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Research Paper
Image Guided Surgery

Accuracy of experimental mandibular osteotomy using the image-guided sagittal saw

P. Pietruski[1], M. Majak[2], E. Swiatek-Najwer[2], M. Popek[2], D. Szram[3], M. Zuk[2], J. Jaworowski[3]

[1]Department of Plastic Surgery, Medical Centre of Postgraduate Education, Warsaw, Poland; [2]Department of Biomedical Engineering, Mechatronics and Theory of Mechanisms, Wroclaw University of Technology, Wroclaw, Poland; [3]Maria Sklodowska-Curie Memorial Cancer Centre and Institute of Oncology, Warsaw, Poland

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Abstract. The aim of this study was to perform an objective assessment of the accuracy of mandibular osteotomy simulations performed using an image-guided sagittal saw. A total of 16 image-guided mandibular osteotomies were performed on four prefabricated anatomical models according to the virtual plan. Postoperative computed tomography (CT) image data were fused with the preoperative CT scan allowing an objective comparison of the results of the osteotomy executed with the virtual plan. For each operation, the following parameters were analyzed and compared independently twice by two observers: resected bone volume, osteotomy trajectory angle, and marginal point positions. The mean target registration error was 0.95 ± 0.19 mm. For all osteotomies performed, the mean difference between the planned and actual bone resection volumes was $8.55 \pm 5.51\%$, the mean angular deviation between planned and actual osteotomy trajectory was $8.08 \pm 5.50^{\circ}$, and the mean difference between the preoperative and the postoperative marginal point positions was 2.63 ± 1.27 mm. In conclusion, despite the initial stages of the research, encouraging results were obtained. The current limitations of the navigated saw are discussed, as well as the improvements in technology that should increase its predictability and efficiency, making it a reliable method for improving the surgical outcomes of maxillofacial operations.

Key words: computer-assisted surgery; image-guided surgery; intraoperative navigation; orthognathic surgery; accuracy.

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Intraoperative navigation, also referred to as image-guided surgery (IGS) or computer-assisted navigation (CAN), continues to gain credibility in the field of craniomaxillofacial surgery. The main function of intraoperative navigation systems is to allow the surgeon to precisely locate the surgical instruments or bony anatomical landmarks in the three-dimensional (3D) surgical field in real-time. This feature, in conjunction with advanced preoperative virtual planning and options for the prediction of postoperative results, makes computer-assisted navigation technology a powerful tool facilitating surgical operations in the technically challenging head and neck region.

Despite the fact that in recent years there have been many reports describing the scope and range of current clinical applications of this technology in craniomaxillofacial surgery,[1–5] as well as many accuracy tests on modern navigation system tip-pointers,[6–12] there appears to have been no research to establish the level of accuracy of mandibular osteotomies performed using the image-guided surgical saw. Therefore, the purpose of this study was to perform an objective evaluation of the precision of mandible model osteotomies performed using the image-guided resection technique reported recently by the present authors.[13]

Materials and methods

Image data acquisition

Thirteen titanium microscrews (diameter 1.0 mm, length 4.0 mm) were inserted into a plastic mandible model (type A20; 3B Scientific GmbH, Hamburg, Germany). The skull with the mandible model was scanned using a 32-slice CT scanner (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany) with the following parameters: the 512 × 512 pixels dataset was acquired at a resolution of 0.39 mm/pixel and 0.625 mm slice thickness. Image data were saved in Digital Imaging and Communication in Medicine (DICOM) format.

Virtual planning

The DICOM data were transferred to a Windows-based computer workstation with the Maxillo-Facial Surgery System (MFSS), which was created by bioengineers and software engineers from Wroclaw University of Technology in cooperation with the Maria Sklodowska-Curie Memorial Cancer Centre and Institute of Oncology in Warsaw.[13–15] Using the MFSS virtual planning module, these images were reformatted to produce standard two-dimensional (2D) axial, frontal, and sagittal views, as well as a 3D volume-rendered model. Using the bone segmentation option, four separate osteotomies of the mandible were planned (Fig. 1). Next, the microscrew heads were identified manually and labelled as either registration fiducials for registration purposes or target fiducials for target registration error (TRE) estimation, individually for each virtual plan of the osteotomy. Each virtual surgical plan was saved and exported to the intraoperative navigation module of the MFSS system.

