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Comparison of the Fractured and Non-Fractured Orbit Before and After Surgery Using a Titanium Implant or a Resorbable Poly-d,l-lactic Acid (PDLLA) Implant: A Study from a Single Center in Niš, Serbia of 58 Patients with Unilateral Orbital Floor Fracture Using Volumetric Measurement

Authors' Contribution:
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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: A fracture of the orbital floor can lead to complications such as enophthalmos, impaired eye motility, or diplopia, which is why it is necessary to reconstruct the bony walls of the orbit. This study from a single center in Niš, Serbia, included 58 patients with unilateral orbital floor fracture and aimed to use volumetric measurement to compare the fractured and non-fractured orbit before and after surgery using a titanium implant or a resorbable poly-d, l-lactic acid (PDLLA) implant.

Material/Methods: From 2018 to 2022, a total of 58 patients with unilateral orbital floor fractures were treated at the Clinic of Dental Medicine, Niš. Computed tomography examination was used for volumetric measurement of the fractured and non-fractured (contralateral) orbit before and after the surgical procedure. A titanium implant was used in 31 patients, and a PDLLA implant was used in 27 patients.

Results: Orbital volume ratio did not differ statistically significantly in relation to the type of implant (P=0.591). The postoperative volume did not differ statistically significantly from the volume of the contralateral side (titanium, P=0.212; PDLLA, P=0.232). There was a significant correlation between orbital volume and enophthalmos both before and after surgery (P=0.012, P=0.018, respectively).

Conclusions: Measuring the preoperative volume of the injured orbit is sufficient data for an indication because reconstruction depends primarily on the correlation between the volume and enophthalmos. The findings from this study showed that preoperative orbital volumetry using computed tomography evaluated enophthalmos and provide data to assist orbital floor reconstruction.

Keywords: **Enophthalmos • Orbital Fractures • Orbital Implants**

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Background

Orbital fractures involve isolated fractures of the inferior or medial wall of the eye socket, without orbital rim(s) fracture or fracture of other facial bones [1-3]. The European Project on Maxillofacial Trauma (EURMAT) states that, of the total number of maxillofacial injuries, about 16% are injuries to the orbit [4]. Unoperated orbital fractures can lead to significant enophthalmos, which is masked during primary evaluation by posttraumatic soft tissue swelling and hematoma [5]. In addition to enophthalmos, a fracture of the orbital floor can lead to complications, such as eye motility impairment or diplopia, which necessitates the reconstruction of the bone walls of the orbit [6].

Entrapment of bulbar muscles, diplopia, orbital wall defects larger than 2 cm^2, and bulbar malposition are indications for orbital reconstruction [7-9]. Regarding globe malposition, enophthalmos in particular correlates with increased orbital volume (as has been reported, a volume change of as little as 5% causes clinically significant posttraumatic enophthalmos) [10-12]. Also, radiological findings are important for surgical treatment decisions.

The use of computerized tomography (CT) for the purpose of measuring the orbital volume is a useful tool for surgeons in cases of treating enophthalmos caused by trauma to the bone walls of the orbit, as well as for the purpose of reconstructing the orbital volume. The aim of surgical intervention after a fracture of the orbital floor is to correct the position of the eyeball and restore impaired function. Multiplanar reconstruction using CT is the most precise procedure, providing the most detailed resolution of the bony walls of the orbit, but it takes the longest time for measurement [13-15]. Today, there are several methods for volumetric analysis based on DICOM images. Volume measurements can be performed by manual, semi-automatic, and automatic processes. With the development of new software, semi-automatic and automatic segmentations are increasingly being used. Nonetheless, manual segmentation "slice-by-slice" by an expert is considered the criterion standard; it is more precise but very time-consuming and prone to intra- and interobserver variability [15]. Other studies determined the values of orbital volume change as an indication for surgery. However, measurement methods and fracture types vary. Numerous studies have focused on changes in orbital volume [16,17]. Enophthalmos associated with orbital floor fracture is the result of various factors, among which the increase in orbital volume is considered the most common factor, and there are numerous studies that have attempted to evaluate the success of surgical reconstruction by measuring orbital volume [18]. The analysis and quantification of orbital trauma are complex because orbital volume depends on soft tissue components that change over time (posttraumatic edema, periorbital tissue incarceration, late fibrosis, and atrophy) [19]. On the other hand, the size and localization of bone defects, as well as changes in the volume of the orbit, can be of great importance for the final outcome of the treatment. The reason for the frequent preoperative occurrence of enophthalmos in orbital floor fractures is the increase in pressure and weight of the bulb itself on the lower wall [20].

