Journal of Cranio-Maxillo-Facial Surgery 44 (2016) 1706–1712

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

# Measuring zygomaticomaxillary complex symmetry three-dimensionally with the use of mirroring and surface based matching techniques

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ARTICLE INFO

*Article history:*
Paper received 19 January 2016
Accepted 29 July 2016
Available online 6 August 2016

*Keywords:*
Symmetry
Zygomaticomaxillary complex
Computer-assisted surgery
Surface-based matching
Iterative closest point

ABSTRACT

*Objective:* The study aim was to validate a new method for measuring zygomaticomaxillary complex (ZMC) symmetry, which can be helpful in analyzing ZMC fractures.

*Methods:* Three-dimensional virtual hard-tissue models were reconstructed from computed tomography (CT) datasets of 26 healthy individuals. Models were mirrored and superimposed. Absolute average distance (AD) and 90th percentile distance (NPD) were used to measure overall and maximal symmetry. The Intraclass Correlation Coefficient (ICC) was calculated to measure interobserver consistency. In order to determine whether this technique is applicable in ZMC fracture cases, 10 CT datasets of individuals with a unilateral ZMC fracture were analyzed.

*Results:* For the unaffected group the mean AD was 0.84 ± 0.29 mm (95% CI 0.72–0.96) and the mean NPD was 1.58 ± 0.43 mm (95% CI 1.41–1.76). The ICC was 0.97 (0.94–0.98 as 95% CI), indicating almost perfect interobserver agreement. In the affected group the mean AD was 2.97 ± 1.76 mm (95% CI 1.71–4.23) and the mean NPD was 6.12 ± 3.42 mm (95% CI 3.67–8.57). The affected group showed near-perfect interobserver agreement with an ICC of 0.996 (0.983–0.999 as 95% CI).

*Conclusions:* The method presented is an accurate instrument for evaluation of ZMC symmetry, which can be helpful for advanced diagnostics and treatment evaluation.



## 1. Introduction

Zygomaticomaxillary complex (ZMC) fractures are the most frequently encountered midfacial fractures (Gupta et al., 2009; van Hout et al., 2013; Arangio et al., 2014). Untreated, they can cause both functional impairment (e.g. diplopia, infraorbital nerve dysfunction and mechanical obstruction of the coronoid process) and cosmetic deformations (e.g. diminished malar projection, widening of the midface and malposition of the eye). In ZMC fractures the restoration of facial symmetry is the main treatment goal next to functional recovery (Ellis, 2013; Ellis and Perez, 2014). To date many treatment algorithms have been described, but there is still no consensus on the treatment of ZMC fractures (Rana et al., 2012; Forouzanfar et al., 2013; Ellis and Perez, 2014; Litschel and Suárez, 2015). It is generally accepted that non-displaced and minimally displaced ZMC fractures do not require surgical treatment (Ellis et al., 1985; Kelley et al., 2007; Litschel and Suárez, 2015). However, there is no consensus on what amount of displacement justifies surgical intervention. Most

*Abbreviations:* AD, average distance; AMC, Academic Medical Center, University of Amsterdam; CAS, computer-assisted surgery; CI, confidence interval; CT, computed tomography; DICOM, digital imaging and communications in medicine; FOV, field of view; ICC, interclass correlation coefficients; ICP, iterative closest point; kV, kilovolt; mA, milliampere; mm, millimeter; NPD, 90th percentile distance; SBM, surface-based matching; ZMC, zygomatic complex; 2D, 2-dimensional; 3D, 3-dimensional.

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http://dx.doi.org/10.1016/j.jcms.2016.07.034
1010-5182/

surgeons are prone to base their treatment decision on a combination of their clinical and radiological observations. Unfortunately, the visual appraisal of the surgeon has been shown to be less reliable than would be expected (Dubois et al., 2016). Computed tomography (CT) has proved to be the imaging modality of choice for diagnosing midfacial fractures (Luka et al., 1995; Kelley et al., 2007; Ellstrom and Evans, 2013; Wilde and Schramm, 2014; Litschel and Suárez, 2015). However, despite the overwhelming amount of 3D information available, radiological evaluation is still susceptible to the subjectivity of the observer. Through advanced software packages the surgeon is now able to use segmentation and mirroring tools, which are helpful for mimicking the pre-traumatized anatomy. Computer-assisted surgery (CAS) has shown its value and has become an essential part of the workflow in several fields of oral and maxillofacial surgery (Cutting et al., 1986; Cevidanes et al., 2007, 2009; Tai et al., 2010; Nada et al., 2011; Moubayed et al., 2012; Swennen, 2014; Schepers et al., 2015). Subsequently, reliable (semi-)automated registrations have been introduced to facilitate the integration and application of CAS reconstructions of midfacial defects (Schramm et al., 2009; Wilde and Schramm, 2014; Jansen et al., 2016; Blumer et al., 2015; Wagner et al., 2015; Dubois et al., 2015). CAS can potentially play an important role in objective radiological evaluation.

The aim of this study was to validate a new semi-automatic method of quantifying hard-tissue symmetry of the ZMC in order to objectively analyze and evaluate the ZMC, which may facilitate the decision making process in ZMC fracture cases.

