Adaptation of Complete Denture Base Fabricated by Conventional, Milling, and 3-D Printing Techniques: An In Vitro Study

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ABSTRACT

Aim: The aim of this study was to compare the adaptation of complete denture base (CDB) manufactured by three different techniques: conventional, milling, and three-dimensional (3-D) printing.

Materials and methods: A master cast was duplicated to create 60 gypsum casts. Twenty casts (n = 20) were attributed to each group. In the computer-aided design and computer-aided manufacturing (CAD/CAM) groups (milling and 3-D printing), the 40 gypsum casts reserved for these two groups were scanned. An STL file was obtained and a master CDB was designed and then fabricated according to each technique. In the conventional group, a polyvinyl siloxane putty mold was obtained from the milled CDB, and this mold was used to fabricate 20 conventional denture bases by compression molding using the silicon–gypsum technique in a bronze flask. The inner surfaces of the obtained 60 CDB were scanned and superimposed over their corresponding master cast. Deviation analyses were calculated using digital subtraction technique. Five functional areas (posterior palatal seal, anterior border seal, crest of the ridge, maxillary tuberosities, and palate) were selected to evaluate the variations in CB adaptation.

Results: Based on the results and color maps of all selected regions, milling technique offers the best adaptation. The crest of ridge in the conventional technique showed the least adaptation and the posterior palatal seal in the 3-D printing technique showed the best adaptation.

Conclusion: Within the limitations of this study, the CAD/CAM fabrication techniques seem to offer better adaptation of CDB compared to the conventional fabrication technique. Milled CDBs presented the most homogeneous distribution of adaptation, yet the 3-D printing process seems a promising technique that needs to be addressed and perfected.

Clinical significance: The CAD/CAM technologies can help overcome many limitations related to conventional impressions and therefore should be well investigated to improve the edentulous patient’s quality of life.

Keywords: 3-D printing, Adaptation, Complete denture base, Conventional, Milling.

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INTRODUCTION

Complete dentures remain the ultimate solution for edentulous patients.¹,² Denture materials and processes have evolved throughout the last 100 years, with a major aim to overcome the lack of accurate fit between the denture bases and underlying tissues.³ Polymethyl methacrylate (PMMA) used in combination with a compression molding technique⁴ led to undesirable shrinkage, which in turn led to the introduction of the pouring technique that presented some drawbacks such as incorporation of air bubbles during processing and poor bonding between denture base and teeth.⁵ This was followed by the injection molding technique,⁶ which was considered an improvement because it reduced the shrinkage significantly.⁷ The dimensional change in the denture during processing is affected by the anatomic contour of residual ridges and the manufacturing technique of the denture base.⁸ This deformation would decrease the adaptation of the denture base.⁹

With advances in digital technologies, the CAD/CAM has emerged as a popular option for the design and fabrication of complete dentures.¹¹,¹² Computer-aided technologies imply either subtractive manufacturing or additive manufacturing. The result of in vitro studies revealed superior mechanical and physical properties, enhanced fit accuracy, less denture tooth movement and increased toughness, and higher flexural strength and elastic modulus of CAD/CAM milled dentures compared to the conventionally manufactured dentures.¹³ Different methods were used to detect the location and the amount of deformation occurring during complete denture processing. Among these,
the digital subtraction technique is considered as a relevant tool to evaluate the dimensional change resulting from denture processing. The surface adaptation of CAD-CAM dentures were investigated, the digital light processing (DLP)-printed denture base has been reported to achieve clinically acceptable accuracy of tissue surface adaptation within 100 μm when compared to the milled denture base. Jin et al. evaluated the effect of build angle on the tissue surface adaptation of DLP-printed complete denture bases (CDBs) and found no statistical difference of the overall tissue surface adaptation among the different groups. However, published studies evaluating the adaptation of 3-D printed, milled, and conventional CDBs are scarce in the literature. Therefore, the aim of this study was to compare the adaptation of CDBs manufactured by three different techniques: conventional pack and press technique, milling, and 3-D printing.

**Materials and Methods**

This *in vitro* study was conducted in the Department of Prosthodontics, Lebanese University, Faculty of Dental Medicine, Beirut, Lebanon.

**Fabrication of the Master Cast**

An edentulous maxillary master cast was obtained by duplicating a typodont ideal maxillary arch (EDE 1002-UL-UP-FEM; Nissin, Japan) following ideal residual ridge morphology classified as type I by the American College of Prosthodontists. The residual ridge had a class I morphology with absence of undercuts. The master cast was duplicated with a polyvinyl siloxane material (Imprint 3, 3M-ESPE; Seefeld, Germany). Sixty stone casts were obtained using a type IV dental stone (SheraPure; SHERA Werkstoff-Technologie, Germany). Twenty casts (*n* = 20) were attributed to each group. In the milling and 3-D printing groups, the stone casts were attributed and scanned after 24 hours using a laboratory scanner (Ceramill Map400, Amann Girrbach, Austria) generating an STL file. A master CDB was designed (Exocad; Amann Girrbach) and fabricated according to each of the two techniques. For the conventional group, the CDB were fabricated directly over the master cast using the pack-and-press technique without the need for any cast scanning.

