Measurements of Orbital Volume Change Using Computed Tomography in Isolated Orbital Blowout Fractures

Jaehwan Kwon, MD; Jose E. Barrera, MD; Tae-Young Jung, MD; Sam P. Most, MD

Objectives: To measure the orbital volume of unilateral pure blowout fractures with computed tomography before and after surgery and to compare 3-dimensional (3-D) imaging systems.

Methods: Twenty-four patients were evaluated with facial computed tomographic scans before and after surgery. Both the orbital volume and the displaced soft tissue volume were measured by 2 operators using 2 different 3-D software programs (Vitrea; Vital Images Inc, Minnetonka, Minnesota; and Dextroscope; Bracco AMT Inc, Princeton, NJ).

Results: The mean (SD) normal orbital volumes calculated by Vitrea and Dextroscope were 25.5 (2.4) mL and 24.8 (3.0) mL, respectively. The average preoperative orbital volumes were 28.3 (2.3) mL and 27.6 (3.1) mL, while the postoperative volumes were 25.8 (2.5) mL and 24.9 (3.0) mL. Vitrea showed that the average volume of displaced orbital soft tissue was 2.8 (1.9) mL before surgery and that it was reduced to 0.3 (1.3) mL after surgery, while Dextroscope showed that the average displaced orbital soft tissue was 2.9 (1.4) mL before surgery and that it was reduced to 0.1 (1.2) mL after surgery. There was no statistical difference between the 3-D analysis programs.

Conclusions: Consistent volume measurements can be obtained using different 3-D image analysis programs. Measuring preoperative and postoperative volume changes and postoperative reduction can ensure a good surgical result and thereby decrease the incidence of enophthalmos.

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HE DEVELOPMENT AND ROUTINE USE OF COMPUTED TOMOGRAPHY (CT) IN PATIENTS WITH ORBITAL BLOWOUT FRACTURES HAS LED TO IMPROVED DETECTION OF CRANIOMAXILLOFACIAL INJURIES AND ORBITAL FRACTURES IN PARTicular. Three-dimensional (3-D) reconstruction of CT data and measurement of orbital volume may become useful in the assessment of orbital blowout fractures. Numerous articles have highlighted the importance of orbital volume measurement of blowout fractures. However, few studies have examined the changes in orbital volume before and after surgery in patients with blowout fractures. We sought to evaluate orbital volume in such patients using 2 unique 3-D analysis software packages to document the changes in orbital volume and to compare the accuracy of the 2 separate 3-D measurement systems.

METHODS

PATIENTS

From 2004 to 2007, a total of 24 patients with unilateral pure orbital blowout fractures that were treated surgically were identified and included in this study. The human subjects committees of both related study centers approved the study protocols. There were 10 orbital floor fractures, 11 medial wall fractures, and 3 combined medial wall and floor fractures. All patients included in the study were treated with surgical repair. In cases involving orbital floor fractures, the fracture was exposed transantrally or transorbitally and supported by a porous polyethylene channel implant (Medpor Surgical Implant; Porex Surgical Products Group, Newnan, Georgia) or a bioresorbable perforated plate of 70:30 poly(l-lactide-co-D,L-lactide) (MacroPore; Medtronic Inc, Minneapolis, Minnesota). For medial orbital wall fractures, endoscopic endonasal reduction surgery was performed using a Silastic sheet splint or a MacroPore implant. The CT examinations were performed in all patients before and after surgery, and charts were retrospectively reviewed. Exclusion criteria were bilateral orbital wall fractures, evidence of old orbital wall fractures in the contralateral orbit, orbital wall fractures combined with zygomatic bone, ethmoid and/or maxillary fractures, orbital wall fractures not treated with surgical repair, and lack of, or inadequate, postoperative CT scans. Contralateral orbital volume measurements were used as controls.
CT SCANS AND ORBITAL VOLUME MEASUREMENT

