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Integration accuracy of laser-scanned dental models into maxillofacial cone beam computed tomography images of different voxel sizes with different segmentation threshold settings

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Objective. The aims were to examine the influence of cone beam computed tomography (CBCT)-scanned voxels and segmentation threshold settings on the accuracy of surface-based registration.
Study Design. The samples were obtained from 10 adults. Each laser-scanned model was registered into a CBCT model by use of the iterative closest point algorithm. We calculated the shell-to-shell deviations between the 2 models and evaluated the results with color-mapping methods. The centroid coordinates were used to calculate the positional differences. Thresholds were expressed in relative Hounsfield units (RHU).
Results. There was a statistically significant difference in shell-to-shell deviations between the 0.20-mm-voxel group and the 0.40-mm-voxel group ($P < .001$). There was a statistically significant difference in anteroposterior and superoinferior directions between the 200- and 700-RHU threshold models in 2 groups ($P < .05$).
Conclusions. The results indicated that the accuracy of the integration of laser-scanned dental models into CBCT images is higher with a high-RHU threshold setting in 0.20- and 0.40-mm voxel sizes. (Oral Surg Oral Med Oral Pathol Oral Radiol 2014;■:1-7)

An accurate 3-dimensional (3D) virtual model of maxillofacial skeletal structures and occlusion is essential for computer-aided surgical simulation (CASS) protocols for orthognathic surgery. Cone beam computed tomography (CBCT) has recently received attention as a new standard diagnostic tool because it is able to accurately represent the 3D shape and position of the jaw with the advantages of low cost, easy accessibility, and low radiation dose compared with multislice computed tomography.[1-3] However, the major obstacle is that CBCT imaging cannot provide detailed surface dental morphology and accurate interocclusal relationships, owing to the limited scanning resolution and streak artifacts caused by radiopaque dental restorations (e.g., metal crown) or orthodontic brackets.[4,5]

Different methods have been described in the literature by investigators attempting to solve this problem. Several researchers have used fiducial markers, which can lead to an acceptable degree of registration accuracy. However, the procedures are more complicated for practitioners making fiducial markers (e.g., titanium spheres, ceramic balls, or gutta percha), reference splints, or double computed tomography (CT) scanning for integration.[6-8] In addition, Swennen et al.[1] adopted a triple CBCT scan procedure, with triple-voxel-based rigid registration not involving fiducial markers for registration. However, the procedures are still rather complicated, and the participants were scanned with CBCT more than once.

Other researchers[4,9,10] used a method of surface-based registration, which also enabled them to achieve a satisfactory registration accuracy without fiducial markers. The registration was implemented by the use of an 'iterative closest point' (ICP) algorithm, which accurately aligns the 3D polygon mesh data sets of the digital models. The registration uses the surface information from two 3D models to calculate the rotation and translation between the 2 models. The corresponding points and shapes are searched automatically by the software, and the distance between 2 models is minimized after rotation and translation. The registration error, represented as shell-to-shell deviation in the software, measures the 3D Euclidean distances in whole 3D models between each point on the 3D model and the nearest neighbor point on another 3D model.[10-12]

Statement of Clinical Relevance

The accuracy of the integration of laser-scanned dental models into cone beam computed tomography images is higher with a high threshold setting in 0.20- and 0.40-mm voxel sizes.