**Milling Group**

Each specimen was fabricated from the scan file of each of the 20 casts in the group. The CDB was fabricated with a five-axis milling machine (Ceramill Motion2; Amann Girrbach) and PMMA blocks (Vita Vionic Base; Vita Zahnfabrik, Germany). The milled denture bases were ultrasonically cleaned in alcohol for 10 minutes.

**The 3-D Printing Group**

Each specimen was fabricated as in the previous group from the scan file of each of the 20 casts in that group. The same design of the master CDB was used to fabricate 20 specimens using an industrial UV LED light 3D-printer (Micro Plus X; envisionTEC Inc., USA) with its corresponding PMMA material (E-Denture 3D+; EnvisionTEC) following the manufacturer’s instructions. After printing, the denture bases were ultrasonically cleaned in alcohol for 10 minutes.

**Conventional Group**

A polyvinyl siloxane putty mold was obtained from the milled CDB; this mold was used to fabricate 20 conventional denture bases by compression molding using the silicon–gypsum technique in a bronze flask. The wax denture was covered with silicone putty (Platinum95; Zhermack, Badia Polesine, Italy). The overall procedure was similar to that used by Becker et al. The denture bases were polymerized with Vertex RS resin (Palapress vario, Kulzer GmbH) at 74°C for 9 hours in a slow curing cycle. After polymerization, the curing flasks were bench cooled to room temperature, and the denture base samples were retrieved from the working cast. The denture bases were polished with a wet rag wheel and pumice, ultrasonically cleaned in alcohol for 10 minutes, and stored in distilled water at 37°C for 14 days before the measurement.

**Superimposition**

All completed denture bases were hydrated and their inner surface was scanned using dental lab scanner (Ceramill Map400, Amann Girrbach) generating an STL file for each CDB’s intaglio surface. The STL file of each denture base was superimposed over its corresponding cast using surface-matching software (Geomagic Control X; 3D Systems, Canada) and measurements were made at 80 points for each of the denture base using an overlay denture base perforated at 80 points to confirm the disposition of the performed measurements. The adaptation of the CDB with the cast was calculated and analyzed visually with a color surface mapping.

In addition to the overall measurement, CDB adaptation was evaluated in the five functional areas, namely, posterior palatal seal, anterior border seal, crest of the ridge, maxillary tuberosity, and palatal area.

**Statistical Analysis**

The overall and area-related adaptation of CDBs manufactured by three different techniques were compared statistically using two-way analysis of variance (ANOVA) with post hoc test using IBM SPSS statistics, v24.0 (IBM Corp software). *p* < 0.05 was considered to be statistically significant.

**Results**

Descriptive statistics including the average and standard deviations values of adaptation are shown in Tables 1 and 2. The measurements performed and the surface superimposition provided the evidence for overall evaluation of adaptation discrepancies of CDB as well as specifically in the following areas: posterior palatal seal, anterior border seal, crest of the ridge, maxillary tuberosities, and palate. The ANOVA test revealed statistically significant differences in variation among the three processing techniques at each of the five locations.

**Overall Adaptation of CDB**

Color maps of the surface-matching variations among the three techniques and their corresponding cast are shown in Figure 1. Blue zones indicate overcompression of the denture base over the cast. Red to yellow zones indicate a spacing between the denture base and cast. An entirely green map represents the absence of any processing deformation and consequently a perfect adaptation of the denture base to the cast. Of the three techniques evaluated, the milling technique demonstrated the most uniform distribution of

|          | Min.   | Max.   | Avg. | SD    |
|----------|--------|--------|------|-------|
| Conventional | 0.086  | 0.141  | 0.105| 0.019 |
| Milled    | 0.049  | 0.066  | 0.058| 0.005 |
| Printed   | 0.06   | 0.1    | 0.080| 0.0075|
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Table 2: Region-specific mean misfit values, standard deviations, and mean values

| Results by location          | Technique       | Conventional | Milling | 3-D printing |
|-----------------------------|----------------|--------------|---------|--------------|
| Posterior palatal seal      | Mean           | 0.118AB     | 0.030AC | 0.108BC      |
|                             | Standard deviation | 0.0224    | 0.0072 | 0.063        |
| Anterior border seal        | Mean           | 0.127AB     | 0.0419AC | 0.0762BC     |
|                             | Standard deviation | 0.082    | 0.0064 | 0.0107       |
| Crest of the ridge          | Mean           | 0.088a1,c1  | 0.0325a2d1 | 0.0581c2d2  |
|                             | Standard deviation | 0.098    | 0.0025 | 0.0128       |
| Maxillary tuberosities      | Mean           | 0.0109b1,c1 | 0.02b2,C | 0.0218c2,C   |
|                             | Standard deviation | 0.058    | 0.0179 | 0.005        |
| Palate                      | Mean           | 0.0177b1,c1 | 0.0644b2d1 | 0.025c2d2  |
|                             | Standard deviation | 0.0029  | 0.0091 | 0.007        |