The CT scans (Aquilion TSX-101A; Toshiba Medical Systems Corp, Tokyo, Japan) were obtained using continuous 2-mm-thick axial slices by tilting each patient’s head parallel to the Frankfurt plane. All images were obtained in a high-resolution osseous window level setting and transferred to 2 different 3-D reconstruction software programs (Vitrea Version 3.4; Vital Images Inc, Minnetonka, Minnesota; and Dextroscope Version 1.0; Bracco AMT Inc, Princeton, NJ). The software was used to configure area and volume. Two independent operators measured orbital volume using each software package. In cases of medial orbital wall fractures, axial scans were used, while in cases of inferior and combined inferior-medial fractures, coronal reformed scans were used. The bony orbit on each scan was measured using the cursor to trace the orbital wall on the screen. On the axial CT scans, the anterior orbital boundary was defined by a straight line connecting the medial and the lateral orbital rims, and the regions lacking a bony boundary (ie, superior orbital fissure, inferior orbital fissure, lacrimal fossa, and optic canal) were traced with a straight line (Figure 1). On the coronal CT scans, the anterior border was determined as the CT slice in which 50% of the inferior orbital rim was visible, with the posterior limit being the orbital apex (Figure 2). In the case of missing bone of the lateral orbital wall (owing to the lateral wall being out of plane) on coronal CT scans, a line was drawn similar to that of the closest slice in which the whole orbital bone was seen and was used to demarcate the extent of the orbital volume (Figure 3). The areas of these outlines were measured on each scan and summed for orbital volume.

To reduce measurement errors, the bony orbit area on each scan was measured twice, with at least a 1-week interval, and then averaged, and the scan images were magnified to enhance accuracy. In cases of obscure lining, the former and the next slides were referenced. The volume of the fracture was measured as the discrepancy in volume between the fractured and the normal contralateral orbital volumes.

STATISTICAL ANALYSIS

The results are expressed as means (SDs). A paired t test was used to compare group differences with an SPSS software package (Version 12.0; SPSS Inc, Chicago, Illinois). A P value of less than .05 was considered statistically significant.

RESULTS

The mean (SD) age of the patients (21 men and 3 women) was 33.2 (14.3) years (range, 13-69 years). Seventeen of 24 fractures were on the left side, and 7 were on the right side. The mean (SD) normal orbital volumes calculated by Vitrea and Dextroscope were 25.5 (2.4) mL and 24.8 (3.0) mL, respectively. The average preoperative orbital volumes on the fractured side were 28.3 (2.3) mL and 27.6 (3.1 mL), respectively, while the postoperative volumes were 25.8 (2.5) mL and 24.9 (3.0) mL (Table 1). With Vitrea, the overall volume of displaced orbital soft tissue was 2.8 (1.9) mL before surgery and was reduced to 0.3 (1.3) mL after surgery, while with Dextroscope, the overall displaced soft tissue was 2.9 (1.4) mL.
mL before surgery and was reduced to 0.1 (1.2) mL after surgery (Table 2). There was no statistical difference between the 3-D analysis programs (P=.12). Orbital volume as measured on postoperative CT scans showed a statistically significant volume reduction compared with that of preoperative CT scans using both Vitrea and Dextroscope (Tables 1 and 2).

Orbital blowout fractures are one of the most common injuries observed in the facial region, and one of the most important points of reconstruction of orbital wall fractures is restoration of normal orbital volume. Therefore, accurate preoperative measurement of orbital volume is invaluable in predicting and, if it leads to operative intervention, preventing postinjury enophthalmos, which is a common complication. Furthermore, orbital volume measurements can be considered important for treatment planning by providing an accurate estimation of orbital implant volume, which is necessary for optimal reconstruction of enophthalmos.

However, several problems can arise when CT scans are used to measure the orbital volume with standard computer-based programs. Difficulties in measuring the exact orbital volume include (1) bony orbital cavities, which are roughly the shape of a quadrilateral pyramid with its base directed forward and laterally, not exactly located horizontally or perpendicularly to the axial or coronal plane; (2) bony defects, which in some locations can introduce errors in measurement (eg, orbital apex, inferior orbital fissure, superior orbital fissure, lacrimal sac, and orbital base, with errors caused by including the missing anterior wall of the orbit); (3) interoperator or intraoperator variability; and (4) errors caused by the use of different measurement techniques and software programs. Recently, with the development of 3-D software programs, it became easier to measure the orbital volume. Ploder et al, in their experimental studies using orbital fractured models on dried skulls, demonstrated that both 2-D and 3-D measurement methods are accurate for assessing the fracture area and herniated tissue volume of isolated blowout fractures, but they found that 2-D–based calculations involved less processing time and fewer errors.

Axial and coronal CT scans can provide information on the location and size of the fracture. In several previous studies, volume measurement of the orbital blowout fractures was performed using axial CT scans. Studies using coronal CT scans are few. Charteris et al used axial CT scans to measure orbital volume in 31 patients with pure orbital floor fractures; however, the fractures were not clearly visible. It is widely accepted that coronal CT is considered to be the best method for diagnosing orbital floor fractures. Therefore, in the present study, the axial scans were used only for medial orbital wall fractures, and coronal scans were used for inferior and combined inferior-medial fractures.