Defects of the orbital floor could be reconstructed using individual orbital implants from the alloplastic group, such as resorbable poly-d, l-lactic acid (PDLLA) implants [21], as well as titanium mesh [22].

Koenen et al analyzed the etiology, pathophysiology, epidemiology, and treatment of this type of injury and concluded that an interprofessional approach to a blow-out fracture is recommended, with a team consisting of an ophthalmologist, maxillofacial surgeon, and radiologist [23].

Therefore, this study, from a single center in Niš, Serbia, included 58 patients with unilateral orbital floor fracture and aimed to use volumetric measurement to compare the fractured and non-fractured orbit before and after surgery using a titanium implant or a PDLLA implant.

Material and Methods

From 2018 to 2022, a total of 58 patients with unilateral orbital floor fractures were surgically treated in the Department of Maxillofacial Surgery, Clinic of Dental Medicine in Niš. This research was retrospective. The study adhered to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Clinic for Dentistry in Niš (20/7-2018-3EO). Each patient signed a document of informed consent, which allowed the data from their medical records to be used in the preparation of a scientific article and stated that their identity would be anonymous. Those patients were followed up for at least 6 months. A titanium implant was used in 31 patients, and PDLLA (Resorb X, KLS Martin, Tuttlingen, Germany) implant in 27 patients.

The exclusion criteria were as follows: (1) bilateral orbital floor fractures, (2) ophthalmopathy associated with thyroid gland diseases, and (3) orbital tumors, since they can all cause increased orbital volume and measurement errors.

Ophthalmological Tests

The Hess-Lancaster diplopia test and Hertel exophthalmometry test were performed before surgical treatment. Hypoesthesia of the infraorbital nerve was identified.

The Hess-Lancaster test schematizes the position of the eyes and the function of the extraocular muscles and was applied to all patients 6 months after surgery.

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The Hertel exophthalmometry determines the position of the eyeball in the eye socket. In this test, the distance between the apex and the outside of the cornea and the lengths of the orbit edges were simultaneously measured in both eyes. Although the absolute values themselves are not very important, they should be compared and monitored.

A difference of up to ±2 mm from the normal value is negligible, while values greater or less than this indicate the existence of a pathological process in the orbit. In order to assess the presence of secondary enophthalmos, the Hertel test was applied 6 months after surgery.

Surgical Technique

Surgical interventions were performed under general endotracheal anesthesia, after adequate preoperative preparation. Access to the fracture site was performed through a transpalpebral approach with a sharp and blunt preparation, the lower orbital edge was accessed, and after the orbital tissue exploration, the existing orbital floor defect was identified. The trapped orbital content was released and returned to the orbit by the periosteal elevator. Defects of the orbital floor were reconstructed using individual orbital implants from the alloplastic group, namely a 0.3 mm-thick titanium mesh (Mikro-Orbita-Mesh, KLS Martin, Tuttlingen, Germany) and resorbable poly-d, and manually modeled l-lactic acid (PDLLA) implant (Resorb X, KLS Martin, Tuttlingen, Germany). The mesh plate was cut and molded to match the anatomy of the fracture site and inserted under the periosteum on the floor of the eye socket. Resorbable PDLLA implant plates were modeled using a bath of a warm physiological solution at a temperature of 55°C to 70°C. The physical properties of the plates can be changed because they become soft and can be modeled without altering their chemical characteristics. They were placed in the region of the orbital floor defect. The implant covered the defect, passing over the peripheral edges of the healthy bone by 2 to 3 mm. The forced withdrawal test was performed to check if there was no limitation in bulbar mobility.

Sutures were removed 7 days after surgery. Patients were monitored once a week for the first month after surgery, and then monthly. In the first and sixth month after surgery, clinical improvement was assessed by clinical signs and diplopia was assessed within the central visual field. "No diplopia" was defined as an absence of diplopia.

