Evaluation of a complete denture trial method applying rapid prototyping

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A new trial method for complete dentures using rapid prototyping (RP) was compared with the conventional method. Wax dentures were fabricated for 10 edentulous patients. Cone-beam CT was used to scan the wax dentures. Using 3D computer-aided design software, seven 3D denture images with different artificial teeth arrangements were made and seven trial dentures per patient were fabricated accordingly. Two prosthodontists performed a denture try-in for one patient using both conventional and RP methods. The prosthodontists and patients rated satisfaction for both methods using a visual analogue scale. Satisfaction ratings with both conventional and RP methods were compared using the Wilcoxon signed-rank test. Regarding prosthodontist’s ratings, esthetics and stability were rated significantly higher with the conventional method than with the RP method, whereas chair time was rated significantly longer with the RP method than with the conventional method. Although further improvements are needed, the trial method applying RP seems promising.

Keywords: Complete denture, CAD/CAM, Rapid prototyping, Evaluation, Trial

INTRODUCTION

In dentistry, computer-aided design (CAD)/computer-aided manufacturing (CAM) technologies have been applied in the field of prosthodontics since the 1980s. More specifically, the application of CAD/CAM technologies to restorative dentistry and fixed prosthodontics has increased considerably in recent years. Computer-aided technologies allow more precise and systematic modeling, and could therefore reduce the burdensome steps of both chair-side and laboratory work, saving vital time. Rapid prototyping (RP) is a CAD/CAM technology that was originally developed to fabricate prototypes for industrial purposes. This method automatically constructs physical models from computerized three-dimensional (3D) data. RP has recently seen successful application in various medical fields, such as in the fabrication of implant surgical guides, maxillofacial prosthetics and frameworks for removable partial dentures. The manufacturing of complete dentures in the conventional manner was introduced about 70 years ago, and is cumbersome and dependent on proficient skills from dentists and dental technicians. This new technology of RP might therefore also help to reduce the complexity and technical sensitivity of creating complete dentures.

To date, the use of CAD/CAM technologies has primarily been focused on fixed prosthodontics. In contrast, few reports have been published on the use of CAD/CAM technologies for denture prosthetics. Maeda et al. were the first to fabricate complete dentures using 3D laser lithography to fabricate plastic shells of the dentition and record base. Kawahata et al. developed a removable-denture duplication procedure using CAD/CAM with a computerized numerical control (CNC) processor and ball-end mills. Sun et al. constructed virtual flasks according to the finished CAD digital models of removable complete dentures and created individual physical flasks using a 3D printer. The artificial teeth were inserted one by one, and the complete denture was finally finished with traditional laboratory procedures such as packing and polishing. They indicated that a 3D printer would be useful for fabricating complete dentures. The arrangement of artificial teeth, flashing and resin packing can thus be improved successfully. Despite these reports, however, applying these methods in a clinical setting has remained difficult.

To further enhance the implementation of CAD/CAM technologies successfully to design complete dentures, a new method has been developed. In this method, the pre-existing dentures that the patient has been using are scanned using cone-beam computed tomography (CBCT) to obtain data of the mucosal surface and jaw relationship records. The pre-existing dentures are modified, if necessary. Data for the denture space are registered and imported to a workstation. Using 3D CAD software, denture shapes are designed. In this step, only the artificial teeth arrangement and polishing surface are designed. The complete denture bodies are then developed by applying a CNC processor. Next, complete dentures are completed by inserting artificial teeth into dimples in the denture bodies. Thus far, however, with the use of this method, performances of a trial insertion, discussing the arrangement of the anterior teeth with the patient and verifying jaw relationship records at the trial insertion appointment are still not feasible.

