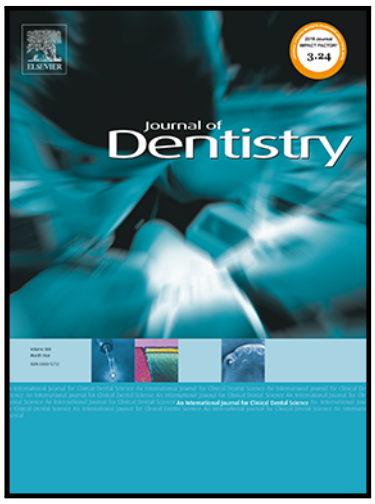
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Comparison of DLP and LCD 3D Printing Technologies: Effects on Denture Base Accuracy, Weight, Residual Material, Resin Consumption, and Production Time

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Comparison of DLP and LCD 3D Printing Technologies: Effects on Denture Base Accuracy, Weight, Residual Material, Resin Consumption, and Production Time

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Abstract

Objective: The aim of this study was to compare the geometric accuracy, weight, residual material, and fabrication time of complete denture bases produced at different build orientations using Digital Light Processing (DLP) and Liquid Crystal Display (LCD) technologies.

Methods: An edentulous maxillary model (Frasaco B-3 NH,Germany) was scanned by using an extraoral scanner (7Series Dentalwings,Straumann,Montreal,Canada) and a 2mm-thick reference denture base was designed (Exocad DentalCAD 3.1**,**Germany). The base was manufactured by using resin-based 3D printing technologies such as **DLP (n=35) (Sega Pro, DentaFAB, Istanbul, Türkiye) and LCD(n=35) (Whale 3Ultra 14K,Nova 3D,Shenzhen,China) at building angles of 0°, 45°, and 90°, oriented labially, buccally, and palatally. For each 3D printing technology, seven different production types were considered based on build angles and orientations (for DLP and LCD technologies: 0° single; 45° and 90° in buccal, labial, and posterior positions). A minimum of five specimens per production type was included, resulting in a total of at least 70 denture base specimens in the study**. All bases were scanned and compared with the reference model. Geometric deviations were evaluated using a metrology software (Geomagic Control X,3D Systems, South Carolina,USA). Material consumption and residual amounts were calculated by measuring the masses of the materials before and after manufacturing using a precision balance with 0.001 g sensitivity (Radwag, Radom, Poland). **The fabrication duration for each specimen was recorded. Statistical analyses were performed using one-way ANOVA to compare build orientations within each technology, independent samples t-tests to compare DLP and LCD systems for each orientations, and two-way ANOVA to assess interaction effects between manufacturing method and build orientation ($\alpha = 0.05$).**

Results: Denture bases fabricated using DLP technology exhibited higher geometric accuracy, lower weight, and less residual material compared to those produced with LCD technology ($p < 0.001$). The highest precision was observed at the Labial 45° and Labial 90° orientations, while the greatest deviation occurred at the Buccal 90° orientation ($p < 0.001$). Two-way ANOVA indicated that the interaction between manufacturing method and build orientation was significant for all measured parameters ($p < 0.001$). Additionally, DLP technology demonstrated shorter fabrication time ($p < 0.001$) and lower resin consumption ($p = 0.007$), indicating a more efficient production process.

Conclusion: DLP printing of denture bases provides a viable and clinically acceptable method, offering reduced material waste and shorter production times compared to LCD. Build orientation also significantly affects accuracy, emphasizing the importance of optimizing printing parameters. Overall, DLP printing appears to be an efficient and clinically promising approach for denture base fabrication.

Clinical significance: This study demonstrates that optimizing the build orientation and printing angle in additive manufacturing significantly influences the production accuracy of complete denture bases. Among the tested techniques, DLP printing showed superior performance by providing higher geometric accuracy, reduced material waste, and shorter production times compared to LCD. These findings highlight the importance of selecting the appropriate build orientation and printing method, making this study a valuable guide for achieving the most accurate denture base fabrication in clinical practice.

Keywords: Denture Bases, Additive Manufacturing, Geometric Accuracy, Residual Material

1. Introduction

For many years, removable prostheses have been fabricated using conventional methods. However, with the advancement of CAD/CAM technologies, digital design and manufacturing of complete dentures have become more precise, rapid, and personalized options for patients[1]. Digital workflows reduce the number of clinical sessions and overall treatment time, enabling the creation of complex geometries through continuous layering. By minimizing workflow steps, the risk of errors decreases, thereby enhancing prosthesis quality[2].

Three-dimensional (3D) printing systems offer faster production and reduce labor costs by minimizing manual and time-consuming procedures, thus enabling more efficient and cost-effective manufacturing processes[3]. The subtractive CAD/CAM approach, which stores digital data, facilitates easy remanufacture of prostheses in cases of breakage or loss. Moreover, these digital records can later be utilized for implant planning and surgical guide preparation [4].

Complete dentures can be produced using CAD/CAM systems via two main approaches: computer numerical control (CNC) subtractive manufacturing and additive manufacturing (3D printing) [5]. Subtractive manufacturing involves obtaining restorations from prefabricated blocks using CNC machines. These machines employ milling tools to shape the material according to programmed commands. However, unused portions of disks or blocks generate material waste [6].

In contrast, additive manufacturing converts powder- or liquid-based materials into a solid object by building the desired shape layer by layer [7]. This method does not require abrasive milling tools and offers reduced production costs through lower material waste and energy consumption [8]. Digital workflows further reduce laboratory-induced errors[9]. In additive manufacturing, parameters such as print orientation, laser intensity, and speed substantially affect part accuracy, flexural strength, and surface roughness. Several studies have evaluated the impact of these parameters on the mechanical and surface properties of printed objects [10]. Among additive technologies, Digital Light Processing (DLP) and Liquid Crystal Display (LCD) are the most widely used in dentistry. DLP polymerizes liquid resin via a projector and a digital micromirror device (DMD), curing an entire layer in a single exposure, repeated layer by layer until the object is complete[11]. LCD technology is similar, curing each layer simultaneously; however, light passes through an LCD panel rather than being projected [12]. A key distinction between DLP and LCD is light intensity [13], which is critical for photopolymerization, determining the degree of curing and printing speed [14]. Only about 10% of light in LCD systems passes through the panel, with the remaining 90% absorbed. Light-sensitive resins designed for DLP devices can be used in LCD printers by adjusting exposure time or initiator concentration. LCD technology offers advantages such as lower cost and high resolution [14,15].