Radiology

CT examinations were performed using a 64-detector CT scanner (GE Revolution EVO 64; GE Healthcare, Milwaukee, WI, USA). The standard CT protocol for orbit examinations included scanning fields from the hard palate level to the level superior to the frontal sinuses. The patients were examined in the supine position. Scanning parameters included 120 kV and 220 mA, with an X-ray tube rotation of 0.33 s and slice thickness of 0.625 mm. After the software reconstruction of CT scans, all datasets were transferred and processed in 2-dimensional (2D) and 3D projections on a diagnostic workstation (Advantage Workstation 4.7; GE Healthcare, Milwaukee, WI, USA) using AW Volume Share 7 software (General Electric Company, Waukesha, WI, USA). Then, postprocessing techniques of 3D volume rendering and multiplanar reconstruction were used. A multiplanar analysis was conducted in the coronal, sagittal, and axial planes.

All the volumetric measurements were semi-automatically conducted. First, manual segmentation was performed by using a freehand drawing cursor region of interest in the axial plane by an experienced radiologist. Next, the isolated regions were visually inspected and manually adjusted. Segmented orbital contours were reconstructed as 3D images, and orbital volumes were automatically calculated. All measurements were evaluated 3 times by one radiologist, and the arithmetical value was estimated to reduce the measurement error. The anterior orbital border was defined as a line connecting medial and lateral orbital rims, while the posterior orbital border was defined as the orbital apex. A CT examination was used for the volumetric measurement of the fractured and non-fractured (contralateral) orbit before and 6 months after the surgical procedure. In addition, we preoperatively observed the location of orbital floor fractures, incarceration of orbital soft tissue, and extraocular muscles. Orbital implant position and the effect of orbital wall reconstruction were evaluated after surgery.

A CT examination was used for volumetric measurement of the fractured and contralateral (uninjured) orbit before and after the surgical procedure. The calculation formula for orbital volume ratio is: orbital volume ratio (OVR)=(1-(A-B/B))×100% (A: volume of fractured orbit after surgery; B: volume of contralateral [uninjured] orbit).

In the situation when the volume of the fractured orbit after surgery is equal to that of the uninjured orbit, the OVR is 100%. When the volume of the fractured orbit after surgery is 20% greater than that of the uninjured orbit, the OVR is 80%.

Statistical Analysis

Data are statistically presented in the form of arithmetic mean ± standard deviations, as well as minimum and maximum values. The comparison of numerical variables in relation to implants and time between trauma and surgery was performed by a *t* test and Mann–Whitney test. The comparison of categorical variables was performed using the chi-square test. The hypothesis was tested with a significance threshold of $P<0.05$.

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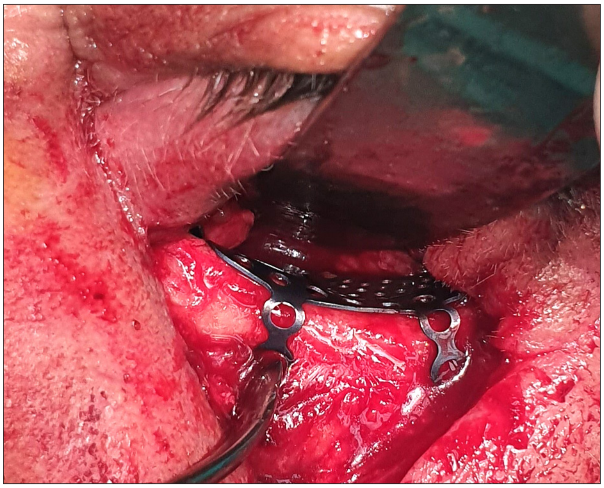

Figure 1. Orbital floor reconstruction with titanium mesh. *Windows photo editor 10.0.1001116384 © 2020 Microsoft Corp.*

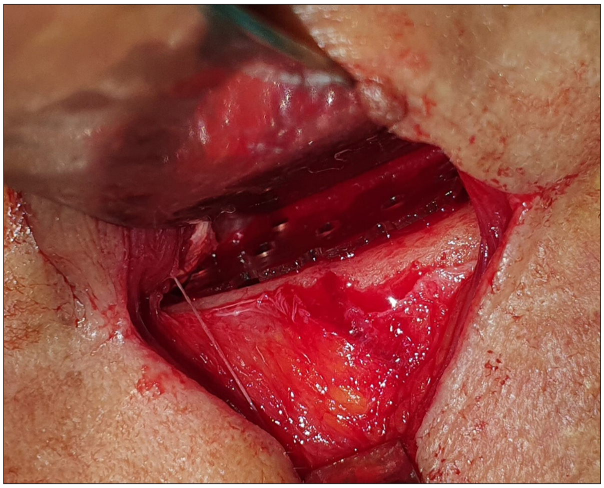

Figure 2. Orbital floor reconstruction with resorbable poly-d, l-lactic acid (PDLLA) implant. *Windows photo editor 10.0.1001116384 © 2020 Microsoft Corp.*

Statistical analysis was performed in R 4.1.3 for Windows (R Core Team 2013).

