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Influence of the print orientation and cast thickness on the accuracy of DLP master casts for fixed dental prostheses

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Abstract

Background This study aimed to evaluate the influence of different print orientations and external shell thickness on the accuracy of master casts printed with direct light processing (DLP) technology for fixed dental prostheses.

Methods Seventy-two maxillary hollow master casts were printed with a DLP printer from a standard tessellation language (STL) reference file with dental preparations for a single crown and a 3-unit fixed partial denture. Study groups consisted of six groups ($n = 12$) according to the print orientation (0, 10, and 20 degrees) and the external shell thickness of the cast (2 mm and 4 mm). Each specimen was digitized with a laboratory scanner. Discrepancies between the reference STL and the experimental STL of the printed cast were measured by using the root mean square (RMS) error. Data were statistically analyzed using one-way ANOVA and Tukey's HDS test to evaluate the trueness, and precision was assessed using the Levene test ($\alpha = 0.05$).

Results No significant differences were found in the overall trueness and precision between the groups analyzed for the print orientation and the shell thickness. The 2-mm external shell thickness demonstrated the best trueness on selected points.

Conclusions The print orientation in the range of 0 to 20 degrees and the cast thickness did not influence the overall accuracy of DLP-printed master casts for fixed prostheses with clinically acceptable range values. Trueness was affected by the external shell thickness on selected points.

Keywords Dental casts, Accuracy, 3DPrinting, Direct light processing printer, Print orientation, External shell thickness

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Introduction

In recent years, dentistry, especially prosthodontics, has evolved significantly with the development of digital technologies such as subtractive manufacturing and additive manufacturing (AM) techniques [1–5]. One of the most important applications of AM in dentistry is printing dental casts [6, 7]. Accurate dental arch replicas are essential for fabricating prostheses with proper internal and marginal fit, proximal contacts and contours, and occlusion [8]. Physical casts are particularly necessary when ceramic layering is applied and when details about adjacent and occluding teeth are crucial [9]. Poor cast accuracy can lead to misfit and extra adjustments, potentially compromising the prosthesis structure and reducing longevity, sometimes requiring work repetition [8]. Therefore, studying master casts fabricated by AM methods is crucial to ensure their reproduction accuracy and reliability in clinical applications.

To fabricate dental casts, only three of the seven categories described by the American Society for Testing and Materials (ASTM) are the most commonly used AM technologies, which are material jetting (Multijet), material extrusion or fused deposition modeling (FDM), and vat-polymerization, including stereolithography (SLA) and digital light processing (DLP) [10]. Studies have shown that SLA, DLP, and PolyJet technologies are particularly accurate in fabricating full-arch dental models [10]. Recently, vat-polymerization has emerged as the predominant AM technology for producing dental casts [11]. Differences in the vat-polymerization technology are based on the light source used for the polymerization [12, 13]; SLA uses ultraviolet (UV) laser light to polymerize the object point by point, offering greater precision in a longer time, while DLP uses a digital light projection screen to polymerize a cross-sectional layer of resin completely at once, offering high precision in a shorter time [5, 10, 12, 13].

Accuracy is defined by trueness and precision [14]. According to the International Organization for Standardization (ISO) [15], the trueness of a printed cast is defined as the deviation from the original STL file, while precision refers to repeatability, measured as the deviation of the casts from each other. Previous studies have evaluated the accuracy of diagnostic models by establishing a clinically acceptable manufacturing range (100 mm to 300 mm) [16–27]. This accuracy is determined by a multitude of variables, such as the type of resin [28–30], intraoral scanning [31], the 3D printer technology used [32–34], the geometry of the design [35, 36], slicing procedures [29], the support structures [33–35, 37–39], post-processing methods [40, 41], printing orientation [42, 43], and base type [44, 45]. For this reason, controlling these factors is crucial for obtaining highly accurate dental models. However, the scientific literature on the impact of these variables on the accuracy of printed master casts is scarce and often contradictory [46, 47]. Furthermore, there is a lack of established guidelines for optimal print settings.

Among all factors, printing orientation can significantly influence the mechanical properties of printed materials, thereby affecting printing accuracy [48, 49]. Another factor is the shell thickness. Shell thickness in 3D printing refers to the thickness of the outer walls of a printed object and plays a critical role in determining the final print's accuracy, strength, and surface finish [50]. Therefore, it is crucial to validate the clinical effectiveness of various 3D printer settings through comparative evaluations of volumetric discrepancies and quantitative deviations among AM-fabricated complete-arch casts produced [51]. Understanding and improving the accuracy of 3D-printed prosthetic models is crucial for achieving optimized outcomes in prosthesis fit, functionality, treatment success, durability, and longevity facilitated by minimizing replacements, streamlined fabrication processes, and enabling customization tailored to individual patient needs [52]. Therefore, the aim of this in vitro study was to evaluate the effect of the external shell thickness and the print orientation on the accuracy (trueness and precision) of master casts for fixed prosthodontics printed with an industrial DLP 3D printer. The null hypothesis was that no differences would be found in the accuracy (trueness and precision) of the DLP master casts manufactured with different print orientations and external shell thickness.

