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Research article

Evaluation of the influence of different build angles on the surface characteristics, accuracy, and dimensional stability of the complete denture base printed by digital light processing

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A R T I C L E I N F O

Keywords:
Build angle
Denture base
Surface characteristics
Accuracy
Dimensional stability

A B S T R A C T

Purpose: This study aims to investigate the influence of the build angle on the surface characteristics, accuracy, and dimensional stability of digital light processing (DLP) printed resin bases.
Material and methods: Rectangular and complete denture base samples were fabricated at 0, 45, and 90-degree angles (n = 5 for rectangular samples; n = 10 for maxillary and mandibular denture base samples) using a DLP printer. Surface morphology and roughness were assessed using a profilometer, followed by measuring hydrophilicity with a contact angle meter. Accuracy (trueness and precision) and dimensional stability were evaluated at intervals of 1, 3, 7, 14, 28, and 42 days after base printing using best-fit-alignment and deviation analysis in 3D software. Statistical analysis was performed using one-way ANOVA for surface characteristics ($\alpha = 0.05$), multi-way ANOVA for accuracy and dimensional stability data, and Tukey's test for post-hoc comparisons.
Results: The 0-degree group exhibited significantly lower mean roughness (1.27 ± 0.19 μm) and contact angle (80.50 ± 3.71°) ($P < 0.001$) compared to the 90-degree and 45-degree groups. The 0-degree build angle led to superior trueness (maxilla: 77.80 ± 9.35 μm, mandible: 61.67 ± 10.32 μm) and precision (maxilla: 27.51 ± 7.43 μm, mandible: 53.50 ± 15.16 μm) compared to other groups ($P < 0.001$). Maxillary base precision was superior to mandibular base precision ($P < 0.001$). The maxillary base exhibited less dimensional deviation than the mandibular base. The 90-degree group showed the highest deviation compared to the other two groups, and all groups' deviations increased over time ($P < 0.001$).
Conclusions: The build angle significantly influences the surface characteristics, accuracy, and dimensional stability of DLP-printed denture bases. A 0-degree build angle provides the most favorable performance. The maxillary base displayed superior precision and dimensional stability than the mandibular base.

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1. Introduction

Complete dentures remain a cost-effective and convenient treatment choice for partially edentulous patients. Traditional denture base fabrication involves many laboratory procedures and heavily relies on the expertise of technicians [1]. Recently, advances in computer-aided design and computer-aided manufacturing have introduced more efficient options for prosthetic production, such as 3D printing (additive manufacturing) and milling techniques. Additive manufacturing has gained traction in dentistry due to its benefits, including rapid production [2], accuracy, and reduced material wastage [3]. This technology is employed for various dental applications, such as provisional crowns, surgical guides, and dental models [4]. Digitally produced complete dentures offer enhanced accuracy compared to traditional dentures, resulting in decreased patient consultation and appointment durations and higher patient satisfaction [5,6]. Although milling techniques still dominate complete denture fabrication [7], 3D printing is garnering increased attention due to its advantages [8,9].

3D printing technology is based on the contours of imported digital files, which are cured and bonded in layers by UV light to form denture bases. To optimize the performance of 3D-printed products, dental research primarily focuses on parameter settings during the 3D printing process. Prior studies [10–12] have revealed that factors like build angle, layer thickness, post-processing, and others influence the quality of 3D-printed objects. Among these factors, the build angle is a critical parameter in the initial stages of the 3D printing process. One study [12] achieved the highest dimensional accuracy for 3D-printed surgical guides at a 45-degree build angle. Hussein et al. [13] observed that the build angle significantly impacts the accuracy of 3D-printed removable partial denture frameworks. Additionally, Osman et al. [14] assessed the effect of the build angle on the accuracy of DLP-printed full crowns and determined that the most precise results were obtained at a 135-degree build angle. Currently, a consensus is lacking regarding the optimal build angle settings for various dental applications.

To achieve satisfactory restorative outcomes for edentulous patients, the ideal denture base should possess essential features, including a smooth surface, precise tissue surface fit, excellent marginal closure, and adequate retention. A previous study [15] reported that approximately half of denture wearers experience denture stomatitis. The oral environment is complex, with the presence of saliva and various microorganisms that can accumulate on the denture base over time. The surface characteristics of the denture base are closely linked to microorganism attachment [15,16]. As mentioned earlier, base accuracy is crucial for denture retention, which is directly related to the satisfaction of edentulous patients. The retention of a complete denture relies on the proximity of the base to the mucosa, and the accuracy of the base significantly affects denture retention. According to ISO 5725-1, accuracy includes both trueness (consistency between test and reference objects) and precision (consistency among test objects under the same conditions). Furthermore, long-term dimensional stability is crucial for denture bases intended for extended use in the oral cavity.