Results

Demographics

In the period from 2018 to 2022, 58 patients (49 men and 9 women) who were injured were included in the research. The average age of the studied population was 43.60±16.42 years (range 18 to 86 years).

Operative Details

A titanium implant was used in 31 patients, and a resorptive PDLLA was used in 27 patients (**Figures 1, 2**).

The average number of days from injury to surgery was 8.37±8.14. After trauma, diplopia and paresthesia were present in 60.3% and 98.3% of patients, respectively. Postoperative diplopia and paresthesia were present in 6.9% and 43.1% of patients, respectively (**Table 1**).

Preoperative limited extraocular muscle motility was present in 56.9% of patients, and postoperative limited motility was present in 6.9% of patients. The preoperative volume of the fractured side was statistically significantly higher than that of the contralateral side (*P*<0.001). The postoperative volume of the fractured side was not statistically significantly different from that of the contralateral side (*P*=0.104).

Outcomes

The mean volume of all reconstructed orbits was 25.20±2.75 cm^3. The mean postoperative volume difference was 0.81±1.51cm^3. The postoperative OVR was 96.50% (**Figure 3A-3D**).

The comparison of demographic and clinical parameters in relation to the installed implants showed a statistically significant difference in the preoperative volume (*P*=0.028), postoperative volume (*P*=0.005), and volume of the contralateral side (*P*=0.008). The OVR was not statistically significantly different in relation to the type of implant (*P*=0.591). With both implants, the preoperative volume of the fractured side was statistically significantly higher than that of the contralateral side (titanium, *P*<0.001; PDLLA, *P*<0.001), and the postoperative volume of the fractured side was not statistically significantly different than that of the contralateral side (titanium, *P*=0.212; PDLLA, *P*=0.232) (**Table 2**).

Follow-up was statistically significantly longer in patients in whom titanium was used (*P*<0.001). There was a significant correlation between orbital volume and enophthalmos both before and after surgery (*P*=0.012, *P*=0.018, respectively). Similarly, a statistically significant correlation was found between orbital volume difference and enophthalmos both before and after surgery (*P*<0.001, *P*=0.003, respectively). Early enophthalmos of at least 1 mm was found in 46 patients (79.3%). Postoperative diplopia was resolved in all but 4 patients (6.9%) who had persisting ocular motility impairment that needed correction with prism glasses (**Table 3**).

Exophthalmometry at the last follow-up appointment showed a normal globe position in 32 patients (55.1%) and enophthalmos ≤2 mm in 23 patients (39.7%), and 3 of the patients (5.1%) were subjectively disturbed by their globe position.

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Table 1. Demographic and clinical characteristics of the studied population.

	Mean±SD#/Count	Min-Max#/(%)
Age# (years)	43.60±16.42	18-86
Sex		
Male	49	84.5%
Female	9	15.5
Side of injury		
Right	28	48.3
Left	30	51.7
Mechanism of injury		
Explosive	1	1.7
Fall	10	17.2
Work	7	12.1
Traffic	11	19.0
Sport	5	8.6
Fight	24	41.4
Number of days from injury to surgery	8.37±8.14	0-40
Implant		
Titanium	31	53.4
PDLLA	27	46.6
Diplopia preoperatively	35	60.3
Paresthesias preoperatively	57	98.3
Diplopia postoperatively	4	6.9
Paresthesias postoperatively	25	43.1
Enophthalmos preoperatively# (mm)	-2.03±1.36	-6-0
Enophthalmos postoperatively# (mm)	-0.71±0.96	-4-0
Extraocular muscle motility preoperatively limited	33	56.9
Extraocular muscle motility postoperatively limited	4	6.9
Volume preoperatively# (cm^3)	27.39±3.05*	22.15-35.89
Volume postoperatively# (cm^3)	25.20±2.75**	21.21-31.33
The volume of the healthy side# (cm^3)	24.38±2.64	20.14-31.10
The orbital volume difference preoperatively# (cm^3)	3.03±2.07	-0.41-12.20
The orbital volume difference postoperatively# (cm^3)	0.81±1.51	-3.07-4.86
OVR# (%)	96.50±6.08	81.65-110.55

Data are expressed as mean±standard deviation; * volume preoperative versus contralateral: p<0.001;
** volume postoperative versus contralateral: p=0.104.

