Validation of cone beam computed tomography−based tooth printing using different three-dimensional printing technologies

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Objective. Our aim was to determine the accuracy of 3-dimensional reconstructed models of teeth compared with the natural teeth by using 4 different 3-dimensional printers.

Study Design. This in vitro study was carried out using 2 intact, dry adult human mandibles, which were scanned with cone beam computed tomography. Premolars were selected for this study. Dimensional differences between natural teeth and the printed models were evaluated directly by using volumetric differences and indirectly through optical scanning. Analysis of variance, Pearson correlation, and Bland Altman plots were applied for statistical analysis.

Results. Volumetric measurements from natural teeth and fabricated models, either by the direct method (the Archimedes principle) or by the indirect method (optical scanning), showed no statistical differences. The mean volume difference ranged between 3.1 mm^3 (0.7%) and 4.4 mm^3 (1.9%) for the direct measurement, and between −1.3 mm^3 (−0.6%) and 11.9 mm^3 (+5.9%) for the optical scan. A surface part comparison analysis showed that 90% of the values revealed a distance deviation within the interval 0 to 0.25 mm.

Conclusions. Current results showed a high accuracy of all printed models of teeth compared with natural teeth. This outcome opens perspectives for clinical use of cost-effective 3-dimensional printed teeth for surgical procedures, such as tooth autotransplantation. (Oral Surg Oral Med Oral Pathol Oral Radiol 2016;121:307-315)

Over the last decade, rapid prototyping (RP) has become popular in dental and maxillofacial applications, especially for treatment planning and further development of oral and maxillofacial surgical aids. RP refers to a number of different interrelated technologies that can be applied for building complex physical models and prototype parts straight from 3-dimensional (3-D) computer-aided design (CAD) models. Focusing on dentistry applications, all 3-D printing technologies essentially rely on 3-D models, which can be achieved through cone beam computed tomography (CBCT) data.

Although stereolithography (SLA, 3-D Systems, Inc., Rock Hill, SC) is widely considered the gold standard for medical RP applications, its cost-effectiveness and efficiency remain highly debatable, limiting its use in the clinical practice settings.[1-4] Moreover, some studies suggest superiority of other technologies, such as Polyjet printers in smaller and more complex structures, compared with SLA.[5]

Shahbazian et al.[6] used CBCT-based SLA models to produce 3-D tooth replicas for tooth autotransplantation. This novel approach not only provides accurate tooth replicas but also guarantees a more predictable treatment outcome for the TAT procedure.[6,7]

Use of the CBCT-based tooth replica is a clinically valuable treatment option; however, models other than the CBCT-based SLA have been investigated. Additionally, a number of less expensive 3-D printing techniques are now available. Despite the fact that some of these approaches were tested using linear measurements on dimensional jaws[8-10] these techniques have not yet been validated for CBCT-based tooth printing. The aim of the present study was to determine the accuracy of 4 different models for 3-D tooth replica

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Statement of Clinical Relevance

The use of 3-dimensional printed replicas and medical tools is gaining importance in oral and maxillofacial surgery. The possibility to use low-cost 3-dimensional printers opens perspective for clinical use. However, validation of this technique is necessary.

Fig. 1. Two dry mandibles (M1 on the left, M2 on the right) with three teeth for each: #34, #44, and #45.

printing by assessing the volumetric and morphologic differences compared from authentic teeth.

MATERIALS AND METHODS

Study sample and collection

This study was carried out on 2 intact, dry, adult, human mandibles of unknown gender collected from the Department of Anatomy, KU Leuven, Belgium (Figure 1). The study was approved by the Ethical Review Board of the University Hospitals Leuven (ML9535/ML9248, ERB University Hospitals Leuven).

Two dry mandibles with 3 teeth for each, #34, #44, and #45, were used within this study (see Figure 1). The mandibles were scanned using the 3-D Accuitomo 170 (J. Morita, Kyoto, Japan), which produced high-definition 3-D images owing to a fine voxel size (0.16 mm), a superior sensitivity, a CsI scintillator flat panel detector, and a precise grayscale differentiation capability (Figure 2). The machine displayed a wide field of view (80 × 80 mm) and produced 360° scans within 17.5 seconds. A copper filter of 0.5 mm was used in front of the x-ray beam source to simulate soft tissue. Teeth were stable in a dry mandible, mounted on a plastic tray, during CBCT acquisition.[11]

The selection of premolars was based on the root anatomy of the mandibular premolars that were most suitable for the replacement of the upper central incisors in the autotransplantation procedure.[6,7]

All data sets were exported into the Digital Imaging and Communication in Medicine (DICOM) file format.

Data processing

All 6 premolars were segmented from the DICOM images by using the 3-D planning software SimPlant Pro (version 12.01, Dentsply Implants, Mölndal, Sweden), according to a predefined protocol: The segmentation was done by using a global threshold based on image intensity values, often used for CT-based bone segmentation. However, the density of teeth is very different from crown to apex, as the contrast between the root and bone decreases. If a single threshold parameter is applied for segmentation, it would not be possible to visualize the crown and the root apex at the same time. Therefore, tooth segmentation would require more than 1 threshold level.[12,13] In the present study, the threshold level was adjusted at 3 levels (coronal, middle, apical), since tissue densities and images from crown to apex are different, followed by the application of region growing to extract the tooth out of the CBCT volume.[14]

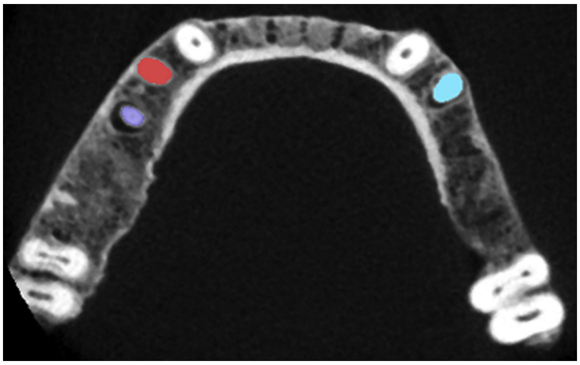

Fig. 2. Cone beam computed tomography scan of mandible M2.

The 3-D models were made from the segmented teeth using the 3-matic software (version 9.0, Materialise NV, Leuven, Belgium) and exported as stereolithography (STL) files to be printed by the 3-D printers.

Model manufacturing

The STL files of the 6 segmented teeth were sent to 4 3-D printers: SLA, Objet Eden 250 (Stratasys, Eden Prairie, MN), Objet Connex 350 (Stratasys), and UP Plus 2 (Dynamism, Beijing, China).

These 4 printers belong to 3 different technologies of RP. The first uses SLA, which is a process in which an ultraviolet laser draws the object in a vat of liquid ultraviolet curable photopolymer resin in order to build the part layer by layer. Objet printers use the Polyjet technology, in which drops of photopolymer resin are jetted in the same way as with an inkjet printer. An ultraviolet lamp cures the resin, and a new layer of drops is sprayed. The UP Plus 2 uses a third technology, namely, extrusion of fused material, such as polyacrylonitrile butadiene styrene; this technology is called fused deposition modeling (FDM). Table I presents the specifications of the 4 printers used in this study, with 3 different technologies.

In total, 24 tooth replicas were produced. Figure 3 shows an example of a premolar tooth and the corresponding printed replicas.

Controlled accuracy assessment

To assess accuracy, volume differences between the natural teeth and the printed models were evaluated using the Archimedes principle (direct method).