However, the influence of the build angle on the surface characteristics, accuracy, and dimensional stability of 3D-printed complete denture bases has not been comprehensively explored. To optimize the performance of 3D-printed denture bases in clinical settings, this study aims to evaluate the effect of different build angles (0, 45, and 90°) on the surface characteristics, accuracy, and dimensional stability of complete denture bases. This research endeavors to provide guidance and data support for the production of 3D-printed denture bases. The null hypothesis for this study is that there are no differences in surface characteristics, accuracy, and dimensional stability among bases printed at different build angles.

2. Materials and methods

For the assessment of surface characteristics (roughness and hydrophilicity) of 3D-printed denture bases at different build angles, a rectangular specimen (25mm × 25mm × 3 mm) were designed using UG 3D build software (Unigraphics NX, Siemens PLM Software) referring to a previous study [17]. Additionally, data from a pair of maxillary and mandibular edentulous models (Fig. 1A and B) conforming to class I-type A of the American College of Prosthodontists classification were selected from the dental laboratory as reference models [18,19]. Subsequently, complete denture base data were designed based on the reference models using professional dental software (Dental System, 3SHAPE A/S) to evaluate the dimensional accuracy and stability of the bases.

The designed base data were imported into the DLP printer (IBEE300, UNIZ) for typesetting. The dentition surface of the base was

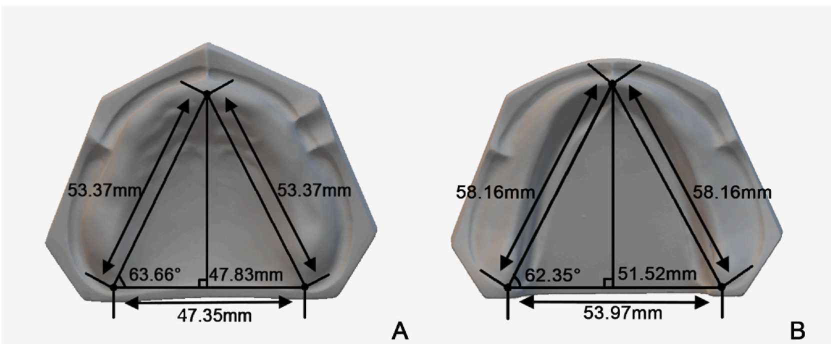

Fig. 1. Schematic representation of the dimensions of the reference model data. A, Maxillary model. B, Mandibular model.

positioned facing downward to ensure it was parallel to the build plate, forming the 0-degree build sample. Subsequently, the base was rotated counterclockwise by 45 and 90° to create the 45-degree and 90-degree samples, respectively. Support structures were established on the dentition surface of the base (Fig. 2). The effect size (df = 0.922869) was calculated using G Power (3.1.9.7, University of Düsseldorf) based on the result of a previous study [20]. The sample size of each group was calculated to be 8 with a significance level of 0.05 and a power (1-β) of 0.95. This study's sample size was increased to 10 in each group. The maxillary and mandibular bases were printed using resin base materials (20220331, SINO-DENTEX) (detailed components are shown in Table 1) using the DLP printer at different build angles (0, 45, and 90°) (n = 10). According to the manufacturer's guidelines, the printing parameters were set as follows: the LED light source wavelength was 405 nm, and the printing layer thickness was selected as 50 μm. The number of layers of the denture base varies with different build angles (Table 2). After printing, the excess resin was cleaned, and support structures were removed in 90 % isopropyl alcohol solution. Then cure 2 min after using a UV curing furnace (UV OVEN, Prismlab) (405 nm) according to the manufacturer's instructions. Rectangular blocks were typeset and printed in a similar manner (n = 5).

Following the printing of the samples, their surface characteristics were tested. Four regions, each with an area of approximately 500 × 700 μm^2, were randomly selected on the opposite side plane of the rectangular sample support structure. The 3D morphologies, magnified 400 times, were analyzed using the Keyence morphological contour microscopic system (VK-X150 K, Keyence), and roughness was subsequently analyzed. To measure the hydrophilicity of the base resin, the sessile drop method was employed. The sample block was placed on the sample table of a contact angle meter (SCI3000F, Beijing Global Hengda Technology), and deionized water droplets were transferred to the sample surface using a specialized syringe. Images were captured and then imported into Image J software (Image J, NIH) to analyze the left and right contact angles. Three measurements were taken for each sample, and the average value was recorded [21].

