Evaluation of accuracy and position of milled and printed teeth in digital complete dentures

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Abstract

Purpose: To compare the accuracy of milled vs printed complete denture bases and teeth and to assess the position of the teeth on the corresponding denture bases. Materials and Methods: Two different manufacturing techniques were used in this study. In group A, 10 complete dentures were digitally designed and fabricated by milling prepolymerized blocks of polymethyl
methacrylate. In group B, 10 complete dentures were digitally designed and fabricated using the 3D printing technique. The accuracy of the maxillary and mandibular denture bases and teeth and the position of the teeth on the corresponding denture bases were evaluated using Geomagic Control X software. Data were presented as mean and SD values. Statistical analysis of the resultant data was performed using Student t test. The significance level was set at $P \leq .05$.

**Results:** The results revealed lower surface deviations of the maxillary and mandibular milled denture bases (group A) with values of $0.158 \pm 0.024$ and $0.117 \pm 0.022$, respectively. Lower surface deviations of the printed teeth (group B) were found with values of $0.18 \pm 0.016$ for the maxillary teeth and $0.153 \pm 0.02$ for the mandibular teeth, and for position of teeth on the corresponding denture bases, the values were $0.4 \pm 0.08$ for the maxillary teeth and $1.003 \pm 0.027$ for the position of the mandibular teeth. **Conclusion:** The milling technique yields complete denture bases with superior accuracy, while printing technology provides denture teeth with better accuracy and positioning on the corresponding denture bases. *Int J Prosthodont 2022.* doi: 10.11607/ijp.7984

**Introduction:**

The studies on digital complete dentures (CDs) are evolving. Some studies compared between digital and conventional complete dentures.\(^{1,2}\) However, none of the previous studies evaluated the accuracy and the position of the denture teeth on the denture bases fabricated by CADCAM milling and 3D printing (rapid prototyping).

Fabrication of digital CDs involves scanning of the final impressions or casts as well as maxillomandibular records. Then the denture bases are designed, and the teeth auto populate in a
pre-set position in accordance to the anatomical landmarks and are then arranged to suit the patients' specifications. Finally, the denture is manufactured by an additive or a subtractive technique.\(^{(3-6)}\)

Digital complete dentures could be either milled as one unit (monolithic denture) or as a denture base upon which denture teeth are bonded (split denture). Monolithic denture fabrication may be limited due to the large size of the pucks that cannot be inserted into some milling machines. Thus, the denture bases and the teeth are milled separately and then bonded together.\(^{(6,7)}\)

Denture bases that are milled from pre-polymerized PMMA have less residual monomer and minimal porosity. This may result in stronger denture bases with smoother surfaces which reduces the harboring of micro-organisms.\(^{(8)}\)

3D printing technology has been widely used in dentistry as it allows the fabrication of objects with unlimited geometries and finer details. Moreover, it is fast, and has minimal material waste. The intensity and the direction of light as well as the angle of printing affect the accuracy of the process. The number of the printed layers and the supporting structures as well as the post-curing process also influence the accuracy of 3D printing.\(^{(9,10)}\)

Up to date, no clear conclusions were made concerning the superiority of CAD-CAM milling or 3D printing regarding complete denture accuracy.\(^{(11)}\) Thus, this study was conducted to compare between the accuracy of milled and printed complete dentures and to evaluate the position of the denture teeth on the corresponding denture bases which were separately manufactured. The first null hypothesis was that there was no statistical difference between the two techniques regarding the accuracy of the denture bases. The second null hypothesis was that there was no
statistical difference between the two techniques in the accuracy of the denture teeth and their position on the denture bases.

**Materials and methods:**

The maxillary and mandibular master casts as well as the jaw relation record of a completely edentulous patient were scanned using the 3Shape D850 desktop scanner (D850, 3Shape, Copenhagen, Denmark). The dicom (DCM) files were imported to the 3Shape dental system software (3shape dental designer, 3Shape A/S, Copenhagen, Denmark) to design a complete denture following the software protocol.

