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Intra- and interreader variability of orbital volume quantification using 3D computed tomography for reconstructed orbital fractures

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ABSTRACT

Purpose: Management of orbital fractures continues to present some difficulties, particularly regarding the prediction of late complications. Radiographic assessment provides a detailed evaluation, but the results lack consistency to be considered a standard factor in the decision-making process. Studies focusing on reliability of post-operative imaging are lacking.

Materials and methods: We performed a retrospective study using patients from a major trauma center with unilateral orbital floor fracture who underwent surgery. Using three-dimensional volume assessment software, we performed a volume calculation and determined the intra- and interreader variation by intraclass correlation coefficient analysis.

Results: Twenty-four orbits were assessed. Mean orbital volume (SD) was 24.02 (2,43) cm^3 for reader 1 and 24.08 (2,51) cm^3 for reader 2. The intraclass correlation coefficient (95% CI) was 0.95 (0.91–0.98) between readers and 0.96 (0.91–0.98) for intra-reader variability. Normal and reconstructed orbits assessed separately also showed very high correlation coefficient for both intra- and inter-subject variability.

Conclusion: Results show an almost perfect agreement of volume assessment between readers. The presence of reconstruction material does not seem to add variability. Although reproducible and reliable, radiological volume assessments have not yet shown a clear correlation with clinical outcomes and post-operative management decisions should be based mainly on clinical findings.

1. Introduction

Orbital fractures represent more than 40% of all facial fractures in contemporary craniomaxillofacial trauma (Morris and Tiwana, 2013). Because of the close relation to the eye, they may be associated with high-morbidity complications such as altered globe position, diplopia, and significant or even total visual loss, a complication reported among 0.6–4% of patients with orbital fractures (Ochs et al., 2019) Post-traumatic enophthalmos is one such complication, which is defined as recession of the globe into the orbit (Tahernia et al., 2009) It was found to be the most common post-traumatic facial deformity (Chen et al., 2006) and simultaneously the one with the worst treatment results. The exact incidence remains unclear, with reports between 8% and 22% of all orbital fractures (Morris and Tiwana, 2013). One of the proposed underlying mechanisms of enophthalmos is a discrepancy between the volume of the orbital soft tissue and the bony orbital cavity (Chen et al., 2006). Loss of ligament support, fat atrophy, scar contracture, displacement and change in the shape of orbital soft tissues may serve as concurrent or alternative explanations (Manson et al., 1986).

Many authors have tried to identify methods to analyze computed tomography (CT) measurements to predict long-term enophthalmos and thus to create a more evidence-based rationale for reparative surgery (Vicinanzo et al., 2015).

Quantitative determination of orbital volume is valuable to evaluation and management of many conditions affecting the orbit, such as intraorbital tumors, inflammatory conditions, congenital diseases, and, of particular interest to the authors, traumatic orbital

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fractures (Shyu et al., 2015). The goal of surgical intervention in orbital fractures is the restoration of orbit's bony anatomy. This should result in correction of the globe position within the orbital cavity and should assist in correcting visual symptoms such as diplopia, exophthalmos, enophthalmos or dystopia (Shyu et al., 2015). Empirical assessment formed the basis of decision-making processes within the operating room for many years, and still does in some centers. However, this often results in over or undercorrection, with highly unpredictable post-operative results (Glassman et al., 1990).

Many studies have demonstrated CT to increase surgical planning accuracy of these reconstructions (Forbes et al., 1985; Gellrich et al., 2008; Rana et al., 2012). More recently, numerous authors have included in their evaluation the newest 3D technologies, such as volume rendering and region of interest (ROI)–based volume computations (Scolozzi et al., 2008; Alinasab et al., 2011; Zhang et al., 2012; Shyu et al., 2015; Jansen et al., 2016).

After nonanatomical reconstruction of orbital fractures, failure to re-establish normal orbital volumes is considered to be the cause of late post-operative enophthalmos (Tahernia et al., 2009). Nonetheless, there is not a well-established association between magnitude of discrepancy between orbital volumes and incidence or severity of post-operative enophthalmos. Tomographic volume measurements of orbital volumes can be taken into account when deciding between a surgical and a non-surgical treatment but have not yet been used on reconstructed orbits to predict the development of complications.