Following the printing of the base, its accuracy was assessed. To obtain reference data for the base, the designed maxillary and mandibular base data were imported into 3D analysis software (Geomagic Wrap 2015, 3D Systems). The tissue surface of the base was then intercepted based on the centerline of the base edge, defined as reference data (REF). On the day of printing (day 0), the tissue surface of the base was scanned using a scanner (E4, 3SHAPE A/S) with a scan accuracy of 6.9 μm (ISO12836), and the scan data was saved in standard triangle language (STL) format. Calibration was performed before each scan to ensure scanner accuracy. Once the scan was completed, the day 0 data and REF were aligned using the best-fit-alignment method in Geomagic Wrap. After alignment, the REF profile was displayed on the surface of the day 0 data. At this point, the test data were obtained by clipping with the "curve clipping" tool based on REF.

Trueness was represented by the best-fit-alignment and deviation analysis results between the test data on the day of processing (day 0) and the REF using Control X software (Geomagic Control X 2020.1, 3D Systems). Precision was determined by performing best-fit-alignment of test data within each build angle (n = 45) in pairs. The nominal deviation for superposition analysis was set at ± 50 μm, and the maximum critical value was ±500 μm [22]. Following the deviation analysis, color-code difference images and root mean square error (RMSE) were generated for each base. Green areas in the color-code difference images indicated that the surface matching deviation was within 50 μm, while the blue areas indicated that the base test data were smaller than the reference data, and the opposite applied to yellow and red areas. The alignment difference was expressed as RMSE, calculated as follows:

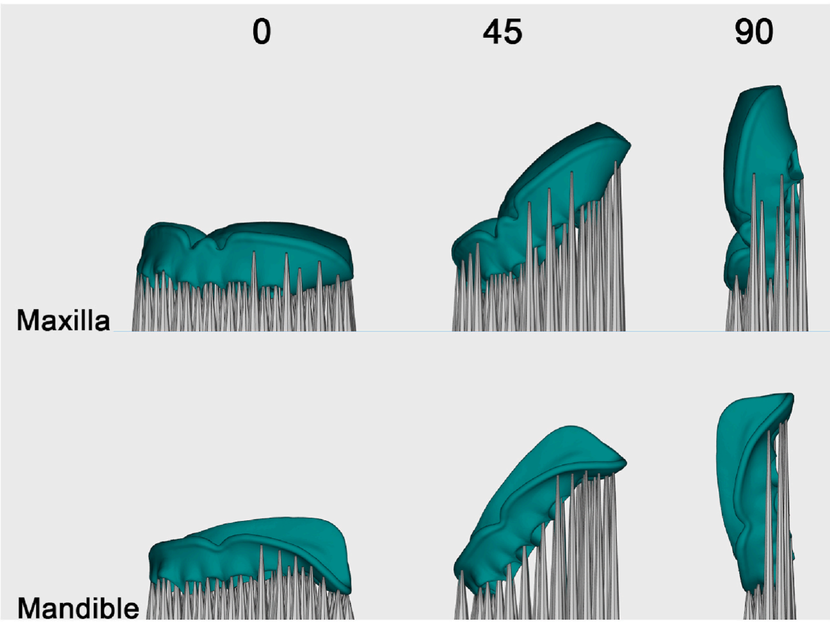

Fig. 2. Maxillary and mandibular base typesetting in 3 build angles (in degrees).

Table 1
Composition of resin base material for 3D printing complete denture in this study.

Components	Content
Di-2-methylpropanoic acid acyloxyethyl-2,2,4-trimethylhexane di-carbamate	23.3 %
1,6-Hexanediyl bis(2-methylacrylate)	21.5 %
Diacrylic acid, diester with 3,3'-(isopropylidene)bis (*p*-phenyleneoxy)]di (propane-1,2-diol)	19 %
Strontium glass powder	12 %
Barium glass powder	12 %
Silicon powder	10 %
The others (Camphorquinone,4-Methoxyphenol,Ferric oxide)	2.2 %

Table 2
Number of layers of the denture base at different build angles.

Group	0°	45°	90°
Maxillary base	561	1070	1260
Mandibular base	570	1069	1249

$$\mathrm{RMSE}=\frac{1}{\sqrt{n}}\sqrt{\sum_{i=1}^{n}\left(x_{1,i}-x_{2,i}\right)^2}$$

where $x_{1,i}$ is the measurement point i of the base reference data; $x_{2,i}$ is the measurement point i on the test data, and n is the total number of measurement point pairs on each sample. A larger RMSE value indicates a larger error between the two sets of base data, and vice versa.

