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ORIGINAL ARTICLE

Comparative Evaluation of Dimension and Surface Detail Accuracy of Models Produced by Three Different Rapid Prototype Techniques

K. Murugesan · Ponsekar Abraham Anandapandian · Sumeet Kumar Sharma · M. Vasantha Kumar

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Abstract Rapid prototyping (RP) is a technology that produces physical models by selectively solidifying ultra violet (UV) sensitive liquid resin using a laser beam. These models can be formed using various techniques. A study was undertaken to compare the dimensional accuracy and surface details of three prototype models with a 3D STL (standard template library) image. In this study the STL file was used to produce three different rapid prototype models namely; model 1—fused deposition model (FDM) using ABS (acrylonitrile butadiene styrene), model 2—Polyjet using a clear resin and model 3—a 3 dimensional printing using a composite material. Measurements were made at various anatomical points. For surface detail reproductions the models were subjected to scanning electron microscopy analysis. The dimensions of the model created by Polyjet were closest to the 3D STL virtual image followed by the 3DP model and FDM. SEM analysis showed uniform smooth surface on Polyjet model with adequate surface details.

K. Murugesan (✉)
1/1, Angadi Street, V P Colony, Ayanavaram, Chennai, Tamil Nadu 600023, India
e-mail: mgsan2k@yahoo.com

K. Murugesan · P. A. Anandapandian · M. Vasantha Kumar
Department of Prosthodontics, SRM Dental College, Ramapuram, Chennai, India

S. K. Sharma
Department of Prosthodontics, GITAM Dental College, Vizag, Andhra Pradesh, India

Keywords Rapid prototyping · Fused deposition modeling · Three dimensional printing · Polyjet resin · Standard template library

Introduction

Successful implant therapy requires systematic and meticulous planning with sound clinical judgement to determine the ultimate prognosis. Hitherto three dimensional (3D) reconstructed images derived from computed tomography (CT) were the best option available for evaluation and treatment of surgical procedures in implant dentistry. The major drawback of this modality is that the reconstructed image could not be analysed comprehensively in various planes and sections as it only represents as a picture on the screen [1].

Rapid prototyping (RP) is a relatively new technology that produces physical models by selectively solidifying UV sensitive liquid medium using a laser beam. RP technology in implant prosthodontics provides information about the size, direction and location of implants and anatomical limitations such as the path of the mandibular canals, the distance of maxillary sinus etc.

The basic principle of this technology is building up a 3D structure based on captured CT scan digital data. Several RP technologies exist such as stereolithography, fused deposition modeling (FDM), subtractive milling, and 3D printing. They adhere to the basic principle but the difference is mainly the material and the method used to produce them.

This study was under taken to evaluate the dimensional accuracy and surface reproducibility in biomedical prototype models produced by FDM, 3D printing, Polyjet resin model in comparison with 3D Standard Template Library (STL) model which was used for the fabrication of the prototype models.

Materials and Methods

The aim of the study was to evaluate the dimensional accuracy of the prototype models and their surface anatomic details using SEM (scanning electron microscope).

Creation of 3D Image

Cross sectional CT images were obtained from the mandible. The CT data acquisition was performed using a Somatom plus 4 (Siemens, Erlangen, Germany) with a 0.6 mm section thickness in spiral mode and a 512 × 512 matrix. The gantry tilt was zero degrees and the scanning was carried out with a tube current of 200 mA at 120 kvp. The resultant 2D image data was stored in DICOM (digital imaging and communications in medicine) format. The transformation from the slice image to STL format was carried out using Materialize software (Fig. 1).

Creation of RP Models

Model 1

Fused deposition modeling (FDM) consists of a movable head which deposits a thread of molten medical grade acrylonitrile butadiene styrene (ABS) material on the substrate. The build material is heated to 0.5°C above its melting point so that it solidifies about 0.1 s after extrusion and cold welds to the previous layer (Fig. 2).

Model 2

The Polyjet system builds models by addition of photopolymer resin layers. A CAD-3D STL file is virtually sectioned in 16-mm thick layers using the system software. A print head, composed of hundreds of micro jetting heads, injects a 20-mm thick layer of resin on the build tray only in the areas that correspond to the cross-sectional profile previously prepared, and leave the rest of the area free of resin. Simultaneously, the resin is cured with UV light, and each layer is adjusted to 16 mm by a roller that is moved

