Three-Dimensional Facial Simulation in Bilateral Sagittal Split Osteotomy: A Validation Study of 100 Patients

Jeroen H. F. Liebregts, DDS, Maarten Timmermans, MD, DMD,† Martien J. J. De Koning, MD, DMD,‡ Stefaan J. Bergé, MD, DMD, PhD,§ and Thomas J. J. Maal, PhD||*

Purpose: Three-dimensional (3D) virtual planning of orthognathic surgery in combination with 3D soft tissue simulation allows the surgeon and the patient to assess the 3D soft tissue simulation. This study was conducted to validate the predictability of the mass tensor model soft tissue simulation algorithm combined with cone-beam computed tomographic (CBCT) imaging for patients who underwent mandibular advancement using a bilateral sagittal split osteotomy (BSSO).

Materials and Methods: One hundred patients were treated with a BSSO according to the Hunsuck modification. The pre- and postoperative CBCT scans were matched and the mandible was segmented and aligned. The 3D distance maps and 3D cephalometric analyses were used to calculate the differences between the soft tissue simulation and the actual postoperative results. Other study variables were age, gender, and amount of mandibular advancement or rotation.

Results: For the entire face, the mean absolute error was 0.9 ± 0.3 mm, the mean absolute 90th percentile was 1.9 mm, and for all 100 patients the absolute mean error was less than or equal to 2 mm. The subarea with the least accuracy was the lower lip area, with a mean absolute error of 1.2 ± 0.5 mm. No correlation could be found between the error of prediction and the amount of advancement or rotation of the mandible or age or gender of the patient.

Conclusion: Overall, the soft tissue prediction algorithm combined with CBCT imaging is an accurate model for predicting soft tissue changes after mandibular advancement. Future studies will focus on validating the mass tensor model soft tissue algorithm for bimaxillary surgery.

J Oral Maxillofac Surg 73:961-970, 2015

The predictability of soft tissue simulation has become one of the most important research subjects concerning orthognathic surgery since surgeons and orthodontists shifted their attention from occlusion-based planning to soft tissue-based planning.[1,2] The recent introduction of 3-dimensional (3D) virtual planning of orthognathic surgery in combination with 3D soft tissue simulation has been a major step forward toward real-time planning. For the surgeon, orthodontist, and patient, 3D soft tissue simulation allows an assessment of 3D changes in a real-time environment, allowing quick adaptations to treatment planning when presented with an unfavorable soft tissue simulation. Changes in the frontal view owing to surgical corrections of the mandible and maxilla in the midline can be an integrated part of the decision-making process.

Previously, no long-term validation study on soft tissue simulation predictability using cone-beam

Received from the Department of Oral and Maxillofacial Surgery, Radboud University Medical Centre, Nijmegen, The Netherlands; and the Facial Imaging Research Group, Nijmegen and Bruges, Belgium.

*Resident.

†Resident.

‡OMF Surgeon.

§Professor, Head Department OMF.

||Head Department 3D Lab.

Drs Liebregts and Timmermans contributed equally to this study.

Address correspondence and reprint requests to Dr Maal: Department of Oral and Maxillofacial Surgery, PO Box 9101, Radboud University Medical Centre, 6500 HB Nijmegen, Postal Number 590, Netherlands; e-mail: t.maal@mka.umcn.nl

Received January 23 2014

Accepted November 4 2014

0278-2391/14/01711-X

http://dx.doi.org/10.1016/j.joms.2014.11.006

computed tomographic (CBCT) imaging has been published with a large number of patients undergoing a single type of orthognathic operation.

The aim of this study was to assess the accuracy of the mass tensor model algorithm used in Maxilim 2.2.2.1 (Medicim NV, Mechelen, Belgium) for the simulation of surgery on CBCT images. The influence of a patient's age and gender and the amount of mandibular advancement and rotation were independently assessed to explain possible discrepancies.

Materials and Methods

PATIENTS

One hundred patients (35 male and 65 female) were included in this study. All patients underwent mandibular advancement using a bilateral sagittal split osteotomy (BSSO) according to the Hunsuck modification[3] from January 2007 to December 2010 at the Department of Oral and Maxillofacial Surgery, Radboud University Medical Centre (Nijmegen, The Netherlands). This study was conducted under ethics committee approval (study protocol 181/2005). All patients were older than 13 years, with an average age of 31.6 years at the time of surgery (range, 13 to 68 yr). Two weeks before surgery, a CBCT scan was acquired. Furthermore, for all patients, a postoperative CBCT scan was acquired at least 6 months after surgical correction (mean, 13.4 months after surgery); thus, skeletal relapse was not a factor.

Inclusion criteria were a nonsyndromic mandibular hypoplasia, patients undergoing orthognathic surgery at the authors' center, a signed informed consent, and the availability of an extended-height CBCT scan before and at least 6 months after surgery.

The exclusion criteria were a chin support used during CBCT scanning, previous orthognathic surgery, other orthognathic procedures including chin osteotomy performed simultaneously, presence of orthodontic appliances when the postoperative CBCT scan was obtained, patients who were edentulous, the absence of upper incisors or lower incisors, or extensive restorative dental work after surgery.

IMAGE ACQUISITION

The extended-height CBCT scan was acquired using the i-CAT 3D Imaging System (Imaging Sciences International, Hatfield, PA). All patients were scanned while seated with the head in a natural position using the same i-CAT machine. They were asked to swallow, relax their lips, and keep their eyes open. All patients were scanned with a wax bite to ensure proper condylar seating.

The acquired data from the CBCT scans were exported in Digital Imaging and Communications in Medicine (DICOM) format to Maxilim. In Maxilim, the skull and skin tissue of the pre- and postoperative scans were segmented using a threshold technique, resulting in an accurate 3D reconstruction.

VOXEL-BASED REGISTRATION

After reconstruction, pre- and postoperative CBCT scans were matched using voxel-based registrations on an unaltered subvolume.[4] This subvolume consisted of the cranial base, forehead, and zygomatic arches. After matching the images, the mandible was segmented, as described by Swennen et al,[5] on the preoperative scan and the bone cuts were made for the BSSO on the preoperative scan according to the postoperative result.

SIMULATION OF SOFT TISSUES

After registration of the preoperative and postoperative CBCT scans, the simulation of the soft tissues could be computed. A mass tensor model soft tissue simulation algorithm was applied to the preoperative soft tissue surface. The preoperative mandible was optimally aligned with the postoperative mandible, representing exactly the transformation reached during surgery using the surface-based registration method described by Besl and McKay.[6] Based on the transformation of the mandible, a simulation of the soft tissues was computed. Thus, the result of the soft tissue simulation could be compared with the actual postoperative soft tissue result.

VALIDATION OF SOFT TISSUE SIMULATION

Validation of the soft tissue simulation was performed using cephalometric analysis (method A) and a 3D volume measurement using distance mapping (method B).

3D Cephalometric Analysis (Method A)

To investigate the differences between the actual postoperative result and the soft tissue simulation, a cephalometric soft tissue analysis was performed. The first step was to set up a hard tissue reference frame (Fig 1A). The pre- and postoperative 3D reconstructions were marked with cephalometric points for the subnasale, labiale superius, stomion, labiale inferius, sub-labiale, and soft tissue pogonion. To compute the actual hard tissue movements, additional hard tissue landmarks were indicated for the upper incisor landmark, lower incisor landmark, the mesial buccal cusps of the first molars in the upper jaw, and the pogonion. After the cephalometric analysis was performed, the euclidean distances were computed for all corresponding cephalometric landmarks between the preoperative simulation and the actual postoperative result. This euclidean distance represented the degree of