The tissue surface of the base was scanned using a scanner on days 1, 3, 7, 14, 28, and 42 after printing, and the scans were saved in STL format. The test data were obtained in the same manner as for accuracy assessment. Best-fit-alignment was carried out by superimposing the test data of each group onto the day 0 profile in Geomagic Control X. Subsequently, a deviation analysis was performed to obtain the base's dimensional deviation at various time following printing.

SPSS 26.0 software (IBM Corp) was utilized to test the normal distribution of experimental data. Surface characteristics of the samples were analyzed using one-way ANOVA and Tukey's test for post hoc comparisons. To examine differences in base accuracy, a two-way ANOVA was employed, considering arch position and build angle as the two independent factors, followed by a Tukey's test for post hoc analysis. Additionally, for dimensional stability, a multi-way ANOVA was conducted with arch position, build angle, and time as the three independent factors. The significance level was set at $\alpha = 0.05$.

3. Results

Fig. 3 shows the distinctive three-dimensional morphologies of rectangular samples at different build angles. The 0-degree group exhibits a surface with evenly distributed block-like protrusions surrounded by depressions (Fig. 3A). The 45-degree group displays a stepped shape with large differences in height between protrusions and depressions (Fig. 3B). In contrast, the 90-degree group exhibits uniform, parallel strip ridges and grooves on the surface (Fig. 3C). Table 3 provides the mean values and standard deviations of surface roughness and contact angle for the three build angle groups. The 45-degree group shows the highest mean surface roughness (2.76 ± 0.18 μm), followed by the 90-degree group (1.69 ± 0.24 μm) and the 0-degree group (1.27 ± 0.19 μm). These groups differ significantly in terms of surface roughness ($P < 0.001$). Regarding hydrophilicity, the 0-degree group has a significantly smaller average contact angle (80.50 ± 3.71°) compared to the 45-degree group (98.86 ± 2.99°) and the 90-degree group (93.69 ± 1.84°) ($P < 0.001$), and the 90-degree group was smaller than the 45-degree group ($P < 0.05$).

Concerning trueness, there is no significant interaction observed between the build angle and arch position ($F = 1.550$, $P = 0.222$). Significant differences are found among the build angles ($F = 90.260$, $P < 0.001$), but no significant difference is noted between the maxillary and mandibular arches ($F = 2.366$, $P = 0.130$). Precision analysis reveals no significant interaction between the two factors

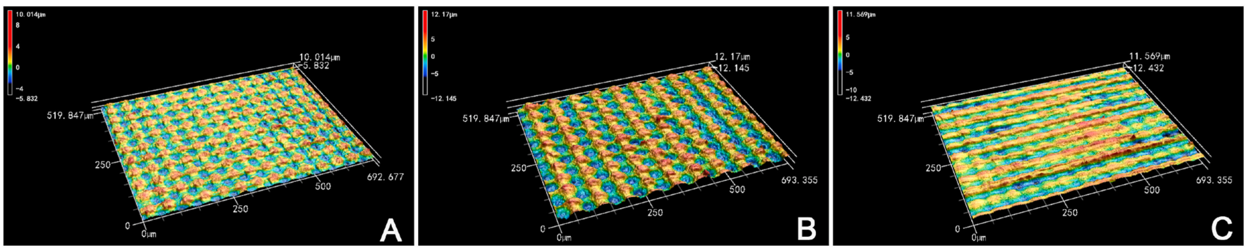

Fig. 3. Three-dimensional topography of the base surface with different build angles. A, 0-degree group. B, 45-degrees group. C, 90-degrees group.

Table 3
The surface characteristics of specimen with different build angles. ($n = 5$, surface roughness (μm), Contact angle (degree)).

Group	0°	45°	90°	F	P
Surface roughness	1.27 ± 0.19^c	2.76 ± 0.18^a	1.69 ± 0.24^b	274.522	<0.001
Contact angle	80.50 ± 3.71^c	98.86 ± 2.99^a	93.69 ± 1.84^b	51.511	<0.001

The normal distribution data in the table are expressed as "mean ± standard deviation". Different superscript letters indicated significant difference among different angle groups (P < 0.05).

