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CLINICAL ORAL IMPLANTS RESEARCH

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Designing a novel dental root analogue implant using cone beam computed tomography and CAD/CAM technology

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Abstract

Objectives: The study aim is to introduce a novel preemptively constructed dental root analogue implant (RAI) based on three-dimensional (3D) root surface models obtained from a cone beam computed tomography (CBCT) scan, computer aided designing and computer aided manufacturing technology.

Materials & Methods: One partially edentulous mandibular human cadaver was scanned with the Accuitomo 170 CBCT system. The scan volumes and datasets were used to create 3D surface models of the tooth. A 3D surface mesh of the tooth was stored as a standard triangulation language (STL) file. A high-end selective laser melting technology was used to fabricate the RAI from the STL file. The RAI was produced in a biocompatible titanium alloy (Ti6Al4V). Optical scanning technology was used to measure the RAI, as well as the natural tooth that was extracted. To validate the accuracy of the CBCT 3D root surface and the manufactured Titanium RAI, both surfaces were superimposed on the optical scan of the tooth, which served as the gold "reference" standard.

Results: The differences between the RAI and the optical scan of the original tooth are most noticeable at the level of the apex and the cementenamel junction areas on the buccal and lingual side (divergence of more than 0.15 mm). Surface area measurements show an overall decrease in surface area of 6.33% for the RAI in comparison with the original tooth and an increase of 0.27% when comparing the 3D surface model with optical scan of the original tooth.

Conclusion: With the use of currently available technology it is very well feasible to preemptively create a custom RAI in titanium. However, clinical evidence evaluating the success of this novel dental implant approach is needed.

The application of digital technology in dentistry is becoming more widespread. There is an increasing shift towards utilizing Computer Aided Designing (CAD)/Computer Aided Manufacturing (CAM) especially in implant dentistry. This technology has rapidly evolved in the past two decades and was initially applied in restorative dentistry (Duret et al. 1988). In implant dentistry, individualized implant abutments and abutment copings as well as other components have been successfully produced using CAD/CAM technology (Priest 2005). Currently, there is a burgeoning interest in applying the principles of digital diagnostics, computerized treatment planning and guided implant surgery together with CAD/CAM technology for the fabrication of implant-supported fixed prosthesis.In addition, Cone Beam Computed Tomography (CBCT) scan technology is combined with CAD/CAM to produce surgical guide templates (Tahmaseb et al. 2009).

One of the new possibilities with these innovative techniques is to produce a customized dental root analogue implant (RAI) as an alternative to the traditional threaded, straight or tapered implant systems intended to replace a missing tooth. This new implant would have similar dimensions to the original root and should be congruent with the root socket. Anticipated benefits include uncomplicated immediate implant placement, decreased number of surgeries and increasing patient comfort. Moreover, mimicking root features might result in higher aesthetic outcome. Few studies describing

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techniques of creating and placing custom, root analogue implants have been noted in the literature (Kohal et al. 1997; Pirker & Kocher 2009). However, a significant shortcoming with previously reported techniques is that the process entails laser scanning or machine copying of an extracted root with placement of the subsequently created RAI at a second surgery.

It would seem more efficient to obtain a root replica prior to tooth extraction thus allowing for immediate implant insertion negating the need for a subsequent surgery. The aim of this study is to introduce a new method of creating single rooted titanium RAI by combining CBCT 3D data acquisition with CAD/CAM technology.

Materials and methods

Sample preparation and radiographic scan

One partially edentulous human mandibular cadaver not identified by age, gender or ethnic group was obtained from the functional anatomy department. The cadaver was sectioned at the mid-ramus level and fixed in formalin and stored. A declaration was obtained from the functional anatomy department to use this human remains material for research purposes. The lateral lower incisor was selected for this experiment. The tooth was sound with no amalgam fillings or external root resorption and showed no peri-apical laesions. The mandible was scanned with the Accuitomo 170 CBCT system (AccuiTomo 170, 90 kVp, 5 mA, 30.8 s, 4 × 4 cm Field of View [FoV]; Morita Inc., Kyoto, Japan). The scan position was with the occlusal plane parallel to the floor following the manufacturer's recommendations. The isotropic voxel size and slice interval were 0.08 mm.