- Similar superscripts indicate no statistically significant difference between the compared groups as follow: A, when \( p > 0.05 \) between conventional and milled; B, when \( p > 0.05 \) between conventional and 3-D printed; C, when \( p > 0.05 \) between milled and 3-D printed
- Dissimilar superscripts indicate a statistically significant difference found between the compared groups as follow: \( p < 0.05 \) between conventional (a1) and milled (a2); \( p < 0.001 \) between conventional (b1) and milled (b2); \( p < 0.001 \) between conventional (c1) and 3-D printed (c2); \( p < 0.05 \) between milled (d1) and 3-D printed (d2)

adaptation with the lowest deviation \( [0.058 \text{ mm}, \text{ standard deviation (SD)} = 0.005] \) as shown in the color maps (Fig. 1). The conventional technique exhibited the least uniform distribution of adaptation.

Area-related Adaptation of CDB

When evaluating the area-related distortion of CDBs, it was concluded that all the studied processing techniques showed some degrees of deformations depending on the area evaluated. The region-specific adaptation SDs and average values are listed in Table 2. The greatest extent of misfit was found in the anterior border seal. Milled CDBs showed lower distortions in the anterior border seal area \( (0.0419 \text{ mm}, \text{ SD} = 0.064) \) when compared to the other studied techniques. Conventionally manufactured prostheses showed the highest values of deviation in this region \( (0.127 \text{ mm}, \text{ SD} = 0.082) \).

The comparison of adaptation over preselected regions of interests (Table 2) revealed that the adaptation in the conventional CDB was significantly higher than the milled and printed groups with regard to the palate (\( p < 0.001 \) for both) and the maxillary tuberosities (\( p < 0.001 \) for both) and lower in crest of ridge (\( p < 0.05 \) and \( p < 0.001 \), respectively). No significant differences were observed in the adaptation of other investigated regions of interest for the conventional CDB. Milled CDB demonstrated significantly higher adaptation when compared to the printed group in the crest of ridge (\( p < 0.05 \)) and lower adaptation in the palate (\( p < 0.05 \)). The differences were not significant in the adaptation of milled CDB when compared to the printed group in maxillary tuberosities (\( p > 0.05 \)), posterior palatal seal (\( p > 0.05 \)), and anterior border seal (\( p > 0.05 \)), though the adaptation in the milled CDB was higher in these regions.

Fig. 1: Color map shows the complete denture base adaptation

The comparison of adaptation of CDB manufactured by the three different techniques demonstrated an improved adaptation in the milled technique in the overall denture as well as in the regions of interest. While the conventional technique revealed the highest mean values corresponding to a decreased adaptation and increased misfit when compared to the other techniques.

Discussion

The aim of this in vitro study was to compare the adaptation of CDB manufactured by three different techniques, namely, conventional, milling, and 3-D printing. Based on the results of this study, the null hypothesis that there is no significant difference in the adaptation of the CDBs fabricated with different techniques was rejected. The difference in the adaptation between different test groups may be attributed to the difference in the processing techniques. In conventional fabrication technique, the acrylic resin polymers have been introduced as denture base materials and the majority of denture bases are fabricated using PMMA. These materials have optimal physical properties and excellent esthetics with relatively low toxicity compared to other plastic denture base materials. However, shrinkage and dimensional changes in denture bases during resin polymerization are inevitable and have been well-documented. Such problems increase the gap between the denture base and underlying mucosa, compromising the adaptation of dentures. In this study, the reduced degree of adaptation found in the conventional technique might be due to the polymerization shrinkage. However, it is worth mentioning that the conventionally adopted protocol for complete denture fabrication, which has been
employed for many years, is still widely adopted and reports good patient satisfaction.

Milling and 3-D printing share a common starting point, i.e., the digital designing of the prosthesis by a CAD software, and they completely differ by the fabrication steps. In the subtractive technique, a PMMA block and a computer-controlled five-axis milling machine are used. In the 3-D printing technique, photosensitive liquid resins are being applied over a support structure, layer-by-layer, and processed by a light source until the final denture is obtained. Milling complete dentures from prepolymerized PMMA blocks might exclude porosities and shrinkage created by the polymerization of resin. Therefore, the material properties would be ameliorated and the residual monomer levels would decrease. However, the residual monomer content of the milled complete dentures has been reported to be not markedly reduced when compared with conventional heat-polymerized complete dentures and significantly lower than that of complete dentures manufactured from autopolymerizing resin.