(F = 1.293, $P = 0.276$). The influence of build angle (F = 135.552, $P < 0.001$) and arch position (F = 174.836, $P < 0.001$) on precision is significantly different. Maxillary precision is notably superior to mandibular precision. As shown in Table 4, the RMSE for trueness is largest in the 90-degree group, followed by the 45-degree and 0-degree groups. A similar trend is observed in precision, where the mean RMSE value in the 0-degree group is significantly lower than in the 45-degree and 90-degree groups. Significant differences are observed in the mean values of trueness and precision RMSE among the three groups ($P < 0.001$).

Fig. 4 shows color-code difference images for trueness (Fig. 4A) and precision (Fig. 4B) of the maxillary and mandibular bases in the three build angle groups. The color-code difference images for trueness show positive deviation in the maxillary palatine rugae area and negative deviation in the palatine fovea area in the 90-degree and 45-degree groups. With increasing molding angle, the color of the maxillary tuberosity area gradually shifts from light orange to orange-red in all three groups. Similar color shifts occur in the mandibular retromolar pad area and the lingual region at the top of the alveolar crest. In the precision color-code difference images, only a few changes are observed in the maxillary and mandibular 0-degree groups. The 90-degree and 45-degree maxillary bases show scattered positive and negative deviations, while the mandibular base displays negative deviations at the alveolar crest. Overall, the trueness color-code difference images exhibit a broader range of positive and negative deviations compared to the precision color-code difference images.

The three-way ANOVA analysis of dimensional stability revealed significant interactions between arch position and build angle (F = 9.647, $P < 0.001$), as did the arch position and time (F = 10.409, $P < 0.001$). The arch position (F = 93.433, $P < 0.001$), build angle (F = 29.554, $P < 0.001$) and time (F = 50.916, $P < 0.001$) all had significant influence on dimensional stability. The maxillary base displayed a smaller dimensional deviation compared to the mandibular base (Fig. 5A), and the 90-degree group demonstrated a significantly larger deviation in comparison to the 45-degree and 0-degree groups (Fig. 5B). Furthermore, the dimensional deviation of the bases progressively increased over time (Fig. 5C).

Table 5 shows the RMSE values of the maxillary and mandibular bases in the three build angle groups at six observation time points, namely, days 1, 3, 7, 14, 28, and 42. The dimensional deviation of both maxillary and mandibular bases significantly differed among the three groups after 42 days of printing in comparison to the first day ($P < 0.001$). Over time, the dimensional deviation of the maxillary base (RMSE) exhibited relatively modest increases (Fig. 6A), while the mandibular base's dimensional deviation increased considerably (Fig. 6B). Additionally, the RMSE value of the 0-degree maxillary base (excluding the first day) was significantly smaller than that of the other two groups ($P < 0.05$). For the mandibular base's dimensional deviation (RMSE), significant differences were observed in the first 7 days ($P < 0.05$), and the dimensional deviation of the three angle groups gradually increased after 14 days, with no significant differences between them.

4. Discussion

This study demonstrates that the 0-degree group exhibits significantly lower surface roughness, enhanced hydrophilicity, and superior accuracy when compared to the 45-degree and 90-degree groups. Furthermore, the maxillary base exhibits better dimensional stability compared to the mandibular base, and the 90-degree build angle exhibits notably poorer stability. Therefore, the null hypothesis was rejected.

In the context of long-term use of complete dentures, issues related to plaque buildup, cleaning, and surface discoloration are closely associated with the denture base's surface characteristics [15,16]. Surface roughness and hydrophilicity are key factors influencing these characteristics. It is well known that the surface of the complete denture base is irregular. To avoid possible deviation between samples, rectangular resin samples were used in this study to test the roughness of base materials with different build angles [17]. The roughness values of the samples in the current study range from 1.27 to 2.76 μm, which are larger than the results obtained in a previous study (ranging from 0.39 to 1.09 μm) [23], which may be attributed to different printing technology implementations in

Table 4
RMSE values of the accuracy of denture bases with different build angles (Trueness [$n = 10$], Precision [$n = 45$], μm).

	Group	0°	45°	90°	F	*P*
Maxilla	Trueness	77.80 ± 9.35^c	105.82 ± 3.95^b	139.27 ± 22.20^a	47.685	<0.001
	Precision	27.51 ± 7.43^c	42.46 ± 7.32^b	68.12 ± 18.65^a	124.674	<0.001
Mandible	Trueness	61.67 ± 10.32^c	99.70 ± 19.65^b	141.67 ± 24.02^a	44.913	<0.001
	Precision	53.50 ± 15.16^c	70.74 ± 18.82^b	89.09 ± 20.40^a	42.748	<0.001

The normal distribution data in the table are expressed as "mean ± standard deviation". Different superscript letters indicated significant difference in RMSE among different angle groups (P < 0.05).

