The Trueness of Obturator Prosthesis Base Manufactured by Conventional and 3D Printing Techniques

Running title: Trueness of 3D-Printed Obturator Prosthesis Base

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This is the author's manuscript of the article published in final edited form as:
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Conflict of interest statement: The authors have no conflict of interest to disclose
Accepted date: May 25, 2021

Abstract

Purpose: To compare the intaglio surface trueness of obturator prosthesis bases manufactured by traditional compression molding, injection molding, and 3D printing techniques.

Materials and Methods: A complete edentulous master cast with Aramany Class I maxillary defect was selected for this in vitro study. Four study groups (n=10/group) were included in this study, Group A: Compression Molding, Group B: Injection Molding, and Group C: Cara Print 3D DLP Printer, and Group D: Carbon 3D DLS Printer. All obturator prostheses' intaglio surfaces were scanned with a laboratory scanner (E4; 3Shape Inc, New Providence, NJ) and the dimensional differences between study samples and their corresponding casts were calculated as the root mean square (measured in mm, absolute value) using a surface matching software.
One-way Analysis of variance (ANOVA) and Fisher’s least significant difference (LSD) test were used to compare groups differences in RMS ($\alpha = .05$).

**Results:** There was a significant effect of manufacturing technique on the RMS values for the 4 conditions [$F(3,36)=5.743$, $p=.003$]. Injection Molding (0.070 mm) and Compression Molding groups (0.076 mm) had a lower interquartile range, and the Cara Print 3D-Printer group (0.427 mm) and Carbon 3D-Printer (0.149 mm) groups had a higher interquartile range. The Injection Molding group showed the best and uniform surface matching with the most area in green in the color maps. The Injection Molding group (0.139 ±0.049 mm) had significantly lower RMS than all other groups ($p<.001$ for all comparisons). Compression Molding (0.269 ±0.057 mm), Cara Print 3D-Printer (0.409 ±0.270 mm), and Carbon 3D-Printer (0.291 ±0.082 mm) groups were not significantly different from each other (Compression Molding versus Carbon 3D-Printer, $p=.59$; Compression Molding versus Cara Print 3D-Printer, $p=.25$; Cara Print 3D-Printer versus Carbon 3D-Printer, $p=.40$).

**Conclusion:** Obturator prosthesis bases manufactured with injection molding technique showed better intaglio surface trueness than ones made by the compression molding technique and 3D printers. Although obturator prosthesis bases manufactured from different 3D printers showed similar trueness, a DLP 3D printer produced less consistent outcome than a DLS 3D printer.

**Keywords:** 3D printing; CAD/CAM; digital light processing; digital light synthesis; compression molding; injection molding; fit; tissue adaptation; removable prosthesis
In the past few decades, there have been consistent developments of complete denture processing techniques to resolve the limitations of traditional denture fabrication methods, including compression molding and injection molding techniques. Proper denture processing should generate a prosthesis that shows intricate mucosal adaptation leading to good retention, stability, and reinforcement with minimal fabrication error. To fabricate a maxillofacial prosthesis (obturator prosthesis) to close an intraoral congenital or acquired tissue opening requires even more elevated clinical and laboratory skills.

Compression molding, or the pack-and-press technique, is one of the most common denture processing techniques. The use of polymethylmethacrylate (PMMA) contributes to this technique's pitfalls because the polymerization shrinkage and processing errors can result in poor adaptation between the denture base and the underlying tissues. In addition, the compression molding technique is costly and not suitable in complex dental designs. Injection molding technique was introduced in 1942 and commercialized in 1970. Injection molding improves denture processing accuracy. Complete dentures fabricated with the injection molding technique exhibit better palatal adaptation than those made with the compression molding technique. The injection molding technique also combines the benefits of heat polymerization of the compression molding method, but is less time-consuming.

