 45.5	0.81 (0.09-1.36)		197.0 (0.0-313.0)		3.55 (0.00-5.10)	
Sex		.257		.210		.310
Male	0.81 (0.03-1.57)		222.5 (0.0-345.0)		3.66 (0.00-5.62)	
Female	0.64 (0.11-1.22)		186.0 (0.0-280.0)		3.21 (0.00-4.89)	
Mechanism of injury						
Assault		.562		.408		.408
Yes	0.66 (0.11-1.38)		186.0 (0.0-320.0)		3.40 (0.00-5.09)	
Fall on the ground		.308		.595		.841
Yes	0.84 (1.00-1.46)		210.0 (0.0-320.0)		3.47 (0.00-5.43)	
Bicycle		.597		.442		.597
Yes	0.75 (-0.11-1.03)		181.5 (0.0-216.5)		3.67 (0.00-4.50)	
Sports		.848		.820		.519
Yes	0.72 (0.04-1.28)		209.0 (0.0-332.0)		4.05 (0.00-6.27)	
Hit by a blunt object		1.000		.447		1.000
Yes	0.49 (0.00-1.14)		271.0 (157.0-343.0)		3.47 (2.28-5.31)	
Fall from height		.670		.987		.646
Yes	0.73 (0.11-1.26)		202.0 (0.0-323.0)		3.68 (0.00-5.09)	
Motor vehicle accident		.442		1.000		.989
Yes	0.26 (0.04-1.10)		192.5 (0.0-319.5)		3.40 (0.00-5.08)	
Unknown		.723		.282		.723
Yes	0.82 (0.21-1.33)		261.0 (162.0-345.0)		4.60 (2.82-6.23)	
Fracture site						
Isolated orbital floor		.004		.214		.316
Yes	0.63 (0.04-1.15)		189.0 (0.0-305.0)		3.44 (0.00-5.05)	
Isolated medial wall		.203		.017		.044
Yes	0.41 (-0.16-1.07)		142.0 (0.0-211.0)		3.21 (0.00-3.87)	
Combined orbital floor and medial wall		<.001		.003		.012
Yes	1.21 (0.29-1.95)		280.0 (0.0-475.0)		4.46 (0.00-6.23)	
Fracture side		.686		.178		.686
Right	0.75 (0.11-1.56)		233.0 (0.0-335.0)		3.70 (0.00-5.34)	
Left	0.65 (0.04-1.26)		187.0 (0.0-304.0)		3.47 (0.00-5.08)	

(Continued)

Table 2. Cont'd

	Volume		Fracture Area		Fracture Depth	
	Median (IQR) Ml	*P* value	Median (IQR) mm2	*P* value	Median (IQR) mm	*P* value
Displacement of recti muscles						
Grade 1 Mild or no displacement		<.001		<.001		<.001
Yes	0.41 (0.00-1.09)		134.0 (0.0-261.0)		2.72 (0.00-3.83)	
Grade 2 Moderate displacement		.010		<.001		<.001
Yes	0.95 (0.32-1.65)		280.0 (168.0-374.0)		4.68 (3.32-6.46)	
Grade 3 Severe displacement		.003		.003		<.001
Yes	1.38 (1.17-2.38)		312.0 (276.0-489.0)		7.77 (5.10-9.79)	

Abbreviation: IQR, interquartile range.
* Age cut-off based on the median value.

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Based on the univariate analysis (Table 6), fracture extent, fracture type and positions of recti muscles predicted surgery. Only 1 of the 3 predictor variables (fracture depth) was retained in the final adjusted model to ensure minimal collinearity. In the adjusted model, 4 variables were statistically significant. Age was a modestly significant factor for surgical treatment. For every unit increase in age, patients were 3% less likely to have surgical treatment (OR 0.97, 95% CI 0.95, 1.00; P = .025). Isolated medial wall fractures were less likely to be treated with surgery (OR 0.05, 95% CI 0.003, 0.74; P = .030). Patients with a higher maximum fracture depth were 40% more likely to have undergone surgery (OR 1.40, 95% CI 1.21, 1.62; $P < .001$). Patients with moderate and severe displacement of recti muscles were at least 6 times and 30 times more likely to have undergone surgery, respectively, compared to those with no or mild displacement (OR 6.15, 95% CI 2.84, 13.32; $P < .001$) and (OR 30.75, 95% CI 4.88, 193.88; $P < .001$).