The trial insertion appointment is an important step in complete denture treatment. This step not only needs the patient to make judgments of esthetics and
pronunciation, but also requires verification of jaw relationship records, including orientation of the occlusal plane, vertical dimension, tongue space, tooth positioning, palatal seal and soft tissue support for proper external form. This should be viewed as a time of approval and acceptance by both the dentist and patient. Finally, any instructions to be provided to the patient must be given. Fabrication of complete dentures without a trial insertion appointment is thus not practical. For this reason, to enable the successful trial insertion appointment with the use of CAD/CAM technologies, the following steps were added to the procedures of fabricating complete dentures. After registration of the denture space, data for trial dentures with different denture shapes are designed using 3D CAD software. Trial dentures are then fabricated by applying RP. With these trial dentures, arrangement of the anterior teeth can be discussed with the patient and jaw relation records verified at the trial insertion appointment.

To date, however, no study has examined try-in of a trial denture using RP. Efficiency of the try-in with a trial denture applying RP thus remains unclear. The purpose of this study was to evaluate a new method of fabricating trial dentures using RP and to compare this approach with the conventional method using wax dentures. The null hypothesis of this study was that no difference exists between the RP method and the conventional method.

MATERIALS AND METHODS

Participants

Ten edentulous patients under maintenance control (mean age, 78.1 years; standard deviation (SD), 5.6 years) and 20 prosthodontists (mean age, 35.2 years; SD, 7.9 years; mean clinical experience, 10.0 years; SD, 7.5 years) were enrolled in this study at the University Hospital of Dentistry at Tokyo Medical and Dental University. Power analysis was performed to estimate the sample size needed to achieve at least 80% power and a significance level of 0.05. Data from a preliminary study were used to estimate the necessary sample size.

Inclusion criteria for patients for this study were edentulous patients who wore complete dentures made in the University Hospital of Dentistry, Tokyo Medical and Dental University. Patients were excluded if they were rated ≤20 points on the Revised Hasegawa Dementia Scale, which is a scale of dementia, or if they had symptoms of severe myopia or daltonism. Patients using complete dentures rated <80 points according to the method of Sato et al. were also excluded. This method is a quantitative assessment of complete denture quality to clarify the degree of contribution of each clinical factor on a scale from 0–100 and is considered to objectively assess complete dentures. No patient was excluded after these preliminary examinations. Inclusion criteria for prosthodontists for this study were dentists who had been working at the University Hospital of Dentistry at Tokyo Medical and Dental University for more than 4 years.

All research protocols were approved by the ethics review board at Tokyo Medical Dental University, Faculty of Dentistry (No. 372). No conflicts of interest were present in this study.

Fabrication of the trial denture

Figure 1 provides a simplified flow chart for this study. For each patient, maxillary and mandibular duplicate dentures were made using an auto-polymerizing resin (Fit Resin, Shofu, Kyoto, Japan) at the first appointment. These dentures were based on dentures that had been made properly by experienced prosthodontists in the Prosthodontic Department of the University Hospital of Dentistry at Tokyo Medical and Dental University. The shape of duplicate dentures and jaw relation records were modified using a self-cured acrylic resin (Unifast III, GC Corporation, Tokyo, Japan), if necessary. Duplicate dentures were used to take impressions and jaw relation records with a silicone impression material (Exadenture, GC Corporation, Tokyo, Japan) and a vinyl polysiloxane impression material (Correct Plus Bite Superfast, Jeneric/Pentron, Wallingford, CT, USA). The final impressions were taken without border molding. The final casts were made and mounted to the articulator. Wax dentures were then made according to the conventional method. Figure 2 shows a wax denture. A CBCT (Finecube, Yoshida Dental Manufacturing, Tokyo, Japan) scanned the wax dentures. CT images were reconstructed and transferred into 3D...
images using a Digital Imaging and Communication in Medicine (DICOM) Viewer (OsiriX, The OsiriX Foundation, Geneva, Switzerland). These 3D images were imported into a workstation as standard triangulated language (STL) files. Using 3D CAD software (CATIA V5R19, Dassault Systemes, Vélizy-Villacoublay, France; and FreeForm, SensAble Technologies, Woburn, MA, USA), the following seven denture 3D images were made: one denture with the same shape as the wax dentures (a); two dentures with changes in the size of the artificial teeth (one size smaller and larger; b and c); two dentures with lip support adjusted by 2 mm (backward and forward; d and e); and two dentures with the position of occlusal plane changed by 2 mm (lower and higher; f and g). Figure 3 shows artificial tooth arrangement after application of 3D CAD software. According to these 3D images, a RP machine (EDEN250, Objet Geometries, Rehovot, Israel) was used to fabricate the seven trial dentures for each patient. Figure 4 shows the RP machine, which was used in this study. This RP machine sprays state-of-the-art photopolymer materials in subsequent ultra-thin layers onto a building tray until the part is completed. Each photopolymer layer is cured by ultraviolet light immediately after it is sprayed, producing completely cured models that do not require any post-curing. The RP machine was used with ultraviolet-cured acrylic-based resin material (FullCure720, Objet Geometries, Rehovot, Israel), which is approved for medical use in terms of cytotoxicity, irritation and sensitization according to the United States Pharmacopeia (USP) Class VI. Trial dentures were painted using prosthetic composite resins (Gradia Gum GUM Opaque, HPO-04 OB3, GC Corporation, Tokyo, Japan) by one of the authors. Figure 5 shows a completed trial denture after application of RP. One experienced prosthodontist took the final impressions and determined jaw relation records, made the wax dentures, operated the 3D CAD software and completed the trial dentures applying RP.