Methods

Master cast design

A maxillary master cast was scanned using a dental lab scanner (T710; Medit, Seoul, South Korea) with an accuracy of 4 μm to obtain an STL reference file named STL0. The master cast was a 3D-printed reference model designed to replicate a clinical scenario with dental preparations for cut-back zirconia restorations. The preparations included a single crown on the right first molar and a 3-unit fixed partial denture (FPD) extending from the left central incisor to the left canine (Fig. 1A). The abutment teeth were designed with a chamfer finish line, rounded preparation angles, an axial reduction of 1 mm, and a 6-degree convergence angle to optimize prosthetic adaptation (Fig. 1B and C).

Printer settings and study groups

The reference STL0 file was used to fabricate the experimental hollow casts using a DLP printer (Microlay Versus 385, Microlay 3D Printers, Madrid, Spain) with a 50 μm layer thickness, a horizontal resolution of 65 μm, and a vertical resolution (Z-axis) ranging from 100 to 200 μm. The prints were produced using a methacrylate-based

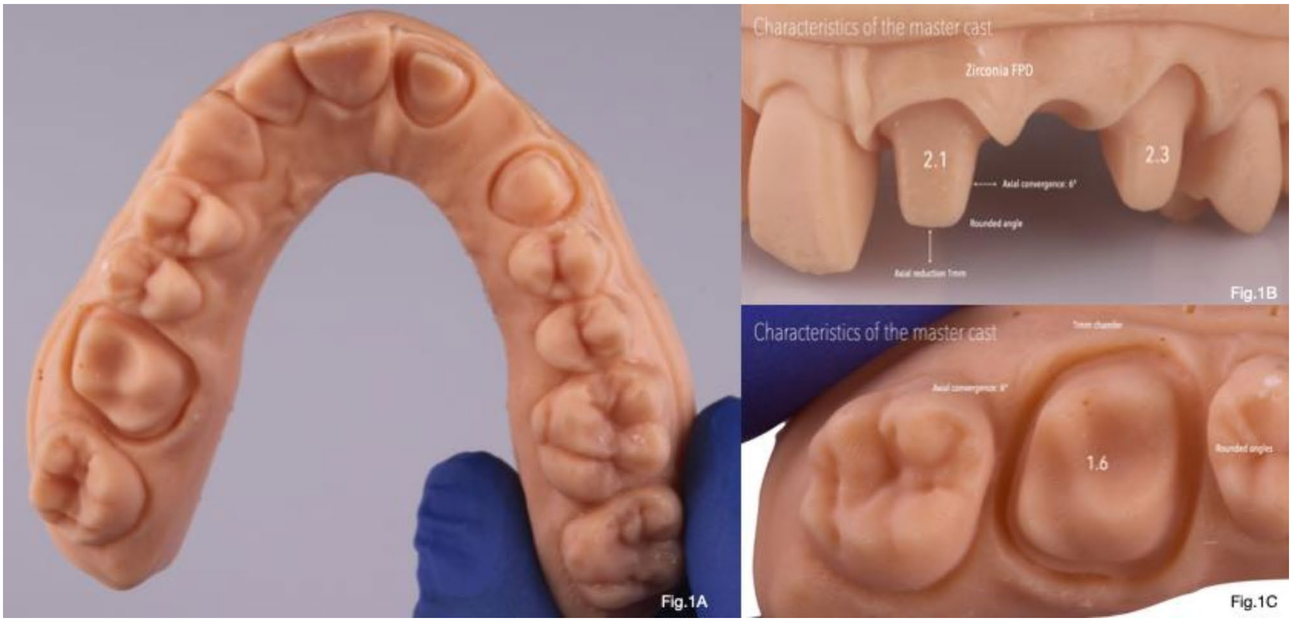

Fig. 1 **(A)** An overview of a printed master cast with two frequent dental preparation designs for fixed cut-back zirconia restorations. **(B)** The abutment teeth for a three-unit fixed partial denture (FPD) from the left maxillary central incisor to the left maxillary canine. **(C)** The abutment tooth for a single crown on the right first maxillary molar

Table 1 The classification of study groups according to cast thickness and print orientation, visualizing the six groups within the study, each with different print orientations and external shell thicknesses

Group	*N*	Thickness (mm)	Print orientation (degree)
G1	12	2	0
G2	12	2	10
G3	12	2	20
G4	12	4	0
G5	12	4	10
G6	12	4	20

resin (FotoDent model2 385 nm beige, Dreve, Unna, Germany) with a viscosity of 0.8–1.2 Pa·s, a flexural strength of ≥ 85 MPa, an elongation at break of ≥ 8%, an elastic modulus of ≥ 1,900 MPa, and a final hardness of 80–86 Shore D. Prior to the study, an expert operator (I.G.G.) calibrated the 3D printer to ensure accuracy.

Six groups were created based on the external shell thickness of each printed cast: 2 mm and 4 mm, and the print orientation used to fabricate the casts: 0-, 10-, and 20-degree (Table 1). The sample size calculation was conducted using a software program (G*Program 3.1.9.4). The calculation revealed a minimum of 12 casts per group, with an effect size of 1.2 at 0.8 power and a significance level of 0.05. A total of 72 master casts were included in the study.