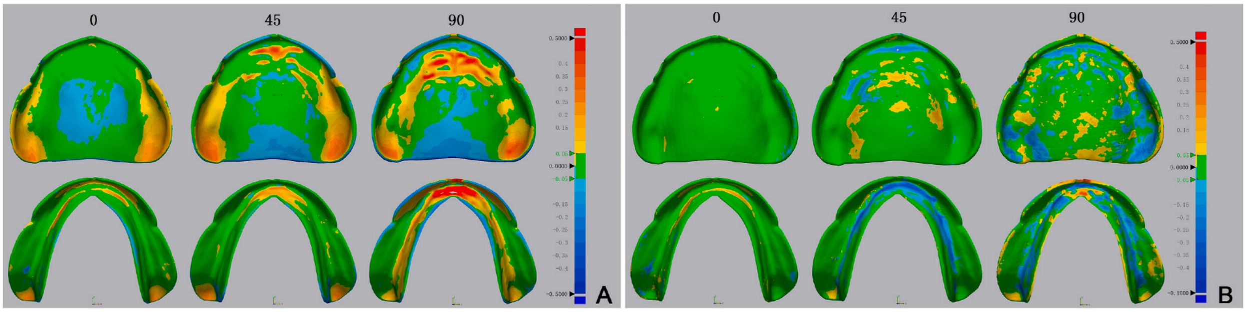

Fig. 4. Color-code difference images of accuracy. A, Trueness. B, Precision. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

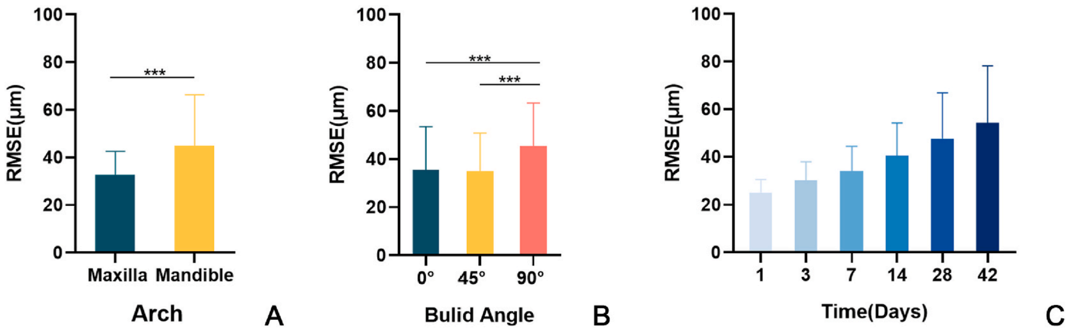

Fig. 5. The dimensional stability of denture bases varied with position, angle and time. A, Dimensional deviation of the maxilla and mandible bases. B, Dimensional deviation of different build angles. C, Dimensional deviation of the denture base over time. *** represents extreme statistically significant differences between groups. ***$p < 0.001$.

Table 5
Dimensional changes of maxillary and mandibular basewith different build angles over time (RMSE) (n = 10, μm).

Angle (degree)		1 Day	3 Day	7 Day	14 Day	28 Day	42Day	*F*	*P*
Maxilla	0	21.07 ± 3.03	22.37 ± 4.01	22.07 ± 4.67	26.4 ± 4.20	28.71 ± 8.44	33.89 ± 9.82	6.313	<0.001
	45	22.56 ± 3.62	25.64 ± 4.01	31.72 ± 6.15	35.10 ± 5.65	37.22 ± 7.05	37.76 ± 6.21	12.750	<0.001
	90	26.20 ± 4.67	37.85 ± 3.08	39.37 ± 3.84	42.94 ± 2.56	45.91 ± 3.27	49.94 ± 5.64	42.483	<0.001
	F	4.383	47.871	30.307	36.595	16.840	12.615		
	P	0.22	<0.001	<0.001	<0.001	<0.001	<0.001		
Mandible	0	29.69 ± 6.84	33.07 ± 6.19	38.30 ± 8.77	45.72 ± 13.30	57.28 ± 18.19	67.87 ± 26.59	9.542	<0.001
	45	22.19 ± 3.19	26.09 ± 4.39	29.15 ± 7.74	37.95 ± 14.66	51.92 ± 20.30	62.09 ± 24.67	11.261	<0.001
	90	29.39 ± 4.47	36.93 ± 6.21	44.63 ± 9.98	53.29 ± 17.50	64.75 ± 23.93	73.86 ± 28.37	9.251	<0.001
	F	7.023	9.414	7.687	2.527	0.946	0.490		
	P	0.004	0.001	0.002	0.099	0.401	0.618		

The normal distribution data in the table are expressed as "mean ± standard deviation".

