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Orbital Bone Fracture Repair Evaluation Through 3-Dimensional Computational Reconstruction and Orbital Volumetric Assessment

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Background: Three-dimensional (3D) models generated from computed tomography (CT) images efficiently and accurately complement surgical comprehension. Additionally, computer modeling provides a substrate for comparative analysis of the treated orbit volume. This study aimed to investigate cases of orbital bone fractures with regard to orbital-defect correction, through 3D computational structural modeling and evaluation of orbital volume.
Methods: A total of 136 cases of orbital fractures with a diagnosis and surgical treatment were identified, of which 15 were selected based on inclusion and exclusion criteria. The construction of the preoperative and postoperative 3D models was based on CT images, supported by a medical imaging design system; this technique enabled the calculation of orbital volumetric measurements with the normal contralateral orbit as a reference.
Results: Three-dimensional modeling in the preoperative and postoperative periods was performed for each patient. This study revealed that (1) preoperatively, the affected side had greater volume followed by postoperative reduction and (2) after surgical correction, the affected side had smaller volume and was equivalent to the unaffected side. However, there were no statistically significant differences between the periods (preoperative and postoperative) with regard to the mean and distribution of orbital volume or between the mean orbital volumes of the 2 sides.
Conclusions: Using 3D computer modeling of bone structures, it is possible to evaluate orbital bone fractures after surgical correction. The effectiveness of preoperative and postoperative treatments was confirmed by comparing orbital volumetrics. It was not possible to assess soft tissues due to postoperative edema. *(Plast Reconstr Surg Glob Open 2024; 12:e6409; doi: 10.1097/GOX.0000000000006409; Published online 20 December 2024.)*

INTRODUCTION

The first reports on the treatment of facial fractures date back to ancient Egypt in the 17th century B.C., and important advances have been made in this area in the last century. The introduction of computed tomography (CT) into the routine practice of craniomaxillofacial surgeons has brought great advances in diagnostics, with this examination being of essential importance since the 1980s.[1–3]

Orbital bone fractures are among the most common and challenging facial fractures, with a prevalence of approximately 50%, owing to high exposure of the orbit.[1,2,4,5] Most orbital fractures occur in young adult men, where car accidents and assaults are the primary cause of trauma.

Symptoms include orbital pain, ecchymosis, subcutaneous emphysema, functional abnormalities (vision, changes in extraocular muscles, and diplopia), aesthetic changes (ocular and orbital asymmetry), and changes in sensitivity (hypesthesia or anesthesia in the topography of the infraorbital nerve). Because there are so many common alterations, it is important to emphasize the need for reconstruction.[6]

The surgical approach (subciliary, transcaruncular, transconjunctival, subtarsal, or endoscopic) is dependent on the specific characteristics of the fracture.[7] The

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transconjunctival or transcutaneous approaches are common methods used for orbital floor fractures and the choice of most surgeons; alternative methods can be the retroseptal or preseptal approach.[8,9] Suboptimal surgical outcomes can lead to debilitating morbidities with significant emotional, functional, and occupational damage, resulting in large socioeconomic losses.[10]

The orbital bone fracture surgical corrections are frequently supported by preoperative control using CT, a practice that is routinely performed in craniomaxillofacial services. Three-dimensional reconstructions of CT images are a relatively new tool for the analysis of facial fractures and can complement their diagnostics. Ghareeb et al[11] used differential volumetric orbital restoration for treating ocular malposition resulting from severe orbital fractures. Utilizing 3D CT scans and orbital volumetry, the study emphasizes the importance of accurately restoring both the volume and location of intraorbital contents to achieve optimal outcomes. Sirin et al[12] demonstrated that craniomaxillofacial surgeons feel comfortable and make efficient assessments of orbital bone fractures with the support of 3D reconstructions of anatomical structures.

In the literature, most studies evaluating orbital volume in orbital bone fractures do not compare preoperative and postoperative results to evaluate the surgical outcomes involved in orbital volumetric variations, although these measurements can be decisive for evaluation and surgical decisions.[13,14]

This study aimed to investigate orbital bone fractures treated at a tertiary facial trauma center, focusing on evaluation of the correction of orbital defects, by comparing the affected orbit to the nonaffected one, through 3D computational structural modeling and orbital volumetric assessment.