Post-processing procedure for casts and superimposition

After printing, all specimens underwent a similar post-processing procedure following the manufacturer's instructions. Rinsing was carried out by washing with 96% isopropyl alcohol at 20 °C and 50% humidity for 10 min, and then the casts were dried and polymerized using a curing unit (Otoflash G171, NK-Optik) for 6 min. All specimens were stored at room temperature (23°C) in a dark container. Each printed cast was digitized using the same dental lab scanner (T710), which was calibrated before data acquisition and after the 12 scans of each group, following the manufacturer's recommendations, and no later than 48 h after printing. To avoid errors in the superimposition of the STL generated, irregular areas were eliminated. The STL files were imported into a reverse engineering software program (Geomagic Control X; 3D Systems, Rock Hill, SC) for further analysis.

The casts were aligned and superimposed by using the best-fit technique [43, 53]. The measurements obtained in the STL0 file were used to measure the discrepancy with the experimental STL files. The root mean square (RMS) and average maximum and minimum values were displayed in the software. Furthermore, 36 points were marked in critical areas of each experimental cast—including the cusps of all teeth, the finish line, and the middle of the pontic area—to evaluate deviations from the STL0 file based on point location (anterior or posterior) (Fig. 2; Table 2). Additionally, in the regions designated for fixed prostheses, reference points 5, 6, 7, 13, 16, 21, 22, 23, 24, 25, 26, 27, and 28 were analyzed along the X, Y, and Z axes. The buccolingual variation was assessed along the X axis, mesiodistal variation along the Y axis, and occlusogingival variation along the Z axis. By evaluating these deviations, it was possible to determine

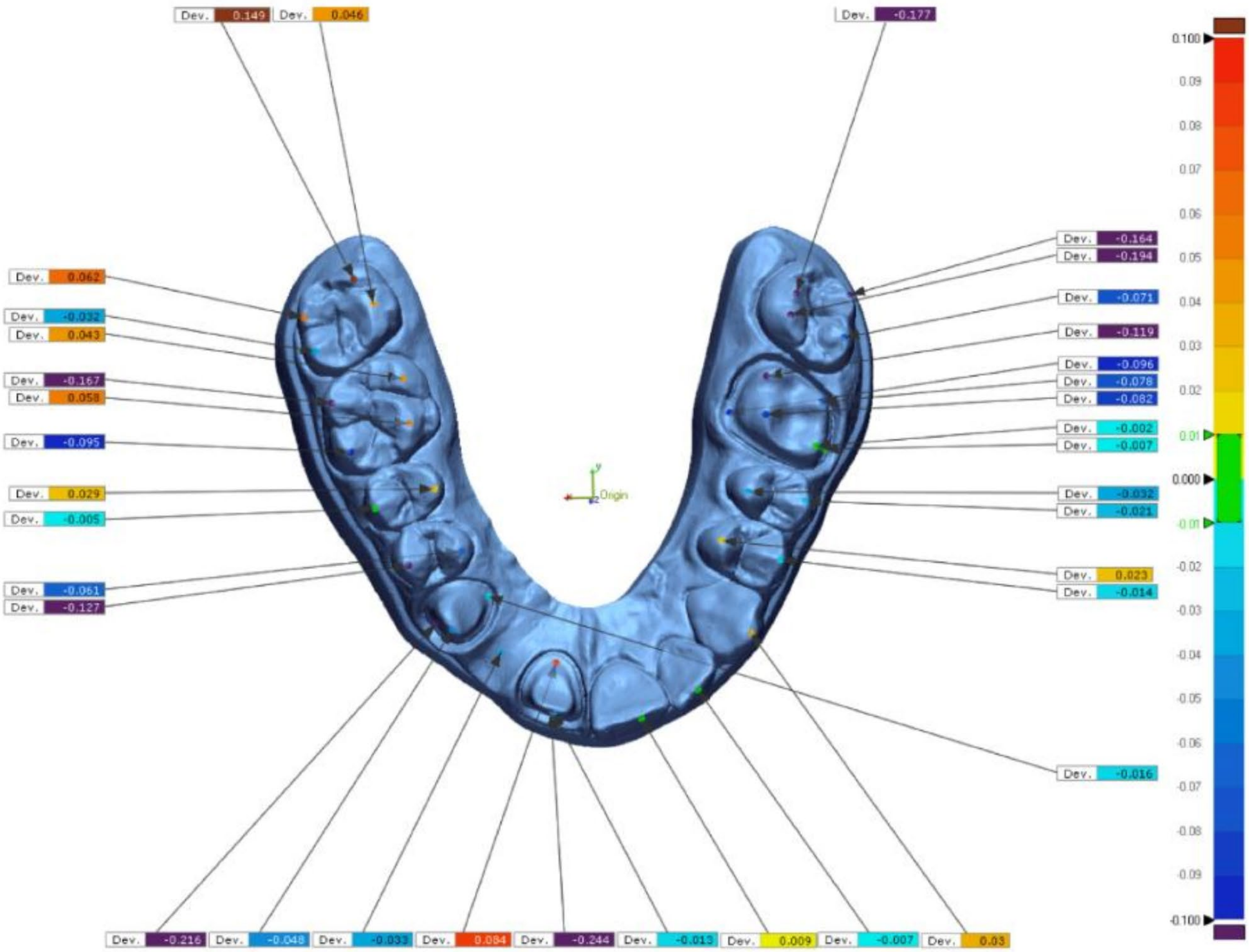

Fig. 2 The digital file of the complete-arch cast displays 36 points marked in critical areas, indicating where measurements were taken on each cast

whether, despite the overall model showing no significant differences in accuracy based on RMS values, discrepancies might still occur in the critical areas essential for restoration fabrication. Specifically, deviations in the X axis could result in improper seating on the finish line or over-contouring, while discrepancies in the Y axis could cause the restoration to sit incorrectly on the finish line or lose contact with adjacent mesial and distal teeth. Similarly, variations in the Z axis could lead to an inadequate fit, either failing to sit on the finish line or leaving excessive occlusal space that would need to be compensated for with cement, ultimately compromising the restoration's adaptation.

