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The validity and reliability of computed tomography orbital volume measurements

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ABSTRACT

Purpose: Orbital volume calculations allow surgeons to design patient-specific implants to correct volume deficits. It is estimated that changes as small as 1 ml in orbital volume can lead to enophthalmos. Awareness of the limitations of orbital volume computed tomography (CT) measurements is critical to differentiate between true volume differences and measurement error. The aim of this study is to analyze the validity and reliability of CT orbital volume measurements.
Materials and methods: A total of 12 cadaver orbits were scanned using a standard CT maxillofacial protocol. Each orbit was dissected to isolate the extraocular muscles, fatty tissue, and globe. The empty bony orbital cavity was then filled with sculpting clay. The volumes of the muscle, fat, globe, and clay (i.e., bony orbital cavity) were then individually measured via water displacement. The CT-derived volumes, measured by manual segmentation, were compared to the direct measurements to determine validity.
Results and conclusions: The difference between CT orbital volume measurements and physically measured volumes is not negligible. Globe volumes have the highest agreement with 95% of differences between −0.5 and 0.5 ml, bony volumes are more likely to be overestimated with 95% of differences between −1.8 and 2.6 ml, whereas extraocular muscle volumes have poor validity and should be interpreted with caution.

1. Introduction

Restoring facial symmetry is a key principle of reconstructive craniofacial surgery. Surgeons must restore the projection, height, and width of the face. However, when reconstructing internal orbital fractures, orbital volume and shape must also be considered. Changes in orbital volume can lead to either exophthalmos, as seen in Graves' ophthalmopathy, or enophthalmos (Fig. 1), which is commonly seen after traumatic injuries of the orbit (Wiersinga et al., 2013; He et al., 2012). Small acute changes in volume can cause a change in the axial position of the eye; reliable estimates suggest that a 1-cm^2 increase in orbital volume can lead to 1 mm of enophthalmos (Sung et al., 2013) (see Fig. 2).

In current practice, orbital volume changes caused by orbital fractures are often visually estimated without direct volumetric calculation, and not re-calculated following internal orbital reconstruction. With current advancements in imaging, software technology, and increase in the use of patient-specific implants, orbital volume measurements are becoming more prevalent, and potentially more useful in clinical practice (Nkenke et al., 2011; Gellrich et al., 2002; Fan et al., 2003; Rana et al., 2012). However, there remains a significant incidence of postoperative enophthalmos despite orbital fracture repair, and the exact correlation between orbital volume changes and eye position are not precisely understood (Hoşal and Beatty, 2002).

Over the last 30 years, numerous studies have evaluated the validity of orbital volume measurements (Forbes et al., 1983, 1985; McGurk et al., 1992; Lutzemberger and Salvetti, 1998; Deveci et al., 2000). Current CT technology has become significantly more advanced, offering thinner slices and higher-resolution images. Furthermore, most studies focus only on bone volume measurements, lacking analysis of soft tissue measurements such as the intraorbital fat and the extraocular muscles. The goal of this study is

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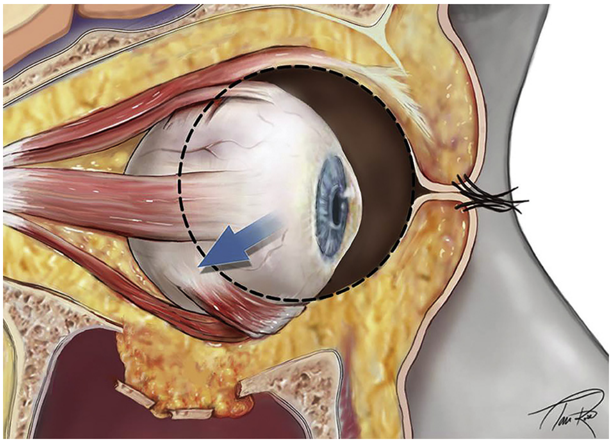

Fig. 1. Herniation of fat through an orbital floor fracture causing posterior and inferior displacement of the globe resulting in enophthalmos.

to provide a comprehensive analysis of the validity and reliability of orbital volume measurements derived using contemporary thin-section CT datasets from scanned cadaver specimens, including bony, extraocular muscle, intraorbital fat, and globe volumes, with physical measurements from the cadaver specimens serving as a reference standard.

