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COMPARISON OF DIMENSIONAL ACCURACY BETWEEN PROFESSIONAL DLP AND CONSUMER LCD 3D PRINTERS FOR DENTAL MODEL FABRICATION

Alexandru-Victor Burde[1], Michel Beyer[2,3], Marius Ciprian Manole[4]*, Rareş Mario Borşa[5], Sabina-Gabriela Crețu[1], Mihaela Hedeșiu[6], Cosmin Sinescu[7]

[1] "Iuliu Hațieganu" University of Medicine and Pharmacy, Cluj-Napoca, Romania, Faculty of Nursing and Life Sciences, Department of Dental Technology ,400012 Cluj-Napoca, Romania
[2] University Hospital Basel, Department of Oral and Cranio-Maxillofacial Surgery, 4031 Basel, Switzerland
[3] Medical Additive Manufacturing Research Group (Swiss MAM), Department of Biomedical Engineering, University of Basel, 4123 Allschwil, Switzerland
[4] "Iuliu Hațieganu" University of Medicine and Pharmacy, Cluj-Napoca, Romania, Faculty of Dentistry, Department of Dental Propedeautics and Aesthetics, 400012 Cluj Napoca, Romania
[5] Institute of BioMedical Research—MedFUTURE, Department of NanoSciences, 400349 Cluj-Napoca, Romania
[6] "Iuliu Hațieganu" University of Medicine and Pharmacy, Cluj-Napoca, Romania, Faculty of Nursing and Life Sciences, Department of Oral and Maxillofacial Surgery and Radiology, 400012 Cluj Napoca, Romania
[7] "Victor Babes" University of Medicine and Pharmacy, Faculty of Dentistry, Department of Prosthesis and Dental Materials, 300041 Timisoara, Romania

Corresponding author; *e-mail:* marius.manole@umfcluj.ro

ABSTRACT

Aim of the study: The aim of this study was to compare the dimensional accuracy of dental models fabricated using a medical-grade DLP printer and a consumer-grade LCD printer. **Materials and methods**: Standardized maxillary and mandibular STL models were printed using a DLP system (Bego Varseo S) and an LCD system (Phrozen Mini 8K S). A total of 20 models were digitized and compared with the reference files using three-dimensional surface deviation analysis. Dimensional trueness was assessed using root mean square (RMS) and squared mean surface distance (SMSD) metrics, followed by non-parametric statistical analysis. **Results:** Both systems produced comparable dimensional accuracy, with no statistically significant differences in RMS or SMSD values between groups. Maxillary models showed higher deviations than mandibular models for both technologies. A strong correlation was observed between RMS and SMSD values. **Conclusions:** Within the limitations of this study, consumer-grade LCD printing demonstrated dimensional accuracy comparable to that of a medical-grade DLP system for dental model fabrication.

Key words: digital dentistry, 3D printing, dental models, dimensional accuracy, vat photopolymerization

INTRODUCTION

The integration of digital technologies into dental medicine has fundamentally transformed the workflow for prosthetic and orthodontic rehabilitation, changing the approach from conventional analog methods to computer-aided design and computer-aided manufacturing (CAD/CAM) (1). A key component of this digital workflow is the production of physical dental models, which form the basis for diagnostic assessment, treatment planning, and the fabrication of prosthetic devices (2). Prior to the adoption of digital dentistry, the accuracy of dental models

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relied on the physical characteristics of impression materials and dental stone (3). With the transition to digital workflows, accuracy is now defined by the quality of intraoral scanning and the precision of additive manufacturing technologies.

Additive manufacturing techniques, particularly 3D printing, have emerged as pivotal tools in this paradigm shift, enabling the creation of intricate dental models with previously unattainable geometric complexities and material efficiencies (4)

Among the various additive manufacturing technologies available, vat photopolymerization has emerged as the dominant method in dentistry due to its high resolution and surface finish quality (5). This category primarily includes Stereolithography (SLA), Digital Light Processing (DLP), and the more recently developed Liquid Crystal Display (LCD) technology. While SLA relies on a laser beam to cure resin point-by-point, DLP and LCD technologies cure entire layers simultaneously, significantly reducing production time (6).