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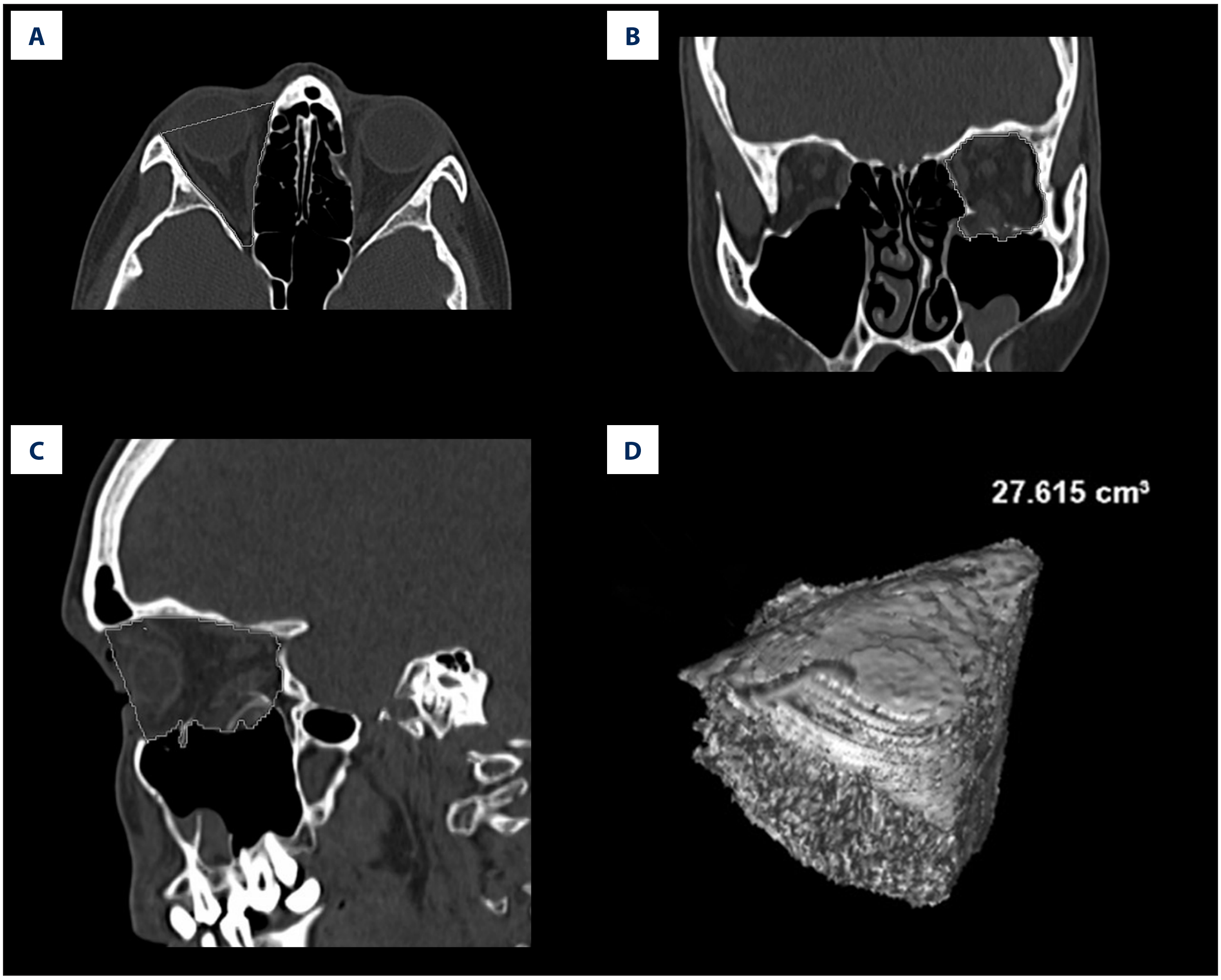

Figure 3. (**A**) Example of orbital volume measurement in the bone window using multiplanar reconstruction (MPR) in the axial plane. (**B**) Example of orbital volume measurement in the bone window using MPR in the coronal plane. (**C**) Example of orbital volume measurement in the bone window using MPR in the sagittal plane. (**D**) Volume rendering reconstruction of the orbit with calculated volume. *Images created with AW Volume Share 7 software (General Electric Company, Waukesha, WI, USA) at Advantage Workstation 4.7 (GE Healthcare, Milwaukee, WI, USA).*

Discussion

The main goals of surgical intervention in orbital floor fractures are the decarceration of herniated orbital tissues and the reconstruction of bone parts of the orbit, with the restoration of its shape and volume. Also, correction of diplopia, enophthalmos, and limitations of extraocular muscle movement are important tasks [24,25]. Usual indications are the presence of diplopia that lasts longer than 2 weeks, restriction of extraocular muscle movement, radiological finding of extensive fracture, and enophthalmos caused by increased orbital volume [26].