The developing computer-aided design and computer-aided manufacturing (CAD/CAM) technology could further improve complete denture processing techniques. CAD/CAM complete dentures can improve the accuracy of the intaglio surface of the dentures, thereby improving retention of the dentures and patient satisfaction. The CAD/CAM dentures can be either milled or 3D printed. CAD/CAM milled dentures were introduced as early as 1990, and more recent research shows it displays superior cost-effectiveness, accuracy, dimensional stability, and material properties. 3D printed complete dentures have become increasingly popular with the development of affordable 3D printers. Stereolithography (SLA) and digital light processing (DLP) are commonly

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used 3D printing technologies in dentistry. SLA printer utilizes mirrors referred to as galvanometers, which quickly aim a laser beam across a vat of light-polymerizing resin. The laser beam selectively solidifies different points on a cross-section of the 3D object and builds it up layer by layer. DLP uses a digital light projector to flash an image of a layer across the entire platform and polymerize all points on a cross-section of the 3D object at once.

Milled dentures show comparable tissue adaption to ones fabricated by injection molding technique, and superior trueness of the intaglio surface to the 3D printed dentures. However, the outcome of a milled prosthesis is greatly limited by the complexity of its design. For instance, an obturator prosthesis usually includes an undercut that can't be adequately milled. A large prosthesis may also exceed the available dimensions on a CAD/CAM puck and render the milling impossible. While 3D printed complete dentures may not be as accurate as milled ones, many 3D printers are smaller and more affordable than milling units. 3D printed complete dentures have become a more economical option than the milled dentures. 3D printing also made the manufacturing process of hollow obturator prosthesis significantly easier. It is more time-consuming and technique-sensitive when using the conventional compression molding and milling processes to fabricate a hollow obturator prosthesis. Different portions of prosthesis need to be fabricated separately and joined together subsequently with auto-polymerizing resin. The porosity and polymerization shrinkage may compromise the bond between the two parts.

Based on the International Organization for Standardization 5725-1, the accuracy of a measurement includes trueness and precision. The trueness is defined as the closeness of agreement between the arithmetic mean of measurement results and the true or accepted reference value, and the precision is defined as the closeness of agreement between measurement results. Studies addressing the trueness of 3D printed obturator prosthesis...
bases are lacking. The purpose of this study was to compare the intaglio surface trueness of obturator prosthesis bases fabricated by the traditional compression molding, injection molding, and 3D-printing techniques. The null hypothesis was that the manufacturing techniques would not affect intaglio surface trueness of obturator prosthesis bases.

MATERIAL AND METHODS

A complete edentulous master cast with Aramany Class I maxillary defect was selected for this in vitro study (Fig 1). According to different manufacturing techniques, four study groups (n=10/group) were included in this study, Group A: Compression Molding, Group B: Injection Molding, and Group C: Cara Print 3D Printer, and Group D: Carbon 3D Printer. For Group A and B, a silicone-based impression material (Vivid Image; Pearson Dental, Sylmar, CA) was used to duplicate the master cast, and 20 stone study casts were poured using Type IV scannable dental stone (Silky-Rock; Whipmix Corp, Louisville, KY). All stone study casts and master cast were digitized using a laboratory scanner with a scanning accuracy of 4 μm (E4; 3Shape Inc, New Providence, NJ) and the scanned files were exported in the Standard Tessellation Language (STL) format. A master obturator prosthesis was designed on the digitized master cast in a CAD/CAM software program (Dental System 2020; 3Shape Inc, New Providence, NJ) (Fig 2). The design file of master obturator prosthesis base was exported in the STL file format and printed with a 3D printer (Form 2; Formlabs Inc, Somerville, MA) and light-polymerizing castable resin (Castable Wax Resin; Formlabs Inc).

After removing undercuts at the intaglio surfaces, all 3D printed obturator prosthesis bases were adapted on 20 stone study casts. Denture teeth (SR Vivodent DCL A14 and SR Orthotype DCL N5; Ivoclar Vivadent AG, Amherst, NY) were placed on the occlusal surfaces of 3D printed bases. Molten base plate wax (Shur Wax X-Hard Pink; Kulzer North America, South
Bend, IN) was used to stabilize denture teeth in the 3D printed bases and seal the 3D printed bases onto the stone study casts. Ten obturator prostheses were processed with compression molding technique and heat-polymerizing acrylic resin (Lucitone 199 Denture Base Resin; Dentsply Sirona, York, PA), and 10 were processed with injection molding technique (SR Ivocap Injection System; Ivoclar Vivadent AG).

