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Assessing the precision of posttraumatic orbital reconstruction through "mirror" orbital superimposition: A novel approach for testing the anatomical accuracy

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ABSTRACT

Orbital reconstruction in cases of trauma is usually performed using the unaffected side orbital volume as a reference, but this measurement does not fully consider the anatomical characteristics of orbital surfaces.

We propose a novel procedure based on the registration of 3D orbital segmented surfaces. Reconstructed orbits from 20 patients and healthy orbits from 13 control subjects were segmented from the post-operative CT-scans. The 3D orbital model from the unaffected orbit was "mirrored" according to the sagittal plane and superimposed onto the reconstructed one, with calculation of volumes, asymmetry index and point-to-point RMS (root mean square) distances. Inter- and intra-observer errors were tested through Bland–Altman plot. Differences in volume, asymmetry index and RMS value between the control group and the treated patients were assessed through two-way ANOVA and Student's t-test ($p < 0.05$).

According to Bland–Altman test, intra- and inter-operator repeatability was respectively 87% and 89%. No significant differences in volume or asymmetry index between the control group and the treated patients were observed ($p > 0.05$), but the RMS value was significantly larger in the latter ones (on average, 0.90 ± 0.26 mm vs. 0.67 ± 0.17 mm, $p < 0.05$).

Results show that the reconstructed orbits present a morphologically different surface from the unaffected ones.

1. Introduction

Posttraumatic orbital fractures are frequently seen in traumatology: isolated involvement of the orbital floor amounts up to 22–47% (Ellis et al., 1985; Antoun et al., 2008; Kozakiewicz et al., 2009) and are usually due to blow-out fractures, with preservation of orbital rim (Burm et al., 1999). In these cases, the main task is to restore orbital size and shape to avoid anatomical and functional alterations. Orbital reconstruction is currently being performed through the application of different resorbable and non-resorbable plates (Zimmerer et al., 2016; Zavattero et al., 2017). Titanium was chosen as the reference standard for orbital restoration thanks to its advantages such as availability, conformability, biocompatibility and low susceptibility to infections (Tong et al., 2001; Ellis et al., 2004). Two main kinds of meshes are currently in use: the first is based on standard preformed orbital plates, available in different sizes, aiming at reaching the best adherence with the anatomical characteristics of orbital wall and floor. On the other hand, the second approach is based on individualized orbital implants, which are obtained by reverse engineering using the contralateral orbit from the patient's CT-scans (Burm et al., 1999; Tang et al., 2010; Park et al., 2015; Zimmerer et al., 2016; Kim et al., 2017).

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With time, several approaches have been applied to verify the anatomical accuracy of different reconstruction models; the most used is the calculation of orbital volume through segmentation on CT-scans. Several authors evaluated the accuracy of reconstruction comparing the volume of the restored orbit with the contralateral unaffected one (Scolozzi et al., 2008, 2009, 2010; Tang et al., 2010; Park et al., 2015; Zimmerer et al., 2016; Zavattero et al., 2017; Sugiura et al., 2017). In all these studies, the difference in volume between the unaffected and restored orbits is considered an index of anatomical accuracy in surgical reconstruction. Nonetheless, as recently underlined by Zavattero et al. (2017), a correct restoration should consider orbital shape alongside with volume.

In the last years the widespread diffusion of 3D image acquisition systems and the introduction of software for 3D image elaboration has enhanced the procedures for assessing 3D information, adding novel hints for a more accurate analysis of anatomical structures: an example can be found in the 3D-3D superimposition techniques, recently applied in the field of facial analysis (Codari et al., 2016; Gibelli et al., 2017).

This procedure provides a registration between two 3D virtual models of the structure and the calculation of the point-to-point and RMS (root mean square) distances between models; in addition, the software portrays a chromatic sheet, with areas colored in blue, green and red, according to the reciprocal distances between the two scans.

The possible advantages of this approach in comparison to the mere volume calculation are clear: the superimposition can allow researchers to verify not only the differences between unaffected and restored orbit, but also the localization of possible discordant areas. Moreover, RMS values provide a more detailed indication concerning differences between orbits, as they are based on the superimposition between the whole surface of the 3D models (Gibelli et al., 2017). The procedure may enable a more detailed and anatomically respectful reconstruction of fractured orbit, geometrically adherent to the unaffected one.