METHODS

This retrospective observational study with a prospective evaluation of functional results comprised 15 patients with orbital fractures from the craniomaxillofacial plastic surgery ambulatory at Hospital das Clínicas, Faculty of Medicine of the University of São Paulo between 2018 and 2020. The study followed the principles outlined in the Declaration of Helsinki.

The medical records of patients who had experienced orbital fractures and received both diagnosis and surgical treatment were selected. The diagnostic confirmation of these patients was conducted through physical examination of the face and using CT.

The inclusion criteria were as follows: (1) both genders, (2) all ages, (3) minimum 1-year postoperative follow-up, and (4) fractures of the floor, lateral and medial orbital walls, and zygomaticomaxillary complex.

The exclusion criteria were as follows: (1) complex fractures that included multiple facial bones (including the mandible) and were associated with other body fractures requiring hospitalization in an intensive care unit; (2) clinical, laboratory, and radiological conditions that made surgery impossible; (3) psychological instability; and (4) refusal to sign an informed consent form.

Takeaways

Question: What is the efficacy of orbital-defect correction as evaluated by correlating the affected orbit with the nonaffected orbit through 3-dimensional computational structural modeling and orbital volume evaluation?

Findings: This retrospective study of 15 cases found that, preoperatively, the affected side had greater volume followed by postoperative reduction, and postoperatively, the affected side had smaller volume and was equivalent to the unaffected side. Mean and distribution of orbital volume or mean orbital volumes of the 2 sides did not differ significantly between preoperative and postoperative periods.

Meaning: Computed tomography-based 3-dimensional modeling enables evaluation of surgical correction for orbital bone fractures requiring repair and reconstruction.

The variables analyzed were age, sex, diagnosis, and treatment. The outcomes explored were the radiological assessment of the 3D model development and the final volume of the reconstructed orbit.

The initial statistical test used the Shapiro–Wilk test to assess the normality of the data, ensuring the appropriate statistical tests were selected. The paired Student *t* test was used to provide insights into the effectiveness of the surgical intervention (preoperative and postoperative measurements). The Wilcoxon test for paired samples was used for nonnormally distributed data, ensuring a robust analysis.

CT: Image Capture and 3D Image Reconstruction

CT scans of the facial bones were obtained without the use of intravenous contrast and with thin slices that were 0.625 mm thick, which allowed isotropic 3D reconstructions.

This image reconstruction methodology consisted of the following steps: initially, the Philips Isite imaging program (Philips, Netherlands) was used to visualize the CT scan in multiple planes (sagittal, axial, and coronal). Subsequently, the images of interest were segmented using Mimics (version 19.0; Materialise, Leuven, Belgium) and 3-matic (version 11.0; Materialise) imaging programs.

Analysis of Orbital Volume

To compare the pretreatment and posttreatment orbital volumes, measurements of the contralateral nonfractured orbit were used as controls. Volumetric determination of the orbit was calculated by two analysts using Mimics (version 19.0; Materialise) and 3-matic (version 11.0; Materialise) software. Orbital volume was measured as described by Forte et al.[15]

Statistical Analysis

Frequency distribution was used to describe the measures of central tendency (mean and median) and variability (range and SD).

The parametric paired Student *t* test was used to compare preoperative and postoperative measurements between the unaffected and affected sides. The Shapiro–Wilk test was used to verify the normality of the numerical data. A significance level set to 5% was adopted for all statistical tests. All analyses were performed using the R[16] statistical software environment.

RESULTS

A total of 136 cases of orbital fractures with a diagnosis and surgical treatment were selected between 2018 and 2020, of which 121 were excluded based on exclusion criteria. The datasets were extracted from the 15 patients who underwent surgical repair.

Modeling the 3D Constructions

After collecting the CT data, images were processed. Figures 1 and 2 illustrate the final model obtained using Mimics Innovation Suite software.

Figure 1 shows an example of a 3D model of the facial bone surface, showing the healthy orbit and the fractured orbits and of the model obtained after surgery to fix the metal meshes. Cut-outs were made in the regions of interest for surgical evaluation.