Printing of 3D models

Due to the fact that the mandible model was made of plastic and cutting it with a surgical saw would cause the osteotomy edges to melt, thus preventing a reliable analysis of the objective postoperative results, it was decided to produce an exact model reproduction made of plaster. Using the MFSS software, the mandible DICOM data were converted to stereolithography file (STL) format and sent to the CAD/CAM facility (Department of Laser Technology, Automation and Organization of Production, Wroclaw University of Technology, Wroclaw, Poland) where four exact plaster mandibles, with no significant loss of fiducial marker accuracy, were fabricated using generative 3D printing technology.

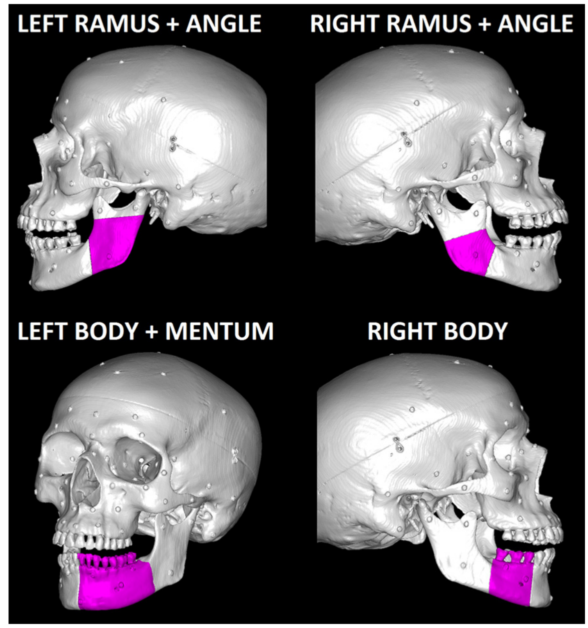

Fig. 1. Virtual mandibular osteotomies.

Image-guided model osteotomy

All surgical procedures were performed in a real operating theatre setting, according to the same operating protocol. A dynamic reference frame (StealthStation Spine Referencing Set; Medtronic, Minneapolis, MN, USA) was attached rigidly to the mandible and an optical tracking adapter (SureTrak II Universal Tracker; Medtronic) was installed on the handle of the sagittal surgical saw (GB129R; Aesculap, Pennsylvania, PA, USA) (Fig. 2). Image-guided support was provided by the intraoperative navigation module of the MFSS, integrated with the infrared tracking camera of the commercial intraoperative navigation system (StealthStation S7; Medtronic). The registration process, based on six characteristic points marked as registration fiducials, was performed with a tip-pointer (Passive Planar Blunt Probe; Medtronic), according to the rigid-body point-based alignment of coordinate systems. After each registration procedure, the target fiducials in the area of interest, adjacent to the planned osteotomies, were used to determine TRE parameters, computed as the square root of the sum of squared deviation in all three spatial directions.[16] The acquired mean registration procedure accuracy, expressed as a fiducial registration error (FRE), and the mean intraoperative navigation accuracy, expressed as TRE, were archived. An average FRE of <1.00 mm and an average TRE of <1.50 mm were considered indicative of a successfully conducted registration process.

Next, the calibration of the sagittal surgical saw blade was carried out with the use of a navigated pointer.[17] During this procedure, the tooth edge width and length, along with the long axis plane of the blade were determined, allowing this tool to be navigated precisely. The position of the saw blade contours was shown in real-time on a screen in multiplanar 2D (axial, coronal, and frontal planes) and 3D views of the operative field. The accuracy of the saw blade navigation was evaluated by applying it to the target fiducial points of the mandible and comparing its position and angle in virtual and physical space. If the surgical instrument navigation was considered accurate, the calibration procedure was completed and the resection of bone structures was performed in accordance with the virtual surgery plan. Due to the image-guided support, the position and the tilt of the saw blade were displayed on