The STL file of the design was used to fabricate twenty identical complete dentures using two different manufacturing techniques. Thus, two groups were defined: Group A: The denture bases and the teeth were milled separately. Group B: The denture bases and the teeth were 3D printed.

In group A, pink pre-polymerized polymethyl methacrylate blocks (Pink PMMA blocks, Glorious dental materials, Shandong, China) of 98 mm diameter and 25 mm height were used to fabricate the milled denture bases while white Polymethyl methacrylate blocks (white PMMA blocks, Glorious dental materials, Shandong, China) of 98 mm diameter and 15 mm height were used to fabricate the teeth using a 5-axis milling machine (Roland DWX-51D, Roland DG Corporation, Japan) (Fig.1,2). The denture bases and the teeth were retrieved from the blocks.

In group B, the STL files of the denture bases and the teeth were imported separately to the Netfab software (Netfab software, Autodesk Media and Entertainment, USA) to create the supporting arms. The supporting arms were placed at the polished surface avoiding the fitting surface and the recesses of the teeth.
New STL files of the denture bases and the teeth with their supporting arms were generated (Fig. 3). The 3d printing machine (Phrozen printer, Phrozen Tech Co. Ltd, Taiwan) was loaded with pink denture base printing resin (NextDent Base, NextDent, Soesterberg, Netherlands) to fabricate the printed denture bases. One upper and one lower denture bases were printed per cycle. The bases were printed at a 45°. The same was applied for the denture teeth using white teeth printing resin (NextDent C&B MFH, NextDent, Soesterberg, Netherlands).

After the printing process was completed, the denture bases and the teeth were rinsed twice in a 96% ethanol solution in an ultrasonic bath for 3 minutes followed by a second rinse in a clean solution for approximately 2 minutes. Then the denture bases and the teeth were placed in a post curing light box (Phrozen Cure Luna, Phrozen Tech Co. Ltd, Taiwan) for 30 minutes for further polymerization.

**Evaluation of the accuracy of the denture bases and the teeth:**

The denture bases and the sets of the teeth were lightly coated with antiglare spray (Shera scan spray, SHERA Werkstoff-Technologie, Germany) before they were scanned separately using the 3shape desktop scanner, outputting DCM files that were exported as STL files. The STL files were imported to the matching software (Geomagic Control X 64 software) to evaluate the accuracy of the denture bases. The STL file of each denture base was superimposed with the original STL file of the design using the best fit alignment option. 3D compare was used to evaluate the overall accuracy of the measured data (Fig. 4). These steps were repeated for all the upper and lower denture bases and sets of denture teeth (Fig. 5).

**Evaluation of the position of denture teeth to the denture bases:**
The milled denture teeth were bonded to their corresponding denture bases using a self-curing bond (Ivoclar Bond, Ivoclar Vivodent, Liechtenstein) (Fig.6&7). The printed denture teeth were bonded to their corresponding denture bases using pink denture base printing resin (NextDent Base, NextDent, Soesterberg, Netherlands). Then they were scanned and imported to the matching software (Geomagic Control X 64 software) to evaluate the position of the teeth in their corresponding sockets by comparing the scanned STL files with the original files of the design (Fig. 8).

The accuracy was presented in the form of a color scale where yellow to red colors indicated impingement of the scanned STL on the original design and blue color indicated space between them. The green color reported the best match between scanned STL on the original design. The root mean square (RMS) values of the accuracy of the upper denture bases, lower denture bases, upper denture teeth and lower denture teeth were tabulated and statistically analyzed using students t test.

The data were all collected and statistical analysis was performed with IBMSPSS (IBM Corporation, NY, USA) (SPSS, Inc., an IBM company) statistics version 20 for windows. Data were presented as mean and standard deviation values. Statistical analysis of the resultant data was performed by using student’s t-test. The significance level was set at P ≤ 0.05.