The most important criterion for orbital reconstruction is orbital volume change. It is commonly accepted that the increase in orbital volume is accompanied by the appearance of enophthalmos [11].

Approximately half of the patients (53.4%) who were surgically treated were asymptomatic before surgery, and 32.8% had only mild symptoms such as diplopia or pain in extreme gaze directions.

In this study, the mean age of patients with titanium implants was 46.13 years, and in the group with PDLLA it was 40.70 years; the male: female ratios of these groups were 9.3: 1 and 3.5: 1, respectively. Enophthalmos was persistent in 44.8% (≤2 mm) of patients but clinically relevant in only 5.1% (≥2 mm).

The results of orbital floor reconstructions were obtained by calculating the volume ratio between the injured and the contralateral orbit before and after surgery. In this study, orbital volume was measured in a smaller number of patients (59) and a longer follow-up period of 6 months.

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Table 2. Demographic and clinical characteristics of the studied population in relation to the implant.

	Titanium		PDLLA		p[1]
Age# (years)	46.13±15.24		40.70±17.52		0.21[2]
Sex##					
Male	28	90.3	21	77.8	0.341[2]
Female	3	9.7	6	22.2	
Side of injury##					
Right	15	48.4	13	48.1	0.986[2]
Left	16	51.6	14	51.9	
Mechanism of injury##					
Explosive	1	3.2	0	0.0	0.057[2]
Fall	6	19.4	4	14.8	
Work	6	19.4	1	3.7	
Traffic	7	22.6	4	14.8	
Sport	0	0.0	5	18.5	
Fight	11	35.5	13	48.1	
Number of days from injury to surgery#	8.58±9.19		9.48±8.59		0.356[2]
Diplopia preoperatively##	18	58.1	17	63.0	0.704[2]
Paresthesias preoperatively##	30	96.8	27	100.0	1.000[2]
Diplopia postoperatively##	2	6.5	2	7.4	0.886[2]
Paresthesias postoperatively##	15	48.4	10	37.0	0.545[2]
Enophthalmos preoperatively# (mm)	-1.87±1.56		-2.22±1.09		0.294[2]
Enophthalmos postoperatively# (mm)	-0.84±1.04		-0.56±0.85		0.261[2]
Extraocular muscle motility preoperatively limited##	18	58.1	15	55.6	1.000[2]
Extraocular muscle motility postoperatively limited##	2	6.5	2	7.4	1.000[2]
Volume preoperatively# (cm^3)	28.22±3.23*		26.39±2.52*		0.028
Volume postoperatively# (cm^3)	26.14±2.81**		24.11±2.28		0.005
The volume of the healthy side# (cm^3)	25.27±2.62		23.37±2.31**		0.008
The orbital volume difference preop# (cm^3)	2.96±2.48		3.11±1.49		0.269[3]
The orbital volume difference postop# (cm^3)	0.87±1.89		0.74±0.91		0.488[3]
OVR (%)#	96.32±7.52		96.70±3.99		0.591
Follow up# (months)	22.42±9.65		12.07±12.83		<0.001

Data are expressed as mean±standard deviation; ## count and percentage; [1] t test,; [2] Chi-squared test; [3] Mann-Whitney test;
Titanium: * volume preoperative versus contralateral: p<0.001; ** volume postoperative versus contralateral: p=0.212;
PDLLA: * volume preoperative versus contralateral: p<0.001; ** volume postoperative versus contralateral: p=0.232.

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Table 3. Globe position in the study population.

	mm	Preoperatively		Postoperatively	
		No	%	No	%
Enophthalmos	-6	1	1.7	0	0.0
	-4	3	5.2	1	1.7
	-3	23	39.7	2	3.4
	-2	12	20.7	8	13.8
	-1	7	12.1	15	25.9
	0	12	20.7	32	55.2
	Total	**58**	**100.0**	**58**	**100.0**

In this study, we performed a manual segmentation with semiautomatic calculation but without mirroring the contralateral orbit. Also, the results showed that the linear correlation between postoperative orbital volume and long-term enophthalmos was statistically significant. The mean volume of the contralateral (uninjured) orbit was 24.38±2.64 cm^3, which agrees with the results of Baek et al, Choi et al, and Andrades et al [27-29]. Our research results agree with those of Park et al [30] because the enophthalmos correction in our patients was 0.82 mm per 1 cm^3 of orbital volume reduction.