In the 3-D printing technique, complete dentures are manufactured out of unpolymerized resin; and after processing each layer, a final light polymerization step is intended to complete the procedure. The dentures being incompletely polymerized before this last step makes the polymerization shrinkage an eventual phenomenon associated with the 3-D printing manufacturing technique. Deformation might take place while disassembling the partially polymerized prosthesis from the build platform. On the contrary, 3-D printing technology presents some advantages such as less waste of raw materials and low-cost infrastructure.

Establishing an ideal, complete denture retention requires an understanding of the contribution of each anatomical area. Incorporation of these determinants into the prosthesis through adequate design and technique leads to a successful treatment. Maxillary complete dentures are prone to dislodgment due to gravity, mastication, and adhesive forces from food and tissues around the peripheral border of the denture. In order to remain in place, these prostheses must, therefore, exhibit sufficient retention and be appropriately sealed around the borders. The increased adaptation of the CAD-CAM manufacturing techniques when compared to conventional technique in the anterior and posterior palatal seals is in favor of an increased retention of the digitally fabricated denture bases. However, when it comes to the palatal region, the increased adaptation observed in the conventional and the 3-D printed technique is not always considered as a favorable factor. Many reports are available on the effects of palatal covering with a base, including those related to sensory function and swallowing in the oral cavity.

It was shown that hypoesthesia might result from constant pressure exerted by palatal base on the palatal mucosa. Such pressure may also result in the loss and degeneration of Merkel cells, abundant mechanoreceptors in the palatal rugae as well as degeneration of adjoining nerve fibers. Palatal coverage may also reduce masticatory efficiency and disturb sensorimotor function. Therefore, a harmonious adaptation over the anatomical areas determining the supporting tissues of CDB is desired without any tissue impingement over any particular zone. This configuration has been best provided by the subtractive technique.

In the literature, the CAD/CAM techniques have been reported to be clinically predictable and to have a better performance than the conventional techniques. Previous studies comparing the accuracy of CDB adaptation among milling, 3-D printing, and conventional techniques are scarce. The results of the present in vitro study demonstrated that the adaptation of the CAD-CAM milled CDB was statistically better than that of the 3-D printed CDB, followed by that of the conventionally fabricated CDB, both for the overall CDB surface and for preselected regions of interest. This harmonious distribution in the milled CDB seems in accordance with the results of Kalberer et al. who compared the CAD-CAM milled and 3-D printed complete dentures and concluded the superiority of milled dentures in terms of trueness of the intaglio surfaces. Furthermore, Goodacre et al. investigated the accuracy of the fit of milled vs conventional denture bases and reported an improved adaptation of Avadent Digital Dentures when compared to the conventionally processed dentures. Steinmassl et al. confirmed that subtractive technology produces dentures with higher tissue congruence than conventional denture fabrication. Srinivasan et al. on the contrary, reported a higher precision of fit in the conventional prostheses group when compared to the milled group. Our results support those of Goodacre et al. and Steinmassl et al. in the superiority of milled complete dentures performance when compared to the conventional dentures but also to the 3-D printed dentures. However, the clinical relevance of this variation in adaptation is not evident since various studies have mentioned the predictable clinical performance and patient satisfaction related to the two other manufacturing techniques.

On the contrary, many advantages are related to the additive technology over the subtractive one and therefore this technique should be seriously addressed and perfected even though the 3-D printed CDB adaptation was inferior to the milled CDB. The 3-D printers are much less expensive than the milling units and they consume less energy with a reduced loss of raw material.

It is worth to mention that the current study has several limitations. The processing technique associated with the least degree of distortion, thus providing the closest adaptation of the denture base to the cast, was considered as the best technique. However, when applied clinically, the soft tissue resilience and compression would definitely contribute to the prosthetic treatment outcome which could not be simulated and addressed properly in this in vitro protocol. This study was conducted on a cast presenting an ideal clinical situation with a class I residual ridge and absence of undercuts. The incorporation of different anatomical situations such as the presence of alveolar resorption, the presence of undercuts, different palatal forms (high or shallow), and various mucosal surface configurations (granular or smooth) would influence the adaptation of the processed denture bases.

**Conclusion**

Within the limitations of this in vitro study, the following conclusion may be drawn:

- The CAD/CAM fabrication techniques offer better adaptation of CDB compared to the conventional fabrication technique.
- Milled CDBs presented the most homogeneous distribution of adaptation, yet the 3-D printing process seems to offer a promising denture base adaptation.

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