**Results:**

The mean and SD as well as the p values regarding the accuracy of the upper and lower denture bases, upper and lower sets of teeth and the position of the teeth to their corresponding denture bases were presented in tables (I-III).
The results revealed higher surface deviations (lower accuracy) of the upper denture bases in group B (printed) than group A (milled) with values 0.215 ± 0.014 mm and 0.158 ± 0.024 mm respectively. These differences were statistically significant (p < 0.0001). The same results were found regarding the accuracy of the lower denture bases with values 0.18 ± 0.016 mm and 0.117 ± 0.022 mm respectively (p < 0.0001). (Table I)

Regarding the accuracy of the upper teeth, group A (milled) showed higher statistically significant surface deviations (less accuracy) 0.28 ± 0.02 mm than group B (printed) 0.18 ± 0.016 mm. (p < 0.0001). The same was found in the accuracy of the lower teeth with values 0.187 ± 0.016 and 0.153 ± 0.02 mm (p = 0.0007). (Table II)

Evaluation of the position of the upper denture teeth to the corresponding denture bases showed less deviations (better position) for group B (printed) than group A (milled). The difference was statistically significant. The values of deviations were 0.4 ± 0.08 mm and 1.003 ± 0.027 mm respectively (p < 0.0001). The same was found in the position of the lower teeth to the denture bases with values 0.84 ± 0.09 mm and 1.016 ± 0.058 mm (p < 0.0001). (Table III)

**Discussion:**

The main objective of an efficient complete denture is the restoration of mastication. The retention and stability of the prosthesis will depend on the accuracy of the construction technique. An inaccurate prosthesis will also have a detrimental effect on the occlusion, which may require massive modifications of the occlusal surface that destroys the anatomy of the artificial teeth. Thus, the accuracy of both the denture bases and the teeth should be considered during the evaluation of the accuracy of digital complete dentures.
The 3Shape D850 scanner utilized in this study has accuracy within 7-8μm. The amount of the deviation reported in the previous studies was higher than the threshold of the scanner, hence the measurement technique in the study appeared to be suitable for assessing the variances.\textsuperscript{(12,13)}

The Geomagic control X software was used to assess the accuracy of the complete dentures. Surface matching and best-fit algorithms were used to superimpose the denture bases and the denture teeth separately with the initial designs allowing digital measurements to be recorded, which are more accurate than the traditional physical measurements.\textsuperscript{(13,14)}

After the initial measurements were made, the teeth were bonded to their corresponding denture bases then rescanned as one unit to be compared with their initial designs to assess the deviation of the teeth from their sockets in the denture bases.\textsuperscript{(13,15)}

In some studies, 3D analysis was performed by superimposing the scan data of the fitting surface of the denture with the corresponding cast by three point match or best-fit alignment methods. However, the difference in digital processing has a possible misfit that generates positive and negative values; hence the overall mean value may be almost zero. Therefore, to remove the impact of the positive and negative signs, the square root of the arithmetic mean of the squares of the values (RMS) was used by squaring the error which could reduce the experimental result errors.\textsuperscript{(11,12,15-20)}

The outcomes of the evaluation of the accuracy of the denture bases in this study coincide with a previous study that reported that trueness of the fitting surfaces of CAD-CAM milled complete dentures was superior to the 3D printed complete dentures. Thus, the first null hypothesis was rejected.\textsuperscript{(17)}
The improved accuracy of the milled denture bases may be attributed to the use of pre-polymerized PMMA blanks. Prefabricated blanks do not undergo polymerization shrinkage that may cause dimensional deformation of the denture bases. On the other hand, deformation of printed denture bases may result from the incomplete polymerization process before the final post curing procedure. This could explain the reduced accuracy of the denture bases of group B recorded in the study. This finding is similar to results of a previous study (21).