Discussion

The present study clarified the factors that affect the treatment decision of isolated unilateral orbital blowout fractures and introduced a computer-aided method for measuring volume change, area and depth of orbital fracture. We hypothesized that bony fracture shape and fracture extent, particularly the volume change, are leading factors for surgical treatment. Our hypothesis was partly confirmed; volume change, fracture area and fracture depth were strongly correlated and our findings highlight the role of fracture area and fracture depth as at least as important variables for surgery as volume change. Positions of recti muscles independently guided the decision for surgical treatment.

Our findings of IRM/MRM are in line with the previous studies of this subject.[11,12] Grade 1 displacement was often treated nonsurgically whereas Grade 3 displacement strongly guided toward choice of surgical repair. Grading of recti muscles' displacement from CT-scans could thus be used as 1 of the primary tools when evaluating the need for surgery as suggested by Schouman et al.[11] However, the dislocation is not directly related to symptoms, as even 75.0% of surgically treated patients with dislocated rectus muscle were asymptomatic.

Several publications have explored the relationship between volume change caused by orbital fracture and resulting diplopia or enophthalmos.[9,13-15] Therefore, volume change is worth addressing more specifically. The literature has presented that on average a 1-mL change in orbital volume would lead to 1-mm of enophthalmos.[7,8,14,16] Because preinjury CT images

Table 3. ASSOCIATIONS BETWEEN FRACTURE EXTENT AND SURGICAL TREATMENT IN 293 PATIENTS WITH AN ISOLATED AND UNILATERAL ORBITAL BLOWOUT FRACTURE.

Variables		Surgical	Nonsurgical	*P* value
Volume difference (mL)	Median (IQR)	1.08 (0.42, 1.91)	0.58 (0.02, 1.24)	.008
	Range	-1.1 to 12.14	-1.93 to 5.3	
Fracture area (mm2)	Median (IQR)	302 (198, 391)	156 (0, 292)	<.001
	Range	0-988	0-887	
Maximum fracture depth (mm)	Median (IQR)	5.69 (3.82, 7.77)	2.95 (0, 4.12)	<.001
	Range	0-31.17	0-10.04	

Abbreviation: IQR, interquartile range.

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Table 4. THE ASSOCIATION BETWEEN SEVERITY OF SYMPTOMS AND MEDIAN VOLUME DIFFERENCE, FRACTURE AREA, FRACTURE DEPTH, POSITIONS OF RECTI MUSCLES AND TIMING OF SURGERY.

		Symptoms Before Surgery (n = 82)		
		Severe Symptoms n = 17	Mild Symptoms n = 37	No Symptoms n = 28
Volume difference (mL)	Median	0.42	1.25	1.11
	Range	-0.7 to 4.02	-1 to 5.74	-1.1 to 12.14
Fracture area (mm2)	Median	168	307	318
	Range	0-587	0-988	117-700
Maximum fracture depth (mm)	Median	3.12	6.54	6.00
	Range	0-16.93	0-11.89	2.41-31.17
IRM/MRM position		n (% of 17)	n (% of 37)	n (% of 28)
	Grade 1	1 (5.9)	4 (10.8)	7 (25.0)
	Grade 2	13 (76.5)	27 (73.0)	17 (60.7)
	Grade 3	3 (17.6)	6 (16.2)	4 (14.3)
Time between the incident and primary surgery (in days)	Median	1	7	8
	Range	0-8	3-55	3-16

Abbreviations: IRM, inferior rectus muscle; MRM, medial rectus muscle.