To evaluate the accuracy of the trial denture after application of RP, some of the above-mentioned (a)-shaped RP dentures were scanned using CBCT (Finecube, Yoshida Dental Manufacturing, Tokyo, Japan). Using the DICOM Viewer (OsiriX, The OsiriX Foundation, Geneva, Switzerland), CT images were reconstructed and transferred into a 3D image. These 3D...
images were then imported into a workstation. Deviation analysis between wax dentures and RP dentures was performed using 3D CAD software (CATIA V5R19, Dassault Systemes, Vélizy-Villacoublay, France). This analysis allowed evaluation of deviation between all nodes in both forms of CAD data.

**Evaluation of the trial insertion applying the conventional and RP methods**

Twenty prosthodontists evaluated trial insertions. Each patient was assigned two prosthodontists, creating ten test groups. Two prosthodontists performed a trial insertion for one patient using the conventional method and the RP method. They evaluated esthetics, stability, and occlusion of the trial dentures. Only one of the two prosthodontists performed arrangement of the artificial teeth. The order of the two trial insertion methods was decided using a random number table and the blocked randomization method. With the RP method, the prosthodontists placed a few trial dentures that had been judged suitable in terms of esthetics into the patient’s mouth. In this study, neither patients nor prosthodontists could be blinded to the methods, since the appearance of trial dentures was easily distinguished. The 10 patients as well as the 20 prosthodontists rated satisfaction levels with the two methods on a 100-mm visual analogue scale (VAS). Prosthodontists were blinded to each other’s scores. Items on the patient questionnaire were: esthetics; predictability of final denture shape; stability; comfort of the dentures; and overall satisfaction. Items on the prosthodontist questionnaire were: esthetics; stability; operator friendliness for verifying jaw relation records; chair time; and overall satisfaction.

**Statistical analysis**

Ratings of satisfaction with each conventional and new method were compared using the Wilcoxon signed-rank test. Significance level was set at the level of \( p = 0.05 \).

Data were analyzed using a statistical program (SPSS. Version 16.0 for Windows, SPSS, Chicago, IL, USA).

**RESULTS**

**Deviation analysis**

The results of deviation analysis for wax dentures and trial dentures applying RP were as follows. On the maxillary denture, about 92% deviation ranged from −0.4 mm to 0.4 mm. Mean deviation was −0.0051 mm (SD, 0.19 mm). On the mandibular denture, about 95% deviation ranged from −0.3 mm to 0.3 mm. Mean deviation was −0.023 mm (SD, 0.16 mm). Figure 6 shows the results of deviation analysis for one of the maxillary trial dentures at the occlusal surface. The deviation range was −0.63 mm to 1.04 mm. The histogram and noted percentages show the frequency distribution. The green area represents no deviation, while the red and blue areas represent a positive and negative deviation, respectively.