The primary objective of this study was to comprehensively evaluate the internal surfaces of complete dentures fabricated using Digital Light Processing (DLP) and Liquid Crystal Display (LCD) technologies. A precise quantitative digital analysis was performed to assess the extent of distortion associated with each manufacturing approach. In addition, key fabrication parameters—including denture base weight, residual material, production time, and resin consumption—were systematically measured to provide an integrated assessment of the efficiency and accuracy of these additive manufacturing methods.

The null hypotheses were formulated as follows: Denture bases fabricated using DLP and LCD technologies, across various build orientations, would not exhibit statistically significant differences in (a) geometric accuracy, (b) base weight, (c) residual material, (d) production time, or (e) resin consumption, either among themselves or when compared with the reference design. Furthermore, no statistically significant interaction effect between the manufacturing technology and build orientation is expected. Any observed differences would be attributed to random variation rather than systematic factors.

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2. Methods

Ethical approval was deemed unnecessary since the study did not utilize any patient records or data.

2.1.Sample Size Selection

A sample size calculation was performed using G*Power 3.1.9.4 for two-way ANOVA (main effects and interaction), with a significance level of α = 0.05, power (1-β) = 0.80, and a large effect size (f = 0.52). The study included two additive manufacturing technologies (Digital Light Processing(Sega Pro, DentaFAB, Istanbul, Türkiye) and Liquid Crystal Display [LCD, Whale 3Ultra, Nova 3D, Shenzhen, China]) and seven predefined build orientations (0° single; 45° and 90° in buccal, labial, and posterior positions). Five specimens were produced for each build orientation within each technology, resulting in a total of 35 specimens per group and 70 specimens overall. This design ensured sufficient statistical power to detect the expected effect size under the specified parameters.

In this study, an edentulous maxillary model was selected to manufacture a complete denture. The model was scanned utilizing an extraoral scanner**(7Series Dentalwings,Straumann,Montreal,Canada).** The 3D scan data was a digital reference for designing a removable complete denture base, measuring two millimeters in thickness, as illustrated in Figure 1, using **Exocad DentalCAD 3.1 software (Exocad GmbH, Darmstadt, Germany)** with the **Full Denture Design Module**.

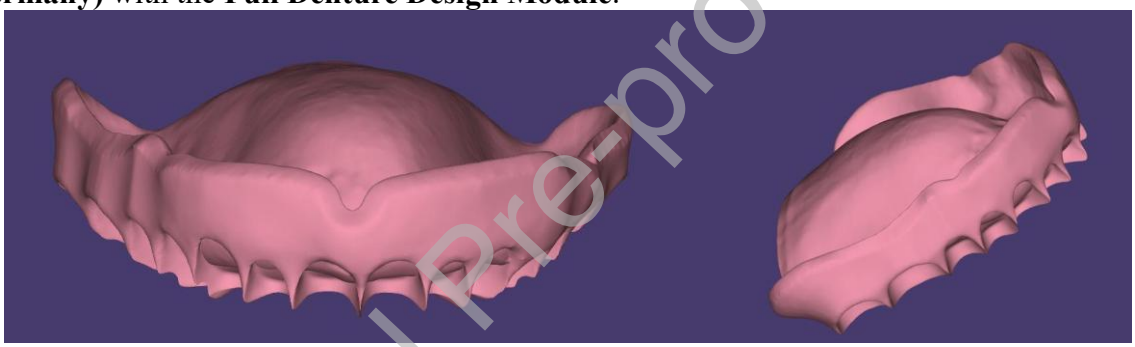


Figure 1.Reference Denture Base Design

2.3. Additive Manufacturing Process

The designed denture base was fabricated using two types of resin-based 3D printers employing DLP and LCD technologies (DentaFab, Saga pro and Whale 3Ultra, respectively).

The design was fabricated using seven build orientations, incorporating angles of 0°, 45°, and 90° in the buccal, posterior, and labial directions, as referenced in the study by Song et al. and illustrated in Figure 2 [15].

Five samples were systematically placed onto the printer building platform for each build orientation and type of 3D printer technology. Consequently, a total of seventy denture bases were fabricated (refer to Figure 3). Throughout the manufacturing process, a consistent layer thickness of 50 µm was maintained, utilizing a certified resin **(Power Resins Denture Resin)**, **which is suitable and compatible for use with both DLP and LCD 3D printers**. Importantly, support structures were automatically generated by the 3D printer software, and it was ensured that no support structures were placed on the intaglio surface.

Support structures were carefully removed using a side cutter. Then, following the manufacturer's instructions, excess material was removed by rinsing twice in 96% ethanol solution with the help of a moistened brush. After the first 3-minute rinse, a second rinse was performed in clean 96% ethanol solution for approximately 3 minutes. Since excessive

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rinsing can cause surface defects in complete dentures, the manufacturer recommends a maximum of 6 minutes of alcohol rinsing. The fully cleaned bases were then subjected to post-curing to optimize material properties and ensure biocompatibility. The curing process was performed for 15 minutes using the Fastcure device (CamCube, Montreal, Canada).

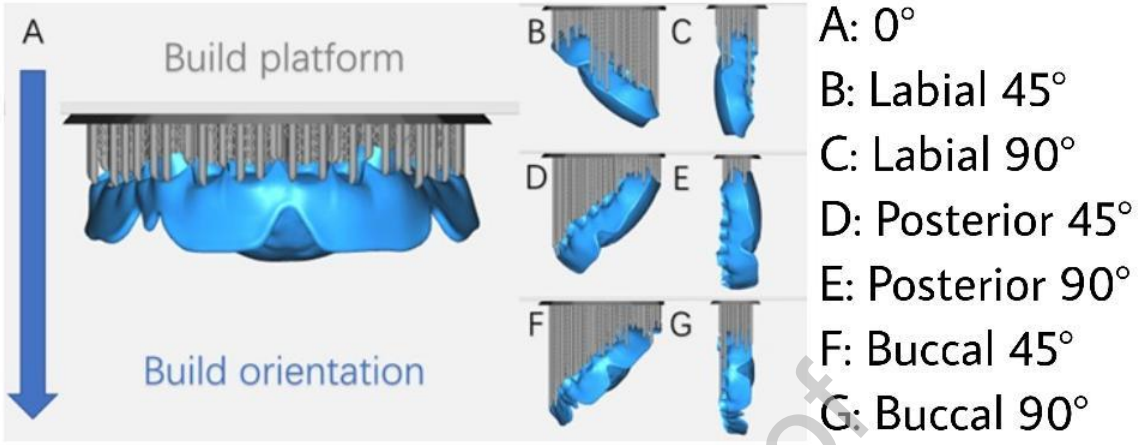


Figure 2.Build orientations[16]

Before the commencement of manufacturing, the mass of the resin was accurately measured employing a precision scale. After the manufacturing process, the residual resin contained in the printer's tank was returned to its original container to quantify the amount utilized. Additionally, the duration of the manufacturing process for each respective building platform was meticulously documented.