In general, the demonstrated orbital volume reconstruction showed satisfactory correction. We found mild enophthalmos (≤2 mm) in patients with an under-correction of the orbital volume. These findings underline that bone orbital volume plays an important role in the development of enophthalmos and diplopia lately. During the postoperative follow-up period, no infection caused by the orbital implant, dislocation or exposure of the implant, or loss of vision due to the presence of the orbital implant was observed. The non-significant difference between contralateral orbital volumes before and after surgery indicates the reliability of the contralateral (healthy) orbit measurements.

There was no significant difference in OVR groups dependent on the type of orbital implant during postoperative follow-up. Regarding postoperative complications, we did not find any except for 4 patients with persistent diplopia that needed correction with prismatic glasses. No patients required reoperation. Most cases of enophthalmos were well corrected after orbital floor reconstruction.

The results of this study showed that both reconstructive materials had similar effects on the outcome of treatment. Although we expected significantly higher persistent enophthalmos in patients with PDLLA implants, both implant types showed good results without significant differences in the follow-up period. We can safely use both types of implants. We found a statistically significant correlation between orbital volume difference and enophthalmos both before and after surgery. Both implant types showed no significant differences regarding extraocular muscle motility and diplopia. These results suggest that factors such as a surgeon's preference, patients' requests, or cost-effectiveness, could be appropriate for implant selection. Namely, both implant types seem to be equally effective and safe for orbital floor reconstruction. In cases of inferior orbital wall fractures, these implants are particularly effective for improving enophthalmos. The preoperative volume calculation of the fractured orbital forms sufficient data for an orbital reconstruction if there is a correlation between the increased volume and enophthalmos.

Alloplast materials, both resorptive and permanent (non-resorptive), are commonly used in the reconstruction of orbital floor defects. The choice of materials for orbital floor repair remains controversial, as there is no perfect implant available for all types of fractures and each one has advantages and disadvantages [26]. A resorptive implant should have a tensile strength greater than that of the orbital walls and gradually transfer the load from the disintegrating implant, allowing time for adequate bone and/or fibrous tissue formation in the bone defect. It should be completely resorbed to minimize the risk of foreign body reaction, infection, and the need for removal [3145]. Permanent implants such as titanium mesh have the benefits of good tensile strength and support of the orbital tissue. Multiple studies that compared the clinical outcomes of orbital fracture reconstruction using resorptive implants and permanent implants (including diplopia, enophthalmos, and ocular motility restriction) demonstrated comparable results, and their authors concluded that resorptive implants are suitable for isolated orbital floor reconstructions [31,36-39]. Some surgeons used resorptive mesh plates owing to their ease of use and complete resorption [40]. Some authors showed that the connective tissues around the resorptive mesh plate could not completely replace the bone structures after plate resorption, which can result in late enophthalmos [41].

Additionally, postoperative fibrosis cannot support the orbital structure, and it could persistently lead to enophthalmos [42].

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Titanium mesh is known to be biocompatible and has been widely used for various craniofacial fractures. It can be easily adapted to bone structures and cut to the desired shape [43]. As foreign bodies, titanium plates could also lead to different late complications, such as infection, extrusion, implant migration, and permanent diplopia [44].

Resorb X, used in this study, is a resorptive system that is solely derived from 50: 50 poly (D, L-lactide) lactide. PDLLA is a purely amorphous compound that degrades in vitro without releasing crystalline by-products that might be involved in causing foreign-body reactions. An in vivo light microscopic examination showed that pure PDLLA disappears from the extracellular space within 72 weeks of implantation. Moreover, PDLLA maintains 90% of its bending strength at 6 weeks after implantation and 60% at 12 weeks [45]. Orbital volume measurements have been used for direct comparisons, OVR calculation, or the measurement of herniated tissue volume. Most authors calculate the OV using manual segmentation. Several studies have shown a correlation between an increased OV and enophthalmos. OVR is a parameter that can standardize this inter-individual variability. It has been described as a better predictor of enophthalmos onset [11,18,46-51].