Figures 2 and 3 represent the final 3D models of the 2 patients after surgical reconstruction in different planes of view (Figs. 2A, B and 3A, B) and visualization of the orbits used to measure the respective volumes (Figs. 2C, D and 3C, D).

Descriptive Analysis of Orbital Volume Data

An inferential analysis was performed by applying statistical tests. First, the Shapiro–Wilk Normality test was applied to determine which statistical tests would be most appropriate. Finally, the tests chosen were paired Student *t* test and Wilcoxon test for paired samples.

Based on the data in Table 1, descriptive and inferential analyses were performed.

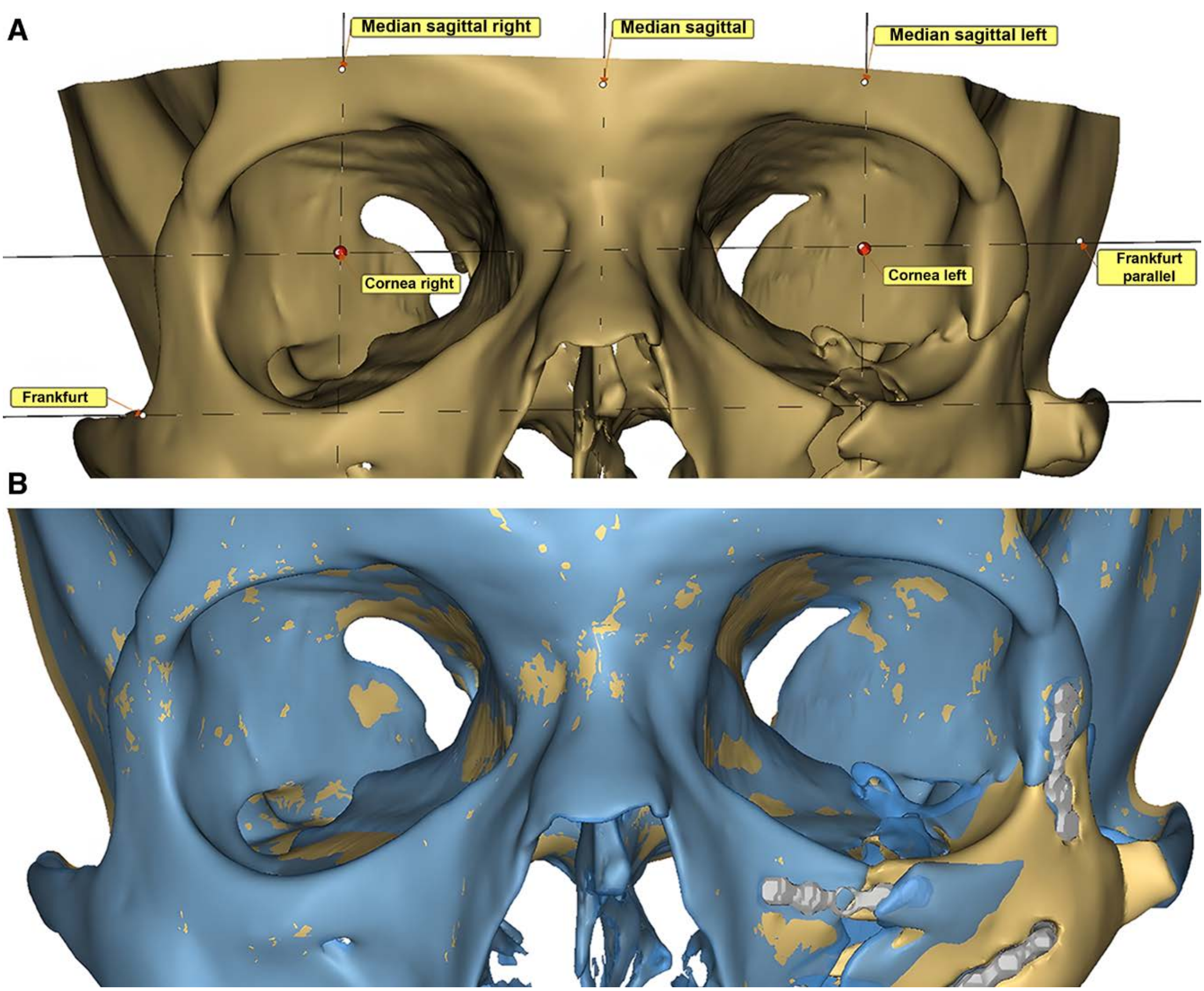

Fig. 1. Example of the model construction representing the (A) preoperative and (B) postoperative periods.