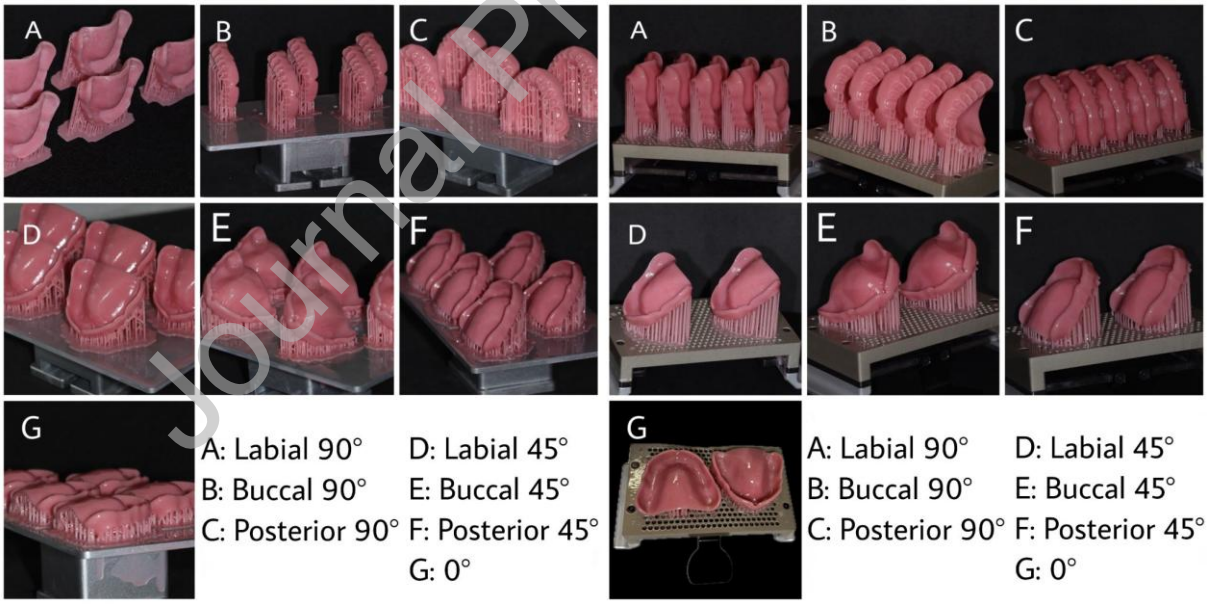


Figure 3.Denture bases manufactured using DLP and LCD technologies

2.4. 3D Deviation Analysis

A comprehensive 3D deviation analysis was conducted for each sample denture base to assess manufacturing accuracy. Before this analysis, all sample denture bases were scanned utilizing an extraoral scanner**(7Series Dentalwings,Straumann,Montreal,Canada)** to acquire the corresponding 3D geometric data. The 3D deviation analysis was carried out using Geomagic Control X metrology software (3D Systems, South Carolina, USA). In this procedure, the 3D geometric data obtained from the scanner for each denture base sample

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were initially aligned with the reference denture base design employing the best-fit option. Subsequently, a 3D comparison between the datasets was performed, generating a 3D deviation map, as illustrated in Figure 4. Within this map, the nominal deviation was established at ±50 µm, while the critical deviation was set at ±300 µm. These parameters are deemed adequate for denture base manufacturing, as corroborated by the existing literature [16,17].