Comparisons between groups and statistical analysis

To evaluate the external shell thickness, the following comparisons were established between groups G1 and G4, G2 and G5, and G3 and G6. To assess the print orientation, differences were established between the groups G1 and G2, G2 and G3, G1 and G3, G4 and G5, G5 and G6, and G4 and G6. The overall cast accuracy (trueness and precision) and the accuracy at the selected 36 points were evaluated. Trueness was defined as the closeness of each of the experimental casts with the reference scan, and precision was defined as the RMS error variations or standard deviation (SD) per group [43, 53].

The Shapiro-Wilk test revealed that the RMS data presented normal distributions ($p > 0.05$). One-way ANOVA and the post hoc Tukey HDS multiple pairwise comparisons were employed to analyze the overall trueness. Precision was assessed by using the Levene test. For the accuracy analysis of the selected points, given the non-normality of data, the Kruskal Wallis test was applied. The statistical analysis was performed with statistical software (IBM SPSS Statistics, v.26; IBM Corp, Armonk, NY). ($\alpha = 0.05$).

Table 2 Selected points indicating the exact position of each point correspond to each tooth

Tooth	Points
17	14 (palatine cuspid), 15 (vestibular cuspid), 19 (palatine cuspid), 20 (vestibular cuspid)
16	13 (palatine mesial cuspid), 16 (vestibular mesial cuspid), 21 (vestibular distal cuspid), 22 (palatine mesial cuspid), 23 (vestibular finish line), 24 (palatine finish line)
15	12 (palatine cuspid), 17 (vestibular cuspid)
14	11 (palatine cuspid), 18 (vestibular cuspid)
13	10 (cuspid)
12	9 (middle incisal edge)
11	8 (middle incisal edge)
21	6 (middle incisal edge), 26 (vestibular finish line), 27(palatine finish line)
22	7 (middle pontic area)
23	5 (cuspid), 25 (vestibular finish line), 28 (palatine finish line)
24	4 (palatine cuspid), 36 (vestibular cuspid)
25	3 (palatine cuspid), 35 (vestibular cuspid)
26	2 (palatine cuspid), 31 (vestibular cuspid), 32 (vestibular cuspid), 33 (palatine cuspid)
27	1 (palatine cuspid), 29 (vestibular cuspid), 30 (vestibular cuspid), 34 (palatine cuspid)

Table 3 Descriptive statistics for MinDV (the minimum deviation of the models with respect to the original STL), MaxDV (the maximum deviation of the models with respect to the original STL), and RMS error calculations (the global deviation of the models with respect to the original STL) among the tested groups

Group	minDV	maxDV	RMS
1	-0.362 ± 0.127	0.207 ± 0.067	0.145 ± 0.049
2	-0.472 ± 0.534	0.181 ± 0.056	0.141 ± 0.06
3	-0.325 ± 0.069	0.2 ± 0.043	0.131 ± 0.027
4	-0.304 ± 0.071	0.203 ± 0.064	0.132 ± 0.028
5	-0.331 ± 0.088	0.192 ± 0.075	0.138 ± 0.041
6	-0.319 ± 0.077	0.233 ± 0.076	0.142 ± 0.032

minDV, Minimum deviation value (mm) [(Overall Mean ± SD)]; maxDV, Maximum deviation value (mm) [(Overall Mean ± SD)]; RMS, Root Mean Square

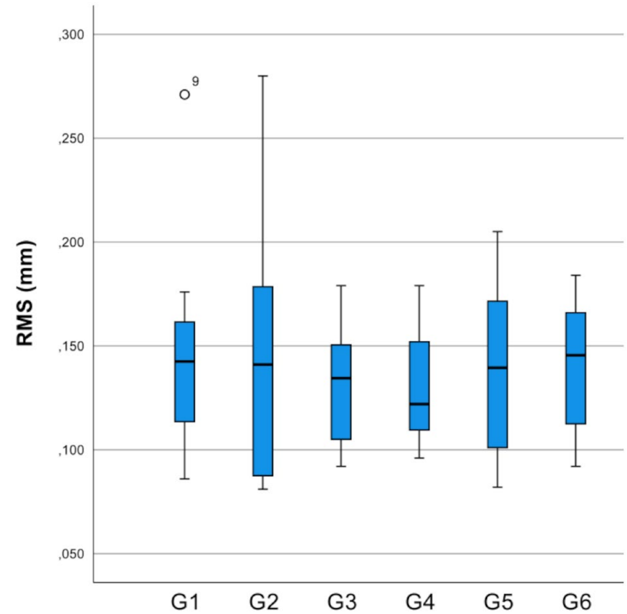

Fig. 3 Box plot for overall RMS error discrepancies (mm) for each of the analyzed groups