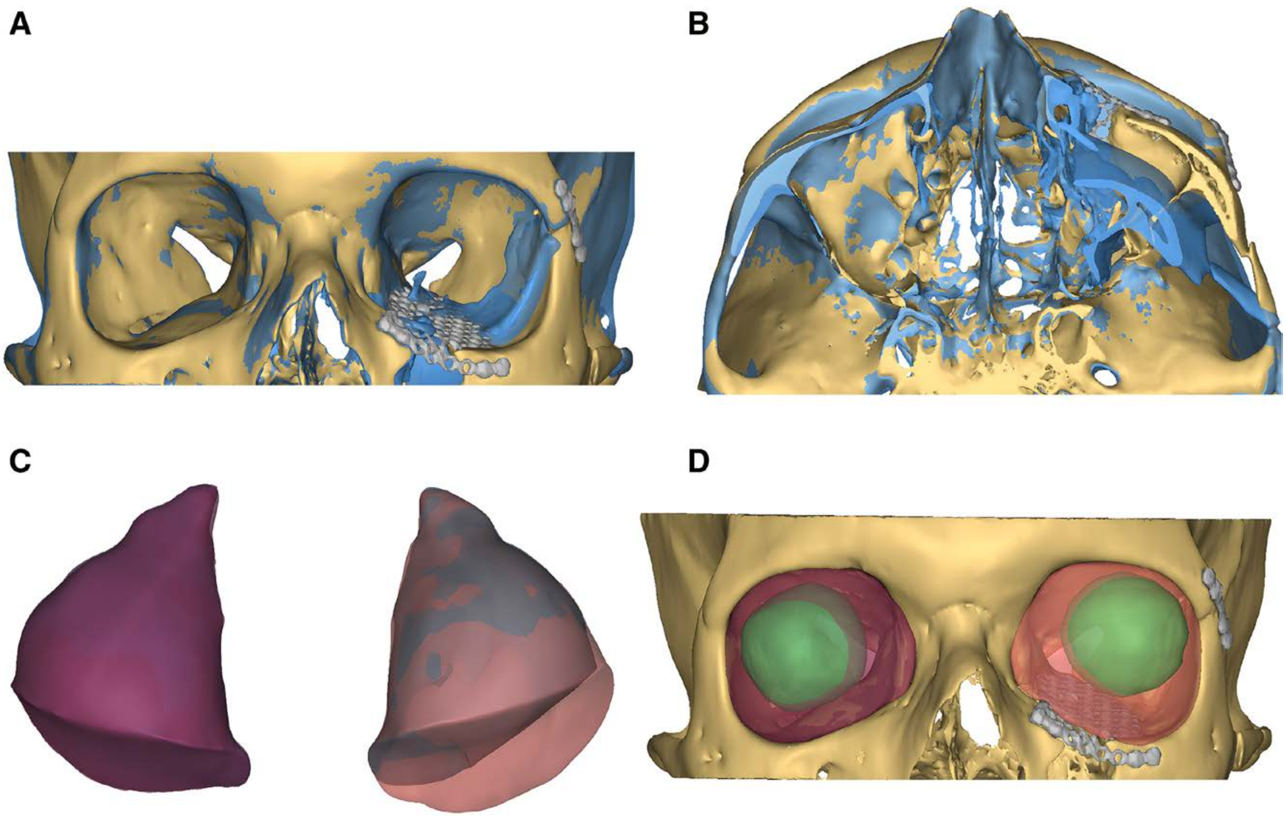

Fig. 2. Final modeling. A, Reconstruction in blue and yellow represents the preoperative and postoperative periods, respectively. Gray represents metal. B, Reconstruction in blue and yellow represents the preoperative and postoperative periods, respectively. Gray represents metal. C and D, Reconstruction in purple, blue, pink, and burgundy represents the preoperative right orbit, preoperative left orbit, the left orbit after reconstruction, and the postoperative right orbit, respectively.