This parallel layer curing mechanism contributes to their efficiency, making them particularly attractive for dental applications where rapid prototyping of multiple models is often required (7). However, differences in light source and pixelation between DLP and LCD printers can lead to variations in the dimensional accuracy of the fabricated models (8).

Digital Light Processing has traditionally been regarded as more efficient and faster than stereolithography, rendering it particularly suitable for high-precision dental printing applications (9). These systems utilize a digital micromirror device (DMD) to project a high-definition image of the layer onto the resin, offering exceptional detail and reliability. Consequently, DLP printers are often marketed as specialized medical device ready compliant systems with price points reflecting their industrial-grade components and closed ecosystems (10).

Conversely, LCD technology (also known as Masked Stereolithography or MSLA) utilizes a liquid crystal display panel masked by an LED light source to cure the resin. Initially regarded as a hobbyist technology, LCD printers have seen rapid advancements in resolution (moving from 2K to 16K and beyond) and light uniformity. Recent advances in LCD printing technology have enabled affordable systems to achieve resolutions comparable to those of established professional DLP printers (11). As a result, low-cost LCD printers are increasingly being explored as viable tools for dental model fabrication, with the potential to meet the accuracy and consistency requirements of clinical practice. However, a thorough investigation into the dimensional accuracy differences between professional DLP and consumer-grade LCD 3D printers, especially concerning the intricacies of dental model fabrication, remains crucial to validate their clinical utility and inform procurement decisions (11,12).

Therefore, the objective of this study is to conduct a comparative in vitro analysis of the dimensional accuracy of dental models fabricated using a professional-grade DLP printer and a consumer-grade LCD printer. By evaluating the trueness and precision of these systems against a standardized CAD reference, this research aims to determine if modern LCD technology offers a scientifically valid and economically efficient alternative for dental model production.

MATERIALS AND METHODS

This in vitro comparative study was designed to evaluate the dimensional accuracy of dental models fabricated using two distinct vat photopolymerization technologies: professional Digital Light Processing (DLP) and consumer-grade Liquid Crystal Display (LCD). In order to establish a control for the analysis, a standard reference dataset consisting of one ideal maxillary arch and one ideal mandibular arch in STL format was selected, representing anatomically complete, well-aligned dentitions without restorations or pathological features. A total of 20 full-arch models were included in the study, comprising 10 maxillary and 10 mandibular arches. Each arch was printed five times using each printer, resulting in two experimental groups: a DLP group (n = 10; 5 maxillary and 5 mandibular models) and an LCD group (n = 10; 5 maxillary and 5 mandibular models).

Digital reference models were obtained from complete-arch intraoral scans exported in Standard Tessellation Language (STL) format. The same reference files were used for both printing systems to ensure methodological standardization. Model generation was performed using Exocad 3.2 software (Exocad GmbH, Darmstadt, Germany), specifically the Model Creator module. All models were designed as hollow structures with a uniform wall thickness of 3 mm to optimize material consumption while maintaining mechanical stability (13). The insertion axis and base geometry were standardized for all samples to eliminate design-related variability. Finalized digital models were exported in STL format and prepared for additive manufacturing.

Two 3D printing systems were evaluated. The DLP printer was the Bego Varseo S (BEGO GmbH & Co. KG, Bremen, Germany; manufactured in 2019; approximate acquisition cost €12,000). The LCD printer was the Phrozen Mini 8K S (Phrozen Tech Co., Ltd., Hsinchu City, Taiwan; manufactured in 2024; approximate acquisition cost €800). Both systems operate under vat-photopolymerization technology according to ISO/ASTM additive manufacturing classification standards.

For the DLP group, VarseoWax Model Grey resin (BEGO GmbH & Co. KG, Bremen, Germany) was used in combination with Bego CAMcreator software. STL files were inspected for mesh integrity, positioned horizontally on the build platform, and provided with automatic support structures, supplemented manually where necessary.