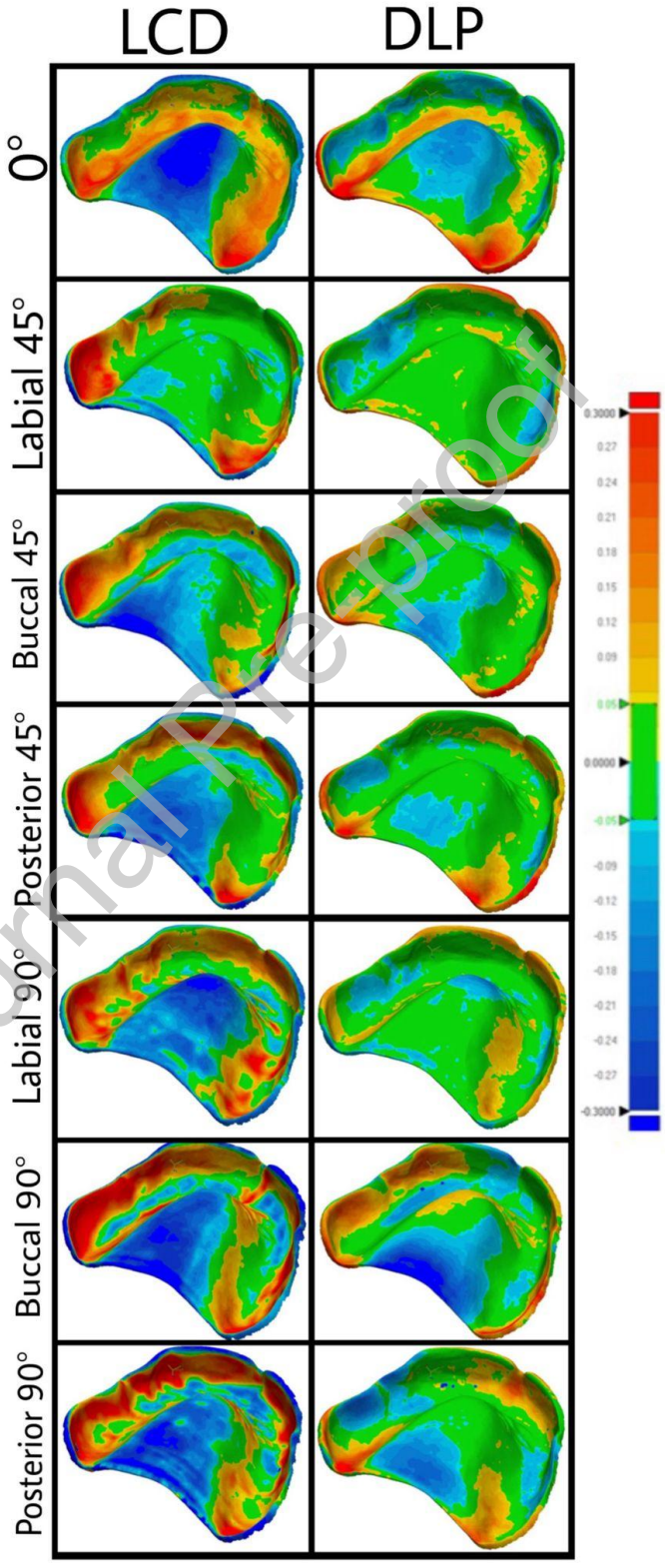


Figure 4.3D deviation map of the manufactured denture bases

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As illustrated in Figure 4, the three-dimensional (3D) deviation map encompasses numerous data points, each of which, along with its corresponding color, signifies a deviation value associated with a specific location on the denture base surface. Within the color-coded map employed to assess 3D surface deviations, a positive deviation (represented by shades ranging from yellow to red) indicates that the intaglio surface of the test denture base is located above the master cast surface, thereby suggesting a potential for tissue compression. Conversely, a negative deviation, depicted in blue, denotes that the intaglio surface of the test denture base is positioned below the master cast surface, signifying the presence of additional space. To facilitate a comprehensive comparison of the geometric accuracy of the denture base samples, the root mean square (RMS) value of these deviations was calculated, yielding a singular RMS value for each denture base sample and providing a quantitative representation of geometric accuracy.

2.6. Resin Consumption Analysis

In order to accurately assess resin consumption during the additive manufacturing process of denture bases, the resin present in the printer tank was measured using a precision scale with a resolution of 0.01 g before and after the manufacturing process. The difference between these two weights provides the total resin consumption. Upon completion of the manufacturing, the support structures on the denture base samples were first removed. Subsequently, the denture base samples were polished. Finally, each denture base sample was weighed, and the residual resin amount was determined by subtracting this weight from the previously calculated total resin consumption.

3. Results

3.1. Assessment of RMS values across different production methods and build orientations

According to the one-way ANOVA results, a statistically significant difference was observed in RMS values across build orientations for both manufacturing technologies (DLP and LCD) ($p < 0.001$). Within this context, for DLP technology, the lowest RMS value was observed at the Labial 45° orientation (0.064212 ± 0.0039), while the highest RMS value was recorded at the Buccal 90° orientation (0.13184 ± 0.0182). For LCD technology, the lowest RMS value was found at the Labial 45° orientation (0.13434 ± 0.0242), and the highest RMS value was observed at the Buccal 90° orientation (0.23287 ± 0.0061). These results indicate that the Labial 45° orientation provides the highest precision for both technologies, while the Buccal 90° orientation exhibits the lowest performance.

The independent samples t-test results revealed statistically significant differences in RMS values between DLP and LCD technologies across all build orientations ($p1 < 0.001$). These findings demonstrate that DLP technology consistently produces lower RMS values compared to LCD technology across all orientations, with the highest performance observed at the Labial 45° orientation.

The two-way ANOVA analysis indicated that the interaction effect between manufacturing method and build orientation on RMS values is statistically significant ($p2 < 0.001$). In this comparison, the best (lowest) RMS value was determined for DLP technology at the Labial 90° orientation (0.06231 ± 0.0064), while the worst (highest) RMS value was observed for LCD technology at the Buccal 90° orientation (0.23287 ± 0.0061).

In conclusion, the Labial 90° and Labial 45° orientations yielded the lowest RMS values for both technologies, while the Buccal 90° orientation produced the highest RMS values. The results demonstrate that DLP technology generates significantly lower RMS values compared to LCD technology across all orientations. The two-way ANOVA analysis confirmed that the interaction effect between manufacturing method and build orientation is a determining factor for RMS values, with this effect being statistically significant. DLP technology exhibited the highest precision at the Labial 90° orientation (0.06231 ± 0.0064), while LCD technology

produced the highest deviation at the Buccal 90° orientation (0.23287 ± 0.0061). These findings suggest that DLP technology, particularly at the Labial 90° orientation, provides more consistent and precise manufacturing outcomes. The findings are presented in Table 1 and Figure 5.

Table 1. Assessment of RMS values across different production methods and build orientations.

Orientation	Technology		p[1]	p[2]
	DLP Technology	LCD Technology		
	mean±S.D.	mean±S.D.		
0°	0,0992[3]±0,0054[C]	0,141[4]±0,0145[AB]	**<0,001**	
Buccal 45°	0,0737[12]±0,0038[AB]	0,1571[5]±0,0089[BC]	**<0,001**	
Posterior 45°	0,0793[2]±0,0104[B]	0,1358[4]±0,0091[A]	**<0,001**	
Labial 45°	0,0642[12]±0,0039[A]	0,1343[4]±0,0242[A]	**<0,001**	**<0,001**
Buccal 90°	0,1318[4]±0,0182[D]	0,2328[7]±0,0061[E]	**<0,001**	
Posterior 90°	0,0983[3]±0,0043[C]	0,212[6]±0,0136[D]	**<0,001**	
Labial 90°	0,0623[1]±0,0064[A]	0,1702[5]±0,0112[C]	**<0,001**	
p	**<0,001**	**<0,001**		

p: One-way ANOVA (Comparison of the production method across build orientations) was performed, with post-hoc multiple comparison test results indicated by uppercase letters.
p[1]: Independent sample t-test.
p[2]: Two-way ANOVA (Interaction effect of production method and build orientation) was conducted, with post-hoc multiple comparison tests indicated by numerical codes.