1. For each period separately (preoperatively and postoperatively), compare the sides (unaffected and affected) with regard to orbital volume.
   For the periods (preoperative and postoperative) related to the surgical intervention, the orbital volume values tended to be lower for the unaffected side than for the affected side. During the preoperative period, the mean orbital volume on the unaffected side was 26.9 cm^3 and that on the affected side was 28.0 cm^3. In the postoperative period, the mean orbital volume for the unaffected and affected sides was 27.2 and 27.8 cm^3, respectively. Although there are these descriptive differences, according to the results of the statistical tests shown in Table 2, there was no statistical difference between the sides in terms of mean orbital volume, either preoperatively ($P = 0.145$) or postoperatively ($P = 0.075$).
2. For each side separately (unaffected and affected), compare the periods (preoperative and postoperative) regarding the orbital volume.
   The orbital volume values for the affected side tended to decrease from the preoperative to the postoperative period. The mean orbital volume of the unaffected side from the preoperative to postoperative period increased by 0.3 cm^3, whereas for the affected side it decreased by 0.2 cm^3. However, although there were these descriptive differences, according to the results of statistical tests, it was observed that for both the affected ($P = 0.727$) and unaffected sides ($P = 0.169$), there was no statistical difference between the periods (preoperative and postoperative) with regard to the mean and distribution of orbital volume.

The graph in Figure 4 shows a visual comparison between the value distributions of the two groups under investigation; there were no outliers in the analyzed dataset.

DISCUSSION

There are several challenges as to the choice of the main indication between the exact moment and type of treatment to be utilized in the treatment of facial bone fractures, particularly orbital fractures. Current studies evaluating changes in orbital volume with images have shown improvements in surgical treatments of this type.[17]

The main objective of this study was to evaluate the efficacy of orbital-defect correction by correlating the affected orbit with the nonaffected one.[18,19] Herein, a 3D computational tool was used to determine whether the proposed surgical corrections restored the volume and shape of the orbit before trauma. Through these observations, the study aimed to understand the volumetric changes induced by isolated orbital fractures.

