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Original Article

Seating Accuracy of Printed Artificial Teeth in Complete Prostheses at Different Print Angles

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Abstract

Background: 3D printers are widely utilized in dentistry for complete prostheses due to fast production, high accuracy, and personal customization.Although these printers have had a significant effect on improving the treatment and manufacturing of tools and prostheses, the techniques used in printing 3D models are still unable to provide ideal quality in all applications, and many variables can affect the accuracy of 3D printing models. The purpose of this study was to compare the difference in the seating accuracy of printed artificial teeth in the resin base cavities of complete prostheses at different print angles with the aim of reducing the created errors.

Methods: First, a scan was prepared from the cast of a patient. Then, the teeth and prosthetic base were designed for a single toothless area, and a total of 60 artificial teeth and bases were printed separately at three angles of 0°, 45°, and 90°. The correct seating of these teeth in the base cavities was evaluated by re-scanning and checking in the software (Dental cad, exocad, GMBH, version 3).

Results: In the palatal region, the midpoint-to-midpoint (M.M.) and vertical measurement at a 45° angle had the most accuracy, while in the cylinder-to-cylinder (C.C.) measurement, the highest accuracy was observed at a 0° angle (P<0.001). In the buccal area, the M.M. measurement demonstrated the highest accuracy at a 90° angle, the C.C. measurement at a 0° angle, and the vertical measurement at a 45° angle (P<0.001).

Conclusion: Based on the findings, there was a significant difference with the gold standard for all printing angles in various measurements of the accuracy of tooth seating in the printed resin base.

Keywords: Complete denture, Edentulous, 3-Dimensional, Printing dentures

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Background

Complete removable dental prostheses, or removable dentures, have been used for years to rehabilitate edentulous patients (1). With the advances in the past several years, today's technology allows using different computer-aided systems, computer-aided design/computer-aided manufacturing (CAD/CAM), and the technology of making movable prostheses, including milling and rapid prototyping (RP) (2). Additive manufacturing, also called three-dimensional printing (3D) or RP, involves techniques that build objects layer by layer. This type of printing, despite being a new technology, has been used in many fields, such as engineering, medicine, and dentistry (3). The 3D printing-aided manufacturing for complete dentures (CDs) refers to using the 3D-printed dentures as a prototype, along with the traditional process, to fabricate final dentures and is an effective alternative when the dentures cannot be directly processed using CAM (4). 3D printers are widely utilized in dentistry for complete prostheses and implants due to fast production, high accuracy, and personal customization. In addition, the applications of 3D printing in dentistry can help provide more personalized services and lower costs to patients (5). CAD/CAM processes are mass production industrial methods. RP is a CAM method for transferring digital models to physical models from CAD using an additive method. Two RP methods, namely, stereolithography apparatus (SLA 3D printing) and digital light processing

(DLP 3D printing), are employed in dentistry. SLA uses a technique where the model is supported by support columns, and multiple ultraviolet (UV) polymerizations are necessary. In contrast, 3D printed models are embedded in a gel-like support material that is removed via waterjet and manual manipulation. For this method, holding columns are not needed, and therefore, only one polymerization method is needed (6). The basis of the construction process is based on 3D computer models to reconstruct a 3D object. In fact, this printing method allows a digital file to be created by a computer using a printer in a 2D cross-sectional area and successively adding layers. Materials such as plaster, metal, plastic, resin, and the like are placed on each other as a physical object, leading to the creation of 3D objects (7). Although these printers have had a significant effect on improving the treatment and manufacturing of tools and prostheses, the techniques used in printing 3D models are still unable to provide ideal quality in all applications, and many variables can affect the accuracy of 3D printing models (8,9). The milling technique yields CD bases with superior accuracy, whereas printing technology produces denture teeth with better accuracy and positioning in the corresponding denture bases (10). Among these influential factors are the type of consumables, print technique, print resolution, the angle of creating the model on the platform screen, and the type and number of supporting structures, which all affect the quality of the final product (11,12). It should be noted that similar studies in this field are limited, and the existing studies do not have the same results. In addition, there are disagreements about the placement angle of the parts to be printed in different studies, and the subjectivity of this project seems necessary. This study was conducted by considering issues mentioned above and the problems created in the placement of artificial teeth in the base cavity printed with pink resin and aiming at reducing this error.