For Group C and D, the master cast was digitized with a laboratory scanner (E4; 3Shape Inc) to create virtual study casts. All virtual study casts were imported in a CAD/CAM software program (Dental System 2020; 3Shape Inc). Using the aforementioned master obturator prosthesis design as a reference, 20 new digital obturator prostheses were designed on virtual study casts. The master obturator prosthesis design was used to standardize the denture base thickness and tooth position in the new digital obturator prostheses. Ten digital obturator prostheses were exported in the STL file format, and prosthesis bases were 3D printed with a digital light projection (DLP) 3D-printer (Cara print 4.0; Kulzer North America) and light-polymerizing denture base resin (dima Print Denture Base; Kulzer North America). The remaining 10 digital obturator prostheses bases were 3D printed with a digital light synthesis (DLS) 3D-printer (M2 Printer; Carbon Inc, Redwood City, CA) and light-polymerizing denture base resin (Luciton Digital Print; Dentsply Sirona). Certified dental laboratories manufactured all obturator prostheses bases following manufacturers' recommendations.

All obturator prostheses were labeled and allowed to be hydrated for 24 hours (Fig 3). All 40 obturator prostheses' intaglio surfaces were scanned with a laboratory scanner (E4) within 3 days of manufacturing and exported in the STL file format. The scanned obturator prostheses intaglio surfaces were superimposed to the corresponding digitized stone, and virtual study casts in a surface matching software (Geomagic design X; 3D Systems, Rock Hill, SC.) using the best-fit alignment method. The dimensional differences between study
samples and their corresponding casts were defined as obturator prostheses' trueness and calculated as the root mean square (RMS) (measured in mm, absolute value).\textsuperscript{23,27} The color map was used to visualize the areas of deviation between study samples and their corresponding casts. Positive deviation was defined as the yellow to red areas where study samples were larger than their corresponding casts, while negative deviation was defined as blue areas where study samples were smaller.\textsuperscript{23,27}

With a sample size of 10 specimens per group, the study had 80% power to detect an effect size of 1.325 between any two groups, assuming two-sided two-sample \( t \)-tests conducted at a 95% significance level. One-way Analysis of variance (ANOVA) and Fisher's least significant difference (LSD) test were used to compare groups differences in RMS (\( \alpha = .05 \)). Analyses were performed using a statistics software (SAS version 9.3; SAS Institute, Cary, NC).

**Results**

Descriptive statistics, including mean and standard deviation (SD), are shown in Table 1. Boxplots were constructed to show the RMS values for each manufacturing technique in Figure 4. The boxplots showed Injection Molding (0.070 mm) and Compression Molding groups (0.076 mm) had a lower interquartile range, and the Cara Print 3D-Printer group (0.427 mm) and Carbon 3D-Printer (0.149 mm) groups had a higher interquartile range.

Color maps of the surface matching differences for each group are shown in Figure 5. Areas in blue indicate negative discrepancies, and areas in yellow and red indicate positive discrepancies when comparing the obturator prostheses samples with the corresponding study casts. The area in green indicates surface matching within ±0.10 mm. The Compression Molding group showed yellow (positive discrepancies) at the mid-palatal region, maxillary defect, and buccal aspect of the alveolar ridge. It also showed blue (negative discrepancies) at the
peripheral denture base extensions. The Injection Molding group showed the best and uniform surface matching with the most area in green. The Cara Print 3D Printer group showed dimensional differences in most areas. It showed blue (negative discrepancies) at the mid-palatal and distal palatal area, maxillary defect, and buccal aspect of the alveolar ridge. It showed yellow (positive discrepancies) at the buccal aspect of the maxillary defect, and parts of the alveolar ridge. The Carbon 3D Printer group showed the most area in green, however, it showed blue (negative discrepancies) at the posterior half of maxillary defect, mid-palatal area, tuberosity, and distal buccal vestibular extension area. It also showed yellow and red (positive discrepancies) at the anterior half of the maxillary defect.

The RMS data distribution was examined, and a natural logarithm transformation was used to conform the data to normality. The null hypothesis was rejected and there was a significant effect of manufacturing technique on the RMS values for the 4 conditions \[F(3,36)=5.743, p=.003\]. One-way ANOVA and Fisher's LSD test showed that the Injection Molding group (0.139 ±0.049 mm) had significantly lower RMS than all other groups (\(p<.001\) for all comparisons). Compression Molding (0.269 ±0.057 mm), Cara Print 3D-Printer (0.409 ±0.270 mm), and Carbon 3D-Printer (0.291 ±0.082 mm) groups were not significantly different from each other (Compression Molding versus Carbon 3D-Printer, \(p=.59\); Compression Molding versus Cara Print 3D-Printer, \(p=.25\); Cara Print 3D-Printer versus Carbon 3D-Printer, \(p=.40\)).