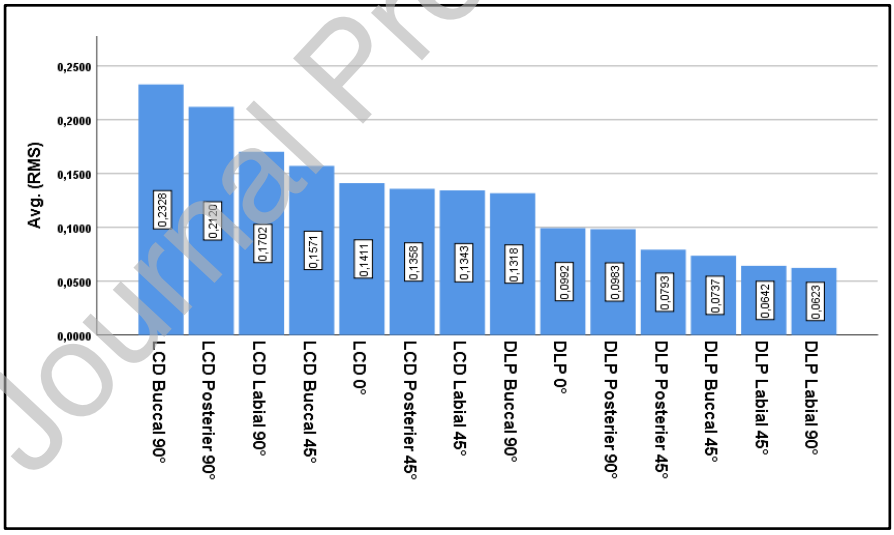


Figure 5.Variation of RMS values concerning manufacturing technology and build orientation

3.2. Assessment of Denture Base Weights across different production methods and build orientations.

According to the one-way ANOVA results, a statistically significant difference was observed in denture base weights across build orientations for both manufacturing technologies (DLP and LCD) (p1 < 0.001). Within this context, for DLP technology, the lowest denture base weight was observed at the Buccal 45° orientation (16.66 ± 0.09), while the highest denture base weight was recorded at the Posterior 45° orientation (16.88 ± 0.09). For LCD technology, the lowest denture base weight was found at the 0° orientation (17.14 ± 0.15), and the highest denture base weight was observed at the Buccal 90° orientation (18.32 ± 0.05). These results indicate that

the Buccal 45° orientation for DLP technology and the 0° orientation for LCD technology provide the lowest denture base weights, while the Posterior 45° and Buccal 90° orientations produce the highest weights, respectively.

The independent samples t-test results revealed statistically significant differences in denture base weights between DLP and LCD technologies across all build orientations ($p2 < 0.001$). These findings demonstrate that DLP technology consistently produces lower denture base weights compared to LCD technology across all orientations, with the highest performance observed at the Buccal 45° orientation (16.661 ± 0.09).

The two-way ANOVA analysis indicated that the interaction effect between manufacturing method and build orientation on denture base weights is statistically significant ($p < 0.001$). According to the analysis results, the best (lowest) denture base weight was determined for DLP technology at the Buccal 45° orientation (16.66 ± 0.09), while the worst (highest) denture base weight was observed for LCD technology at the Buccal 90° orientation (18.32 ± 0.05).

In conclusion, the Buccal 45° orientation for DLP technology and the 0° orientation for LCD technology yielded the lowest denture base weights, while the Posterior 45° and Buccal 90° orientations produced the highest weights, respectively. The results demonstrate that DLP technology generates significantly lower denture base weights compared to LCD technology across all orientations. The two-way ANOVA analysis confirmed that the interaction effect between manufacturing method and build orientation is a determining factor for denture base weights, with this effect being statistically significant. DLP technology exhibited the highest precision at the Buccal 45° orientation (16.66 ± 0.09), while LCD technology produced the highest deviation at the Buccal 90° orientation (18.32 ± 0.05). These findings suggest that DLP technology, particularly at the Buccal 45° orientation, provides more consistent and lower-weight manufacturing outcomes. The findings are presented in Table 2 and Figure 6.

Table 2. Assessment of Denture Base Weights across different production methods and build orientations.

Orientation	**Technology**		**p^1**	**p^2**
	DLP Technology	**LCD Technology**		
	mean±S.D.	**mean±S.D.**		
0°	$16,76^{1}\pm0,19^{ABC}$	$17,14^{4}\pm0,15^{A}$	**<0,001**	
Buccal 45°	$16,66^{1}\pm0,09^{A}$	$17,97^{5}\pm0,23^{CD}$	**<0,001**	
Posterior 45°	$16,88^{1}\pm0,09^{C}$	$17,56^{3}\pm0,12^{B}$	**<0,001**	
Labial 45°	$16,85^{1}\pm0,04^{BC}$	$17,7^{34}\pm0,17^{BC}$	**<0,001**	**<0,001**
Buccal 90°	$16,78^{1}\pm0,12^{ABC}$	$18,32^{6}\pm0,05^{E}$	**<0,001**	
Posterior 90°	$16,7^{1}\pm0,07^{AB}$	$17,8^{45}\pm0,19^{BC}$	**<0,001**	
Labial 90°	$16,76^{1}\pm0,03^{ABC}$	$18,2^{6}\pm0,4^{DE}$	**<0,001**	
p	**<0,001**	**<0,001**		

p: One-way ANOVA (Comparison of the production method across build orientations) was performed, with post-hoc multiple comparison test results indicated by uppercase letters.

p^1: Independent sample t-test.

p^2: Two-way ANOVA (Interaction effect of production method and build orientation) was conducted, with post-hoc multiple comparison tests indicated by numerical codes.