For the LCD group, Dental Model Resin (Phrozen Tech Co., Ltd., Hsinchu City, Taiwan) was used in combination with CHITUBOX Basic v2.3 software. STL files were oriented horizontally using the “Flatten by Face” function, and collision and cavity detection tools were applied to verify model integrity prior to slicing. Automatic support generation was used in both workflows. The layer thickness was standardized at 50 µm for both printers, and comparable orientation and support strategies were employed to minimize confounding variables.

Prior to printing, printer vats and internal components were cleaned using 99.8% isopropyl alcohol to eliminate residual resin contamination. After fabrication, printed models were removed from the build platform and subjected to standardized post-processing procedures, including immersion in isopropyl alcohol to remove uncured resin, air drying to ensure complete solvent evaporation, and ultraviolet post-curing in a dedicated curing unit to achieve final polymerization and optimal mechanical properties. All models were visually inspected to confirm structural integrity and surface completeness (Figure 1 and 2). Post-processing conditions were maintained consistently for both experimental groups.

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Fig. 1. Models printed with the DLP 3D printer

Fig. 2. Models printed with the LCD 3D printer

All printed models were subsequently digitized using an inEos X5 laboratory scanner (Dentsply Sirona, Bensheim, Germany) integrated with inLab CAD software. This five-axis scanner employs robotic positioning to ensure comprehensive surface acquisition. Scanning parameters included Capture Reduced mode and Single Exposure acquisition. Each printed model was exported as an STL file for metrological comparison.

Dimensional analysis was performed using Geomagic Control 2014 software (3D Systems, Rock Hill, SC, USA). Each scanned model was aligned with its corresponding reference STL file using a best-fit alignment algorithm.

Alignment was performed progressively to increase precision: an initial alignment using 300 common points, followed by refinement using 3,000 common points, and a final high-precision alignment using 30,000 common points.

The “3D Compare” function was employed to generate color-coded deviation maps (Figure 3) and extract quantitative deviation data. Deviation thresholds were standardized as follows: maximum deviation ±1000 µm, critical deviation ±500 µm, and normal tolerance ±50 µm. All measurements were expressed in micrometers (µm).

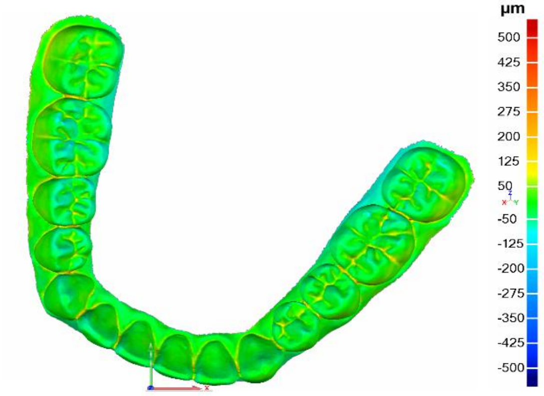

Fig. 3. Color-coded deviation map of the superimposed data-sets of one lower arch model

Dimensional trueness was quantified using Root Mean Square (RMS), calculated as the square root of the mean of squared surface deviations between the printed model and the reference file. Additional parameters included mean positive deviation (representing surface expansion relative to the reference), mean negative deviation (representing surface contraction), and Surface Mean Square Deviation (SMSD), a synthetic parameter derived from mean positive and negative deviations to provide a unified indicator of surface deviation magnitude.

Statistical analysis was performed using Python (version 3.10), using the SciPy and NumPy libraries. Data distribution was evaluated using the Shapiro–Wilk test and Q–Q plot visualization. As RMS and SMSD values did not follow a normal distribution ($p < 0.05$), non-parametric statistical testing was applied. Intergroup comparisons between the DLP and LCD groups were performed using the Mann–Whitney U test, with statistical significance set at $\alpha = 0.05$. The correlation between RMS and SMSD values was assessed using Pearson’s correlation coefficient (r) to determine the strength of linear association between the two accuracy indicators.