## 2. Materials and methods

Computed tomography (CT) scans of 26 randomly selected individuals who met the inclusion and exclusion criteria were selected from the CT database of the Department of Radiology at the AMC. The inclusion criteria for the unaffected cases were participants who had undergone a CT scan for diagnostic purposes in 2014 at the AMC and were scanned with the standardized trauma protocol (Siemens Medical Solutions, Sensation 64, Erlangen, Germany): 120 kV, 380 mAs, max. FOV 300 mm, pitch 0.85, slice thickness 1.0 mm, slice increment 1.0 mm, image matrix 512 × 512, window W1600/L400, hard-tissue kernel H60S. Participants were excluded if they were younger then 16 years of age, if there was a history of facial fractures, facial surgery (e.g. osteotomies), or pre-existing deformities or pathology of the zygomaticomaxillary–orbital complex (Table 1). The CT data were exported in digital imaging and communications in medicine (DICOM) format and imported into Maxilim (version 2.3.0; Medicim NV, Mechelen, Belgium). 3D virtual hard-tissue models were reconstructed from all 26 datasets and were analyzed by four observers, all of whom were experienced users of the software module.

**Table 1**
Inclusion and exclusion criteria for the selected study population.

| |
|---|
| Inclusion criteria for the unaffected cases were |
| - Participants who had undergone a CT scan for diagnostic purposes in the year 2014 in the AMC |
| - Participants scanned with the standardized trauma protocol |
| Exclusion criteria for the unaffected cases were |
| - Participants <16 years |
| - Participants with a history of facial fractures |
| - Participants with a history of facial surgery [e.g. osteotomies] |
| - Participants with a history of pre-existing deformity |
| - Participants with a history of pathology of the zygomaticomaxillary–orbital complex |

### 2.1. Analysis procedure of zygomaticomaxillary symmetry

First, the 3D virtual hard-tissue models were automatically mirrored in Maxilim to obtain a 3D virtual mirrored hard-tissue model (Fig. 1). The built-in surface-based matching method was used to align the original and mirrored hard-tissue models on the original right-sided ZMC. Initially, the models were roughly aligned by minimizing the squared error between four indicated landmarks on the original and mirrored models. The four landmarks indicated by the observers were the anterior point of the root of the temporal bone attached to the zygomatic arch bilaterally, the hard-tissue nasion and the right-sided articular tubercle of the zygomatic arch (Fig. 2). These anatomical landmarks were chosen because they are easy to indicate in a reproducible manner.

After initial positioning, the best fit between the original and mirrored 3D models was computed using the surface-based matching algorithm available in Maxilim. This tool uses an adapted version of the iterative closest point (ICP) algorithm (Besl and McKay, 1992). Surface-based matching was performed using three different surface areas, which were delineated by the observers. First, a triangular area covering the right frontal bone from the zygomatico-frontal suture to the supraorbital midline was selected. Second and third, the left and right roots of the temporal bones with the zygomatic arch were selected (Fig. 3). A maximum search distance of 3 mm was used for surface-based registration.

After alignment, the ZMC boundaries were defined. The outer surface of the ZMC was delineated on the original and mirrored 3D virtual hard-tissue models by the observers. The medial boundary of the ZMC was defined as a plane parallel to the sagittal plane, through the orbital midline. The posterior zygomatic boundary was delineated using a perpendicular line posterior to the external auditory meatus (Fig. 4). A distance map was created in Maxilim between the aligned surfaces of the ZMC; the mean and 90th percentile distances of these distance maps were calculated in Matlab (version 2012b; The Mathworks Inc., Natick, MA, USA) (Fig. 5). The average distance (AD) and 90th percentile distance (NPD) of the absolute distance measures were calculated to serve as a quantification of the overall and maximal symmetry respectively.

To evaluate if the described method is applicable in ZMC fracture cases, a retrospective analysis was performed in 10 randomly selected individuals with a history of unilateral ZMC fractures. All met the previous inclusion and exclusion criteria. The initial CT scan of the patients was selected from the CT database of the Department of Radiology at the AMC. All CT scans were acquired using the previously described standardized trauma protocol and were

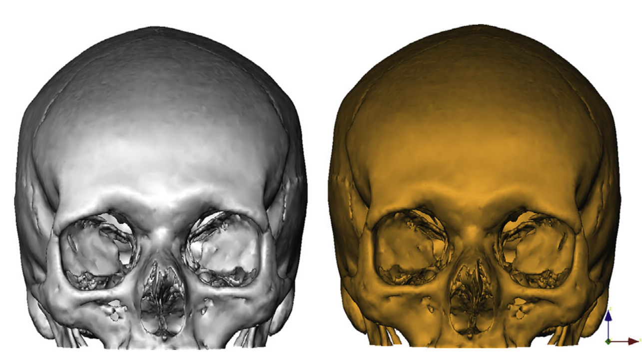

**Fig. 1.** Automatically created original (white colored) and mirrored (orange colored) 3D virtual hard-tissue model in Maxilim (version 2.3.0; Medicim NV, Mechelen, Belgium) after CT data (in DICOM format) has been imported.