Results

The overall minimum, maximum, and mean ± SD RMS error discrepancies (trueness ± precision) are presented in Table 3. The overall trueness mean values obtained for all the casts of the different groups ranged between (0.103 mm and 0.194 mm). Group 1 showed the lowest trueness (0.145 mm), while Group 3 had the best trueness (0.131 mm). One-way ANOVA revealed no significant differences among the groups. No differences were found for the external shell thickness between G1with G4 ($p = 0.429$), G2 with G5 ($p = 0.853$), and G3 with G6 ($p = 0.522$). Likewise, no differences were observed for the print orientation: with G2 ($p = 1$), G1 with G3 ($p = 1$), G2 with G3 ($p = 1$), G4 with G5 ($p = 1$), G4 with G6 ($p = 1$), and G5 with G6 ($p = 1$). Regarding the overall precision, the Levene test showed no significant differences ($p = 0.139$) among the groups. Group 3 obtained the best precision value, and Group 2 the lowest (Fig. 3).

When the comparison between the reference points was made, the Kruskal-Wallis test revealed differences in trueness for the external shell thickness. The groups with 2 mm thickness showed better trueness compared to the groups with 4 mm thickness (Table 4). No differences ($p > 0.05$) were found for the print orientation. Furthermore, a relationship between the points marked in the anterior area and those marked in the posterior region of the cast could not be demonstrated. Finally, when the comparison was made in the X, Y, and Z axis at the selected points on the areas to receive the fixed prosthesis, no differences in trueness were found for the print orientation. However, differences were observed for the external shell depending on the point and axis (Table 5) (Fig. 4A, B, C). The groups with 2 mm thickness demonstrated better trueness for the incisal edge, canine cuspid, and first molar vestibular and palatine mesial cuspid in the X, Y, and Z axis. Regarding the finish line of the abutment teeth, only the canine points showed differences in the three axes. The groups with 4 mm thickness obtained the best trueness (Fig. 4D).

Discussion

Based on the results of the present study, the print orientations and shell thickness of the casts evaluated showed no differences in the overall trueness and precision. However, differences were found in the accuracy of the shell thickness when compared to the reference points evaluated. Therefore, the null hypothesis was partially

Table 4 Kruskal-Wallis results for differences between reference points for the external shell thickness. Statistically significant differences (*p*-value) among all comparisons are indicated. The group with a value closer to STL0, indicating greater trueness, is also identified

Groups	Reference Points	*p*-value
G1 > G4	3	0.009
	20	0.017
	25	0.007
	17	0.056
	35	0.04
G2 > G5	2	0.001
	3	0.001
	5	0.001
	6	0.001
	7	0.001
	8	0.01
	12	0.001
	13	0.024
	16	0.032
	33	0.004
G3 > G6	2	0.015
	3	0.001
	4	0.006
	5	0.001
	6	0.013
	7	0.003
	8	0.004
	11	0.03
	12	0.001
	13	0.001
	36	0.014

accepted, as no statistically significant differences were found at the overall model level, but significant differences did emerge upon evaluating specific selected points. The partial differences can be attributed to the fact that when evaluating the model globally, the discrepancies among millions of points tend to average out or cancel each other. However, when assessing discrepancies at a single point, this averaging effect does not occur. The printed master casts evaluated presented a discrepancy trueness value ranging from −0.141 mm to 0.145 mm. The printed casts manufactured at 0-degree and 2 mm shell thickness had the highest mean value, while the lowest discrepancies were observed in the 10-degree and 2-mm thickness groups.

The trueness values observed in this study ranged from 103 µm to 194 µm. These deviations quantify the differences between the printed casts and the original STL reference file under the selected printing conditions. Although they fall within the range reported by previous studies [16–27] using similar additive manufacturing technologies—representing an expected level of accuracy for dental model fabrication—these values should not be interpreted as thresholds of clinical acceptability. This study focused solely on the accuracy of the 3D-printed casts themselves and did not evaluate the cumulative discrepancies that may arise throughout the complete workflow of prosthesis fabrication, including internal and marginal fit. Therefore, the results must be considered strictly within the scope of cast manufacturing accuracy.

Regarding the variable print orientation, in the study, the 10-degree casts obtained the best trueness, and the 20-degree cast had the best precision. However, no differences in trueness and precision between the different print angulations evaluated (0-, 10-, and 20-degree) were observed. The authors are unaware of previous studies evaluating this variable for full-arch master casts for fixed prostheses, and it was not possible to compare the results of the study. Prior studies evaluating the influence of the print orientation on the accuracy of casts are sparse, and they were made on diagnostic casts. In addition, there is no homogeneity among the studies, and it is thus difficult to draw accurate conclusions and compare the results, as they did not use the same AM technology and degree of orientation. The findings aligned with Short et al. [47], who found minimal discrepancies at 0° and 20° on diagnostic casts, and Revilla-Leon et al. [54], who demonstrated superior trueness at 0° on occlusal devices using an SLA printer. Maneiro Lojo et al. [43] achieved optimal trueness at 22.5° and precision at 67.5°. Ko et al. [46], utilizing a DLP printer, observed the greatest discrepancies at 0° on diagnostic casts. Most authors noted increased differences with greater build orientation yet consistently found best trueness results between 0° and 22° for diagnostic models. This in vitro study assesses the accuracy (trueness and precision) of treatment models crucial for ensuring fixed prosthesis fit. Consequently, the study focused exclusively on angles of 0°, 10°, and 20°. The hollow cast base design with an external shell thickness of 2 and 4 mm was the second variable evaluated in the study.

