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ORIGINAL ARTICLE

Comparison of denture base adaptation between additive and conventional fabrication techniques

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Abstract

Purpose: This in vitro study compared the adaptation of denture bases fabricated by injection molding (IM), compression molding (CM), liquid crystal display (LCD), and digital light processing (DLP) techniques.

Material and methods: A definitive maxillary cast was duplicated using a silicone mold to create 40 gypsum casts that were laser scanned before any fabrication procedures were initiated. For the DLP and LCD groups, 20 denture bases (10 in each group) were virtually designed and manufactured referring to the digitalized data. For the CM and IM groups, 20 denture bases (10 in each group) were molded using gypsum models. A total of 40 gypsum models and their corresponding denture bases were scanned. The scanned intaglio surface of each denture base was superimposed on the scanned reference cast to compare the degree of tissue surface adaptation. The three-dimensional surface deviations of the total intaglio surface, denture border apex, palatal vault, and crest of the ridge were evaluated on the basis of the best fit algorithm technique using inspection software. The data were statistically analyzed using one-way ANOVA and Tukey's multiple comparison test ($\alpha = 0.05$).

Results: According to the superimposing results, for the total intaglio surface, the lowest deviation was present on the injection-molded group and the highest deviation occurred on the LCD group. For the palatal vault, the lowest deviation was present on the DLP group and the highest deviation occurred in the compression molded group. For the crest of the ridge, the lowest deviation was present in the injection-molded group and the highest deviation occurred in the LCD group. For the denture border apex, the lowest deviation was present in the DLP group and the highest deviation occurred in the LCD group.

Conclusions: Maxillary denture bases fabricated using DLP and IM techniques showed higher surface adaptation than the bases fabricated using LCD and CM techniques. Among the conventional techniques, higher compatible dentures can be produced with IM; among the additive techniques, higher compatible dentures can be produced with DLP.

KEYWORDS
additive techniques, denture base, digital light processing, liquid crystal display, three-dimensional printing

To obtain adequate retention and stability in complete dentures, good adaptation between the impression surface of the prosthesis and the tissue surface must occur.[1] During the production phase, the shape of the palatal vault and the residual crest of the prosthesis, the thickness of the base, the base material, and the production steps can cause dimensional deformations.[2,3] The least amount of deformation during the production phase ensures a better adaptation of the mucosa to the base.[4]

The compression molding (CM) technique is widely used in the production of complete dentures. In productions, using the CM technique and polymethylmethacrylate (PMMA), approximately 7% volumetric shrinkage and 0.45%–0.9% linear shrinkage occur.[5,6] The dimensional change in the material reduces the adaptation between the tissue surface of the denture base and the mucosa. In the injection molding (IM) technique, which is an alternative to the CM technique, the material shrinkage is continuously compensated; thus, controlled polymerization is achieved.[7]

Today, with the development of computer-aided design and computer-aided manufacturing (CAD–CAM) technology, subtractive and additive methods have been used in the production of complete dentures. In additive methods, complete denture bases are produced with light-sensitive acrylic-based liquid resins. The methods that are most often used are stereolithography (SLA), liquid crystal display (LCD), and digital light processing (DLP). In these systems, after the production is completed in three-dimensional (3D) printers that process with unpolymerized resins, an ultrasonic bath and isopropyl alcohol solution are applied to purify the surface of excess resin. Afterward, the material is polymerized by applying the post-curing process, resulting in its final properties.[1]

In the DLP technique, a projector is used under the liquid resin reservoir as the light source. The advantage of this system is that it produces a patterned laser light, allowing each layer to be polymerized with one attempt. It can also print with higher precision. This advantage makes the construction time-independent of the relevant layer geometry or the number of objects.[8] The difference between LCD and DLP techniques is the imaging system and light intensity.[9] It is known that light intensity is an important factor for photopolymerization, which determines the printing speed and hardening degree of the object to be produced.[8] Moreover, the use of an LCD as a display system in the LCD technique may cause the sensitivity to be lower than it is in the DLP technique.[8]