Discussions

The null hypothesis was rejected, confirming that manufacturing technique affected the intaglio surface trueness of obturator prosthesis bases. The advantages of 3D printed obturator prosthesis include lowered laboratory cost and increased bond strength between the obturator portion and denture base portion with a seamless adhesion.\textsuperscript{14,25} Results from this study showed

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that the Injection Molding group (0.139 ±0.049 mm) had significantly lower RMS than all other
groups, and showed the best intaglio surface trueness of obturator prosthesis bases.
Compression Molding (0.269 ±0.057 mm), Cara Print 3D-Printer (0.409 ±0.270 mm), and
Carbon 3D-Printer (0.291 ±0.082 mm) groups showed similar intaglio surface trueness
outcomes. In addition, the Cara Print 3D-Printer group showed a widest range of interquartile
range, implying it produced the least consistent intaglio surface adaptation.

The studies on the intaglio surface trueness of obturator prosthesis bases are scarce,
and there was more literature related to the complete dentures. The results from this study
agree with Oğuz et al, where they compared the intaglio surface adaptation of complete
dentures fabricated with compression molding, injection molding, 3D printing, and milling
techniques.28 For the maxillary denture, injection molding produced more accurate denture base
adaptation than the 3D-printing technique (The Vida; EnvisionTEC and E-Denture;
EnvisionTEC) did. In addition, the highest volumetric gap between the denture base and cast
was observed in the compression molding and 3D printing groups at the palatal region.28 Color
maps from this present study also showed the Compression Molding group had positive
discrepancies at the mid-palatal and maxillary defect areas. The Cara Print 3D-Printer and
Carbon 3D-Printer groups had negative discrepancies at the palatal area and maxillary defect.
Positive deviations indicated a gap between obturator bases and their corresponding casts,
which could affect clinical stability and retention of the obturator prosthesis. Negative
deviations implied a strong contact between obturator bases and their corresponding casts, and
clinical adjustment might be needed to alleviate excessive tissue compression.29 These results
also indicated that various manufacturing techniques caused different amounts of
polymerization deformation, with the most deviations observed at thickest areas of obturator
prosthesis. Increased gap (Compression Molding group) or strong contact (Cara Print 3D-
Printer and Carbon 3D-Printer groups) between obturator prosthesis at the palate and

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maxillary defect regions may cause poor fitting, loss of retention, patient discomfort, and prosthesis fractures, therefore, clinicians should be aware of clinical limitations caused by compression molding and 3D printing techniques.

The findings from this study were different than some previous studies. In this present study, Compression Molding and 3D-printing (Cara Print 3D-Printer and Carbon 3D-Printer) groups were not significantly different from each other. Masri et al reported that the 3D printed maxillary complete denture base (RMS of 0.080 ±0.008 mm) had better intaglio surface trueness than the one fabricated with compression molding technique (RMS of 0.105 ±0.019).\textsuperscript{10} In this current study, the compression molding and 3D printing techniques produced comparable intaglio trueness in the obturator prostheses, and the reported RMS values were larger than the findings reported by Masri et al.\textsuperscript{10} The differences in the observations may be due to the usage of different 3D-printer and compression molding system between 2 studies. Furthermore, the obturator prostheses required a larger material volume and may increase the polymerization deformation of resulted prostheses.

Hwang et al also presented different findings on the trueness of CAD/CAM maxillary denture bases manufactured using DLP 3D printing technology.\textsuperscript{30} A significantly lower RMS value was found in the DLP 3D-printing group (0.074 ±0.005 mm), than the milling (0.177 ±0.003 mm, P <.001) and compression molding group (0.165 ±0.056, P <.001). The wide interquartile range of RMS value in the compression molding group (0.075 mm) suggested inconsistent 3D surface deviation within the compression-molded denture bases. In contrast, the narrow interquartile range of RMS values in the 3D-printing (0.004 mm) and milling (0.004 mm) groups suggested a uniform 3D surface deviation from 3D printed and milled denture bases.\textsuperscript{30} Based on Hwang et al, the 3D printed maxillary denture base was more accurate and consistent than the compression-molded one. In the current study, the 3D-printing groups had a
much wider interquartile range of RMS (Cara Print 3D-Printer, 0.427 mm; and Carbon 3D-Printer, 0.149 mm) and mean RMS values (Cara Print 3D-Printer, 0.409 ±0.270 mm; Carbon 3D-Printer, 0.291 ±0.082 mm) than the findings reported by Hwang et al. These findings may further suggest the need for future research on how to improve the trueness and precision of 3D printed obturator prosthesis bases.