RESULTS

A total of 20 printed dental models (10 maxillary and 10 mandibular) were subjected to three-dimensional deviation analysis using Geomagic Control software. Dimensional trueness was quantified using Root Mean Square (RMS), mean positive deviation, mean negative deviation, and Surface Mean Square Deviation (SMSD). For the DLP group, the overall mean RMS value was 89.88 ± 24.96 µm, with values ranging from 60.48 µm to 139.09 µm. The median RMS was 79.47 µm, with an interquartile range (IQR) of 69.30–110.85 µm. In contrast, the LCD group demonstrated a lower overall mean RMS value of 78.64 ± 13.55 µm, with a narrower range between 61.38 µm and 101.44 µm. The median RMS for the LCD group was 78.02 µm (IQR: 66.34–85.41 µm). Detailed RMS values, for each printed model, are presented below.

Table 1. Root mean square (RMS) deviations of dental models fabricated using medical-grade DLP and consumer-grade LCD printers

Printer	Arch	Model no.	RMS (µm)
DLP-Bego Varseo S	Maxillary	1	112.7
		2	139
		3	86.1
		4	112.9
		5	85.2
	Mean ± SD (Maxillary)		107.2 ± 23.6
	Mandibular	6	68.6
		7	66.4
		8	60.4
		9	72.1
		10	70.8
	Mean ± SD (Mandibular)		67.7± 4.5
	Overall Mean ± SD		89.8 ± 24.9
LCD-Phrozen Mini 8K S	Maxillary	11	101.4
		12	87.1
		13	83.6
		14	94.7
		15	85.4
	Mean ± SD (Maxillary)		90.4 ± 7.6
	Mandibular	16	67.6
		17	61.3
		18	66.3
		19	63.2
		20	66.4
	Mean ± SD (Mandibular)		66.7± 2.3
	Overall Mean ± SD		78.6± 13.5

When analysed according to arch type, maxillary models consistently exhibited higher RMS values compared with mandibular models in both printing groups. In the DLP group, the mean RMS value for maxillary models was 107.24 µm, whereas mandibular models was 67.70 µm, corresponding to a mean difference of approximately 39.5 µm. In the LCD group, maxillary models demonstrated a mean RMS of 90.49 µm, while mandibular models showed a mean value of 66.78 µm, resulting in a smaller inter-arch difference of approximately 23.7 µm. A grouped comparison of RMS values per individual model highlights the higher variability observed in the DLP group and the more compact distribution in the LCD group (Figure 4).

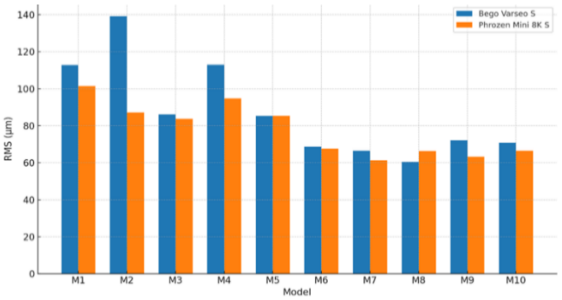

Fig. 4. Grouped Bar Chart Comparing RMS Values per Model (DLP vs. LCD)

Surface Mean Square Deviation

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(SMSD) analysis revealed patterns comparable to those observed for RMS. In the DLP group, SMSD values ranged from 47.57 µm to 102.24 µm, with greater dispersion observed among maxillary models. In the LCD group, SMSD values were more tightly clustered, ranging from 58.28 µm to 73.16 µm for maxillary models and approximately 47–51 µm for mandibular models. The narrower dispersion of SMSD values in the LCD group further supports its more consistent performance (Table 2).