In most previous studies evaluating denture base adaptation, the intaglio surface of the base and the impression surface of its cast were superimposed using the best fit algorithm technique.[10–15] In this technique, an iterative closest point algorithm is used to align the scans and operator-based decisions or errors are ruled out. The alignment is performed by minimizing the mesh distance error between each corresponding data point. By the very nature of this algorithm, alignment minimizes the mesh distance error and spreads the errors evenly over positive and negative deviations. Therefore, if there is a large deviation between the denture base and the cast model, the algorithm attempts to minimize the absolute distance between these two datasets, regardless of the clinical outcome.[16] The precise digitization of the cast model and denture base is also important for the superimposing process. Most previous studies have used dental laboratory scanners for this process.[17–22] The dental scanner used in the present study has two 5-megapixel cameras and can show high-resolution and high-density scanning performance with red laser light technology. It can also scan with an accuracy of less than 15 μm.[23]

Thus, this in vitro study aimed to compare denture base adaptations fabricated by IM, CM, LCD, and DLP techniques. The first null hypothesis was that no difference would be found in the tissue surface adaptation of a denture base to an edentulous maxillary cast among the two additive techniques. The second null hypothesis was that no difference would be found among the conventional techniques and the additive techniques.

MATERIALS AND METHODS

To create the reference gypsum model, an edentulous maxillary model (B-3NM, Frasaco GmbH, Tettnang, Germany) with a Class I, Type A residual crest, according to the classification made by the American College of Prosthodontists (ACP), was used. The edentulous model was duplicated with mold silicone (Verpol RTV-2710, Verpol Boya, İstanbul, Turkey), and a reference gypsum model was created by pouring scannable type-4 dental plaster (Zhermack Elite Master, Zhermack, Rovigo, Italy). Three 2-mm-diameter metal spheres were placed on the reference gypsum model, one on the midline crest and the others on each tuberosity region (Figure 1). Spheres were used to superimpose the model surface more precisely with the denture base.[4,12]

Ten gypsum models were created for each of the DLP, LCD, CM, and IM groups. As a result of power analysis, 95% confidence interval $(1-\alpha)$, 95% test power $(1-\beta)$, $f = 0.8$ effect size, and the number of samples to be taken in each group to be 32 were determined, with a minimum of eight samples. In our study, a total of 40 samples were used, with 10 samples in each group.

A total of 40 gypsum models were produced from the modified reference gypsum model using silicone-based duplication material and scannable type-4 dental plaster. The gypsum models were scanned with a 3D laser scanner (3Shape D800, 3Shape A/S, Copenhagen, Denmark) and transferred to the stereolithography (STL) format. A 2-mm-thick denture base was designed for each of the 40 digital models (Blender Software v3.0, Amsterdam, the Netherlands) by a dental technician with 20 years of experience. The designed denture bases were exported as an STL file.

The denture bases designed for the LCD group (FreeShape 120, Ackuretta, Taipei, Taiwan) and the DLP group

FIGURE 1 Reference gypsum model

(Runyes Chair-Side 3D Printer, DLP-01, Runyes Medical Instrument Co., Ltd., Ningbo, China) were produced with photopolymerized resin (Optiprint Denture 385-hell rosa, Dentona, Dortmund, Germany), which can be used in both types of printers (Table 1). The light source of the printers was a 405-nm wavelength light-emitting diode, and the printing layer thickness was 100 μm. The support structure was attached to the labial surface of the denture base, with a 90° build angle. After the production process was completed, the supports of the denture bases were separated from the production table. The denture bases were cleaned in an ultrasonic cleaner with isopropyl alcohol for 5 min in accordance with the manufacturer's instructions. The bases were removed from the ultrasonic cleaner and placed in the ultraviolet (UV) polymerization unit (UV Box, Ackuretta, Taipei, Taiwan) in accordance with the manufacturer's instructions and left for 3 min after which the post-polymerization process was completed.