Although no study is available on the intaglio surface trueness of 3D printed obturator prosthesis, conflicting results were found on the 3D printed complete denture bases. The conflicting results may be due to different sample sizes, 3D printers and resin materials, and measurement methods. While no other studies focused on obturator prostheses, the results from this present study opened up several questions related to how the 3D printing techniques would integrate with maxillofacial clinical practices. Although 3D printing is fast, easy, and cost-effective, the build angle, the thickness of printing layers, and types of 3D printer and resin may affect the accuracy of a 3D printed denture or obturator prosthesis bases. A previous study has shown that for maxillary complete denture bases, the optimal build angle is 135° for a DLP 3D printer. The layer thickness and build angle were set at 100 μm and 90°. The 100 μm layer thickness and build angle of 90° are the printing strategies for complete denture bases often used by previous studies and manufacturers. However, the clinical implications for build angle may be heavily influenced by dental technicians’ and clinicians’ preferences. Although 90° build angle may produce less accurate 3D printed prostheses, it consumes the least amount of resin material because of self-supporting orientation. In addition, more 3D objects can be fitted onto the build plate and simultaneously and manufactured in a single 3D print cycle. The 90° build angle may come at the cost of 3D printed prostheses with lower accuracy.

A limitation of this study was that milling technology was not investigated. Although milled complete denture base has been shown to have superior accuracy when compared to the
traditional compression molding, injection molding, and 3D printing complete denture bases,\textsuperscript{6,14,20,23} the milling technology may not be recommended for the manufacturing of obturator prosthesis base. Heavy undercut and height of prosthesis exceeding the available dimension of acrylic blocks are two main hurdles to mill an obturator prosthesis base. This in vitro study only evaluated the dimensional differences between obturator prosthesis bases and their corresponding study casts, and the intraoral dynamic characteristics of compressed soft tissue during the masticatory function was not studied. In vivo studies can be conducted in the future to investigate the effects of manufacturing techniques on clinical outcomes. Furthermore, different obturator prosthesis designs, 3D printers, resin materials, and printing strategies can be further studied in the future to seek an optimal manufacturing technique for the obturator prostheses.

Conclusions

Obturator prosthesis bases manufactured with injection molding technique showed better intaglio surface trueness than ones fabricated by the compression molding technique and 3D printers. Although obturator prosthesis bases manufactured from different 3D printers showed similar trueness outcome, a DLP 3D printer produced less consistent outcome than a DLS 3D printer did. Color maps of the surface matching showed uniform tissues adaptation with injection molded bases, however, both negative and positive discrepancies were noted from compression molded and 3D printed bases.
References


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time, and material consumption of additively manufactured surgical templates. J Prosthet Dent;
https://doi.org/10.1016/j.prosdent.2020.09.012

Table 1. Mean values ±standard deviations in root mean square (mm).

<table>
<thead>
<tr>
<th>Group</th>
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<td>D</td>
<td>Carbon 3D-Printer</td>
<td>10</td>
<td>0.291b</td>
<td>0.082</td>
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Note: Mean RMS values with same letter not statistically different, p>.05.

Legends to Figures

Figure 1. Occlusal view of master cast.
Figure 2. Intaglio surface of obturator prosthesis.

Figure 3. Representative intaglio surfaces from 4 study groups. A, Compression Molding. B, Injection Molding. C, Cara Print 3D-Printer. D, Carbon 3D-Printer.
Figure 4. Boxplot showing distribution of root mean square measurements (in mm) in each manufacturing technique group.

Figure 5. Representative surface matching color maps from 4 study groups. A, Compression Molding. B, Injection Molding. C, Cara Print 3D-Printer. D, Carbon 3D-Printer.