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Research Paper
Imaging

Accuracy of three-dimensional facial soft tissue simulation in post-traumatic zygoma reconstruction

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Abstract. The aim of this study was to evaluate the accuracy of novel software-CMF-preCADS-for the prediction of soft tissue changes following repositioning surgery for zygomatic fractures. Twenty patients who had sustained an isolated zygomatic fracture accompanied by facial deformity and who were treated with repositioning surgery participated in this study. Cone beam computed tomography (CBCT) scans and three-dimensional (3D) stereophotographs were acquired preoperatively and postoperatively. The 3D skeletal model from the preoperative CBCT data was matched with the postoperative one, and the fractured zygomatic fragments were segmented and aligned to the postoperative position for prediction. Then, the predicted model was matched with the postoperative 3D stereophotograph for quantification of the simulation error. The mean absolute error in the zygomatic soft tissue region between the predicted model and the real one was 1.42 ± 1.56 mm for all cases. The accuracy of the prediction (mean absolute error ≤2 mm) was 87%. In the subjective assessment it was found that the majority of evaluators considered the predicted model and the postoperative model to be 'very similar'. CMF-preCADS software can provide a realistic, accurate prediction of the facial soft tissue appearance after repositioning surgery for zygomatic fractures. The reliability of this software for other types of repositioning surgery for maxillofacial fractures should be validated in the future.

Key words: computer-aided design (CAD); soft tissue simulation; zygomatic fractures; maxillofacial surgery; 3D stereophotography.

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In orthognathic surgery, facial deformities are corrected by repositioning the bone segments. Computerized prediction of the postoperative facial appearance could be valuable for guiding surgical plans and exploring different treatment options. It may also serve as a tool to allow members of the interdisciplinary team to communicate and provide the patient with the desired outcome. Many software packages have been designed for prediction in orthognathic surgery.[1–3]

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The aim of repositioning surgery for zygomatic fractures is not only the correction of dysfunction, such as limited mouth opening and malocclusion, but also for aesthetic improvement of the facial appearance. Because the final aesthetic result is indicated by the postoperative facial appearance, an accurate three-dimensional (3D) prediction of the soft tissue changes after bony tissue repositioning is essential in preoperative treatment planning.[4,5] To date, no software package designed specifically for the virtual simulation of maxillofacial fracture repositioning surgeries has been developed, and no study on the corresponding soft tissue prediction has been published.

The novel software CMF-preCADS was recently developed for the computerized prediction of 3D facial appearance after maxillofacial repositioning surgeries. It is hypothesized that CMF-preCADS may be useful. However, before use in the clinical setting, its accuracy and reliability must be evaluated objectively based on clinical evidence and a large number of homogeneous patients.