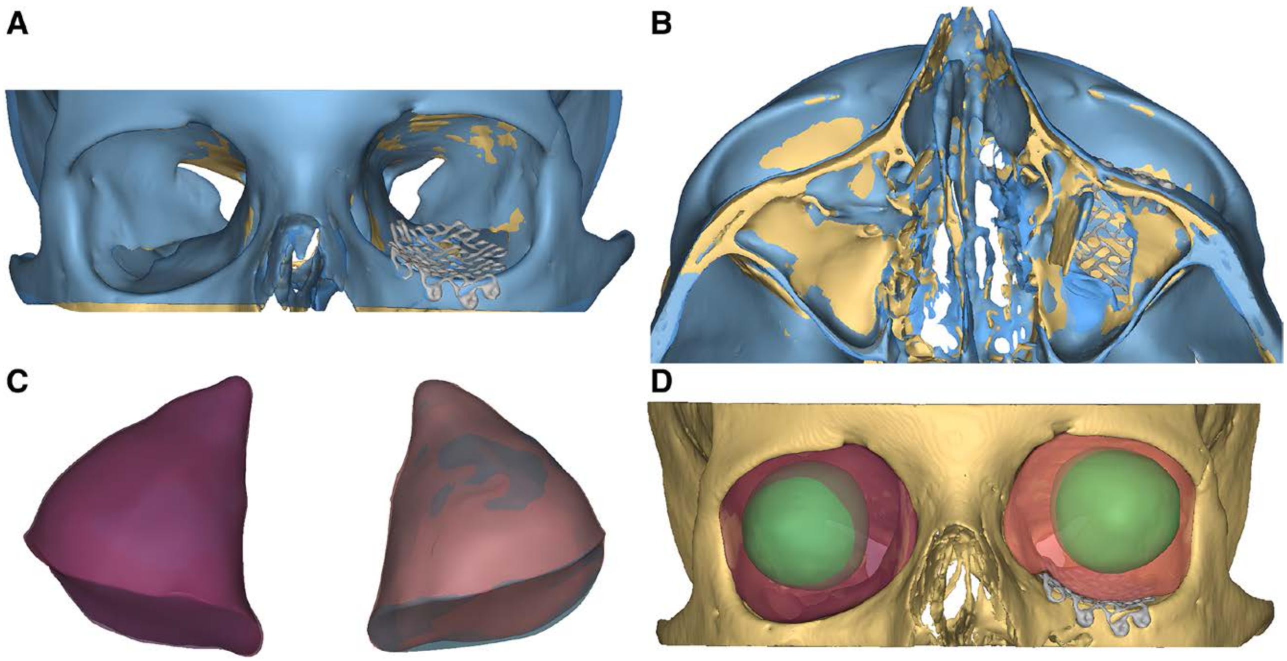

Fig. 3. Final modeling. A, Reconstruction in blue and yellow represents the preoperative and postoperative periods, respectively. Gray represents metal. B, Reconstruction in blue and yellow represents the preoperative and postoperative periods, respectively. Gray represents metal. C and D, Reconstruction in purple, blue, pink, and burgundy represents the preoperative right orbit, preoperative left orbit, the left orbit after reconstruction, and the postoperative right orbit, respectively.

Table 1. Descriptive Statistics of Orbital Volume (cm^3) in Each Group by Period (Pre|Post)

	N	Mean	SD	IQR	Minimum	First Quartile	Median	Third Quartile	Maximum
Not affected side (pre)	15	26.9	2.9	5.3	23.0	24.2	27.4	29.6	31.3
Affected side (pre)	15	28.0	3.5	6.1	22.8	24.9	27.7	31.0	32.6
Not affected side (post)	15	27.2	2.9	5.5	23.2	24.3	27.4	29.9	31.2
Affected side (post)	15	27.8	3.1	4.7	22.2	25.6	27.9	30.3	32.0

Table 2. Results of Tests of Research Hypotheses for Orbit Volume (cm^3)

Comparison	Test	*P*
Affected × not affected (pre)	Paired *t*	0.145
Affected × not affected (post)	Paired *t*	0.075
Pre × post (affected)	Paired *t*	0.727
Pre × post (not affected)	Paired Wilcoxon	0.169

Patients were examined by the Clinical Division of Ophthalmology at Hospital das Clínicas, Faculty of Medicine of the University of São Paulo. Visual acuity, extrinsic ocular motility, and intraocular pressure were measured. These examinations are always performed to rule out more serious injuries and are registered in the medical records. The patients were not required to pay for any part of their treatment, including the imaging techniques and materials used.

The number of orbital fracture cases included in the study group was 15. The main factor contributing to the elevated exclusion rate was the high prevalence of patients presenting with complex fractures that extended beyond the orbital region and involved multiple facial bones or other serious injuries necessitating intensive care.

The average age was 40 years, with half of the patients 40 years of age or older. The ages were more concentrated between 30 and 42 years, with a peak frequency in the 45–50 age group. The average age revealed that most orbital bone fractures occurred in relatively young individuals. The studies by Gomes et al,[20] Paes et al,[21] and Ribeiro Ribeiro et al[22] had an average age of 30 years, as they involved patients from wider age ranges: 2–88, 0–90, and 1–93 years, respectively. Therefore, trauma is the main cause of morbidity and mortality in the young population with an active social life and younger than the age of 40 years, with significant social damage, as it causes aesthetic and functional sequelae such as diplopia and ectropion, which can incapacitate individuals. The overall postoperative complication rate observed in our study was 13.3% (n = 2) for diplopia and enophthalmos, which improved later.