Materials and Methods

The present study was experimentally conducted at Hamedan University of Medical Sciences, Faculty of Dentistry, Department of Dental Prostheses. Ethical approval was not required since the research did not involve human or animal subjects. The sample size (N = 60) for this study was determined based on similar studies, with a confidence level of 95% and a test power of 90%. In this research, the samples were selected according to available methods and non-randomly divided into 3 different angular groups (20 in each angular group).

First, a 3D scan was prepared from a patient cast by the EinScan Pro (Shining 3D Tech. Co., Ltd., Hangzhou, China), and then the teeth and the complete prosthesis base were designed for a single toothless area by the design software Exocad, version 3 (Exocad DentalCAD, exocad GmbH, Darmstadt, Germany). The files were prepared as STL. Next, the teeth were made by temporary resin and CD base with pink resin (Detax GmbH & Co. KG, Ettlingen, Germany) in a number of 60 pieces by Exocode design software (version 3) in two pieces of teeth and the denture base and were separately printed at 23°C at three different angles of 0°, 45°, and 90°. In the designed tooth and complete prosthesis, two evaluation cylinders were designed to evaluate the height. These assessment landmarks, with a height of 2 mm and a length of 5 mm, were located parallel to each other, one in the dental section and the other in the base section. Samples that were incompletely printed were excluded from the study. After being printed by the Asiga Freeform Pro 2 DLP 3D printer (Asiga, Alexandria, Australia), the samples were placed inside each other using CD base resin, and then the teeth were cured by UV rays (385 nm) in their position and fixed in the cavity. After printing and assembling, the resin specimens underwent a standardized finishing and post-curing process. Initially, a two-step cleansing protocol was applied using 90% isopropyl alcohol, with each cycle lasting one minute. Post-curing was then performed in a UV polymerization chamber according to the manufacturer's guidelines. Residual support structures were carefully removed using a low-speed rotary handpiece, followed by finishing both sides of each sample with water-cooled abrasive papers up to a 1200-grit level. Finally, all specimens were immersed in an ultrasonic bath for five minutes to remove any remaining surface contaminants. Each dental and gingival component was fixed together using light-cure pink acrylic resin (Stellar DC Acrylic-Pink) applied within the corresponding cavity in the denture base, supported by structures on buccal and palatal walls. After assembly, each sample was placed under 385 nm UV light for 3 minutes to complete the post-curing process.

After assembling and fixing the two pieces, the samples were coated with scanning spray and scanned using the Shining scanner. The scan files of each group were separately saved in the system and subsequently analyzed using Exocad DentalCAD software, version 3. The evaluations were performed as criteria in the software (Dental cad, exocad, GMBH, version 3) in the measurement part of the software with an accuracy of one thousandth of a millimeter, and then a secondary evaluation was conducted in the final print result to compare with the computer output result at different angles. Each of the scanned samples included two regions (palatal and buccal), and the distances between two points in each region were measured in three distinct ways using the software.

The first measurement calculated the distance from the center of the upper cylinder to the center of the lower cylinder (M.M., Figure 1). The second measurement computed the distance between two cylinders (C.C., Figure 2), and the third measurement was related to the calculation of the vertical distance from the upper point to the lower point (vertical, Figure 3). After completing the measurements, statistical analyses were performed using SPSS, version 23 (SPSS Inc., IL, USA). Further, the difference of means in different angles was compared by the type of measurement using the analysis of variance (ANOVA) test. Tukey's post hoc test was used to compare the difference in the accuracy of measurements between angles. P values < 0.05 were considered statistically significant.

Results

Each of the measurements based on the printing angles (0°, 45°, and 90°) and the measurement type M.M. (the distance between the center of the upper cylinder and the lower cylinder), C.C. measurement (calculation of the distance between two cylinders), and vertical distance (calculation of the vertical distance of the upper cylinder to the lower cylinder) were compared to the gold standard. In addition, the mean and standard deviation of the differences are separately reported for the palatal and buccal regions in Tables 1 and 2. A lower mean indicates a smaller difference between the measurement and the gold standard value, and as a result, provides a more accurate estimate of the true value. Based on the results (Table 1), in the measurement of type M.M. related to the palatal area, the smallest difference with the golden standard measurement was related to the angle of 45° (0.0 ± 118.262). In the C.C. measurement, the smallest difference was associated with 0° angle (0.034 ± 0.076), and in vertical measurement, the smallest difference was related to 45° angle (0.105 ± 0.165). In other words, 45°, 0°, and 45° angles are more accurate in M.M. type measurement, C.C. type measurement, and vertical measurement, respectively. ANOVA test was conducted to compare the mean differences across angles for each measurement type (Tables 1 and 2). Based on the findings related to the buccal region (Table 2), in the measurement of the M.M. type, the 90° angle was more accurate than other angles. In the C.C. measurement and the vertical measurement,