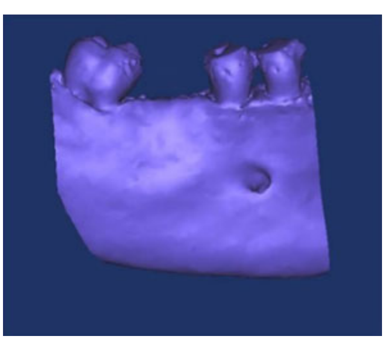

Fig. 1 STL format image generated from the CT scan analysis

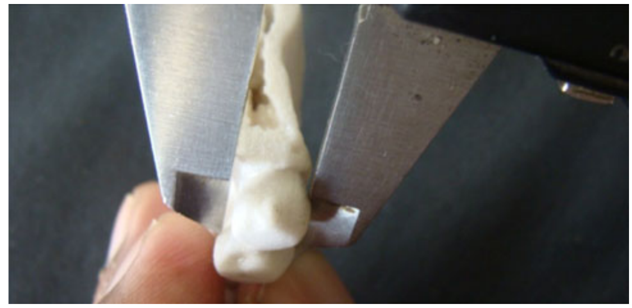

Fig. 2 Bucco lingual measurement on Model 1

Fig. 3 Vertical height measurement on Model 2

across the build tray immediately after deposition. The repeated addition and solidification of resin layers produces a solid three-dimensional model in acrylic (Fig. 3).

Model 3

The 3DP technique consists of printer with a reservoir for ceramic or polymeric powder, a build tray that moves down, a roller to distribute and evenly spread the layer of powder and a print head that distributes a binding material [2]. This technology has a dimensional resolution of about 0.17 mm (Fig. 4).

Evaluation of Dimensional Accuracy

Measurements were made at various anatomical points and tabulated:

M1. Bucco-lingual Measurements of the Crown

The bucco lingual measurements of the crown were measured between the crest of curvature on the buccal surface and crest of curvature on the lingual surface.

M2. Mesio-distal Measurements of the Crown

The mesio-distal measurements of the crown were measured both at the cervical and coronal portion of the tooth. At the cervical portion the readings were recorded at the junction of crown and root on mesial surface and junction

Fig. 4 Edentulous space measurement on Model 3

of crown and root on distal surface. At the coronal portion the readings were recorded at the highest contour of the tooth.

M3. Edentulous Space Measurement

The width of the edentulous span was measured at the cervical constriction and between the marginal ridges in the coronal portion of the mesial and distal abutments.

M4. Vertical height Measurement of the Model

The vertical height of the models were measured from the cervical portion of the tooth to the inferior margin of the model and from the marginal ridge of the tooth to the inferior margin of the model as well.

M5. Bucco-lingual Measurement of the Model

The bucco-lingual measurement of the model was measured at three regions namely at 10 mm from the cervical portion of the tooth in buccal, lingual aspect respectively and at the cervix of the teeth.

The measurements were made using digital electronic callipers. These measurements were recorded for each tooth on all the three specimens. All the measurements were recorded twice by two examiners.

Surface Anatomic Details

All the models were sectioned at middle third in the molar region using a manual frit saw. The specimens were coated with an ultra thin coating of gold, deposited on the samples by low vacuum sputter coating to make them electrically conductive (Fig. 5). All samples were mounted rigidly on a specimen holder called specimen stub. Once the coating was completed all the specimens were visualised in an scanning electron microscope. The objects were magnified at 27×, 15 kv and 500 μ.

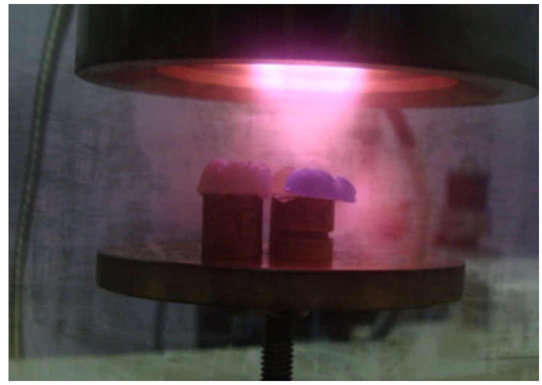

Fig. 5 Gold coating being sprayed onto the models

Statistical analyses were conducted using descriptive statistics (mean and standard deviation) and mean values were compared between two study groups using Mann–Whitney U test. In the present study, $P < 0.05$ was considered as the level of significance.

Results

Dimensional Accuracy

For each linear measurement, dimensional error was calculated as the absolute difference between the values obtained from the models and those from the 3D image Model.

$$\text{Mean absolute difference} = \text{prototype model value - STL Model value}$$

$$\text{Mean relative difference} = \frac{\text{prototype model value} - \text{STL Model value} \times 100}{\text{STL Model value}}$$

All measurements were recorded twice by two observers and results were used for the subsequent comparison of mean values.