The most common trauma mechanisms were automobile accidents (6 patients) and physical aggression (4 patients). Several factors influence the characterization of the most frequent trauma mechanism; for the context of the study, it was deemed the city of São Paulo, a highly populated region with intense daily traffic and a high rate of nonfatal accidents associated with recklessness and lack

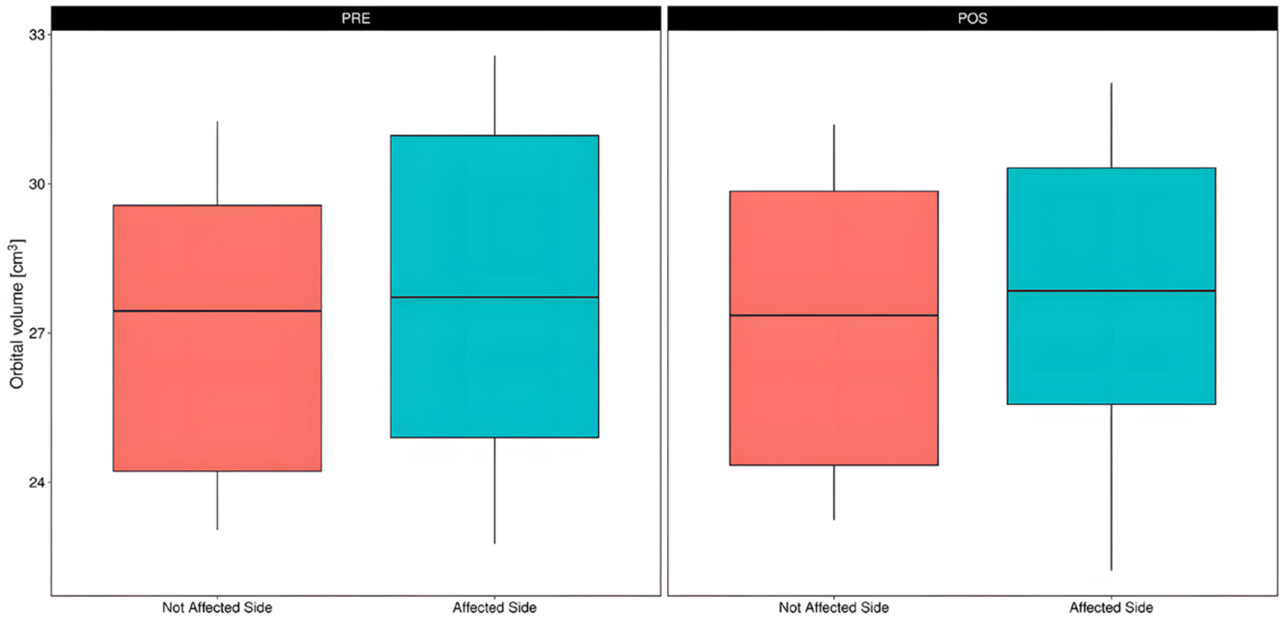

Fig. 4. Comparison of orbital volume (cm³) in each group by period (pre|post).

of traffic education. Falls are the main etiology of facial trauma identified in an analysis of global data.[23]

The proportion of men in the casuistry group was higher (80%). Previous studies investigating the epidemiology of orbital fractures found a similar relationship when analyzing sex. Seifert et al[24] analyzed 1594 orbital floor fractures, of which 1150 (72%) were in men. In a publication on fractures involving the orbital wall carried out at the Royal London Hospital, 82% of the sample consisted of men.[25]

The surgical techniques used to repair and reconstruct these fractures have been well documented in the literature. The approach to orbital fractures should be suitable to the severity of the fracture, and in this study, the transconjunctival approach and titanium mesh were used in all cases. The titanium meshes used as standard material to reconstruct the floor of the orbit have advantages such as good biocompatibility, flexibility, and moldability.[26]

A fundamental tool in modern medicine for facial trauma treatment is CT imaging, which provides detailed cross-sectional images with comprehensive understanding of the anatomical structures that are essential for the management of numerous medical conditions. As technology has advanced, tomography has become an important examination for diagnosis and surgical planning, and images have been used in the preoperative and postoperative periods for postreconstruction surgical analysis and documentation. The imaging protocol adopted was the acquisition of preoperative CT scans for a detailed evaluation of the fracture extent, and postoperative scans performed the day after surgical correction. The postoperative images were requested as part of study objectives; otherwise, the request is made in cases where clinical alterations indicate the necessity of the images. (**See Supplemental Digital Content 1**, which illustrates an algorithm that balances the necessity for comprehensive assessment of postoperative CT scans with the objective of minimizing the incidence of unnecessary imaging, **http://links.lww.com/PRSGO/D728**.)

