Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 15 May 2026
Revised 16 June 2026
Accepted 02 July 2026

Natural Resources for Human Health 2026, Vol. 6 (6s): 987–996

KEYWORDS:
Additive manufacturing, Dental cast, 3-D printing, Digital light processing, LCD printing, Fused deposition modeling, Dimensional accuracy, Intraoral scanner, Prosthetics, Digital dentistry

Dimensional Accuracy of Dental Casts Fabricated Using Digital Light Processing, Liquid Crystal Display and Fused Deposition Modelling: A Clinical Observational Study

Dr. Niranjan Hatagale[1], Dr. Rajiv Kumar Gupta[2], Dr. Akshay Bhargava[3], Dr. Bharti Dua[4], Dr. Aditya Chaudhary[5], Dr. Aarushi Jain[6]

[1] MDS, 3rd Year Postgraduate Student, Department of Prosthodontics and Crown & Bridge, Santosh Dental College & Hospital, Ghaziabad, Uttar Pradesh, India – 201009
ORCID ID: 0009-0008-9464-8030, Email: drniranjanhatagale@gmail.com
[2] Professor & Senior Consultant – Implantology, Department of Prosthodontics and Crown & Bridge, Santosh Dental College & Hospital, Ghaziabad, Uttar Pradesh, India – 201009
ORCID ID: 0000-0002-5945-1290.Email: dentrajiv2@gmail.com
[3] Professor & Dean, Santosh Dental College & Hospital, Ghaziabad, Uttar Pradesh, India – 201009
ORCID ID: Not provided.Email: akshay.bhargava@santosh.ac.in
[4] Specialist (Dental), Ambedkar Nagar Hospital, New Delhi, India
ORCID ID: 0000-0001-8394-408X.Email: drbhartidua@gmail.com
[5] Professor & Head, Department of Prosthodontics and Crown & Bridge, Santosh Dental College & Hospital, Ghaziabad, Uttar Pradesh, India – 201009
ORCID ID: 0000-0003-4296-9699.Email: dr.adityachaudhary@gmail.com
[6] MDS, 3rd Year Postgraduate Student, Department of Prosthodontics and Crown & Bridge, Santosh Dental College & Hospital, Ghaziabad, Uttar Pradesh, India – 201009
ORCID ID: 0009-0009-4710-3983.Email: aarushi26d3@gmail.com
Corresponding Author:
Dr. Rajiv Kumar Gupta, Email: dentrajiv2@gmail.com

ABSTRACT:

Aim. To evaluate and compare the dimensional accuracy of dental casts fabricated using digital light processing (DLP), liquid crystal display (LCD), and fused deposition modelling (FDM) three-dimensional (3D) printing technologies.

Materials And Methods. A clinical observational study was conducted on 14 participants meeting predefined inclusion criteria. Maxillary arches were scanned using an intraoral scanner to obtain STL datasets, which served as the digital reference. Each STL file was used to fabricate three printed casts using DLP, LCD, and FDM technologies, producing a total of 42 printed models. Linear dimensional accuracy was assessed by measuring intermolar width (IMW), intercanine width (ICW), and dental arch length (AL) using an optical multisensory coordinate measuring machine (O-INSPECT CMM, Zeiss). Measurements were repeated three times by the same operator, and the mean values were analysed. Data normality was assessed using the Shapiro–Wilk test, followed by one-way analysis of variance. Effect sizes were calculated to determine the magnitude of intergroup differences.

Results. All three printing technologies produced casts with dimensional deviations that remained within clinically acceptable limits. DLP demonstrated the least numerical deviation from the reference STL dataset across the evaluated parameters, followed by LCD and FDM. Although FDM exhibited comparatively greater deviation, particularly for arch length, no statistically significant differences were observed among the printing technologies for intermolar width ($P = 0.657$), intercanine width ($P = 0.861$), or arch length ($P = 0.976$). Effect size analysis demonstrated minimal influence of fabrication technique on dimensional variability.