Additionally, orbital CT technical specifications of imaging acquisition and post-acquisition analysis vary greatly among centers (Scolozzi et al., 2018; Tahernia et al., 2009; Kwon et al., 2010; Strong et al., 2013), which adds additional difficulty in making specific recommendations on the evaluation of the orbital floor fracture. This premise is particularly evident when using highly sophisticated software for volume calculation. Furthermore, some authors have raised the issue of high discrepancy of ability among radiographic readers, which further confuses this issue (Vicinanzo et al., 2015). Most studies involve only one examination reader, not addressing the issue of reader variability. This presents as an important topic and needs to be taken into account when relying on CT results for treatment and follow-up decisions.

In this study, we aimed to clarify whether 3D-based orbital volume assessment of reconstructed orbits is a well-defined and reproducible method.

2. Materials and methods

We performed a retrospective analysis using clinical records of all patients admitted to the Maxillofacial Surgery Department of our University Hospital presenting with orbital fractures between July 2015 and December 2016. Either isolated floor fractures or floor fractures with medial wall fractures documented by clinical records and CT results were included. We excluded all patients less than 18 years old and patients with a history of orbital fractures or traumatic ocular lesions. We also excluded patients who with presented bilateral orbital fractures as well as other fractures of the facial skeleton. A sample of 112 patients was identified, from which we selected the ones who underwent a post-operative orbital CT scan in our hospital. Due to the retrospective nature of the study, written consent was not obtained from participants for records use, and clinical records were anonymized and labeled prior to analysis. This process identified 12 post-operative scans of unilateral orbital fracture repairs. These examinations were then formatted to a 1-mm-slice axial CT (slice distance: 0.8 mm) and evaluated by a maxillofacial surgeon (reader 1) and a neuroradiologist (reader 2). Using volume assessment software and following a detailed protocol already validated in other publications focusing on orbital volume measurement (Shyu et al., 2015), volume assessment of both reconstructed and “normal” orbits was performed. Orbital volume using region of interest (ROI) function was successfully calculated using the open-source version of OsiriX (Pixmeo; Food and Drug Administration approved). The methodology was as follows. The built-in 3D volume rendering tool was used for 3D image reconstruction of the original 2D dataset. The bony orbital rim was outlined using the 3D “point” tool. This included the zygomatic-frontal processes at the lateral side, the posterior lacrimal crest at the inferior-medial orbital rim, the nasal process of the frontal bone at the superior-medial side, and the supra- and infra-orbital rims. The anterior limit was defined by a line connecting the lateral and medial orbital rim landmarks on each slice. The posterior limit was set at the opening of the optic foramen into the orbit. Based on these landmarks, manual segmentation with the closed polygon ROI tool was used on the 2D axial view to establish the boundaries of the bony orbit (Fig. 1). The optic canal, soft tissue and portions of the globe protruding out of the orbital rim were excluded from volume calculation. After completing the ROIs on consecutive slices, the “Calculate ROI volume” tool was used to automatically determine the volume of the total selected regions (Fig. 2).

Each reader was blinded to the other's assessment, and the results were shared after analysis. After one set of volume measurements, one of the readers performed a second volume evaluation of all bony orbits, using the same methodology.

To evaluate agreement between readers, an intraclass correlation coefficient (ICC) was calculated for orbital volumes using a two-way mixed-effects model. The intraclass correlation coefficient represents the proportion of the total variability in a given measure that can be attributed to the true variability among individuals. It assumes values from 0.0 to 1.0, with values of 0.00 or lower considered poor; greater than 0.00 to 0.20, slight; 0.21 to 0.40, fair; 0.41 to.

0.60, moderate; 0.61 to 0.80, substantial; and 0.81 to 0.99, almost perfect agreement (Vicinanzo et al., 2015). The intraclass correlation coefficient was also calculated between the first and second measurements for one of the readers, to assess intra-reader variability.

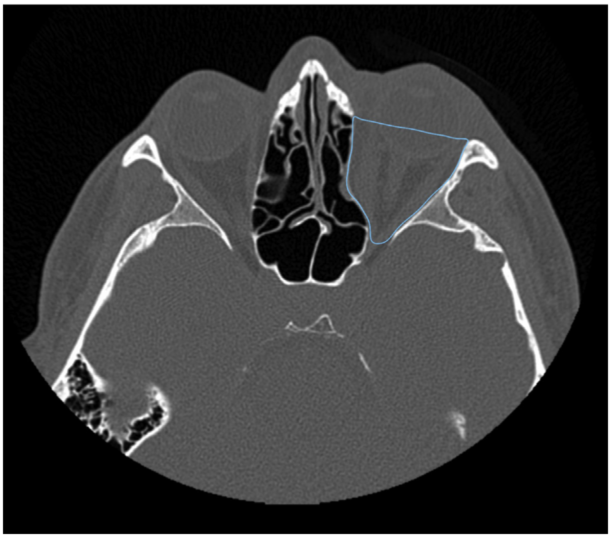

Fig. 1. Axial view of orbital computed tomographic scan, illustrating the definition of bony orbit limits with the “point” tool of the manual segmentation protocol.