To ensure that all the denture bases in the study were the same thickness, the denture bases produced with 3D printers were used as templates for the CM and IM groups.[4] Melted wax was injected into the denture base cavities in the putty mold, and the thickness of the wax was verified using a score periodontal probe.[24] Ten wax denture bases were fabricated using the IM injection system technique (IvoBase Injector, Ivoclar Vivadent, Schaan, Liechtenstein) with a modified PMMA resin (SR Ivocap High Impact, Ivoclar Vivadent, Schaan, Liechtenstein). For the CM group, 10 wax denture bases were fabricated with heat-polymerized PMMA resin (Paladent 20 Heatcure, Kulzer GmbH, Hanau, Germany) (Table 1).

The intaglio surfaces of the produced acrylic resin bases were digitized with a 3D laser scanner (3 Shape D800, 3Shape A/S, Copenhagen, Denmark). The STL files of the casts and the intaglio surfaces of the acrylic resin bases were transferred into surface matching software (GOM Inspect Software V8, GOM GmbH, Braunschweig, Germany) to superimpose each cast and its corresponding denture base scan. A total of 160 superimposing procedures were performed for the DLP, LCD, CM, and IM groups as the total intaglio surface, denture border apex, palatal vault, and crest of the ridge (Figure 2). The superimposing process was carried out according to the "best fit algorithm" method, and the unnecessary areas in the STL model were deleted to ensure that they did not affect the accuracy of the superimposing process. All deviation patterns were visually displayed with color surface maps.

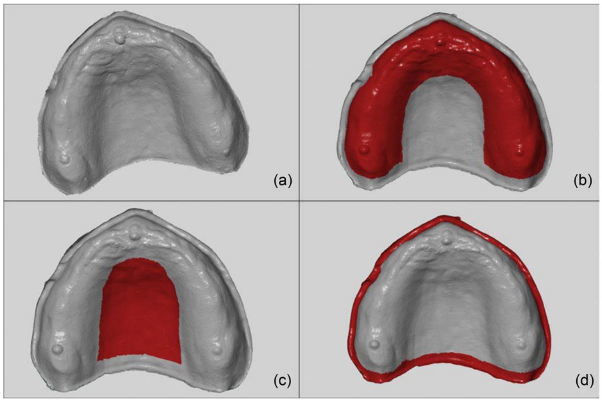

FIGURE 2 Regions where surface adaptation is evaluated: (a) total intaglio surface; (b) crest of the ridge; (c) palatal vault; and (d) denture border apex

Data were analyzed with IBM SPSS V23 software. The conformity to the normal distribution was evaluated using the Shapiro–Wilk test. One-way analysis of variance was used to compare the normally distributed data according to groups, and multiple comparisons were analyzed with Tukey's honestly significant difference test and Tamhane's T2 test. In the analysis results, mean ± standard deviations (SD) are presented as deviation and median (minimum–maximum). The significance level was taken as $p < 0.050$.

RESULTS

Table 2 summarizes the surface adaptation of the denture bases produced with their corresponding gypsum models. Surface adaptation was evaluated for four regions. For the total intaglio surface, the highest deviation value was seen in the LCD group, and the lowest deviation value was seen in the IM group. For the palatal vault, the highest deviation value was seen in the CM group, and the lowest deviation value was seen in the DLP group. For the crest of the ridge, the highest deviation value was seen in the LCD group, and the lowest deviation value was seen in the IM group. For the denture border apex, the highest deviation value was seen in the LCD group, and the lowest deviation value was seen in the DLP group.

According to the results of multiple comparisons, a difference in the total intaglio surface was found between the CM and IM groups ($p < 0.001$). A difference was also found

TABLE 1 Groups and materials

Group	Production technique	Sample size	Device	PMMA
CM	Conventional compression molding technique	10	Standard molding set	Paladent 20 Heat Cure, Kulzer GmbH
IM	Conventional injection molding technique	10	IvoBase Injector, Ivoclar Vivadent	SR Ivocap High Impact, Ivoclar Vivadent
LCD	Liquid crystal display 3D printing technique	10	FreeShape 120, Ackuretta	Optiprint Denture 385-hell rosa
DLP	Digital light processing 3D printing technique	10	Runyes Chair-Side 3D Printer, DLP-01	Optiprint Denture 385-hell rosa

Abbreviation: PMMA, polymethylmethacrylate.