The results showed the best accuracy for the 2-mm thickness casts and the best precision for the 4-mm thickness casts, although no differences could be demonstrated between 2- and 4-mm thickness. The results are consistent with the only previous study, to the best knowledge of the authors, that evaluated the accuracy of full-arch hollow casts printed with a DLP printer and different shell thicknesses (1- and 2-mm) [45]. Limited studies assessed the influence of the base design on the accuracy of full-arch casts. The cast base can be created using different designs. The solid base is used by orthodontists, while in prosthodontics, there are no recommendations on the optimal base cast design [44, 45, 55]. Revilla-Leon et al. evaluated the accuracy of casts with three base designs: hollow, honeycomb, and solid, using a material jetting printer and a DLP printer. The results showed that the hollow base obtained the best accuracy

Table 5 Kruskal-Wallis results for differences between reference points for the external shell thickness, distinguished by X, Y, and Z axes. Statistically significant differences (*p*-value) among all comparisons are indicated. The group with a value closer to STL0, indicating greater trueness, is also identified

Tooth	Point	Axis	Group	Mean (mm)	Group	Mean (mm)	*p*-value
Left maxillary canine	5	X	G1	0.021	G4	0.018	0.004
	5		G2	0.016	G5	0.036	0.001
	25			0.111		0.06	0.001
	28			0.081		0.041	0.001
	5		G3	0.018	G6	0.04	0.001
	25			0.091		0.059	0.022
	28			0.083		0.04	0.048
	5	Y	G1	0.057	G4	0.037	0.043
	5		G2	0.042	G5	0.097	0.001
	25			0.089		0.049	0.001
	28			0.008		0.004	0.012
	5		G3	0.05	G6	0.108	0.001
	25			0.073		0.048	0.022
	28			0.007		0.004	0.039
	5	Z	G1	0.069	G4	0.061	0.043
	25			0.028		0.024	0,003
	5		G2	0.052	G5	0.119	0.001
	25			0.031		0.017	0.023
	28			0.106		0.053	0.012
	5		G3	0.061	G6	0.132	0.001
	28			0.096		0.052	0.045
Left maxillary central incisor	6	X	G2	0.026	G5	0.046	0.004
	6		G3	0.031	G6	0.049	0.001
	6	Y	G2	0.101	G5	0.177	0.001
	6		G3	0.119	G6	0.19	0.001
	6	Z	G2	0.033	G5	0.058	0.004
	6		G3	0.039	G6	0.062	0.001
Right first maxillary molar	13	X	G2	0.004	G5	0.008	0.019
	16			0.013		0.022	0.03
	13		G3	0.003	G6	0.009	0.001
	13	Y	G2	0.007	G5	0.014	0.015
	16			0.012		0.02	0.032
	13		G3	0.006	G6	0.015	0.001
	13	Z	G2	0.047	G5	0.101	0.016
	16			0.057		0.094	0.03
	13		G3	0.04	G6	0.108	0.001

(34.00 ± 45.00 μm) [44]. Park et al. [8] used a DLP printer to print U-shaped casts with two types of resin. The mean trueness values did not differ between both groups, but there was a distribution of the values in the lower 50% in relation to the median value, which could be explained by the two types of resin used, which is reflected in a contraction of the posterior teeth and a need for a stabilization structure of the transverse arch [8]. Shin et al. [56] developed a study with two types of U-shaped arches, without a palate or with a transverse arch plate attached to the palate area. Each group was subdivided into five groups: 1.5-mm and 4-mm thick shell cast, hexagon-filled cast, roughly-filled cast, and fully-filled cast. The results exhibited the best accuracy (trueness and precision) for the transverse arch plate regardless of the intaglio structure [56]. Camardella et al. [24] carried out a study with three different types of bases: regular base, horseshoe-shaped base, and horseshoe-shaped base with a bar, as well as two types of printers (DLP and Polyjet). The results showed that the regular and horseshoe-shaped base with a bar were accurate, regardless of the 3D printer used [24]. However, Park et al. [8] evaluated the dimensional accuracy of 3D complete-arch printed casts with four different printer technologies, showing the results of dimensional variations for the assessed groups. Likewise, Rungrojwittayakul et al. reported that