Conclusion. Among the investigated systems, DLP demonstrated the highest dimensional accuracy and may be preferred for procedures requiring maximum precision, whereas LCD and FDM provide acceptable alternatives for diagnostic, educational and routine clinical applications.

INTRODUCTION

The rapid evolution of digital dentistry has significantly transformed contemporary prosthodontic practice through the integration of intraoral scanning, computer-aided design/computer-aided manufacturing (CAD/CAM), and additive manufacturing technologies. Three-dimensional (3D) printing enables the fabrication of physical dental models directly from Standard Tessellation Language (STL) datasets, providing an efficient alternative to conventional impression and cast fabrication techniques. Compared with traditional gypsum casts, digital workflows reduce material distortion, improve data storage and communication, facilitate reproduction of models, and streamline laboratory procedures.[1–3]

The accuracy of a dental cast is fundamental to the successful fabrication of fixed dental prostheses, removable prostheses, implant-supported restorations and orthodontic appliances. Dimensional discrepancies in printed casts may adversely affect prosthesis fit, occlusal relationships and treatment outcomes. Consequently, the dimensional accuracy of 3D-printed dental models has become an important consideration in digital prosthodontics.[4,5]

Among the available additive manufacturing technologies, Digital Light Processing (DLP), Liquid Crystal Display (LCD) and Fused Deposition Modelling (FDM) are the most commonly used for dental model fabrication. DLP and LCD printers employ photopolymerisation of light-curable resins, producing models with high resolution and surface detail.[6–8] In contrast, FDM fabricates models through layer-by-layer extrusion of thermoplastic filament, most commonly polylactic acid (PLA). Although FDM offers lower manufacturing costs and greater accessibility, its layer deposition process may influence dimensional accuracy and surface quality when compared with photopolymerisation-based systems.[9,10]Several studies have evaluated the accuracy of different 3D-printing technologies. Photopolymerisation-based printers have generally demonstrated superior trueness and precision compared with extrusion-based systems; however, most investigations have reported that all technologies produce models within clinically acceptable limits for prosthodontic applications.[11–18]

Despite these encouraging findings, the majority of published studies have been conducted under laboratory conditions using standardised reference models. Clinical investigations employing patient-derived intraoral scan datasets remain limited, and evidence comparing DLP, LCD and FDM technologies under clinical conditions is still insufficient. Moreover, few studies have evaluated clinically relevant linear arch dimensions using high-precision optical coordinate measuring systems, which are considered reliable tools for dimensional assessment.[19,27]

Therefore, the present clinical observational study aimed to evaluate and compare the dimensional accuracy of maxillary dental casts fabricated using DLP, LCD and FDM 3D-printing technologies with the corresponding STL datasets obtained from intraoral scanning. The null hypothesis was that no statistically significant difference would exist in the dimensional accuracy of casts produced by the three additive manufacturing techniques.

Natural Resources for Human Health
eISSN: 2583-1194

MATERIALS AND METHODS

This clinical observational study was conducted in the Department of Prosthodontics and Crown & Bridge, Santosh Dental College and Hospital, Ghaziabad, India, after obtaining approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants before enrolment, and the study was performed in accordance with the Declaration of Helsinki.

Fourteen participants aged 18–45 years were recruited from the outpatient department. Participants with a complete maxillary dentition (excluding third molars), healthy periodontal tissues and the ability to undergo intraoral digital scanning were included. Individuals with extensive restorations affecting tooth morphology, severe malocclusion, craniofacial anomalies, active orthodontic treatment or inability to cooperate during scanning were excluded.