TABLE 2 The deviation between denture bases and their corresponding gypsum models

		Mean ± SD	Median (min–max)	Test statistics	p
Total intaglio surface	CM	0.0851 ± 0.0163[b]	0.0894 (0.0614–0.1110)	$F = 15.860$	<0.001
	IM	0.0579 ± 0.0099[a]	0.0580 (0.0431–0.0713)		
	LCD	0.0948 ± 0.0180[b]	0.0978 (0.0576–0.1162)		
	DLP	0.0643 ± 0.0072[a]	0.0653 (0.0536–0.0747)		
Palatal vault	CM	0.0363 ± 0.0123[a]	0.0344 (0.0210–0.0643)	$F = 5.580$	0.003
	IM	0.0294 ± 0.0103[ab]	0.0285 (0.0158–0.0537)		
	LCD	0.0234 ± 0.0054[b]	0.0228 (0.0147–0.0321)		
	DLP	0.0219 ± 0.0035[b]	0.0206 (0.0186–0.0293)		
Crest of the ridge	CM	0.0608 ± 0.0112[bc]	0.0567 (0.0477–0.0819)	$F = 10.466$	<0.001
	IM	0.0462 ± 0.0066[a]	0.0433 (0.0388–0.0560)		
	LCD	0.0873 ± 0.0243[b]	0.0896 (0.0398–0.1220)		
	DLP	0.0481 ± 0.0096[ac]	0.0448 (0.0372–0.0666)		
Denture border apex	CM	0.0922 ± 0.0247[c]	0.0944 (0.0646–0.1467)	$F = 19.343$	<0.001
	IM	0.0843 ± 0.0463[abc]	0.0596 (0.0406–0.1819)		
	LCD	0.1272 ± 0.0252[b]	0.1309 (0.0684–0.1541)		
	DLP	0.0587 ± 0.0119[a]	0.0538 (0.0435–0.0801)		

Note: Lowercase letters indicate no statistically significant difference between groups with the same letter. *F*: Analysis of variance test statistic.
Abbreviations: CM, compression molding; DLP, digital light processing; IM, injection molding; LCD, liquid crystal display.

between the CM and DLP groups ($p = 0.008$) and between the IM and LCD groups ($p < 0.001$). A difference in the palatal vault region was found between the LCD and DLP groups ($p < 0.001$). A difference was found between the CM and LCD groups ($p = 0.014$). A difference was found between the CM and DLP groups ($p = 0.004$). A difference in the crest of the ridge was found between the CM and IM groups ($p = 0.019$). A difference was found between the IM and LCD groups ($p = 0.005$). A difference was found between the LCD and DLP groups ($p = 0.006$). For the denture border apex, a difference was found between the CM and LCD groups ($p = 0.044$), between the CM and DLP groups ($p = 0.012$), and between the LCD and DLP groups ($p < 0.001$).

The color analysis results and map are shown in Figure 3. The color distribution of the map was carried out automatically by the software according to the positive and negative deviations. The areas from yellow to red indicate the distance of the denture base from the tissue, that is, the gap between the base and the tissue. The blue areas indicate the negative deviation, that is, the pressure on the tissue. The green areas indicate ideal tissue adaptation. For the denture bases produced with the CM technique, the pressure areas on the tissue were observed at the alveolar crest and away from the tissue in the palate vault. In the LCD group, there was a recession from the tissue in the anterior undercut region and the vault of the palate. It was observed that the green color was generally dominant in the IM and DLP groups. In all the production techniques, there was a recession from the tissue at the edge of the denture base.

DISCUSSION

The results of the study show that the surface adaptation of the DLP denture base was significantly better from that of the LCD denture base. Therefore, the first null hypothesis of the study was rejected. Moreover, statistically significant differences were found between the bases produced by conventional and additive techniques in terms of tissue adaptation. Therefore, the second null hypothesis was also rejected.