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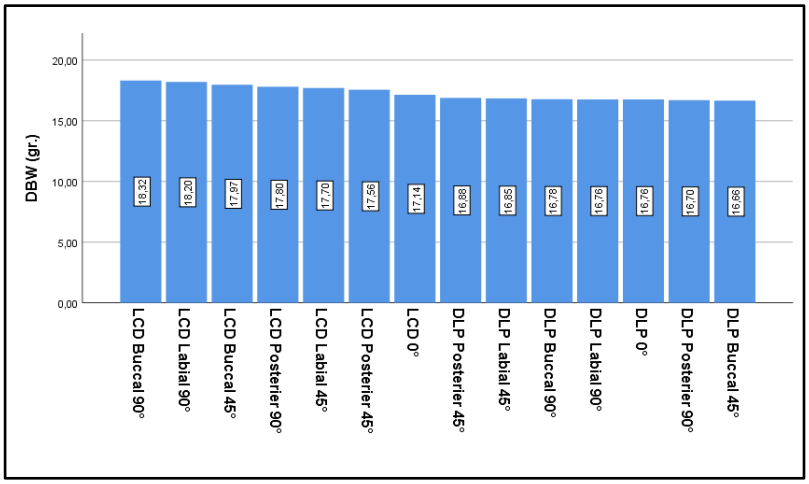


Figure 6.Variation of Denture Base Weights concerning manufacturing technology and build orientation

3.3. Assessment of Denture Base Residual Material across Different Production Methods and Build Orientations

According to the one-way ANOVA results, a statistically significant difference was observed in residual material quantities across build orientations for both manufacturing technologies (DLP and LCD) ($p1 < 0.001$). Within this context, for DLP technology, the lowest residual material quantity was observed at the Posterior 90° orientation (4.5 ± 0.07), while the highest residual material quantity was recorded at the 0° orientation (15.44 ± 0.19). For LCD technology, the lowest residual material quantity was found at the Labial 90° orientation (10.81 ± 0.4), and the highest residual material quantity was observed at the Buccal 45° orientation (21.27 ± 0.23). These results indicate that the Posterior 90° orientation for DLP technology and the Labial 90° orientation for LCD technology provide the lowest residual material quantities, while the 0° and Buccal 45° orientations produce the highest quantities, respectively.

The independent samples t-test results revealed statistically significant differences in residual material quantities between DLP and LCD technologies across all build orientations ($p2 < 0.001$). These findings demonstrate that DLP technology consistently produces lower residual material quantities compared to LCD technology across all orientations, with the highest performance observed at the Posterior 90° orientation (4.5 ± 0.07).

The two-way ANOVA analysis indicated that the interaction effect between manufacturing method and build orientation on residual material quantities is statistically significant ($p < 0.001$). Within this context, the best (lowest) residual material quantity was determined for DLP technology at the Posterior 90° orientation (4.5 ± 0.07), while the worst (highest) residual material quantity was observed for LCD technology at the Buccal 45° orientation (21.27 ± 0.23).

In conclusion, the Posterior 90° orientation for DLP technology and the Labial 90° orientation for LCD technology yielded the lowest residual material quantities, while the 0° and Buccal 45° orientations produced the highest quantities, respectively. The results demonstrate that DLP technology generates significantly lower residual material quantities compared to LCD technology across all orientations. The two-way ANOVA analysis confirmed that the interaction effect between manufacturing method and build orientation is a determining factor for residual material quantities, with this effect being statistically significant. DLP technology exhibited the highest precision at the Posterior 90° orientation (4.5 ± 0.07), while LCD technology produced the highest deviation at the Buccal 45° orientation (21.27 ± 0.23). These findings suggest that DLP technology, particularly at the Posterior 90° orientation, provides more consistent and

lower residual material quantity outcomes. The findings are presented in Table 3 and Figure 7.

Table 3. Assessment of Denture Base Residual Material across Different Production Methods and Build Orientations.

Orientation	Technology		p^1	p^2
	DLP Technology	LCD Technology		
	mean±S.D.	mean±S.D.		
0°	$15,44^{7}±0,19^{F}$	$20,28^{9}±0,15^{F}$	**<0,001**	
Buccal 45°	$13,44^{5}±0,09^{E}$	$21,27^{10}±0,23^{G}$	**<0,001**	
Posterior 45°	$10,22^{2}±0,09^{C}$	$14,3^{6}±0,12^{D}$	**<0,001**	
Labial 45°	$11,5^{4}±0,04^{D}$	$17,94^{8}±0,17^{E}$	**<0,001**	**<0,001**
Buccal 90°	$4,7^{1}±0,12^{B}$	$11,44^{4}±0,05^{B}$	**<0,001**	
Posterior 90°	$4,5^{1}±0,07^{A}$	$13,32^{5}±0,19^{C}$	**<0,001**	
Labial 90°	$4,62^{1}±0,03^{AB}$	$10,81^{3}±0,4^{A}$	**<0,001**	
p	**<0,001**	**<0,001**		

p: One-way ANOVA (Comparison of the production method across build orientations) was performed, with post-hoc multiple comparison test results indicated by uppercase letters.
p^1: Independent sample t-test.
p^2: Two-way ANOVA (Interaction effect of production method and build orientation) was conducted, with post-hoc multiple comparison tests indicated by numerical codes.

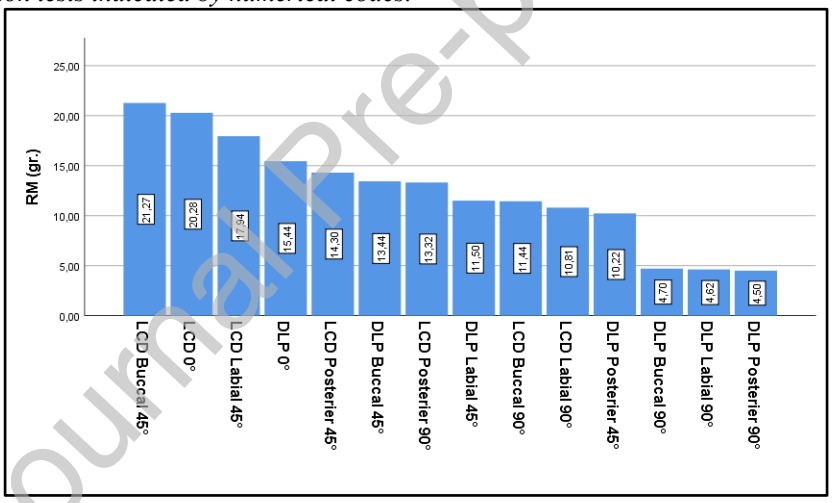


Figure 7.Variation of Residual Material concerning manufacturing technology and build orientation

3.4. Comparison of Manufacturing Technologies Based on Manufacturing Time and Resin consumption

According to the independent samples t-test results, a statistically significant difference was observed in the effects of DLP and LCD manufacturing technologies on production time and resin consumption ($p < 0.001$). Within this context, DLP technology demonstrated a significantly shorter production time, with a mean of 65.29 ± 17.09 minutes, compared to LCD technology, which had a mean of 359.57 ± 92.41 minutes.