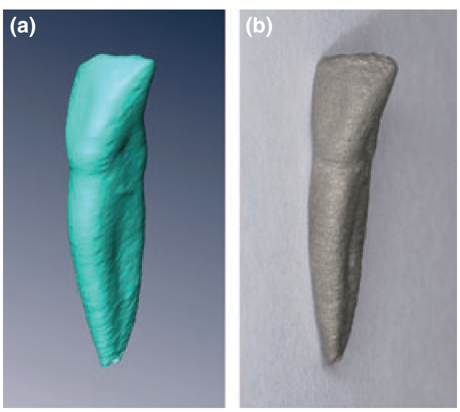

Fig. 1. 3D surface model of the tooth after segmentation (a). CAD/CAM fabricated titanium RAI (b).

Image analysis

The scan volumes were exported in DICOM 3 format and imported into image analysis software Amira (v5.3; VisageImaging, San Diego, CA, USA). The datasets were used to create 3D surface models of the tooth. The exact procedure for segmenting the tooth was the following: A region of interest limited to the tooth and surrounding periodontium was first selected. Subsequently, a threshold value based on the histogram analysis, the local grey level value and image gradient were selected to separate the root and crown from the surrounding bone. The resulting images were processed using interactive processing tools to remove resulting artefacts. A 3D surface mesh of the tooth was then created and stored as a Standard Triangulation Language (STL) file (Fig. 1a).

CAD/CAM process

A high-end Selective Laser Melting (SLM) technology was used to fabricate the RAI from the STL file. This technology is an additive manufacturing technique that is capable of building complex shaped three-dimensional objects by successively depositing and melting of thin metal powder layers. Each individual layer is molten by scanning the successive two-dimensional layers using a focused laser beam. The RAI was produced (Fig. 1b) in a biocompatible titanium alloy (Ti6Al4V) on a proprietary technology SLM machine by LayerWise (LayerWise NV, DentWise Division, Leuven, Belgium).

Optical scanning

Optical scanning technology was used to measure the RAI, as well as the natural tooth that was extracted. The optical system (Atos II SO; GOM GmbH, Braunchschweig, Germany) uses a fringe projection system in combination with two high-resolution optical cameras to detect the deflection patterns of the projected fringes on the surfaces to be measured. By utilizing a small measurement volume, a high measurement accuracy and resolution were obtained (typical measurement accuracy of 10 microns is achieved in X, Y and Z direction).

Matching procedure

To validate the accuracy of the CBCT 3D root surface and the manufactured Titanium RAI, both surfaces were superimposed on the optical scan of the tooth, which served as the gold "reference" standard. The iterative closest point (ICP) registration algorithm was employed to provide maximum alignment. This algorithm brings the two roots to be matched in alignment through minimizing the distance between the two surfaces by calibrating six-degree (three rotation and three translation) transformation parameters (Zhang 1994). The aligned surfaces were compared to each other to establish the difference among the surfaces. The comparison metric was root mean square difference, which calibrates the mean distance between the two surfaces at anatomically corresponding locations. In addition, maximum deviation between two surfaces (Hausdorff distance) and the volume was also calculated in to provide the maximum deviation among the surfaces.

Results

The differences between the RAI and the optical scan of the original tooth are most noticeable at the level of the apex and the cement-enamel junction (CEJ) areas on the buccal and lingual side (Fig. 2). Towards the apical foramen the divergence of the RAI becomes >−0.15 mm (pointed by the blue arrow's in Fig. 2). The RAI has a greater surface in apical area compared with the original root. The buccal and lingual areas of the CEJ surface (pointed with red arrows in Fig. 2) of the original tooth are smaller than those in the RAI. Consequently, resulting in a deviation of more than 0.15 mm. Surface area measurements show an overall decrease in surface area of 6.33% for the RAI in comparison with the original tooth and an increase of 0.27% when comparing the 3D surface model with optical scan of the original tooth (Table 1).