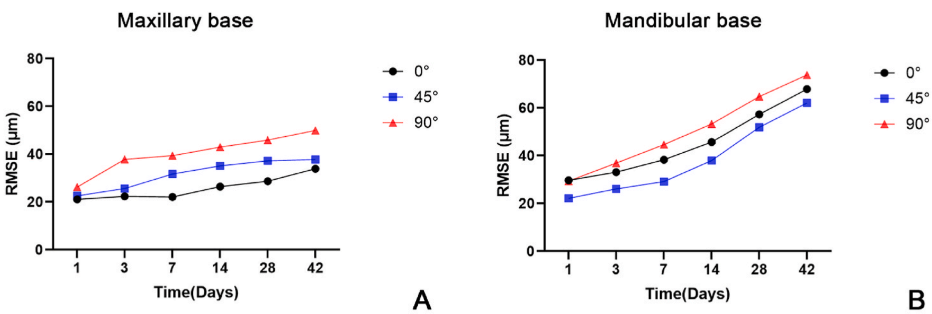

Fig. 6. Dimensional changes of maxillary and mandibular base with different build angles over time. A, Maxillary base. B, Mandibular base.

studies. Additionally, this study results indicate that the build angle significantly impacts the surface roughness of the samples, with the 45-degree group displaying the highest roughness, followed by the 90-degree group, while the 0-degree surface is the smoothest. This is consistent with the results of Lee et al. [24]. However, there are differences with the study of Li et al. [25], in which it was found that the surface roughness of 3D-printed products at 90-degree build angle was the smallest. This may be due to the differences in printing parameters (material, post-curing time, and printing mode) used in the experiments. The effect of build angle on roughness was attributed to the difference in the smaller pitch and tiny peak-to-valley unplanarity of the resin sample surface at different build angles, as observed in the 3D morphological results of the samples (Fig. 4) at the microscopic level. The 45-degree group (Fig. 4B) exhibits more pronounced protrusions and depressions compared to the other two groups. These variations in minor spacing and height differences between peaks and valleys at different angles could be attributed to the step structure variations that arise from the layered fabrication process in 3D printing [26,27].

Additionally, a rough and hydrophobic surface is conducive to plaque adhesion [9,15]. A previous study [28] found that the adhesion of Candida albicans could be reduced by adding a hydrophilic coating to the material's surface. Denture cleaning and Candida infection are important factors in denture stomatitis [15]. These evidences suggest that a hydrophilic base surface reduces the risk of denture stomatitis in patients. Moreover, water diffuses better on a base surface with good hydrophilicity, which contributes to better retention of the denture [29,30]. This findings revealed that the 0-degree group has the most hydrophilic surface, possibly related to surface roughness. A previous study [31] investigated the impact of surface roughness on hydrophobicity and demonstrated that increased roughness associated with stronger hydrophobicity. This same trend was observed in the current study, where the surface roughness of the base is positively correlated with hydrophobicity.