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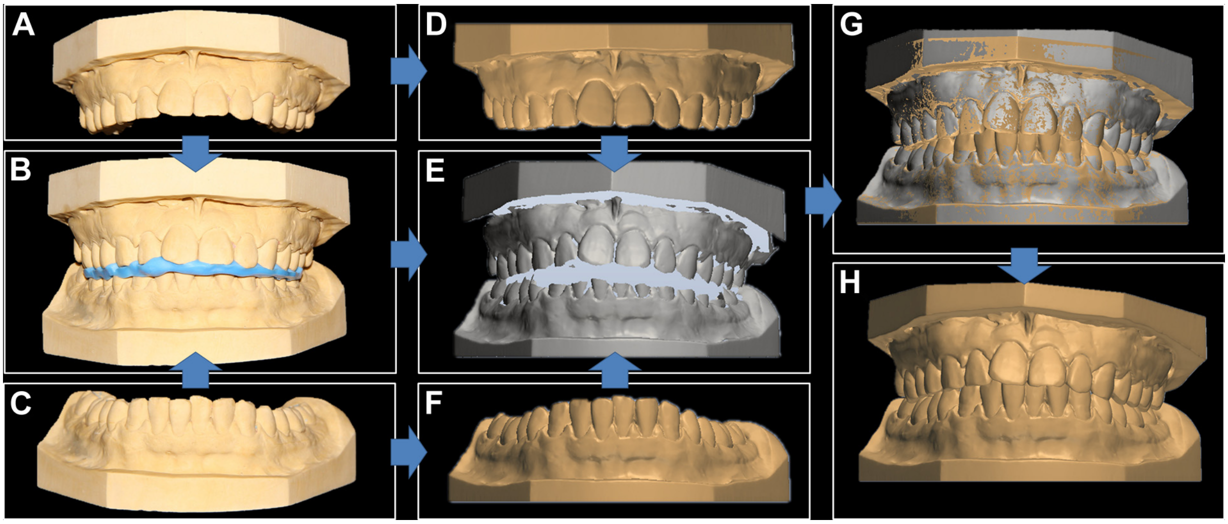

Fig. 1. Laser scan procedures. **A**, Plaster model of maxillary cast. **B**, Plaster models of both casts with a wax bite wafer. **C**, Plaster model of mandibular cast. **D**, Digital model of maxillary cast. **E**, Digital model in occlusion. **F**, Digital model of mandibular cast. **G**, Models aligned automatically by software. **H**, Digital models of both casts in occlusion.

CT uses the Hounsfield unit (HU) as its unit of measure. This is a numeric value used in CT scan interpretation that characterizes the tissue density in the imaged anatomy. However, unlike in conventional CT, CBCT tube voltages vary widely from manufacturer to manufacturer. Therefore, because numerical values for the same tissue show great deviations between CBCT machines,[13-15] measurement in HU does not really apply to most CBCT machines. Only several machines produce values that may be mathematically linked to HU. In addition, the volume accuracy of the CBCT model is affected by the segmentation threshold.[15]

In previous studies, the authors did not discuss the different CBCT scanning voxels and segmentation threshold settings, which may have an effect on registration accuracy. In a previous study, Ye et al.[15] found that the different CBCT-scanned voxels and segmentation threshold settings during segmentation had a great effect on tooth volumetric measurements. The purposes of this study were (1) to examine the influence of the different CBCT-scanned voxels and segmentation threshold settings on the accuracy of surface-based registration and (2) to attempt to find a suitable segmentation threshold and scanning voxel for clinical applications.

MATERIALS AND METHODS

For this study, we enrolled 10 adults (4 men and 6 women; mean age, 25.2 years) who required extraction of impacted third molars and who had intact dentition and no dental restorations or missing teeth. This study was approved by the West China Hospital of Stomatology Institutional Review Board, and all participants signed an informed consent agreement. We have read the Helsinki Declaration and have followed the guidelines in this investigation.

Table I. Preset cone beam computed tomography scan parameters

Group	*Voxel size (mm)*	*Field of view (mm^2)*	*Scan time (s)*	*Tube current (mA)*	*Tube voltage (kV)*
0.20-mm voxel	0.20	140 × 85	23	5	120
0.40-mm voxel	0.40	140 × 85	8.9	5	120

Step 1: laser scan procedure

We prepared dental models by taking impressions using alginate impression material (3M ESPE, Seefeld, Germany) and filled the impressions with plaster. A conventional bite registration in centric occlusion was performed by means of a bite wax wafer (DeLar, Lake Oswego, OR, USA). Each plaster cast was then scanned by 3D laser scanning equipment (3Shape, Copenhagen, Denmark). The laser scan procedures were as follows: (1) scan of maxillary cast; (2) scan of mandibular cast; and (3) scan of maxillary and mandibular casts together, with a bite wax wafer in centric occlusion. The maxillary and mandibular digital models could be automatically aligned in centric occlusion by the software (3Shape, Copenhagen, Denmark) (Figure 1). The digital models of both arches were exported as standard tessellation language (STL) format files.

Step 2: CBCT scan procedure

Before the scanning, air and a cup of water were scanned with a 3D examination scanner (KaVo Dental,