In terms of resin consumption, DLP technology exhibited lower consumption, with a mean of 25.97 ± 4.6 units, compared to LCD technology, which had a mean of 33.44 ± 3.99 units, and this difference was found to be statistically significant ($p = 0.007$). These findings indicate that DLP technology provides more efficient and faster outcomes in terms of both production time

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and resin consumption compared to LCD technology. The findings are presented in Table 4.

Table 4. Comparison of Manufacturing Technologies Based on Manufacturing Time and Resin consumption

Variables	Technology		p
	DLP Technology	LCD Technology	
	mean±S.D.	mean±S.D.	
Manufacturing time (minute)	65,29±17,09	359,57±92,41	**<0,001**
Resin Consumption	25,97±4,6	33,44±3,99	**0,007**

p: Independent sample t-test

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4.Discussion

This in vitro study evaluated build orientation, geometric accuracy, denture base weight, residual material, manufacturing time, and resin consumption for denture bases fabricated using DLP and LCD technologies. The findings provide guidance for clinicians in selecting the appropriate technology, as improved accuracy enhances tissue adaptation and patient comfort, whereas excessive intaglio deviations may cause pressure-related pain and necessitate additional adjustments.[16,17]. Thus, an optimal balance between precise fit and biological tolerance is critical for clinical success.

The null hypotheses of this study posited that denture bases fabricated using digital light processing (DLP) and liquid crystal display (LCD) technologies, across various build orientations, would not exhibit statistically significant differences in (a) geometric accuracy, (b) base weight, (c) residual material, (d) production time, or (e) resin consumption, either among themselves or in comparison with the reference design. It was also hypothesized that no statistically significant interaction effect between the manufacturing method and build orientation would be present, and that any observed variations would be due to random chance.

However, the study results revealed statistically significant differences in geometric accuracy, base weight, residual material, production time, and resin consumption both between the manufacturing methods and among the build orientations. The observation of significant interaction effects between the manufacturing method and build orientation indicates that the effect of the production technique on denture base properties depends on the orientation used during fabrication. These findings further confirm that both the choice of manufacturing method and the selected build orientation systematically affect geometric accuracy, base weight, residual material, production time, and resin consumption, rather than these variations arising from random chance. Consequently, all corresponding null hypotheses were rejected.

Complete edentulism can cause functional, aesthetic, social, and nutritional problems. Although

implants are an alternative, conditions like osteoporosis, bisphosphonate use, radiation, cardiovascular events, smoking, poor oral hygiene, and bone quality limit their use. High costs, especially for the elderly, make conventional complete dentures widely used. [18,19]. Edentulism among the elderly remains a significant public health issue. In the United States, 26% of the elderly population is edentulous, while prevalence rates are reported as 24% in Indonesia, 11% in China, and 23% in Brazil [20]. Studies in Turkey indicate an edentulism prevalence of 48% among individuals aged 65 and above, with higher rates in the 70–74 age group compared to the 65–69 age group [21]. Another study conducted in 2007 reported a complete edentulism rate of 67.4% in those over 65 years old [22]. Data from 2023 indicate an edentulism rate of 2.6% in the 35–44 age group and 48% in the 65–74 age group [23]. These figures demonstrate a high demand for complete dentures among elderly populations.

The prevalence of edentulism indicates that the demand for conventional complete dentures will persist. Hence, ongoing research on complete denture therapy remains essential [24]. Complete dentures, which have been used in prosthetic dental treatment for many years, offer an effective treatment option for edentulous patients [25]. However, the materials and techniques used during manufacturing can cause distortion, adversely affecting the retention and adaptation of the dentures [26]. Conventional manufacturing methods require complex procedures such as waxing, investment, heat polymerization of PMMA materials, and long processing times that can extend the treatment time [27].

Complete denture retention relies on tissue surface adaptation, border seal, and saliva-related factors such as flow, viscosity, and film thickness [28]. Denture base deformation during processing is influenced by palatal shape, ridge form, material type, and processing steps [27]. Minimal distortion is crucial for proper mucosal adaptation, directly affecting retention, stability, and support [26].

Using CAD/CAM technology as an alternative to traditional methods may enhance the adaptation between the denture base and supporting tissues [29]. A high congruence between the edentulous mucosa and denture base can promote retention and mucosal support of the denture and reduce pressure points [30]. Furthermore, additive techniques can contribute to better adaptation and retention of the denture base [31]. These technologies offer shorter production times, increased efficiency, and reduced material waste, thus lowering manufacturing costs. In conventional denture manufacturing, polymerization times and multi-step laboratory procedures are time-consuming, whereas digital production workflows can be completed more rapidly, expediting the treatment process [32].

In the study by Hsu et al., complete denture bases were manufactured using conventional and digital methods, with both silicone replica and 3D digital superimposition methods used for surface comparison. Current literature indicates a preference for digital surface matching programs. In our study, the geometric accuracy of the manufactured base materials was compared using a 3D digital superimposition method; the reference design and post-production scan data were overlapped and analyzed. In this process, deviations between the surfaces were visualized using color coding, and geometric accuracy was evaluated [33].

There is still no consensus regarding the clinical acceptability of surface adaptation for complete denture bases. However, the literature suggests that deviations smaller than 0.3 mm under occlusal loads are clinically acceptable [2]. In this study, the tolerance limits of critical deviation values were determined to be within the range of ±0.3 mm, based on similar studies [33–35].

According to the literature, DLP printers are generally the preferred technology for surface adaptation [31,34]. Different manufacturing angles also significantly affect accuracy. Song et al. investigated the impact of build angle on the accuracy of denture bases and reported that labial 45° and labial 90° angles provided the best accuracy [16]. In our study, among the additive manufacturing methods, the highest accuracy was found in the labial 90° group produced by

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the DLP device.

Comparative studies in the literature show that DLP technology provides higher accuracy and surface adaptation than other methods. For example, Tosun et al. found that denture bases manufactured using DLP had better surface adaptation than those produced by LCD [35].

Lin et al. compared conventional, milling, and additive methods and reported that the milling technology offered better geometric accuracy than traditional techniques. However, additive manufacturing did not show a significant advantage over conventional techniques [36]. Nevertheless, in our study, the RMS value of 0.087 attained by DLP-produced denture bases was lower than the 0.096 RMS value reported by Lin et al. for the conventional method and is considered clinically acceptable. This finding supports that DLP technology yields results comparable to or better than conventional methods.