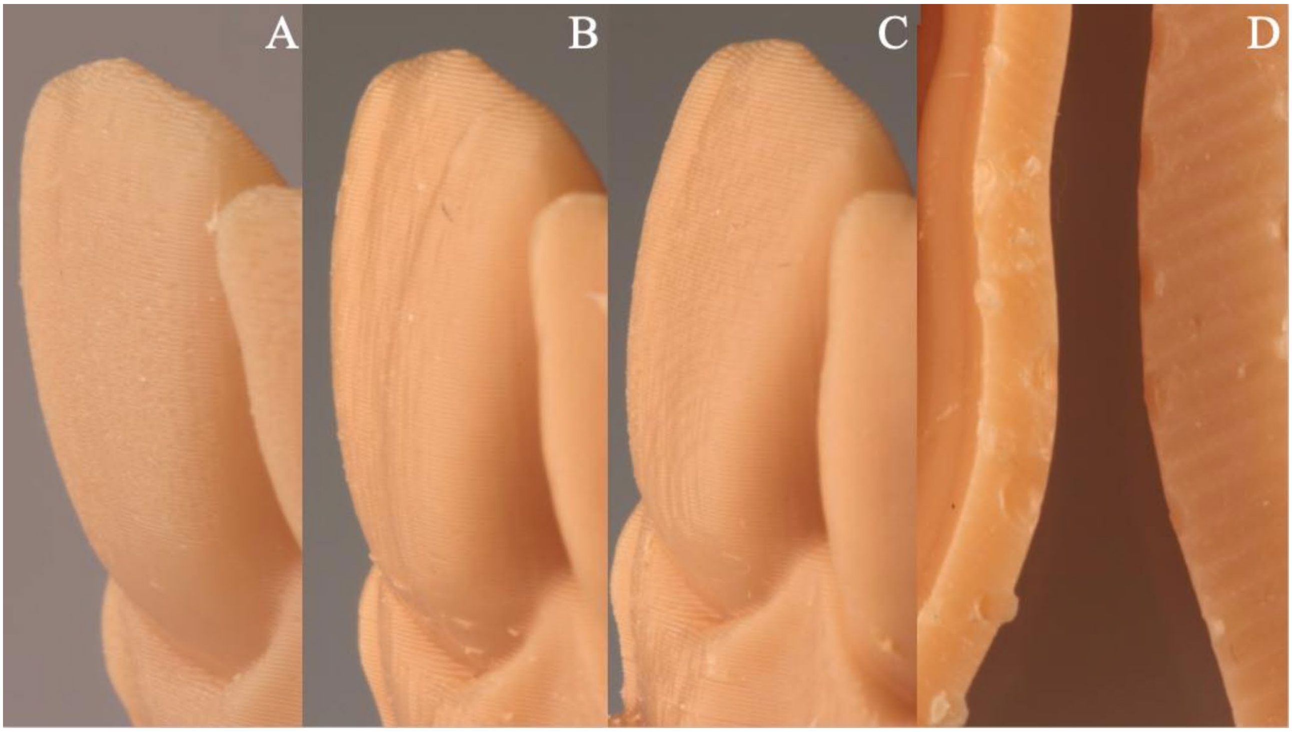

Fig. 4 **(A)**: Surface characteristic analysis of the printed casts based on print orientation (G1); **(B)**: Surface characteristic analysis of the printed casts based on print orientation (G2); **(C)**: Surface characteristic analysis of the printed casts based on print orientation (G3); **(D)**: Surface characteristic analysis of the printed casts based on internal cast thickness (G1, G4)

the accuracy of 3D-printed casts was affected by the printer technology regardless of the base design [55]. The hollow base design is commonly used in dental laboratories for economic reasons, as it minimizes material usage and reduces manufacturing time [44, 55, 56]. This rationale was one of the factors in selecting internal shell thicknesses of 2 mm and 4 mm, as optimizing material consumption is essential for efficiency. However, further studies are necessary to evaluate the influence of the base cast design and the shell thickness with different printers on the accuracy of the printed casts.

In the study, differences in the print orientation trueness could not be demonstrated between the anterior or posterior zone of the casts. However, when the selected points were analyzed, most areas showed better results in casts with 2 mm thickness than with 4 mm thickness, regardless of the angulation degree. Likewise, a cast with 2 mm thickness demonstrated better trueness for the abutment tooth (cuspid and incisal edge) in the three axes. No differences were found for the reference points at the finish line except for the canine. This aspect is significant because the selected points are located in areas of maximum height on the cast, which are essential for ensuring precise adjustments in the final restoration. Achieving greater trueness with a 2 mm shell thickness at these critical points enhances the passive fit of the restoration and improves occlusal accuracy, ultimately contributing to better prosthetic adaptation and clinical outcomes. The evaluation of deviations in the X, Y, and Z directions is a widely accepted approach to assessing the accuracy of printed dental casts. Previous studies have used point-based measurements to analyze discrepancies between experimental and reference models. For instance, Rungrojwittayakul et al. [55] established 48 measurement points on diagnostic casts produced with different 3D printers to evaluate overall discrepancies. However, their study did not specifically assess deviations along the X, Y, and Z axes, nor did it distinguish between the anterior and posterior sectors of the cast, limiting its applicability to understanding spatial variations in accuracy [55]. Similarly, Yoo et al. investigated the accuracy of treatment models for posterior fixed prostheses by measuring deviations at selected points on a prepared molar and a contact point. However, their methodology did not account for axis-specific deviations, and their study utilized different printers and printing parameters, making direct comparisons with our findings difficult [57].