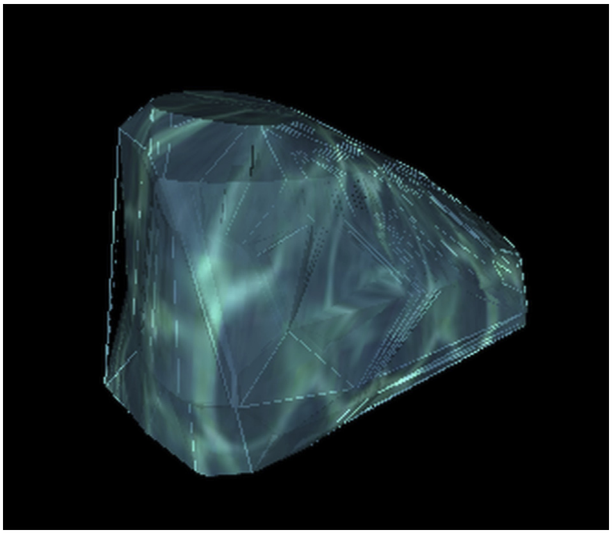

Fig. 2. Three-dimensional reconstruction of the orbit using the automatic "ROI volume" calculation tool.

3. Results

The mean (SD) age of the patients was 47.25 (14.88) years old (range, 30–79 years); there were 8 male and 4 female patients. Surgical repair was performed on eight left orbits and four right orbits. All patients contributed to the study with both fractured and "normal" orbits. The mean (SD) volume measurement for reader 1 was 24.02 (2.43) cm^3 and 24.08 (2.51) cm^3 for reader 2.

For orbital volume quantification, the interclass correlation coefficient for the two observers was 0.95 (95% CI, 0.90–0.98) (Table 1). Concerning intra-reader variability, the ICC calculated for the reader's two observations was 0.96 (95% CI 0.91–0.98). The mean time between the first and second read was 71.58 days. The analysis was also performed for the subgroups of reconstructed and "normal" analysis. Details of the volume assessment from both readers is presented in Tables 2 and 3.

4. Discussion

After statistical analysis, the magnitude of variability showed an almost perfect agreement between the readers for their volume calculations. These results are aligned with most studies (Arger et al., 2001; Alinasab et al., 2011; Diaconu et al., 2017). Even though there is a clear understanding of the issues of small sampling, these results reinforce the premise that orbital volume quantifications, assessed by CT evaluation, are a reliable and reproducible method. Given these results, we believe that this method could prove a powerful adjunctive for the management of orbital fractures, as described by other authors (Charteris et al., 1993; Ploder et al., 2002; Ahn et al., 2008; Tahernia et al., 2009; Alinasab et al., 2011). By analyzing separately reconstructed and "normal" orbits, we were also able to demonstrate that the presence of surgical reconstruction material does not seem to increase the variability of this method. This measurement tool can consequently be used in both a pre- and post-operative scenario.

Table 1
Summary statistics and intraclass correlation coefficient (ICC) for inter and intra-reader variability.

Measure	Value
Sex, n	
Male	8
Female	4
Side of orbital fracture repair, n	
Left	8
Right	4
Mean orbital volume (SD), cm^3	
Reader 1	24.02 (2,43)
Reader 2	24.08 (2,51)
Intraclass correlation coefficient, inter-reader (95% CI)	
Total	0.95 (0.91–0.98)
Reconstructed	0.97 (0.92–0.99)
Normal	0.92 (0.79–0.98)
Intraclass correlation coefficient, intra-reader (95% CI)	
Total	0.96 (0.91–0.98)
Reconstructed	0.98 (0.94–0.99)
Normal	0.93 (0.81–0.98)