The accuracy of the tissue surface of the complete denture base holds significant importance for denture retention. In terms of trueness, the 0-degree group exhibited the highest trueness with the lowest mean RMSE value compared to the 45- degree and 90-degree groups. The 90-degree group showed the worst trueness, meaning that the base had the worst fit to the mucosal tissues in a clinical setting, potentially resulting in inadequate denture retention. The color-code difference images for trueness showed significant positive deviations in the palatine rugae, maxillary tuberosity, and the lingual portion of the mandibular base in the 90-degree group. These deviations reflect the suboptimal fit of the denture bases to the mucosal tissues in these areas, which may lead to reduced denture retention. Additionally, a significant negative deviation was observed in the palatine fovea, suggesting that mucosal tenderness might occur in this region. One reason for the poor trueness in the 90-degree group may be attributed to the fact that this group involves the largest number of printed layers (maxilla: 1260 layers; mandible: 1249 layers) in the z-direction. In bottom-up printing with DLP technology, the cured resin is pulled by the building plate and moved upward away from the bottom of the resin tank. This separation force effect may affect the print trueness of the base [32]. Moreover, during the construction of 3D-printed objects, the laser tends to over-cures the layers, leading to dimensional and positional errors in the z-direction as the layers bond to each other [33]. The more layers involved in the printed object, the greater the probability of potential errors [34,35]. Another possible factor contributing to this effect may be surface roughness. It has been reported that the surface roughness of 3D-printed objects determines the surface accuracy [26]. In this study, the 0-degree group exhibited the smallest surface roughness, implying better printing accuracy. As for precision, the average RMSE values of precision in this study were in the range of 27.51–89.09 μm, which was similar to the precision (50.00–72.00 μm) of base printed by stereolithography technology in a previous study [36]. The 0-degree build angle exhibited higher precision than the 45-degree and 90-degree groups, potentially correlating with the 0-degree group's higher trueness. In the precision color-code difference images, it could be observed that the positive and negative deviations of the base surface of the 90-degree group are scattered, which was not like the characteristic distribution of the trueness color-code difference images. This is related to the different evaluation methods of the two indicators. The precision was obtained by matching and superimposing the print bases to each other at the same angle, and trueness was the result obtained by matching and superimposing the print bases to the same reference data. Furthermore, the analysis of accuracy for the maxillary and mandibular bases revealed that the trueness and precision of the maxillary base were significantly superior to those of the mandibular base, potentially due to differences in the denture base's surface morphology. As shown in the color-code difference images for trueness and precision (Fig. 5), positive and negative deviations are mainly concentrated in areas with large curvature. The curvature of the mandibular base was more obvious than that of the maxillary base, especially at the top of the alveolar crest.

In addition to the base's accuracy, its dimensional stability is also vital for the long-term suitability of a complete denture. This studies revealed that the base's dimensional deviation in all groups increases over time, with a significant difference in dimensional deviation at 42 days compared to day 1 after printing. Previous research [37,38] has observed the dimensional changes of 3D-printed surgical guides and dental models. These studies showed a significant change in the dimension of 3D-printed objects after one month of storage, potentially due to the polymerization shrinkage of the resin material. Moreover, the dimensional deviation of the mandibular base in this study was greater than that of the maxillary base, which might be related to the palatal support structure of the maxillary base. For instance, Camardella et al. [39] found that 3D-printed models with horseshoe-shaped substrates showed significant lateral shrinkage compared to traditional models. Similarly, the model with a palatal support structure displayed greater stability than the one lacking it [40]. Of greater significance is the effect of the build angle on the dimensional stability of the base. The dimensional deviation of the three angle groups were within clinically acceptable range (100 μm) [19]. The 0-degree group (35.54 μm) and 45-degree group (34.95 μm) bases showed better dimensional stability compared to the 90-degree group (45.42 μm) (Fig. 5B). No statistical differences were demonstrated between the 0-degree and 45-degree groups. The study found that storage time may have an impact on the dimensional stability of 3D-printed bases made of liquid resin [22]. Although the denture base was post-processed according to the manufacturer's operating guidelines, the residual monomers on the base surface may still change over time [41]. To confirm the relationship between the dimensional stability of the denture base and its surface residual monomer, the amount of residual monomer on the surface of the denture base at different build angles can be further studied in the future.

This study has certain limitations, as it only investigates a single 3D printing method and resin material. Future research should encompass an evaluation of build angle performance across various manufacturing processes and materials. The present study was carried in vitro. The oral environment is complex, such as the presence of saliva, adhesion of oral flora, and temperature change in the oral cavity, which cannot be achieved under the current experimental conditions. In addition, there are many factors in 3D printing that may affect the results of 3D printing, such as layer thickness and post-curing temperature.These limitations can provide new topics for future research.

5. Conclusion

Within the scope of this study, the following conclusions can be drawn.

1. The 0-degree build angle has the most favorable base surface characteristics, including smooth surfaces and high hydrophilicity.
2. The base printed at a 0-degree build angle demonstrates the best trueness and precision, while the 90-degree group exhibits poor trueness and precision. The precision of maxillary base is superior to mandibular base.
3. The dimensional stability of the base is the worst at a 90-degree build angle, and the dimensional deviation of the 3D-printed resin base increases gradually over time. The maxillary base shows a smaller dimensional deviation than the mandibular base.

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Data availability statement

All data used to support the findings of this study have been included in the submitted documents, and any additional data are available from the first author or corresponding author upon request.

CRediT authorship contribution statement

Shan Yan: Writing - original draft, Software, Formal analysis, Data curation. **Jia-Ling Zhou:** Methodology, Conceptualization. **Ruo-Jin Zhang:** Validation, Supervision. **Fa-Bing Tan:** Writing - review & editing, Supervision, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e24095.

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