Preoperative and postoperative CT scans were essential for gathering data for the calculation of orbital volumes of the affected orbit and the healthy contralateral orbit. This quantitative analysis was important for evaluating the effectiveness of the surgical repair.

Three-dimensional images have been consolidated to provide more information about fractures, and with advances in software development, they have become extremely accurate, particularly for analyzing bone structures. The assessment and managing of orbital volume with the integration of 3D modeling techniques has been an area of research for the author (N.A.), as in Antunes et al[27] on the supportive role of 3D modeling in the correction of facial deformities, emphasizing its accuracy.

The use of the Mimics Innovation Suite (Materialise) tools to analyze orbital volumetry is well established and has been used to evaluate differences in orbit-related pathologies. Antunes et al[27] used a similar software to assess the orbital volume in patients with syndromic craniosynostosis who underwent frontofacial advancement with Le Fort III or monobloc osteotomies. Lu et al[28] evaluated the impact of craniosynostosis type on the evolution of orbital volume in patients with Crouzon syndrome who had not undergone surgery. To analyze orbital fractures and reconstruction, Liu et al[29] used the Mimics software to evaluate the behavior of titanium meshes during floor reconstruction. They used this tool for surgical planning to develop plates for correcting zygomatic and orbital complex fractures in eight fracture cases.

In the current study, the Mimics Innovation Suite was used for evaluation of the final volume of the reconstructed orbit. Orbital volume data were derived from the CT images. The unaffected contralateral orbit was used as a volumetric control.

Based on the preoperative tomographic images, 3D models were created for better visualization and understanding of bone fractures. The volumes of the affected and unaffected orbits were calculated using the models. After surgery, new 3D models were built, and the orbital volumes were calculated again to statistically correlate the volumetric data. This analysis allowed us to understand whether there was a statistical difference in the orbital volumes due to the bone restoration that the patients underwent.

Regarding the results obtained at a significance level of 5%, although there were oscillations in orbital volume values, there was no statistical difference between the affected and unaffected sides, which was maintained throughout the postoperative period. Nair and Senthil Kumar[30] obtained similar results. These results demonstrate the effectiveness of computer modeling in repair/reconstruction surgery.

Furthermore, a comparison of the interquartile range (IQR) values for the affected side at the preoperative (IQR = 6.1) and postoperative (IQR = 4.7) periods showed a reduction in the variability of orbital volume values. Snäll et al[31] found both positive and negative volume variations relative to the healthy side, a finding similar to that of the present study. Differences in orbital volume may be due to different fracture topographies. Inferior wall fractures show greater cavity expansion than medial or lateral orbital wall fractures.[32,33]

However, this study has a few limitations. Although it is considered a tertiary center for emergency and urgent care, the number of medical records selected for research was limited. The preliminary sample included 136 patients with orbital fractures; nevertheless, owing to the exclusion criterion of not having associated fractures and aiming to create a more homogeneous study group, the final sample was restricted to 15 cases. Hence, further studies with larger populations are needed to improve the statistical analysis and understanding of orbital bone fractures and volume comparisons. Therefore, it was not possible to use measurements related to soft tissues because of the postoperative edema.

CONCLUSIONS

This study demonstrated the value of 3D modeling in the assessment and interpretation of surgical correction in patients with orbital bone fractures. Following surgical reconstruction, 3D computational models were instrumental in evaluating the extent of the fractures and the effectiveness of the surgical repairs and provided data for analysis of orbital symmetry and volume, allowing for comparison between the affected and unaffected orbits. Although the volumetric differences were not statistically significant, the findings confirmed that 3D modeling is a useful tool for ensuring that symmetry and orbital volume are restored to a state that closely resembles the pretrauma condition.

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DISCLOSURES

The authors have no financial interest to declare in relation to the content of this article. All datasets for statistical analysis and image modeling were extracted from the patient archives and questionnaires. The software used for modeling 3D images was purchased from Materialise (Leuven, Belgium). The authors evaluated the use of computerized tools in the field of medicine, which have supported the context of surgical corrections.

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ETHICAL APPROVAL

This study adhered to principles of the Declaration of Helsinki. Institutional review board statement was not applicable.

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