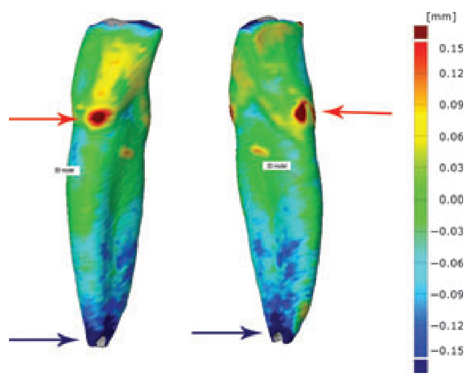

Fig. 2. Superimposed surfaces of the RAI and the optical scan of the original tooth. Measurement in millimetres. Notice: optical scan of the tooth served as the reference surface therefore a positive value is a decrease in surface for the RAI and *vice versa*.

Table 1. **Comparison of volume and surface area change between the optical scan of the original tooth, 3D surface model and fabricated RAI**

	3D surface model vs. Optical scan original tooth	Fabricated RAI vs. Optical scan original tooth	Fabricated RAI vs. 3D surface model
Surface area change (%)	0.27	−6.33	−6.58

Discussion

This experiment was performed as a first step towards preoperatively creating an individual root analogue implant. With the combined use of Cone beam CT 3D data and high-end CAD/CAM technology it was possible to manufacture a RAI with sufficient precision. The 0.27% surface increase of the 3D surface model compared to the original tooth is in concurrence with earlier findings (Al-Rawi et al. 2010). In this particular study by Al-Rawi et al. the accuracy of 3D surface reconstruction of teeth crowns from CBCT scans was reported to be larger than the anatomic truth. During the SLM process of fabricating the RAI a certain amount of smoothing and noise reduction occurs, possibly resulting in a decrease in surface area by 6.33%.

Towards the more apical regions of the root the divergence gradually increases up to more than −0.15 mm (Fig. 2), which indicates data loss. This deviation increase might be explained by the fact that bone mass increases in apical direction. Consequently, making a reliable distinction between apex and bone, difficult during the segmentation process. A particular finding is the disparity in the CEJ-area of more than 0.15 mm (Fig. 2). One plausible explanation is the damage caused from removal of the tooth by forceps. Resulting in "indentation like" anomalies. Furthermore, CBCT device settings including kVp, mA, scan FOV and voxel size influence the accuracy of the image and the 3D model reconstruction (Hassan et al. 2010).

In this experiment the feasibility of creating a RAI was assessed without attempts to perform any changes on the root surface. However, for functional use of an implant both abutment design and osseointegration are two key factors to a clinically successful treatment. To obtain successful osseointegration primary stability following implant placement is crucial (Koh et al. 2010; Grandi et al. 2011). The currently created RAI will not have sufficient primary stability after placement due to lack of macro retention. Adding macro retention, micro retention (acid etching) and/or combining these with osteoinductive surface modifications (e.g. Bone Morphogenic Proteins) will possibly result in an abridged and more successful osseointegration when compared to non-treated surfaces (Liu et al. 2007).

Creation of a RAI requires a complete 3D surface model of the tooth derived from the CBCT scan. Especially the root area is important to be intact. Commonly teeth which need to be replaced are damaged. Reconstructing a mirrored 3D surface model based on the contra-lateral tooth might provide a solution in cases with severe damage to the original tooth. Even in situations where teeth have been very recently removed creating a mirrored RAI of the contra-lateral might be an option. Nevertheless, differences within teeth and there contra-laterals should be taken into consideration.

New possibilities become available after creating the STL file of the tooth. Through computer 3D designing many alterations can be made to the RAI, adding macro retention fins and preoperatively designing the abutment form. Since the information on abutment design is digital the definitive prosthetic (temporary) crown can be made with CAD/CAM technology. In conclusion, a novel approach to create a custom made RAI using CBCT 3D model and CAD/CAM was proposed. With the use of currently available technology it is very well feasible to preemptively create a custom RAI in titanium with the provisional and definitive prosthetic crown prefabricated. However, clinical evidence evaluating the success of this novel dental implant approach is needed.

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