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are rarely available for comparison, orbital volume change caused by unilateral orbital fracture is most often estimated by using the nonaffected orbit as a reference. Although it has been shown that in general intraindividual volume differences are quite small and thus mirroring unaffected orbit is a viable method for fracture volume estimation,[17,18] there are also examples in healthy population where intraindividual volume difference might be greater than 1.5 mL.[18,19] So, the possible anatomic variability should also be noted when interpreting orbital fracture volume measurements.

Even though volume change has typically been underlined as the most important criteria for orbital fracture surgery, a recent study by Schönegg et al[20] revealed no significant correlation between preoperative orbital volume difference and late enophthalmos when the mirroring technique is used. This might be explained by the fact that other factors, such as anatomical location and other characteristics also affect the development of symptoms.[15,20] Thus, simple measurement of volume difference by mirroring the contralateral orbit might not always correctly predict postoperative ocular symptoms and the need for surgical treatment. One possible solution for assessing shape and volume change caused by fracture would be to compare the shape of the fractured orbit to a statistical shape model derived from a large sample of noninjured orbits, which would also allow for analysis of bilateral fractures.[21]

In the present study, even a volume difference as small as -1.1 mL was surgically treated due to symptoms and a volume difference as high as 5.3 mL was left without surgery due to complete subjective absence of symptoms (Fig 4). Patients with muscle entrapment often have severe symptoms and yet fairly

Table 5. SYMPTOMS PRESENT UPON POSTOPERATIVE FOLLOW-UP AT 1, 3 AND 5 MONTHS.

Symptoms Before Surgery			Symptoms in Clinical Follow-up After Surgery					
			1 Mo	n	3 Mo	n	5 Mo	n
Severe	n = 17	{	Severe	2	Severe	1	Severe	1
			Mild	3	Mild	3	Mild	2
			Asymptomatic	9	Asymptomatic	10	Asymptomatic	10
			N/A	3	N/A	3	N/A	4
Mild	n = 37	{	Severe	4	Severe	0	Severe	0
			Mild	16	Mild	11	Mild	8
			Asymptomatic	13	Asymptomatic	19	Asymptomatic	20
			N/A	4	N/A	7	N/A	9
No symptoms	n = 28	{	Severe	0	Severe	0	Severe	0
			Mild	4	Mild	3	Mild	1
			Asymptomatic	21	Asymptomatic	22	Asymptomatic	23
			N/A	3	N/A	3	N/A	4

Abbreviation: N/A, not available.

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small change in orbital volume, which explains why some patients with small volume change require surgical intervention. Despite the previously presented criteria of the importance of volume change, none of the nonsurgically treated patients of the present study required late reconstruction of the orbit.

Measuring orbital volume or orbital fracture dimensions by manually segmenting slice-by-slice is

Table 6. UNIVARIATE AND MULTIVARIATE LOGISTIC REGRESSION FOR SURGICAL TREATMENT OF ORBITAL FRACTURE.

Variable	Unadjusted Odds Ratio	95% CI	*P* value	Adjusted Odds Ratio	95% CI	*P* value
Age	0.99	0.98, 1.00	.099	0.97	0.95, 1.00	.025
Volume difference (mL)	1.59	1.25, 2.03	<.001			
Maximum fracture depth (mm)	1.59	1.40, 1.81	<.001	1.40	1.21, 1.62	<.001
Fracture area (mm2)	1.00	1.00, 1.01	<.001			
Fracture side (ref: right)	1.01	0.60, 1.68	.979			
Sex (ref: males)	0.84	0.50, 1.42	.523			
Fracture site						
Isolated orbital floor (ref)	1			1		
Isolated medial wall	0.06	0.01, 0.48	.008	0.05	0.003, 0.74	.030
Combined orbital floor and medial wall	0.79	0.44, 1.40	.412	0.70	0.32, 1.52	.362
IRM/MRM grade						
Grade 1 Mild or no displacement	1			1		
Grade 2 Moderate displacement	13.5	6.55, 29.79	<.001	6.15	2.84, 13.32	<.001
Grade 3 Severe displacement	79.0	15.4, 799.8	<.001	30.75	4.88, 193.88	<.001
Mechanism of injury						
Assault	0.92	0.53, 1.58	.751			
Fall on the ground	1.07	0.63, 1.82	.808	2.63	0.92, 7.48	.070
Bicycle	0.58	0.10, 2.19	.596			
Sports	2.18	0.95, 5.02	.067	2.63	0.79, 8.76	.116
Hit by a blunt object	2.62	0.34, 20.00	.435			
Fall from height	0.74	0.21, 2.19	.768			
Motor vehicle accident	0.35	0.04, 1.59	.251			
Unknown	1.03	0.10, 6.45	1.000			