(b) Results of deviation analysis for one of the maxillary trial dentures at the mucosal surface. The facial surface of denture teeth shows the maximum deviation.
Fig. 7  (a) Results of deviation analysis for one of the mandibular trial dentures at the occlusal surface. The deviation range was −0.53 mm to 0.80 mm. The histogram and noted percentages show the frequency distribution. The green area represents no deviation, while the red and blue areas represent a positive and negative deviation, respectively.

(b) Results of deviation analysis for one of the mandibular trial dentures at the mucosal surface. The facial surface of denture teeth also shows the maximum deviation.

Table 1  Ratings from 100-mm VAS in 10 patients comparing conventional and RP methods

<table>
<thead>
<tr>
<th>Esthetics</th>
<th>Predictability</th>
<th>Comfort</th>
<th>Stability</th>
<th>Overall satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RP</td>
<td>C</td>
<td>RP</td>
<td>C</td>
</tr>
<tr>
<td>Median</td>
<td>87.0</td>
<td>89.5</td>
<td>95.0</td>
<td>96.0</td>
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<tr>
<td>Maximum score</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Minimum score</td>
<td>50.0</td>
<td>40.0</td>
<td>48.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Mean</td>
<td>85.4</td>
<td>81.7</td>
<td>89.9</td>
<td>89.9</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>14.3</td>
<td>20.4</td>
<td>15.2</td>
<td>12.5</td>
</tr>
<tr>
<td>p</td>
<td>0.61</td>
<td>0.93</td>
<td>0.86</td>
<td>0.68</td>
</tr>
</tbody>
</table>

RP, RP method; C, conventional method. p=Wilcoxon signed-rank tests.

Table 2  Ratings from 100-mm VAS in 20 prosthodontists comparing conventional and RP methods

<table>
<thead>
<tr>
<th>Esthetics</th>
<th>Stability</th>
<th>Verifying jaw relation records</th>
<th>Chair time</th>
<th>Overall satisfaction</th>
</tr>
</thead>
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<tr>
<td></td>
<td>RP</td>
<td>C</td>
<td>RP</td>
<td>C</td>
</tr>
<tr>
<td>Median</td>
<td>23</td>
<td>86.5</td>
<td>80.5</td>
<td>82.5</td>
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<tr>
<td>Maximum score</td>
<td>93</td>
<td>100</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Minimum score</td>
<td>0</td>
<td>44</td>
<td>30</td>
<td>41</td>
</tr>
<tr>
<td>Mean</td>
<td>29.2</td>
<td>81.2</td>
<td>73.1</td>
<td>81.9</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>24.4</td>
<td>15.4</td>
<td>18.7</td>
<td>12.7</td>
</tr>
<tr>
<td>p</td>
<td>&gt;0.00*</td>
<td>0.04*</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

RP, RP method; C, conventional method. p=Wilcoxon signed-rank tests. * Significant difference (p<0.05).
trial dentures. Figure 7 shows the results of deviation analysis for one of the mandibular trial dentures.

**Patient ratings**

Table 1 shows the results of the 100-mm VAS for the 10 patients. No significant difference was seen between the two methods in esthetics, predictability of final denture shape, stability, comfort of the dentures or overall satisfaction.

**Prosthodontist ratings**

Table 2 shows the results of the 100-mm VAS for all prosthodontists. Ratings of esthetics and stability were significantly higher with the conventional method than with the RP method (p<0.05). Ratings of chair time were significantly higher with the RP method than with the conventional method (p<0.01). No significant differences between methods were seen for operator friendliness or overall satisfaction (p>0.05).