Although both observers work in a large academic center, choosing a neuroradiologist and a surgeon as examination readers could add a variability factor. The study design was intended to replicate the daily practice and the multi-specialty interaction involved in the treatment of these patients. Other studies have used non-radiology experts for CT volume assessment with acceptable results (Bentley et al., 2002; Fan et al., 2003; Shyu et al., 2015). Our results show that volume assessment can be performed either by a surgeon or by a neuroradiologist, given that they are used to assessing this type of condition. The greatest advantages of this volume quantification technique are its already proven accuracy (Shyu et al., 2015), the adaptive capacity to most 3D image modalities and its cost-free implementation, which can prove particularly decisive in its routine application. It must be taken into consideration that these results were gathered from a highly specialized center after a thorough analysis of the image processing protocol, which has a learning curve, as do all manual segmentation methods (Wagner et al., 2016). These results may not be reproducible in smaller centers. Application of this quantification method can prove to be time-consuming, with both readers reporting no less than 20 min for each orbital volume quantification. This factor may render the routine implementation of this method difficult. The disadvantages of manual segmentation methods have been identified, and efforts are being made to develop and to validate faster and more user-friendly methods. For now, manual segmentation methods remain the gold standard to which other techniques are compared (Lukats et al., 2012). Other authors have published alternative volume quantification methods, some of them showing very good results with automatic and semi-automatic segmentation methods, either atlas-based or model-based (Jansen et al., 2016). Others have also tested the validity of the volume assessment techniques on cone beam CT, a technology that provides 3D images with lower patient radiation exposure (Friedrich et al., 2016; Wagner et al., 2016). It would be interesting to compare both manual and automatic segmentation protocols on different imaging acquisition modalities. The analysis of intra-reader agreement also confirms it as a very reproducible technique, although it would have been preferable to assess intra-subject variability on both readers. Another option to strengthen our results would have been the inclusion of a third reader.

Large studies focusing on the relation between radiological and clinical findings are still lacking, and surgical decisions regarding treatment and follow-up of orbital floor fractures should be based mainly on clinical findings rather than radiological interpretations. There is a need for a more standardized approach to orbital volume assessment, both pre- and post-operatively. The new, less time-consuming and more intuitive 3D methods should focus on providing an accurate, reliable and reproducible method that can assist physicians with orbital fracture management.

Table 2
Orbital volume measurement of readers 1 and 2, grouped by reconstructed and normal orbits (all values in cm$^{3)}$.

Patient	Gender	Age (y)	Reviewer 1: Reconstructed Orbit	Reviewer 1: Normal Orbit	Reviewer 2: Reconstructed Orbit	Reviewer 2: Normal Orbit
1	M	53	26.14	27.59	26.95	28.17
2	M	35	25.16	25.27	25.3	25.81
3	M	34	25.49	25.15	25.1	25.67
4	M	30	23.50	24.19	22.9	24.66
5	F	55	26.14	25.04	27.2	25.05
6	M	38	21.79	23.41	22.04	22.17
7	M	46	22.17	24.96	21.7	24.21
8	F	42	21.23	22.72	22.12	22.08
9	F	79	19.67	20.96	18.94	21.64
10	F	74	21.25	18.93	21.45	19.99
11	M	38	27.07	24.84	27.52	25.6
12	M	43	27.02	26.67	26.8	24.95

Table 3
Orbital volume measurements of first and second evaluations by reader 1, grouped by reconstructed and normal orbits (all values in cm^3).

Patient	Gender	Age (y)	Reconstructed Orbit	Normal Orbit	2nd Look Reconstructed Orbit	2nd Look Normal Orbit
1	M	53	26.14	27.59	26.19	27.55
2	M	35	25.16	25.27	24.69	25.9
3	M	34	25.49	25.15	24.74	25.29
4	M	30	23.50	24.19	23.56	24.67
5	F	55	26.14	25.04	25.39	24.45
6	M	38	21.79	23.41	22.79	22.28
7	M	46	22.17	24.96	22.28	23.53
8	F	42	21.23	22.72	21.69	22.51
9	F	79	19.67	20.96	19.82	20.27
10	F	74	21.25	18.93	21.08	19.67
11	M	38	27.07	24.84	27.25	25.7
12	M	43	27.02	26.67	26.82	25.28

F, female; M, male.

Conclusion

Our study results show and almost perfect agreement of volume assessment between readers. The presence of reconstruction material does not seem to add variability. Although reproducible and reliable, radiological volume assessments have not yet shown a unequivocal correlation with clinical outcomes and postoperative management decisions should be based mainly on clinical findings.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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