Abbreviations: CI, confidence interval; IRM, inferior rectus muscle; MRM, medial rectus muscle.

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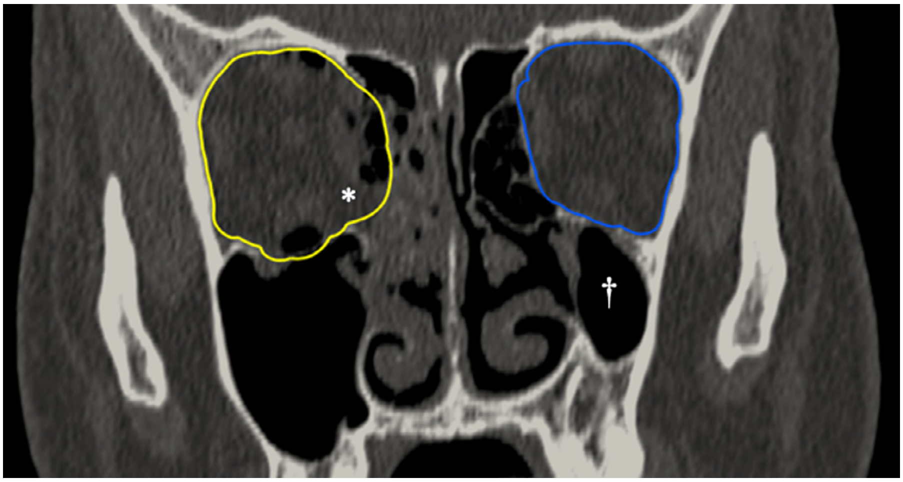

FIGURE 4. A. 40-year-old patient had right side blowout fracture that was left without surgery. Combined orbital floor and medial wall fracture with notable volume difference of 5.3 mL*. Computed tomography imaging showed a significant asymmetry due to hypoplastic maxillary sinus and zygomatic bone† of unknown aetiology. After 5-week follow up, the patient developed 1-mm enophtalmos that did not disturb the patient.

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currently considered the gold standard and has been used as a reference when assessing different automatic and semiautomatic segmentation methods.[22-24] However, this process is relatively time consuming and its results may be somewhat observer-dependent.[24] Compared to manual segmentation of fracture extent, the tool used here was more rapid and its reliability is concordant with manual segmentation,[23] thus allowing analysis of larger datasets. Automatic, rapid measurement of the extent of fracture enables its use in the acute clinical setting in addition to research use and allows for 3-dimensional visualization of orbital volume, fracture surface, and their spatial relationship with anatomic landmarks. Automatic segmentation and quantified measurement of soft tissues within orbital volume, such as extraocular muscles, would also facilitate understanding the relationship between different fracture characteristics and functional outcomes.