**DISCUSSION**

In this study, trial dentures were fabricated applying RP. The results of deviation analysis indicate that RP offers high processing accuracy compared to conventional wax dentures. The mucosa has a displaceability of about 0.14–0.34 mm.

Taking the displaceability of the mucosa into consideration, these deviations can be compensated for in the clinical situation. Trial dentures can thus be fabricated by applying RP. With this method using CAD/CAM technologies, the trial insertion appointment can still be included to advance the quality of denture fabrication.

With regard to the sample size, no research has yet been published in the field of CAD/CAM technologies regarding trial insertion with RP. While a sample size of 10 does indeed seem small, it was determined in advance by power analysis using data from a preliminary study. We will be continuing this study to increase the sample size.

According to patient ratings, RP dentures and wax dentures were evaluated equally in terms of esthetics, predictability of final denture shape, stability, comfort of dentures and overall satisfaction. RP is thus quite applicable to clinical use. At the trial insertion appointment, the dentist should offer to send the trial dentures home with the patient, since RP dentures are no longer necessary in the following laboratory work.

The dentist can reflect on the suggestions of other family members concerning final denture appearance. Within the short term, it is also possible to use RP denture. Regarding esthetics, the RP method is able to take the opinions and personal preferences of the patient into consideration. However, this may be difficult to achieve using the conventional method, as the wax dentures are commonly used for further processing of the final dentures.

At the moment, only one RP material is safe to use orally. As a result, RP dentures have always had inferior esthetics compared to conventional wax dentures, resulting in significantly lower scores. Improved teeth and gum-colored RP materials will eventually be developed. If these materials are correctly applied, esthetics will improve greatly.

Ratings of chair time were significantly higher with the RP method than with the conventional method. In the future, the population of elderly edentulous patients will only increase.

For this reason, the short chair time of the RP method is highly advantageous. Chair time with the conventional method was apparently shorter than that with the RP method when the dentist did not rearrange the artificial teeth at the chair-side, but rearrangement is necessary in most cases during this time. On the other hand, a key disadvantage of the RP method is that arrangement of artificial teeth in the RP dentures cannot be altered at the chair-side, since several trial dentures of different tooth arrangements need to be fabricated well in advance. With the conventional method, moving the anterior artificial teeth is easy. However, some time is required to modify the arrangement of artificial teeth. The RP method is thus much more favorable than the conventional method.

Although RP has a high processing accuracy, RP dentures showed inferior stability compared to wax dentures. The cause of this difference has been the scanning process using CBCT. In particular, three factors are regarded as important. First, the partial volume effect can introduce imprecision to the digital image. Second, using the DICOM Viewer, threshold values can often lead to error. Third, imported data in the CAD software can introduce imprecision to the digital image.

Although a 3D laser scanner would be able to solve these problems, such equipment is very expensive. The scanning data could potentially be compensated for before fabrication by adjusting the CAD data using CAD software during data construction.

No significant differences were seen between the two methods in terms of operator friendliness for verifying jaw relation records and overall satisfaction. The null hypothesis of this study was thus partially rejected.

To date, it is still necessary to take impressions, in the same way as it is done with the conventional method. In the future, the impression procedure might be replaced by scanning the patient’s jaw with CBCT or Magnetic Resonance Imaging (MRI). In terms of patient safety, MRI might be better to discard the difficult impression taking.

Further studies should be performed to evaluate the quality of complete dentures by applying CAD/CAM technology, to examine the arrangement of artificial teeth using a virtual articulator, and to develop new denture base materials that can be used with RP. Moreover, studies are presently underway to investigate face-simulation technology. This technology will enable dentists to determine the shape of dentures properly and to reduce the number of trial dentures. To date, fabricating complete dentures with RP is expensive. If face-simulation technology can be applied properly, savings will be achieved in the costs of the dentures. In
addition, with this technology, dentists and patients will be able to discuss the arrangement of artificial teeth. Although further improvements are needed in esthetics and processing of 3D data, the present results demonstrate that trial insertion can be accomplished when the dentures are fabricated by RP.

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