The accuracy of DLP-printed dental models can be influenced by multiple factors related to the printer's optical and mechanical components. In the X and Y directions, potential inaccuracies stem primarily from the resolution of the DLP engine and the projection system. The DLP technology relies on a digital micromirror device (DMD) to project light patterns onto the resin vat, where the polymerization of each layer occurs. However, the precision of this projection is affected by the pixel size and uniformity of the light intensity across the build platform. Minor distortions in light distribution or pixel placement can lead to small deviations in trueness, particularly in areas with fine details such as margins and occlusal surfaces. In the Z direction, inaccuracies may arise due to the printer's mechanical configuration, rigidity, and the control of the Z-axis elevation. The layer-by-layer curing process depends on precise vertical movement, which is controlled by a stepper motor and guide rails. Mechanical instability, slight misalignments, or variations in resin shrinkage during curing can introduce discrepancies along this axis. The resolution of the Z-axis (100–200 µm) is typically coarser than the horizontal resolution (65 µm), potentially contributing to greater variations in vertical accuracy compared to lateral dimensions. Furthermore, variations in resin properties, such as viscosity, polymerization kinetics, and post-curing shrinkage, may differentially affect accuracy in different spatial directions. To ensure the highest possible accuracy, the printer was calibrated by an expert operator before the study. However, despite these efforts, inherent limitations in DLP printing technology and resin behavior may still contribute to small deviations, particularly in complex anatomical structures.

Additionally, the alignment technique plays a fundamental role in determining the accuracy of 3D-printed dental models [58]. In this study, a global best-fit alignment method was used, ensuring a robust comparison of the printed casts by superimposing STL files based on millions of verification points. This process was performed only when the discrepancy was less than 1 µm, guaranteeing an optimal alignment. While a local best-fit alignment focused on the abutment teeth could have provided additional insights, it might not accurately reflect deviations along the X, Y, and Z axes. These axes are critical in evaluating the settlement and adaptation of the final prosthetic restoration. Additionally, distributing reference points across the entire model permitted the analysis of differences between anterior and posterior regions, further strengthening the validity of the findings.

The comparison of this study's results with previous research is challenging due to variations in AM technologies, printer types, print orientations, resin compositions, cast base designs, and measurement methodologies. Multiple parameters influence the accuracy of AM-fabricated casts (trueness and precision), yet previous studies have not comprehensively analyzed all these factors together. By specifically analyzing discrepancies in the X, Y, and Z directions, this study provides a more detailed understanding of how dimensional accuracy varies in different spatial planes. This approach allows for determining whether deviations in trueness are uniform across the cast or if certain regions are more prone to inaccuracies. This level of detail is particularly relevant for fixed prosthodontics, where precise adaptation in all three spatial axes is critical for optimal fit and function. Consequently, the absence of standardized protocols integrating all these variables makes it difficult to establish definitive guidelines for manufacturing each type of dental product using AM technologies.

Limitations of the current study included the utilization of a singular AM technology, a specific type of resin, uniform printing layer thickness, consistent post-processing procedures, and a standardized base cast design. Another limitation was the use of a global best-fit alignment method, which, while ensuring a standardized assessment, may reduce localized discrepancies by averaging deviations across the entire model. This could potentially obscure minor variations in critical areas such as the abutment teeth, where precise adaptation is essential for prosthetic fit. Future investigations should comprehensively analyze all factors influencing the precision of printed master casts, including varying layer thicknesses, diverse configurations and placements of support structures, and different post-processing protocols. Additionally, research should assess these variables across various types of 3D printers and base cast designs to enhance the robustness of findings. Clear and standardized protocols tailored to each clinical indication and specific 3D dental printer type are essential. Moreover, future studies should incorporate both global and local alignment techniques to provide a detailed evaluation of regional accuracy variations, particularly in areas critical for prosthetic adaptation and clinical outcomes.

The practical implications of this study are significant for both dentists and dental technicians. By adhering to the conditions outlined—specifically using the same additive manufacturing technology, 3D printer, resin material, and post-processing protocols—highly accurate dental models can be achieved for fixed prosthesis treatments. For dental laboratories, these findings define the optimal printing parameters, including print orientation and external shell thickness, for producing treatment models with this specific type of printer. The standardized approach recommends a 2 mm shell thickness and a 20-degree orientation angle, which has been shown to enhance efficiency and accuracy in model fabrication. Similarly, in clinical settings equipped with this particular 3D printer, these findings provide essential guidelines for achieving precise treatment models. This ensures that both dental professionals and patients benefit from consistent and reliable printing parameters, ultimately streamlining workflow and improving clinical outcomes.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. The print orientation tested did not influence the accuracy (trueness and precision) of master casts printed with the DLP printer tested.
2. The shell thickness of the master casts printed with the DLP printer tested did not influence the overall accuracy (trueness and precision). However, when analyzing the selected points, the master casts with 2 mm thickness had better trueness than the 4 mm thickness.
3. All printed master casts achieved a clinically acceptable trueness.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions

Conceptualization: I.G.G. and M.J.S.; Methodology: I.G.G. and J.P.; Software: I.G.G. and V.R.A.; Validation: M.J.S. and J.P.; Formal analysis: I.G.G. and V.R.A.; Investigation: I.G.G. and C.L.S.; Resources: M.J.S. and C.L.S.; Data curation: I.G.G. and J.P.; Writing—original draft preparation: I.G.G., V.R.A., and C.L.S.; Writing—review and editing: M.J.S., J.P., and S.A.M.; Visualization: I.G.G.; Supervision: M.J.S. and J.P.; Project administration: M.J.S. and J.P. All authors have read and approved the published version of the manuscript.

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Data availability

The data presented in this study are available upon request from the corresponding author.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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