Approximately one-third of patients (34.1%) who were treated surgically were asymptomatic preoperatively and 45.1% had only mild symptoms (ie, diplopia or pain in extreme gaze directions). Choice of surgery was often based solely on early globe malposition or the surgeon's estimation that the extent of fracture could lead to subsequent globe malposition without surgical intervention, or both. Up to 10% of unoperated orbital fractures can result in enophthalmos in the affected globe masked by soft tissue swelling.[10] However, Young et al[25] reported a mean residual enophthalmos of 2.1 mm to be clinically irrelevant, and it seems like most nonsurgically treated patients don't have aesthetically disfiguring enophtalmos after 12-month follow-up.[26] Additionally, enophthalmos can persist even after successful surgery.[27] This makes it extremely difficult to evaluate the need for surgical intervention solely based on radiological findings. In our study, 5-month clinical follow-up showed that the more severe symptoms were before surgery, the more likely patient still reported symptoms after surgical treatment. However, surgery caused symptoms to 4 patients of which 1 reported mild symptoms 5 months after surgery. Thus, careful and close follow-up including quality-of-life assessment may be more appropriate than surgery in asymptomatic patients as well as patients with very mild symptoms.

In our study, the mean age for all patients was 49.5 years (range 6.8 to 98.0) and 58% were male. The results from the logistic regression analyses suggested older age to modestly protect from surgical treatment (OR 0.96; P = .013). Previously, Shin et al[28] and Oh et al[13] reported a 4:1 male:female ratio with mean ages of 31.5 and 27.2 years, respectively, in surgically treated orbital fracture patients. In the present study, surgery was also needed in older age groups. When compared to the studies presented by Shin and Oh, of note is the higher mean age in the surgical group (43.11 years) and particularly the age range (6.8 to 90.8 years). Underlying diseases and anesthesia eligibility may certainly influence surgical decision; however, older age should not be automatically considered as an exclusionary factor for surgery.

Consistent with previous studies, isolated orbital floor fracture was the most frequent fracture site (60.4%).[29,30] Approximately one-third of isolated floor fractures (32.8%) and combined orbital floor and medial wall fractures (27.7%) required surgical treatment. Isolated medial wall fractures were mostly treated without surgery (97.0%), which is consistent with previous reports. Alafaleq et al[31] concluded that nonsurgical management is usually sufficient with isolated medial wall fractures. In the present study, isolated medial fractures were less extensive in fracture volume, area and depth than isolated floor fractures. Also surgeon's opinion, and in particular surgical experience, can influence surgical decision-making.

The main limitation of the present study was its retrospective nature. Some limitations related to study variables were present as the amount of enophthalmos was not systematically reported. In particular, preoperative data of globe malposition was partially incomplete. However, swelling due to primary injury complicates clinical evaluation in these cases. It can, however be emphasized that significant (>2 mm) postoperative globe malposition was not registered in any of the surgically treated patients with available follow-up information. Additionally, none of the nonsurgically treated patients applied for secondary evaluation later. In this study, only the muscle position in relation to bony walls of the orbit was evaluated; more accurate, computer-aided analysis of muscle length, size and volume would give more information on how muscle position affects choice of treatment. Prospective long-term follow-up studies for nonsurgically treated patients would be necessary to comprehensively evaluate indications for surgical treatment. In addition, the analysis method used in our study relies on the intact orbit as reference when assessing the extent of fracture and therefore its reliability might be limited in some situations with bilateral orbital fractures or severe preinjury asymmetry.

In conclusion, orbital fracture extent and rectus muscle position are still the main radiological predictors for surgical treatment; however, bony fracture extent variables strongly correlate with each other. Further studies evaluating indications for orbital fracture surgery should include volume change, fracture area and fracture depth to criteria in addition to detailed rectus muscle position. Measurement of bony fracture extent is facilitated significantly by the computer-aided method, which can be implemented to clinical practice in future.

Treatment of blowout fractures is challenging, as there are no clear guidelines in selecting patients who would benefit from surgical treatment, which can lead to underestimating and overestimating the need for surgery. Prospective follow-up studies with comprehensive analysis of fracture shape and other characteristics are required to present convincing fracture size criteria for surgery and long-term outcome assessment.

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