Interobserver and intraobserver discrepancies due to the computer-based measurement method were reported to be within acceptable limits and highly repro-

### Table 1. Comparison of Orbital Volume Using 2 Software Programs Before and After Surgery in Patients With Orbital Fracture

<table>
<thead>
<tr>
<th>Software Program</th>
<th>Bony Orbital Volume, Mean (SD), mL</th>
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<tr>
<td></td>
<td>Contralateral</td>
</tr>
<tr>
<td>Vitrea&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.5 (2.4)</td>
</tr>
<tr>
<td>Dextroscope&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.8 (3.0)</td>
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<sup>a</sup>Version 3.4; Vital Images Inc, Minnetonka, Minnesota.
<sup>b</sup>Version 1.0; Bracco AMT Inc, Princeton, NJ.
<sup>c</sup>P < .05 compared with preoperative volume measurements.

### Table 2. Comparison of Herniated Orbital Soft-Tissue Volume Using 2 Software Programs Before and After Surgery in Patients With Orbital Fracture

<table>
<thead>
<tr>
<th>Software Program</th>
<th>Herniated Soft-Tissue Volume, Mean (SD), mL</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Before</td>
</tr>
<tr>
<td>Vitrea&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.8 (1.9)</td>
</tr>
<tr>
<td>Dextroscope&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.9 (1.4)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Version 3.4; Vital Images Inc, Minnetonka, Minnesota.
<sup>b</sup>Version 1.0; Bracco AMT Inc, Princeton, NJ.
<sup>c</sup>P < .05 compared with preoperative volume measurements.
ducible.9,10 However, to our knowledge, there are no studies that have assessed the variations of different software programs for measuring orbital volume. In our study, the discrepancy of the 2 software programs was minimal according to 2 different observers, with no statistical differences between the results.

Regarding the measurement of normal bony orbital volume, Deveci et al11 reported a mean (SD) volume of 28.41 (2.09) cm³. Forbes et al12 found the normal average bony orbital volume to be 23.9 cm³ in males and 23.63 cm³ in females. According to Furuta,13 the orbital volume is 23.6 (2.0) cm³ in Japanese men and 20.9 (1.3) cm³ in Japanese women. Our study showed orbital volumes of 25.5 (2.4) mL as calculated by Vitrea and 24.8 (3.0) mL as calculated by Dextroscope. It is difficult to compare the results directly because of the differences in race, patient age, and measuring techniques.

There have been many debates about the laterality of orbital volume. Some investigators argue that there is no real difference in orbital volume between the right and the left orbits in individuals.3,13,14 However, according to others, the volume between the right and the left orbits may differ by approximately 7% to 9%.9 In this study, we based the results on the volume of the left and the right orbits being the same, with the opposite orbit being used as a control, without measurement of laterality.

Various articles report measurements of orbital volume and the correlation of enophthalmos of the orbital wall fractures.3,4,15,16 However, there are few reports showing the preoperative and postoperative orbital volume changes on CT scans using 3-D software programs. Ye et al,3 in their study of 16 coronal CT scans of pure orbital floor fractures, reported that the mean (SD) orbital volume of the unaffected orbit was 23.94 (3.47) cm³; the orbital volume of the affected orbit was 28.16 (4.32) cm³; and, after surgery, the orbital volume was 24.08 (3.22) cm³ on the surgical side. Their results are similar to ours.

Our results and those of other investigators demonstrate that it is very difficult to measure the exact bony orbital volume, even after orbital trauma. The ideal measurement method should be available worldwide, be easy to perform on standard radiological scans, have a short learning curve, and be able to be performed in a short amount of time, with low systemic measurement errors.15 We hope that studies such as ours will lead to the development of a computer software program that is specifically designed to measure the volume on CT scans more accurately and reproducibly.

In conclusion, consistent volume measurements can be obtained using different 3-D image analysis programs. Measuring preoperative and postoperative volume changes and postoperative reductions in volume can ensure a good surgical result and thereby decrease the incidence of enophthalmos.

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Author Contributions: Study concept and design: Kwon, Barrera, and Most. Acquisition of data: Kwon and Jung. Analysis and interpretation of data: Kwon, Barrera, and Most. Drafting of the manuscript: Kwon, Barrera, and Jung. Critical revision of the manuscript for important intellectual content: Barrera and Most. Statistical analysis: Most. Administrative, technical, and material support: Kwon, Barrera, and Most. Study supervision: Most.

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REFERENCES