2. Materials and methods

Six cadaver heads (total of 12 orbits) were provided by the University of Maryland Baltimore Anatomical Services. Using a Philips Brilliance 64-slice CT scanner, each head was scanned with a standard CT maxillofacial protocol (120 kV, 300 mAs, 1-mm slice thickness, 0.5-mm overlap). After the CT scan was obtained, each orbit was carefully dissected to remove all soft tissue from the orbital cavity. The entire orbital contents were removed en bloc down to the optic canal. After removal of the soft tissue, extraocular muscles, orbital fat, and the globe/optic nerve were isolated separately and each measured by water (volume) displacement to obtain the direct physical measurements, to be used as the reference standard. The bony orbital cavity was then measured by filing it with sculpting clay (Fig. 3). The anterior boundary of the orbit was defined as a straight plane between the medial and lateral orbital rims. The clay cast was then removed and measured by water displacement to obtain the volume of the bony orbital cavity.

CT measurements were then performed for each volume: bony cavity, extraocular muscles, orbital fat, and globe/optic nerve (Fig. 4). These volumes were calculated by manually segmenting the area of interest in each CT slice using Aquarius iNtuition 3D postprocessing imaging software (TeraRecon; Foster City, CA, USA) to obtain CT Measurements. The bony volume, orbital fat, and globe/optic nerve were segmented in the axial plane using manual slice-by-slice region-of-interest tracing. To calculate the total extraocular muscle volume, first each muscle was segmented separately. The superior and inferior oblique muscles were segmented in the sagittal plane; the lateral, medial, and superior oblique in the axial plane; and the inferior oblique in the coronal plane. These orientations were chosen because they provided the best visualization of the entire muscle and its insertion onto the globe.

Validity of CT-measured volumes was defined as the degree of agreement between the CT-measured volumes and the direct

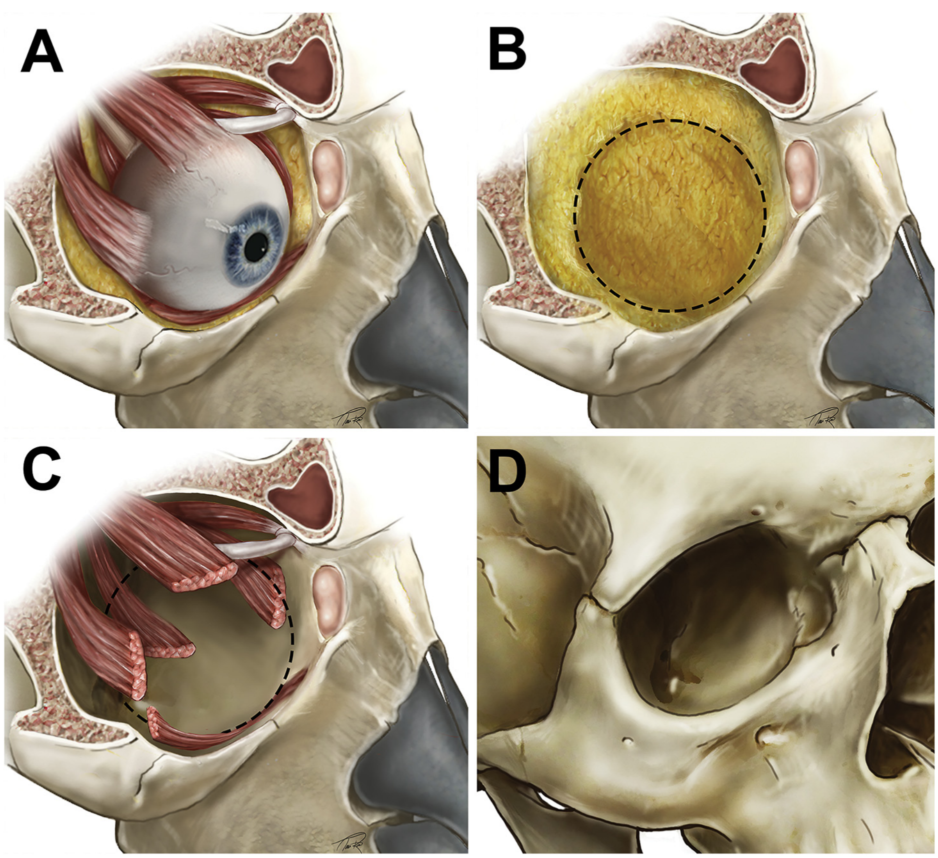

Fig. 2. Oblique views of the orbit depicting volumes of clinical interest (A). Intraorbital fat volume (B). Extraocular muscle volume (C). Bony orbital volume (D).