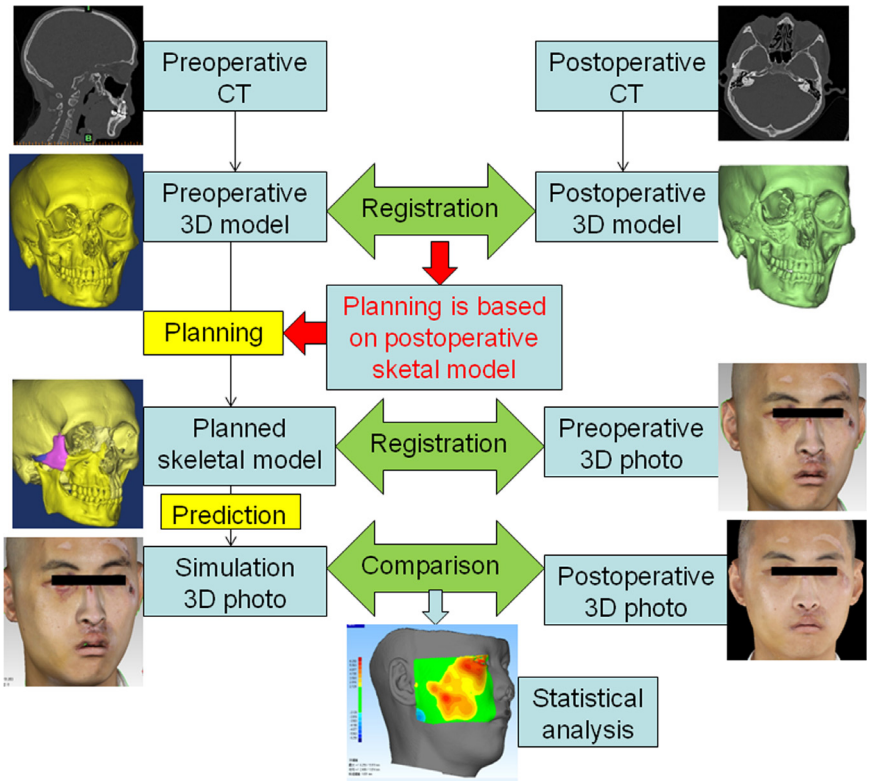

Fig. 1. Flow chart of the data processing procedure.

Materials and methods

The sample consisted of 20 adult Chinese patients who had been referred to the department of oral and maxillofacial surgery of the study institution between January 2014 and March 2015. There were 14 men and six women, and their mean age was 34 years.

The inclusion criteria encompassed the following: patients diagnosed with isolated and old zygomatic fractures and a facial deformity, who agreed to the repositioning surgery involving a semicoronal scalp incision, and who required internal fixation. The exclusion criteria were as follows: patients with pre-traumatic or congenital deformities and facial soft tissue lacerated wounds, scars, swelling, or haematocele, and those requiring additional adjunctive surgical procedures.

This study did not influence the clinical treatment protocols and was approved by the university medical ethics committee. Full informed consent was obtained from all patients. Figure 1 shows a flow chart of the data processing procedure.

Data acquisition and preparation

Cone beam computed tomography (CBCT) and 3D stereophotograph data were acquired preoperatively and at 3 months postoperatively for all patients. To minimize the effect of head position on the soft tissues, each patient was scanned while seated in natural head position looking at his or her image in a mirror, with lips and facial muscles relaxed.

The CBCT scans were performed using a standard protocol (field of view 16 cm diameter, 22 cm height, voxel size 0.4 mm, scan time 40 s, 120 kV) with the same machine (J Morita Mfg. Corp., Kyoto, Japan). CBCT data were stored in DICOM format (Digital Imaging and Communications in Medicine) and imported into CMF-preCADS installed on a personal computer (Lenovo, E540) for rendering of the head skeletal 3D models and facial surface models.

A 3D stereophotograph was captured with a commercial 3D camera system, FaceSCAN3D (3D-Shape, Erlangen, Germany), and stored in .obj format with facial texture information. Prior to use, the camera was calibrated to define a 3D coordinate system.

Prediction of facial soft tissue appearance

Preoperative and postoperative skeletal 3D models were superimposed in CMF-preCADS using surface-based registration on unchanged sub-regions, such as the cranial base, forehead, and normal side, in order to eliminate discrepancies between the planned skeletal displacement and the actual movement. Virtual repositioning surgery was then performed on the preoperative 3D model. The fractured zygomatic fragments were segmented according to the actual osteotomies and aligned to their respective postoperative positions (postoperative skeletal 3D model).

Before simulating the facial appearance, the preoperative 3D stereophotograph was aligned to the CBCT facial surface model for more realistic visualization with a previously validated superimposition method, the iterative closest point (ICP) algorithm.

CMF-preCADS computed the soft tissue deformation caused by the simulated skeletal movements using a finite element method (FEM) algorithm, which has been published previously.[6] The graphical interface in CMF-preCADS makes it possible to preview the patient's new facial appearance.

Analysis of the soft tissue simulation

The predicted 3D facial model and postoperative 3D stereophotograph model were superimposed in Geomagic Studio 11.0 (Raindrop Geomagic, Rock Hill, SC, USA) using surface-based registration on unchanged sub-regions (the forehead and

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