Measuring orbital volume using slice-by-slice manual segmentation is currently considered the criterion standard and has been used as a reference for assessing different automatic and semiautomatic segmentation methods [52-54]. However, this process is relatively time-consuming, and its results can be somewhat observer-dependent. In this study, we used a semiautomatic method for achieving more precise results.

Several studies investigated the relation between the orbital volume change caused by an orbital fracture and, consequently, diplopia or enophthalmos [12,47,55,56]. The literature data has shown that increased orbital volume of 1 cm^3 could lead to enlargement of enophthalmos for 1 mm [10,11,46,48].

Also, it has been demonstrated that intra-individual volume differences are quite small, and mirroring technique of uninjured orbit is a suitable for fracture volume estimation [57,58]. In a healthy population, there are also examples in which intra-individual volume differences might be greater than 1.5 cm^3 [57-59]. Thus, a simple measurement of volume difference by mirroring the contralateral orbit might not always correctly predict postoperative ocular symptoms and the need for surgical treatment.

A recent study by Schönegg et al revealed no significant correlation between preoperative orbital volume difference and late enophthalmos when the mirroring technique was used [60]. This might be explained by the fact that other factors, such as anatomical location, and other characteristics also affect the development of symptoms [56,60].

The present study had some limitations in terms of the small number of patients with postoperative diplopia. One possible solution would be to compare the shape of fractured orbits with a statistical shape model derived from a large sample of uninjured orbits. Also, a statistical shape model could be used for the analysis of bilateral orbital fractures [61]. Patients with muscle entrapment often have severe symptoms despite a relatively small change in orbital volume, which explains why some patients with a small volume change require surgical intervention. Early malposition of the eyeball itself, as well as surgical assessment of the extent of the fracture that can cause enophthalmos, are indications for surgical treatment [56]. Young et al showed a mean persistent enophthalmos of 2.1 mm as clinically irrelevant. Most non-surgically treated patients at the 12-month follow-up had no aesthetically unattractive enophthalmos [58,59]. Nevertheless, enophthalmos could be persistent even after successful surgery [61].

Previously, Shin et al and Oh et al reported a 4: 1 male: female ratio with mean ages of 31.5 and 27.2 years, respectively, in surgically treated orbital fracture patients [27,61]. Underlying diseases and anesthesia eligibility can certainly influence the surgical decision; however, older age should not be automatically considered to be an exclusionary factor for surgery.

Fan et al reported that 0.89 mm of enophthalmos was improved by the reconstruction of fractured orbits by 1 cm^3 in 16 patients [6]. Park et al reported an improvement in enophthalmos of 0.67 mm, with an orbital volume reduction of 1 cm^3 in 14 examinees using a copolymer mesh orbital implant [30]. Ploder et al showed that enophthalmos of 1.2 mm was improved by a 1 cm^3 reduction in refracted orbital volume in 38 patients [62]. Raskin et al concluded that enophthalmos of 0.47 mm was improved by reducing the volume of fractured orbits by 1 cm^3 in 30 patients [48]. Ye et al found that 0.66 mm of enophthalmos was enhanced by reducing 1 cm^3 of fractured orbital volume in 16 patients with blow-out fractures using a porous polyethylene orbital implant [63]. This finding is in accordance with the results of other studies reporting a linear correlation between increased orbital volume and enophthalmos [55].

Limitations of this study were its retrospective nature and the relatively small number of patients in the groups. As we continue to collect more medical data, we will have stronger statistical power to identify more significant differences.

Conclusions

The measurement of orbital volume is a good tool for predicting enophthalmos and planning orbital surgery. It is necessary to develop an easy-to-use technique that allows us to

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quickly and precisely perform measurements and calculations and that can be widely applied.

We must keep in mind that after orbital trauma or after orbital surgery, periorbital tissue retraction can lead to enophthalmos, even if the volume of the bony orbit is completely restored. Planimetry remains the most commonly used technique. Modern software packages for image processing will become more precise, and, therefore, important over time.

Measuring the preoperative volume of the injured orbit is sufficient data for an indication because reconstruction depends primarily on the correlation between the volume and enophthalmos. The CT technique used for volumetric measurement in this study was useful for analyzing the results of orbital floor reconstruction, regardless of which type of reconstructive materials were used. The findings from this study showed that preoperative orbital volumetry using CT was shown to evaluate enophthalmos and provide data to assist orbital floor reconstruction.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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