The present retrospective pilot study aims at proposing a novel approach to assess the anatomical adherence of orbital reconstruction through a procedure of 3D-3D superimposition between the restored orbit and the “mirror” image of the unaffected one.

2. Material and methods

2.1. Selection of patients and control groups

A retrospective study on patients who underwent orbital wall reconstruction after craniofacial trauma between 2008 and 2014 in the Maxillofacial Departmental Structure, Emergency Department, ASST Grande Ospedale Metropolitano Niguarda (Milan, Italy) was performed.

Twenty patients (14 males, 6 females; age range 19–73 years; mean age: 41.6; SD: 15.3 years) who underwent an orbital reconstruction through titanium plates were selected for the study. All the patients had blow-out fractures or a fracture of orbital floor or/and walls, with involvement of zygomatic bone, because of traumatic injuries. Patients affected by cranial deformation due to congenital or previous traumas were excluded from the study, as well as subjects affected by genetic diseases or acquired pathologies able to modify facial structures. They all received a postoperative CT scan 1 day (range: 0–2 days) after reconstructive surgery using a 16-slice CT (Brilliance® Philips, Milan, Italy) with 2 mm thickness-1 mm increment acquisition, 1.5 mm thickness-0.75 mm increment images reconstruction.

In addition, 13 patients (5 males, 8 females; age range: 28–77 years; mean age: 53.3 years; SD: 16.4 years) who did not suffer traumatic injuries and underwent a CT-scan for other diagnostic reasons were recruited as control group. Chi-square test and Student's t-test were applied to test homogeneity respectively of sex and age between the patients and the control group. No statistically significant differences between the two groups were found ($p > 0.05$).

The same CT scanning protocol was used. Subjects with craniofacial deformities and previous traumatic events involving the orbits were excluded from the study.

The experimental study was performed according to Helsinki declaration and local ethical rules. Anonymous and retrospective radiologic data analysis required no previous informed consent acquisition from all patients.

2.2. Surgical technique

Orbital surgery was always performed under general balanced anesthesia with intraoperative controlled systolic hypotension. All surgical approaches were transconjuctival-preseptal (Novelli et al., 2011); 4 patients sustained medial retrocaruncolar prolongation, to reconstruct concomitant medial orbital wall fractures; 2 patients got adjunctive lateral canthotomy with inferior cantholysis (“swinging eyelid approach”) because of restricted lower lid eversion at the “pinch or snap-back test”.

Subperiosteal dissection was used to prepare 2–3 mm of healthy bone surface all around the bony fracture; this was necessary to guarantee a solid support for the titanium reconstruction and to achieve the best fit of the mesh.

Simultaneous lateral and medial periosteal elevation allowed orbito-sinusal hernia reduction, with careful manipulation of inferior rectus muscle and infraorbital nerve. Orbital fat tissue was entirely preserved, to ensure adequate recovery of enophtalmos, and bony blow out fragments were pulled away from the maxillary sinus ostiomeatal complex.

Each reconstruction in this group of patients was obtained with preformed 0.4 mm thickness titanium mesh (Matrix Orbital®, DePuy Synthes, J&J, West Chester, PA). Pre-surgical imaging evaluation was used to estimate the needed anteroposterior mesh length, but this measure was checked directly on the surgical field. Redundant parts were removed to make mesh positioning easier.

Mesh inserting was obtained with a lateromedial rotation - anteroposterior sliding movement; preformed meshes generally reached “spontaneously” their best fit position and subsequently were minimally adapted and stabilized at the inferior orbital rim with just one screw. At the end of the reconstruction, the posterior lamellae flap was released and clinical eyeball projection checked; forced duction test was always performed before conjunctival suture with two half-running 7/0 resorbable polyfilaments.

2.3. Data acquisition and elaboration

Segmentation of volumes was performed from post-operative CT-scans of each patient through free ITK-SNAP software (Yushkevich et al., 2006). Orbital volume was comprised between the anterior opening of the optic canal (posterior limit) and the plane passing through the posterior lacrimal crest and the lateral edge of the orbit (anterior limit) (Scolozzi et al., 2008). The segmentation procedure was manually performed on each CT-scan slide by slide.

The 3D models of both orbits were elaborated through VAM® software (Vectra Analysis Module, Canfield Scientific, Inc., Fairfield, NJ) (Fig. 1). Volumes of unaffected and restored orbits were automatically calculated. The absolute volume difference between the unaffected and reconstructed orbit in patients, and between the right and left side orbit in the control group, was calculated as well.