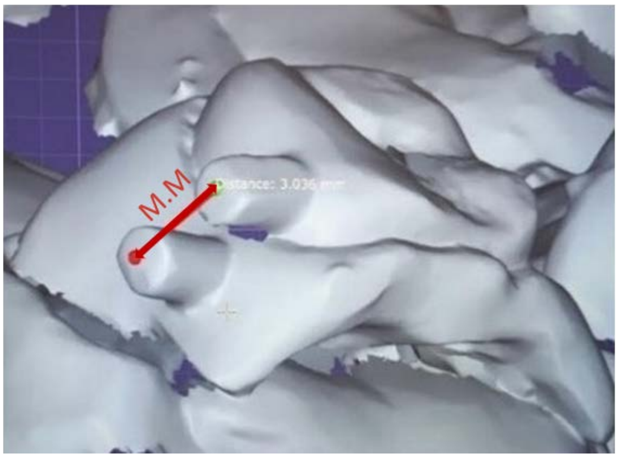

Figure 1. Calculating the Distance From the Center of the Upper Cylinder to the Center of the Lower Cylinder (M.M)

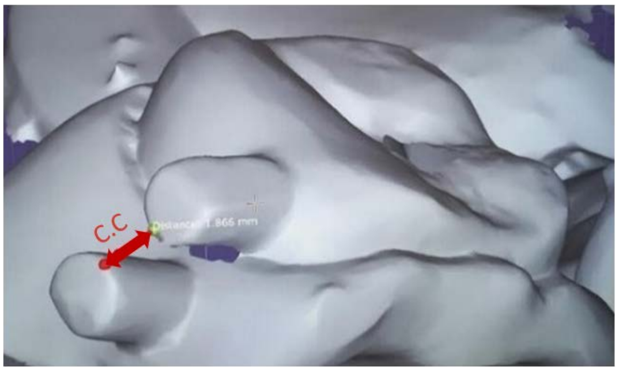

Figure 2. Calculation of the Distance Between Two Cylinders (Cylinder-to-Cylinder)

Figure 3. Calculation of the Vertical Distance From the Upper Point to the Lower Point (Vertical)

Table 1. Description and Comparison of the Average Difference of Various Measurements With the Golden Standard Measurement at Different Angles in the Palatal Area

Measurement Area	Angle	Type of Measurement	Mean ± Std. Deviation	*P*-value (ANOVA)
Palatal	0°	M.M.	0.370 (0.225)	<0.001*
	45°		0.118 (0.262)	
	90°		0.507 (0.224)	
	0°	C.C.	0.034 (0.076)	<0.001*
	45°		-0.044 (0.115)	
	90°		0.160 (0.225)	
	0°	Vertical	0.318 (0.113)	<0.001*
	45°		0.105 (0.165)	
	90°		0.188 (0.166)	

Note. Std. deviation: Standard deviation; ANOVA: Analysis of variance.

Table 2. Description and Comparison of the Average Difference of Various Measurements With the Golden Standard Measurement at Different Angles in the Buccal Area

Measurement Area	Angle	Type of Measurement	Mean ± Std. Deviation	*P*-value (ANOVA)
Buccal	0°	M.M.	0.648 (0.177)	<0.001*
	45°		1.092 (0.309)	
	90°		0.264 (0.369)	
	0°	C.C.	0.055 (0.234)	0.116
	45°		0.111 (0.220)	
	90°		-0.077 (0.385)	
	0°	Vertical	0.350 (0.088)	<0.001*
	45°		-0.069 (0.230)	
	90°		0.097 (0.340)	

Note. Std. deviation: Standard deviation; ANOVA: Analysis of variance.

the 0° and 45° angles were the most accurate. In addition, based on the results of ANOVA related to the buccal area, there was a significant difference in the mean difference of the measurements and the gold standard value for all print angles in the M.M. and vertical measurements, respectively ($P<0.001$). However, this difference was not significant in the measurement of C.C. type ($P=0.116$). Tukey's post hoc test was used to compare the difference in measurement accuracy between angles, the results of which are separately reported for palatal and buccal regions in Tables 3 and 4.