Table 2. Surface Mean Square Deviations (SMSD) of dental models fabricated using medical-grade DLP and consumer-grade LCD printers

Printer	Arch	Model no.	SMSD (µm)
DLP-Bego Varseo S	Maxillary	1	80.1
		2	102.2
		3	66.4
		4	84.9
		5	64.7
	Mandibular	6	49.6
		7	51.1
		8	47.5
		9	54.7
		10	54.6
LCD-Phrozen Mini 8K S	Maxillary	11	73.1
		12	60.2
		13	58.2
		14	69.2
		15	61.6
	Mandibular	16	49.1
		17	47.5
		18	51.1
		19	48
		20	49.1

Normality assessment using the Shapiro–Wilk test demonstrated that RMS values in both groups did not follow a normal distribution ($p < 0.05$). Visual inspection of Q–Q plots confirmed systematic deviations from theoretical normality, particularly for RMS values (Figure 5 and 6). Consequently, non-parametric statistical methods were applied for intergroup comparison.

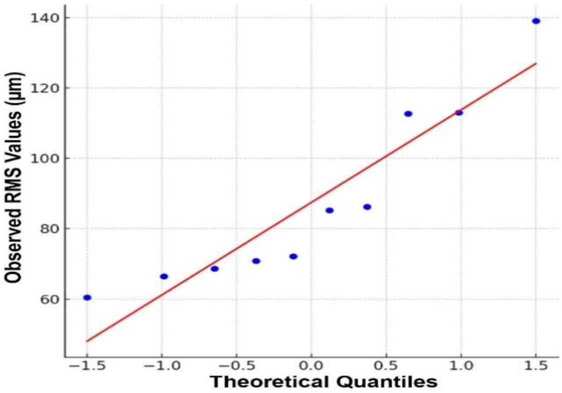

Fig. 5. Q–Q plot illustrating the distribution of Root Mean Square (RMS) deviation values for dental models printed using the Bego Varseo S DLP system.

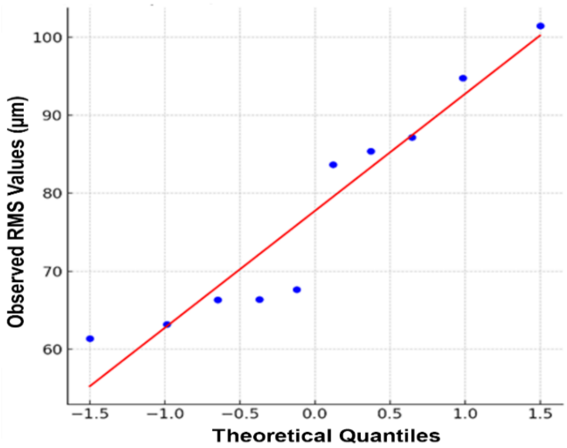

Fig. 6. Q–Q plot illustrating the distribution of Root Mean Square (RMS) deviation values for dental models printed using the Phrozen Mini 8K S DLP system.

Intergroup comparison using the Mann–Whitney U test revealed no statistically significant difference between the DLP and LCD groups in terms of RMS values ($U = 61.0$; $p = 0.427$). Similarly, comparison of SMSD values demonstrated no statistically significant difference between groups ($U = 65.5$; $p = 0.256$). Although descriptive statistics suggested slightly lower mean RMS and SMSD values in the LCD group, these differences did not reach statistical significance at the predefined *α* level of 0.05. Boxplot visualization confirmed comparable medians and overlapping interquartile ranges between groups, while also illustrating the greater variability observed in the DLP group (Figure 7 and 8).