The different parameters of the printing process, the software utilized as well as the need for support arms and post curing may affect the accuracy of the printed objects. Thus all these factors should be considered and controlled to obtain optimum results. (9)

A previous study reported that the color deviation map indicated that superior accuracy was found at the fitting surface of CAD-CAM milled dentures except at the labial slope of the anterior ridge. This was attributed to the presence of a large undercut on the labial slope of the anterior edentulous ridge of the cast which wasn’t accessible to the milling tool. (14)

The results of this study showed that the upper and lower denture teeth in Group B were more accurate than those in group A which indicate least deviations of the form of the teeth. This could be explained by the fact that the intaglio surfaces of the dentures are easier to mill than the tooth surfaces. The reason for this difference is believed to be due to the increased details and complexity involved in milling of the teeth. (22)

Group A (milled) showed higher surface deviations regarding the position of the denture teeth on their bases. Thus, the second null hypothesis was also rejected. These results accord with a previous study which stated that some gaps existed between the milled teeth and their corresponding denture bases. This may be due to the extension of the gingiva onto the cervical
areas of the labial and buccal surfaces of the crowns for better esthetics that created undercut areas which were difficult to be accessed by the milling burs. In addition, the prolonged milling process led to increased heat generation that affected the accuracy of the instruments. (6)

Studies evaluating the different qualities of CADCAM complete dentures are lacking. Further studies are recommended to integrate the benefits of the two techniques of fabrication to obtain optimal results.

**Conclusions:**

- The milling technique yields complete denture bases with superior accuracy.
- 3D printing technology provides denture teeth with better accuracy and position on the corresponding denture bases.

**Recommendations:**

Based on the results of this study, we recommend the conduction of another study to evaluate the use of milled denture bases in combination with printed denture teeth.

**References:**


3- Jurado CA, Tsujimoto A, Alhotan A, Villalobos-Tinoco J, Alshabib A. Digitally fabricated


2019 Apr 1;121(4):637-43.


Table (I): Mean, Standard deviation, and P value of student’s t-test for the comparison between the deviation of the denture bases in the two groups.

<table>
<thead>
<tr>
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<th>Mean(mm)</th>
<th>Std. Deviation</th>
<th>P value</th>
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<tr>
<td><strong>Upper denture base</strong></td>
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<tr>
<td>Group A (milling)</td>
<td>0.158110</td>
<td>0.024778</td>
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<td>Group B (printing)</td>
<td>0.215340</td>
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<tr>
<td>Group A (milling)</td>
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<tr>
<td>Group B (printing)</td>
<td>0.188820</td>
<td>0.016303</td>
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**Table (II):** Mean, Standard deviation, and P value of student’s t-test for the comparison between the deviation of the denture teeth in the two groups.

<table>
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<td>Group B (printing)</td>
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<td>Group B (printing)</td>
<td>0.153700</td>
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</table>

**Table (III):** Mean, Standard deviation, and P value of student’s t-test for the comparison between the position of the denture teeth on the denture bases.

<table>
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<td>Group B (printing)</td>
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<td>0.081520</td>
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</table>

<table>
<thead>
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<th>Lower denture</th>
<th>Mean(mm)</th>
<th>Std. Deviation</th>
<th>P value</th>
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<td>Group A (milling)</td>
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<td>Group B (printing)</td>
<td>0.8430</td>
<td>0.0926</td>
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Figure legends:

Figure 1: Milled lower denture base.

Figure 2: Milled upper and lower denture teeth.

Figure 3: STL file of the denture teeth with their supporting arms.

Figure 4: 3D comparison between the scanned lower denture base and the original STL file.

Figure 5: 3D comparison between the scanned upper denture teeth and the original STL file.

Figure 6: Securing the teeth to the denture bases during bonding.

Figure 7: The milled upper denture base and teeth after bonding.

Figure 8: 3D comparison for the position of the upper teeth to the denture base.