Discussion

This study identified the optimal 3D printing angle for achieving the highest accuracy in CD fabrication. The first measurement was related to calculating the distance from the center of the upper cylinder to the lower point (M.M.). Further, the second measurement was associated with the calculation of the distance between two cylinders (C.C.). Moreover, the third measurement was related to computing the vertical distance from the upper point to the lower point (vertical). Our results revealed that in the palatal region (the measurement of M.M), the smallest difference with the golden standard measurement was related to the angle of 45° (0.0 ± 118.262, $P<0.001$). The behavior of resin-based materials during 3D printing is highly influenced by the print angle, as it determines the distribution of internal stresses during layer curing. At a 45° angle, the stress distribution is more uniform, minimizing deformation during the layering process. Conversely, at a 90° angle, increased layer stacking may contribute to micro-shifts in alignment due to gravity and material flow dynamics, potentially explaining the observed deviations. This aligns with the known thermomechanical properties of photopolymers used in SLA. In the C.C. measurement, the smallest difference with the golden standard corresponded to the 0° angle (0.034 ± 0.076), and in the vertical measurement, the smallest difference with the golden standard was related to the 45° angle (0.0 ± 105.165). In the Buccal region, in the measurement of M.M., the 90° angle had the smallest difference with the standard measurement (0.0 ± 264.369). In the C.C. measurement, the smallest difference was associated with the 0° angle (0.055 ± 234), and in vertical measurement, the smallest difference was related to the 45° angle (-0.069 ± 230). Regarding the comparison of the two angles, it should be noted that in the palatal area, in the measurement of M.M. type, the difference between 0° and 45° angles ($P=0.004$) and 45° and 90° angles was significant ($P<0.001$). However, in the measurement of type C.C., there was no statistically significant difference between the two angles ($P<0.05$). In the measurement of the vertical type, the difference between 0° and 45° angles ($P<0.001$) as well as 0° and 90° angles was significant ($P=0.022$). The observed discrepancies in dimensional accuracy, such as the maximum error of approximately 0.264 mm at certain print angles, have important clinical implications. In the context of CD fabrication, even minor deviations in the fit between artificial teeth and the resin base can affect the retention, stability, and comfort of the prosthesis. An error of this magnitude might lead to micro-gaps that compromise the seating accuracy, potentially resulting in the need for additional clinical adjustments, prolonged chair time, and patient discomfort. Therefore, identifying the printing angle that minimizes such discrepancies is crucial to ensure the fabricated denture closely matches the digital design, optimizing prosthesis fit and function. This underscores the practical importance of our findings in guiding 3D printing protocols for clinically acceptable CDs.

The results of the present study regarding M.M. and vertical measurement in the palatal area and vertical measurement in the buccal area are in line with some of the results of the study by Yoshidome et al (13). They assessed the accuracy and precision of maxillary prostheses designed with SLA and DLP 3D printers. Their study, which included a thermopolymerized PMMA base as a control, evaluated eight support angles (0° to 315°) and identified 45° and 225° as the most accurate angles. Technical differences and differences in the investigated angles are the reasons for the contradiction in some results. Likewise, Hada et al investigated the effects of

Table 3. Pairwise Comparison of Average Measurements at Different Angles in the Palatal Area

Measurement Area	Angle	Type of Measurement	Mean ± Std. Deviation	*P*-value (Tukey)
Palatal	0-45°	M.M.	0.252 (0.075)	0.004*
	0-90°	M.M.	-0.136 (0.075)	0.174
	45-90°	M.M.	-0.388 (0.075)	< 0.001*
	0-45°	C.C.	0.079 (0.048)	0.079
	0-90°	C.C.	-0.125 (0.048)	-0.125
	45-90°	C.C.	-0.204 (0.048)	-0.204
	0-45°	Vertical	0.213 (0.047)	< 0.001*
	0-90°	Vertical	0.13 (0.047)	0.022*
	45-90°	Vertical	-0.083 (0.047)	0.194

Note. Std. deviation: Standard deviation.