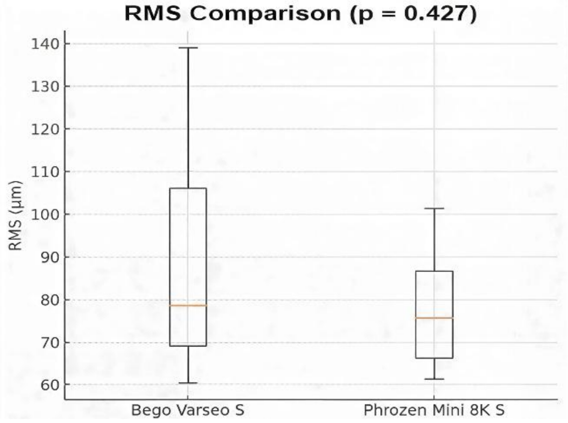

Fig. 7. Boxplot Comparison of RMS Values Between DLP and LCD Groups

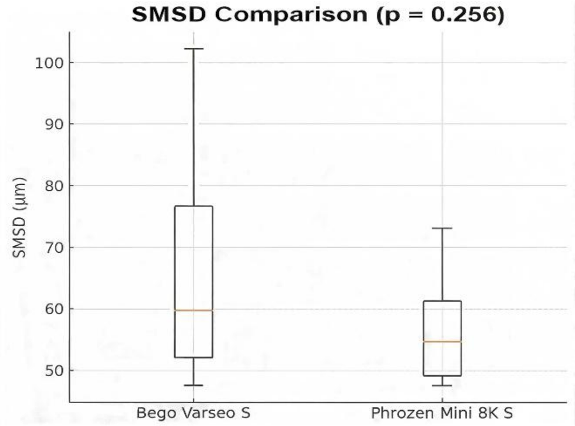

Fig. 8. Boxplot Comparison of SMSD Values Between DLP and LCD Groups

Correlation analysis demonstrated a very strong positive linear relationship between RMS and SMSD values for both printing technologies. Pearson's correlation coefficient was approximately $r = 0.996$ for the DLP group and $r = 0.986$ for the LCD group, indicating that SMSD closely reflects variations captured by RMS. Scatter plot analysis with regression lines further confirmed this near-linear association (Figure 9 and 10).

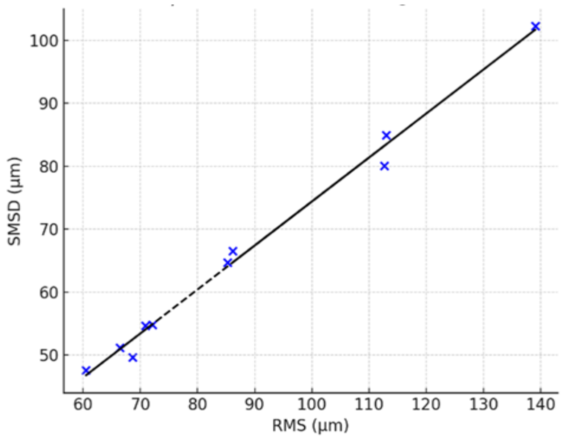

Fig. 9. Scatter plot of RMS vs. SMSD for the DLP system (Bego Varseo S)

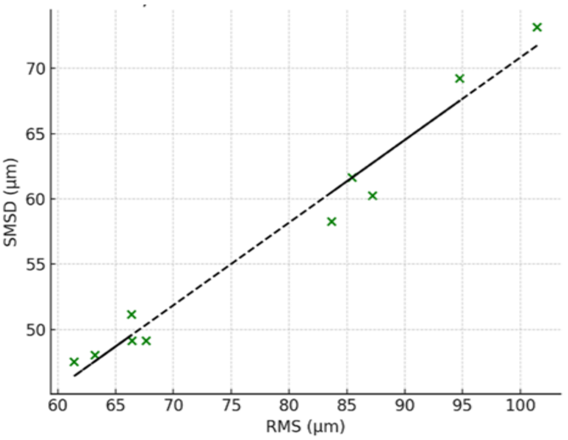

Fig. 9. Scatter plot of RMS vs. SMSD for the LCD system (Phrozen Mini 8K S).

Overall, mandibular models exhibited lower deviation values compared with maxillary models in both groups. The LCD printer demonstrated a more compact distribution of RMS and SMSD values and lower variability, whereas the DLP printer showed wider dispersion and higher maximum deviations, particularly for maxillary models. Despite these descriptive differences, statistical testing confirmed comparable overall dimensional trueness between the two printing systems.