In our study, DLP and LCD technologies were compared across all build orientations. DLP technology demonstrated superior geometric accuracy compared to LCD in all orientations. These findings indicate that DLP technology is a more efficient and precise alternative to LCD across all build orientations.

In digital fabrication of complete denture bases, the minimum technical requirements reported in the literature include photopolymerization using a **405 nm UV light source**, an **XY resolution ≤ 50 µm**, a **layer thickness range of 0.02–0.10 mm**, and compatibility with certified **denture-base resins**.[37] In the study by Kaya et al., the accuracy of denture bases fabricated with LCD and DLP systems was compared to the conventional method, and a denture-base resin that cures at 405 nm was used. The LCD printer utilized in their study (Phrozen Mini 4K) has an **XY resolution of 35 µm** and supports a **layer thickness of 0.01–0.30 mm**. The MSLA printer used in the present study meets — and in terms of XY resolution, exceeds — these requirements; our device provides an **XY resolution of 16.8–24.8 µm**, **Z-axis resolution of 0.01 mm**, a **layer thickness setting of 0.04–0.06 mm**, and operates with a **405 nm light source (#5G Crystal Light Source Engine)**. These parameters fall within the technical limits recommended for denture-base fabrication. Additionally, the same denture-base resin used by Kaya et al. (2025) was utilized in the present study. Therefore, our printer fulfills the necessary resolution, polymerization wavelength, and material compatibility requirements for denture-base production and, in terms of XY resolution, demonstrates higher precision than the printer used in the reference study.

Although many studies examine the effect of manufacturing techniques on surface adaptation and accuracy, there is still no clear consensus on the matter. Some studies report that the DLP manufacturing method provides better surface adaptation and accuracy compared to milling, conventional pressure molding (KBM), and LCD methods [17,35,38]. In contrast, others claim that SLA or milling techniques yield superior results compared to DLP [31,33,39]. These conflicting findings may be due to differences in the printers and resin brands used. Therefore, more comprehensive and standardized studies are needed to compare manufacturing techniques effectively.

Numerous studies in the literature evaluate the geometric accuracy of additive manufacturing methods. However, most of these studies have focused solely on geometric accuracy, overlooking other essential parameters such as manufacturing time, base weight, and the amount of residual material. A comprehensive evaluation of these manufacturing methods, particularly in clinical and laboratory applications, requires assessing geometric precision and analyzing manufacturing efficiency and material waste. In this context, our study aims to fill this significant gap in the literature by evaluating not only geometric accuracy but also manufacturing time, base weight, and residual material. This multifaceted approach enables a more holistic comparison of different manufacturing strategies. Accordingly, in our study, the lowest base weight was observed in the buccal 45° group, while the shortest manufacturing time was recorded at the 0° orientation using DLP technology. **In the literature, there are a**

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limited number of studies specifically focusing on the production time of complete denture bases using different manufacturing technologies. Moreover, the available studies often present inconsistent results, which may be attributed to variations in build orientation, printer settings, and measurement methods. In this context, the present study contributes to the literature by providing a standardized and directly comparable evaluation of production time among additive manufacturing techniques. This approach helps to clarify the material- and time-related efficiency of each method within a clinically relevant framework..[16,40] These findings indicate that building orientation can significantly impact both material usage and manufacturing efficiency.

Dental materials and equipment contribute to the carbon footprint and harm natural resources, making using recyclable or reusable materials imperative. During the subtractive manufacturing of denture bases, a substantial portion of the material is discarded as waste, increasing costs [41]. In our study, DLP technology provided more efficient production processes and less material waste compared to LCD. DLP technology provided more efficient production and lower material loss compared to LCD (35.43% vs. 46.71%).

This study emphasizes the necessity of a multidimensional and comprehensive evaluation of clinical outcomes in assessing manufacturing techniques for complete denture bases. Geometric accuracy alone does not constitute a sufficient performance indicator; parameters such as manufacturing efficiency, material consumption, residual material quantity, and environmental sustainability are also critically important for denture fabrication's effectiveness and long-term success. Accordingly, future research should integrate these multiple parameters with patient-centered clinical evaluations for interdisciplinary and comprehensive analyses.

In this study, the adaptation of the denture base to the tissue surface was evaluated extraorally using overlay of scanned data only. Therefore, the dynamic properties of the soft tissues during mastication, such as mucosal resilience, saliva, adhesion, and cohesion forces, could not be assessed under in-vitro conditions. Future in-vivo studies are needed to evaluate the adaptation considering these factors. Additionally, the study was limited by the use of a single resin brand and a fixed layer thickness of 50 µm. Further research using different resin materials and varying layer thicknesses is recommended to assess their effects on geometric accuracy.

5.Conclusion

This in vitro study meticulously evaluated the build orientation, geometric accuracy, denture base weights, residual material, production time, and resin consumption involved in the fabrication of complete denture bases using Digital Light Processing (DLP) and Liquid Crystal Display (LCD) technologies.

The geometric accuracy of denture bases produced with DLP and LCD technologies was thoroughly examined. The findings indicate that DLP technology provides superior geometric accuracy compared to LCD.

Build orientation significantly affected geometric accuracy in additive manufacturing, with optimal results achieved at the labial 90° orientation for DLP and at the labial 45° orientation for LCD.

Denture base weights and residual material varied depending on the technology used. DLP technology produced lighter bases and lower material loss compared to LCD.

In terms of production time, DLP also allowed for shorter fabrication durations compared to LCD.

The limitations of this study include the use of a single resin brand, a fixed layer thickness of 50 µm, and the in vitro nature of the research. Future studies should incorporate different resin brands and layer thicknesses for more comprehensive evaluations, as well as clinical investigations to verify the relationship between build orientation and clinical outcomes.

In conclusion, DLP technology provides superior geometric accuracy, better surface adaptation,

shorter production times, and improved material efficiency compared to LCD. These advantages highlight the potential of DLP technology for more predictable, time-efficient, and clinically applicable outcomes.

CRediT authorship contribution statement

B.T.: Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – Original Draft, Writing – Review & Editing, Visualization. **E.E.:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – Original Draft, Writing – Review & Editing, Supervision, Project administration. **K.K.:** Software, Validation, Formal analysis, Resources, Writing – Review & Editing. **H.U.:** Methodology, Investigation, Data curation, Writing – Original Draft, Writing – Review & Editing.

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Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Declaration of interests

☒ 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.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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