Table 4. Pairwise Comparison of Average Measurements at Different Angles in the Buccal Area

Measurement Area	Angle	Type of Measurement	Mean ± Std. Deviation	*P*-value (Tukey)
Buccal	0-45°	M.M.	-0.551 (0.091)	0.820
	0-90°	M.M.	0.134 (0.091)	0.319
	45-90°	M.M.	0.189 (0.091)	0.108
	0-45°	C.C.	-0.443 (0.093)	< 0.001*
	0-90°	C.C.	0.384 (0.093)	< 0.001*
	45-90°	C.C.	0.827 (0.093)	< 0.001*
	0-45°	Vertical	0.420 (0.076)	< 0.001*
	0-90°	Vertical	0.253 (0.076)	0.005*
	45-90°	Vertical	-0.167 (0.076)	0.083

Note. Std. deviation: Standard deviation.

the difference in the printing direction of SLA prostheses with 3D printing on accuracy and precision. The average values of accuracy and precision at 0°, 45°, and 90° were statistically compared. The highest accuracy and the most favorable surface compliance occurred when the printing direction was 45° (14). According to our findings, M.M. and vertical measurement in the palatal area and vertical measurement in the buccal area are in line with the results of those obtained by Hada et al. Technical differences in measurement and statistical analysis methods led to some differences. Sağbaş evaluated the effect of the orientation angle on the hardness, tooth height, and accuracy of the tooth made by the MJF process. The samples were printed at 90° and 45°, and their measurement angle, roughness, and dimensional characteristics were measured with optical and tactile precision. It was revealed that the deviation of the 45° sample was higher than that of the 90° sample. Therefore, the accuracy of 90° samples was higher than that of 45° samples (15). According to the results of the present study, the measurement of the M.M. buccal area conforms to the results of the study by Sağbaş. Differences in the number of angles and areas examined and technical differences led to some differences. Park et al investigated the fitting accuracy of prepared CDs using DLP and found statistically significant differences in manufacturing accuracy, printing time, and material consumption among different orientation groups. The 45° and 90° groups demonstrated the best accuracy. Based on their results, 90° manufacturing directions required the least material consumption and the longest printing time, and the 45° group consumed the most printing materials (16). Research shows that fused deposition moulding and SLA techniques have been used to fabricate CDs. The accuracy of the final denture fabricated using SLA printing was better than that of dentures produced using the fused deposition moulding method (17). The findings of the study by Park et al corroborate the results of our study. The differences are only in measuring C.C. of the palatal and buccal area, which is probably due to the difference in the type of 3D measurement software (Tinkercad and Exocad). Variations in measurement precision can also be attributed to differences in the software employed for analysis. For instance, Exocad software relies on specific algorithms optimized for dental applications, while other software, such as Tinkercad, might apply generalized algorithms. These discrepancies highlight the potential influence of computational modeling on results, suggesting the need for standardized analysis protocols across studies. Shim et al evaluated the effect of printing direction on printing accuracy, bending strength, surface characteristics, and microbial response of 3D-printed prosthesis base resin (FLSUN Q5 Delta) at three angles of 0°, 45°, and 90°. They concluded that the samples printed at 90° showed the lowest amount of seating error, and the samples printed at 45° represented a higher statistical error than the other groups ($P < 0.001$) (18). According to the results of our study in the buccal region, in the measurement of M.M., the angle of 90° had the smallest difference with the standard measurement, and it was similar to the results of Shim et al, only in this respect. The absence of significant differences in buccal C.C. measurements across angles may stem from the flat anatomy of the buccal area and the linear nature of this measurement, which minimizes sensitivity to angular variations. The findings of Hada et al indicated that post-printing processes, such as polishing and support removal, can significantly impact accuracy, particularly for SLA methods. Similarly, Shim et al's observation of minimal seating error at 90° suggests that layer stacking stability may be enhanced under specific conditions. These insights highlight the interplay between printing parameters and post-printing workflows, which should be further explored in future studies to understand their combined effects on accuracy. Observations from related investigations imply that post-printing processes (e.g., polishing and support removal) significantly influence accuracy, particularly in SLA-based methods. The minimal seating error observed at a 90° angle indicates enhanced stability in layer stacking under specific conditions. These findings emphasize the complex interaction between printing parameters and post-printing workflows, underscoring the need for further studies to delineate their combined effects on dimensional accuracy. The difference in the rest of the results of this study is probably due to the difference in the type of 3D printing and technical differences. Among our limitations in this study are the number of samples and the number of angles examined. Therefore, it is suggested that more studies should focus on measuring other angles.

Conclusion

Based on the findings, there was a significant difference with the gold standard for all printing angles in various measurements of the accuracy of tooth seating in the printed resin base.

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Competing Interests
The authors declare that there is no conflict of interests.

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Not applicable.

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