Results showed that the dimensions of the Polyjet model (dimensional error of 0.133%) and of the control STL file (criterion standard) were the closest, followed by those obtained for the 3DP models and FDM models (1.67 and 1.73%, respectively).

Surface Details

SEM analysis of model 1 showed a very faint demarcation among the cusps. Developmental grooves were not prominently seen. The surface was uniformly smooth with thick ridges across (Fig. 6).

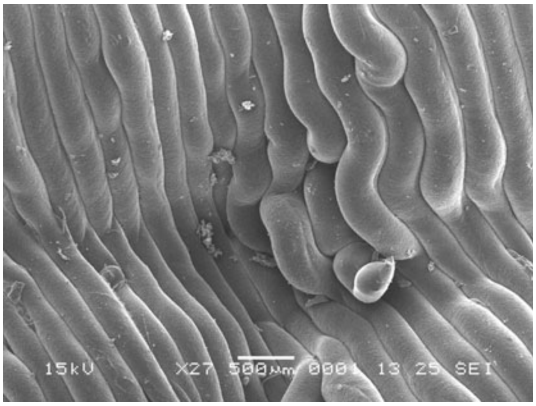

Fig. 6 SEM analysis of Model 1

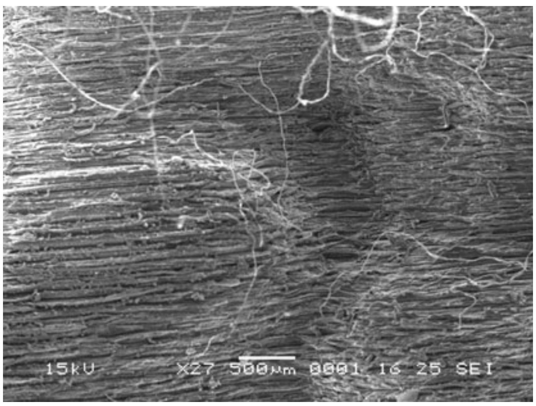

Fig. 7 SEM analysis of Model 2

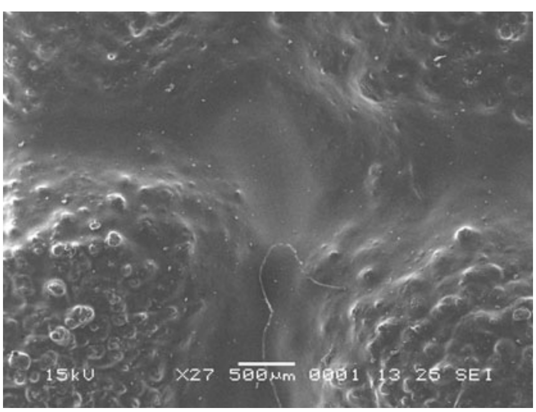

Fig. 8 SEM analysis of Model 3

SEM analysis of model 2 showed clear demarcation among the cusps and developmental grooves. The surface of the model was smooth with fibers running across the surface of the model (Fig. 7).

SEM analysis of model 3 showed clear demarcation among the cusps, but developmental grooves were not well demarcated. The surface of the model showed irregular and rough surfaces (Fig. 8).

Discussion

The advantage of Rapid prototyping is that it produces a surface finish that is comparable to that of numerical control milling [3]. The disadvantages are that the material is expensive, bad odor, toxic and must be shielded from light to avoid premature polymerization [4].

Prototype models are becoming important tools for diagnosis and surgical planning. Although virtual 3D-imaging does provide clear information, there persists certain discrepancy between visualization of the model on screen and manipulation of the 'real' anatomic structures at surgery. Errors may be found at any of the several stages of the RP process, regardless of the technique used. However, dimensional changes should not affect the quality of the final model and its clinical application.

Studies have reported on CT image dimensional errors ranging from 0.9 to 2.16%. The fact is highlighted by a simple observation of the standard deviations resulting from the means of the two observers for each measurement in the present study.

In this study the 3D printing model generated a dimensional error. In this system the infiltration of cyanoacrylate may have contributed to superficial enlargement.

SEM analysis showed uniform smooth surface on Polyjet model with adequate surface details. This can be attributed to jet of water which is used to remove supporting structures and hence provide smooth surface [5].

The surface of the model 3 showed irregular surfaces which can be due to variation in particle size of binder and powder. 3D printing model surface was uniformly irregular and can be contributed for the reason that the binder and the composite material are of different particle size and irregularities were not removed.

Conclusion

From this study rapid prototype models created by Polyjet was dimensionally similar to the virtual 3D STL image, this is followed by the 3DP model and FDM, respectively. Further the Polyjet model showed adequate details with uniformly smooth surface.

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