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DISCUSSION

This study compared the dimensional trueness of dental models fabricated using a medical-grade digital light processing (DLP) system and a consumer-grade liquid crystal display (LCD) system. Under standardized conditions, both systems produced models with comparable RMS and SMSD values. The mean RMS was 89.88 ± 24.96 µm for the DLP group and 78.64 ± 13.55 µm for the LCD group, and the difference was not statistically significant ($p = 0.427$). These values are well below the 250-µm threshold commonly cited for orthodontic models, suggesting that both systems deliver dimensional trueness compatible with clinical requirements (14). Previous comparative studies have consistently shown that DLP systems produce smaller RMS errors than first-generation LCD printers (7), yet high-resolution LCD technology continues to narrow this gap. The present findings, obtained with an 8 K LCD printer, support the notion that contemporary LCD devices can achieve a level of trueness previously associated with professional DLP printers.

The observation of higher deviation values in maxillary models compared with mandibular models in both groups aligns with earlier reports. In a study of 3D-printed dental arches, the occlusal surfaces of posterior teeth on maxillary models exhibited greater distortion than other surfaces (15). The smaller inter-arch difference observed with the LCD system (23.7 µm) relative to the DLP system (39.5 µm) suggests that the LCD printer's higher pixel density and more uniform light distribution may better accommodate complex anatomical geometries. Still, the difference did not reach statistical significance, highlighting that both technologies provide clinically acceptable precision for full-arch models.

A strong positive correlation between RMS and SMSD values ($r \approx 0.996$ for DLP and $r \approx 0.986$ for LCD) was found, indicating that SMSD reliably reflects the magnitude of surface deviations. Because RMS integrates both positive (expansion) and negative (contraction) errors into a single metric, it is particularly useful for comparing technologies. The high correlation also suggests that systematic, rather than random, factors influenced the deviations observed. Potential determinants include the curing mechanism (projector-based vs. direct-pixel exposure), pixel size and pitch and resin formulation (16). These technological differences may explain why the consumer-grade LCD system achieved a level of trueness comparable to the medical-grade DLP printer.

The mean deviations observed in this study fall within the range reported in the literature for vat-photopolymerization systems (17). A systematic review of full-arch model accuracy reported that DLP printers produced models with errors < 100 µm and noted that manufacturing parameters such as layer thickness, base design, and post-processing significantly affect accuracy (18).

Medical-grade DLP systems are expensive and marketed as plug-and-play devices with validated workflows. In contrast, high-resolution LCD printers are considerably less costly and rely on widely available display panels and LED light sources. The present study demonstrates that a consumer-grade LCD printer priced at roughly one-fifteenth of the DLP system can produce models with comparable dimensional trueness.

The present study is subject to several limitations. Firstly, the sample size was modest, incorporating a single printer per printing technology and a single resin formulation, as such the findings may lack generalizability to other printers or resins. Secondly, printing orientation and support structures were standardized, thereby

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preventing the assessment of the effects of alternative build orientations or support structures on dimensional accuracy. Thirdly, the investigation was limited to dimensional trueness, excluding assessments of supplementary metrics including precision and surface topography. Lastly, models underwent in vitro evaluation promptly following post-processing, without the evaluation of prospective dimensional alterations attributable to storage conditions.

CONCLUSIONS

Within the limitations of this in vitro study, no statistically significant difference in dimensional trueness was observed between the evaluated medical-grade DLP system and the consumer-grade LCD system for dental model fabrication. Both printers produced comparable RMS and SMSD values when operated under standardized printing and post-processing conditions. Although the consumer-grade LCD printer demonstrated slightly lower mean deviations and reduced variability, these differences were associated with small effect sizes.

Higher deviation values were consistently observed in maxillary models compared with mandibular models for both systems, indicating that arch geometry influenced dimensional accuracy independently of printer category. Based on the present results, both the medical-grade DLP and consumer-grade LCD systems achieved dimensional accuracy compatible with dental model production within the scope of this investigation. Further studies are required to determine whether these findings extend to other materials, workflows, and clinical indications.

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