In conventional production techniques, complex manipulation methods, dimensional changes of wax, plaster, and PMMA material may reduce the adaptation of the denture base.[2,3] The findings of this study showed that the DLP technique, in particular, can be a good alternative to conventional techniques.

The 3D printing technique uses thin layers of photopolymerized resin continuously for more accurate production. Micromirrors and UV light were used to polymerize these layers.[21] Therefore, the system uses unpolymerized resins that will be polymerized with a light source. After production, an additional post-polymerization process is required, so polymerization shrinkage may also occur in these systems.[14] This production method can also be affected by factors, such as light intensity, printing direction, and angle, the number of layers, the software, the shrinkage between layers, the amount of supporting structure, and the post-processing procedures.[10,15,17,22,25] However, this method is preferred for complete dentures due to its unlimited geometry options, more detailed production process, higher speed, the ability

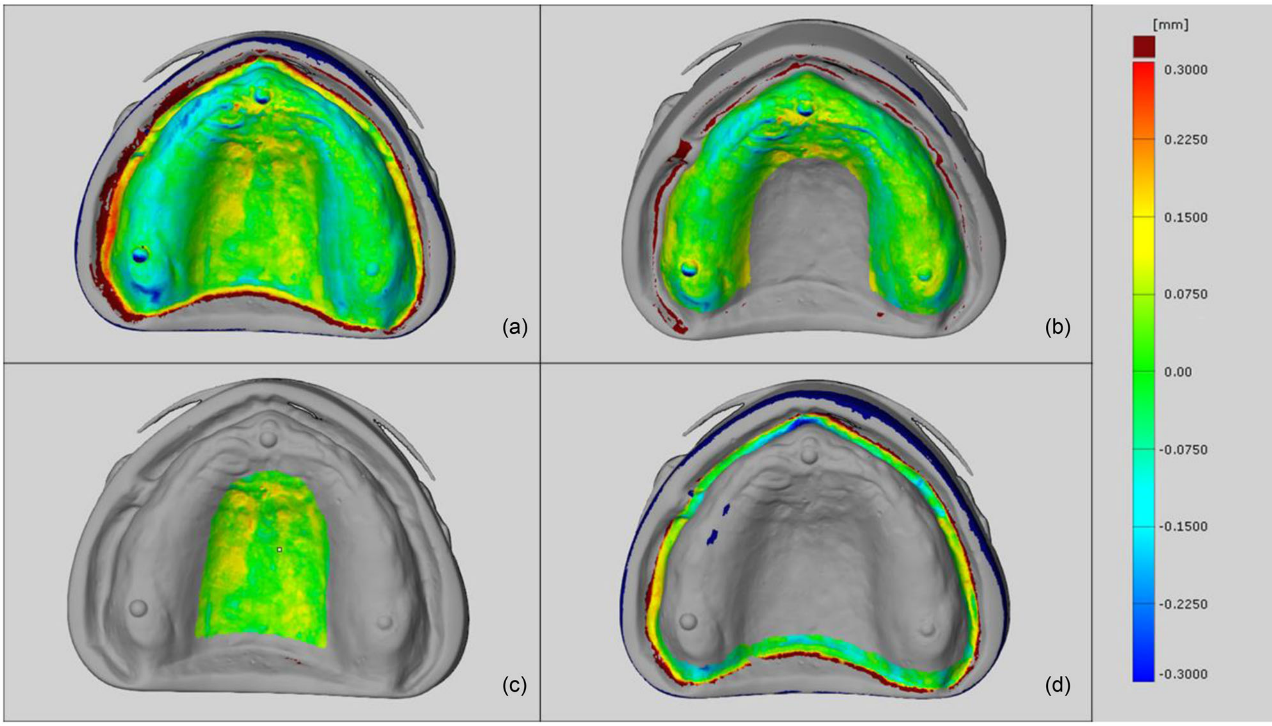

FIGURE 3 Superimposing: (a) total intaglio surface; (b) crest of the ridge; (c) palatal vault; and (d) denture border apex

to mass produce the product, and less material waste.[26] Studies have shown that the additive technique has better results than the conventional technique in terms of tissue adaptation for the production of complete dentures.[1,11,17,18]

Recently, studies have been conducted to evaluate tissue adaptation in complete dentures produced by additive and milling methods. Although the silicone replica method[12] has been used, the superimposing method[1,11,18–21] was preferred in the majority of studies. Hsu et al. used a silicone replica and digital superimposing methods in a study where the maxillary and mandibular complete denture bases were produced under in vitro conditions with CAD–CAM MIL, DLP, IM, and CM.[12] In this study, as in similar studies, the best fit algorithm was used in digital superimposing processes.[10,13,19]

LCD and DLP printing techniques are frequently preferred in studies related to the production of complete dentures instead of the SLA technique.[1,13,18] As the photopolymerized resin used for SLA printers could not be approved for use in Turkey at the time this research was conducted, the SLA printer could not be included in the study. The layer thickness of the denture bases produced with DLP and LCD printers was 100 μm, which is similar to the thickness layer used in other studies.[1,13,14] In a study about the printing direction, Ollison et al[25] reported that the minimum error margin is 0°, whereas other studies recommended that the optimal printing angle should be 120° and 135°.[15,22] However, it has been reported that different printing angles do not have a significant effect on tissue surface adaptation.[21] In the present study, as Unkovskiy et al stated, a 90° printing angle was preferred in the DLP and LCD printers, and supports during the production phase were not put to the tissue surface.[10]

In a study, in which a maxillary complete denture base was produced under in vitro conditions with reference to gypsum models with three different methods (DLP, MIL, and CM), it was reported that the tissue surface adaptation ($\leq$0.1 mm) of the bases produced is better when using the DLP method than the other methods.[1] In a study, in which mandibular complete denture bases were produced under in vitro conditions with reference to gypsum models with three different methods (DLP, MIL, and CM), no statistically significant difference was found between the tissue surface adaptations of the different methods.[11] In the study investigating the effects of hydrothermal aging and microwave sterilization processes on the accuracy of complete denture bases produced with three different methods (SLA, IM, and MIL), the minimum deviation values on the intaglio surface of the produced denture bases were found for the MIL, IM, and SLA techniques.[13]

The silicon index method was used to ensure that the bases produced with CAD–CAM and conventional systems had the same thickness and shape as in similar studies.[4] With this method, the bases produced with CAD–CAM were molded with silicone impression material, and it was provided to be a template for the bases produced with metal molding. In a study, in which maxillary and mandibular complete denture bases were produced in vitro with MIL, DLP, IM, and CM methods, silicone replica and digital superimposing methods were used together, and no statistically significant difference was observed between the tissue surface adaptation of the IM and CM groups.[12]

This study has some limitations. As the polymerized blocks used for the milling technique had certification problems in Turkey at the time this study was conducted, the subtractive methods could not be included in the study. The tissue adaptations of the complete denture bases were evaluated in vitro, and the dynamic characteristics of soft tissue compression or distortion were not included. Positive or negative deviations in tissue adaptation were only evaluated with colored images. Moreover, the printing angles in the 3D printer groups were only 90°. There is a need for additional studies on tissue adaptation of 3D printers, especially those investigating in vivo environments.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions can be drawn. Maxillary complete denture bases produced by DLP and IM methods provide better tissue surface adaptation than bases produced by LCD and CM methods. The IM method can offer prostheses with higher adaptation than the CM method and the DLP technique in comparison to the LCD technique. In all four groups, the lowest mean deviation values were observed in the palatal vault region, and the highest mean deviation values were observed in the denture border apex. In the colored deviation analysis, on the denture base produced with the LCD method, although widely positive deviations were observed in the anterior undercut region of the model, it was observed that the bases produced with the DLP method were generally compatible with the gypsum model in the anterior undercut region.

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CONFLICTS OF INTEREST

We have no conflicts of interest to disclose.

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