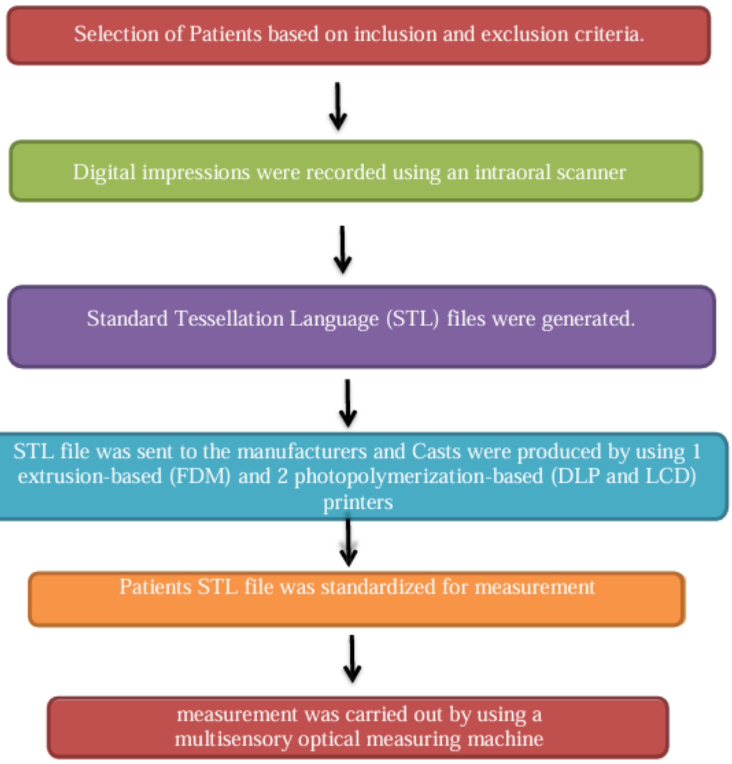


Figure 1- The Series of Steps Involved in Carrying out the Finite Element

Maxillary digital impressions were obtained using an intraoral scanner (Aoralscan 3; Shining 3D, Hangzhou, China) following a standardised scanning protocol. The acquired scans were exported as Standard Tessellation Language (STL) files[4,5,27] and processed using Meshmixer software (Version 3.5.474, Autodesk Inc., USA) for trimming and standardisation of the model base(Figure 1).

Each STL dataset served as the reference model and was used to fabricate three printed casts using different additive manufacturing technologies:

Digital Light Processing (DLP): Aidite EZPRINT T-P1 (Aidite, China)

Liquid Crystal Display (LCD): Elegoo Saturn 4 12K (Elegoo, China)

Fused Deposition Modelling (FDM): Bambu Lab H2D (Bambu Lab, China)

A total of 42 printed casts (14 casts per printing technology) were fabricated.

For the DLP and LCD groups, models were printed using a 405-nm ultraviolet-curable resin with a layer thickness of 50 µm. Following fabrication, the casts were cleaned in 99% isopropyl alcohol, air-dried, post-cured according to the manufacturers' recommendations and the support structures were removed[6–8,14].

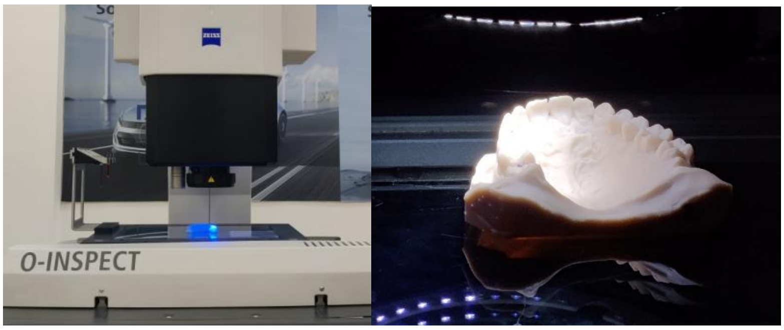
For the FDM group, models were fabricated using 1.75-mm polylactic acid (PLA) filament at a layer thickness of 100 µm. Printing parameters included a nozzle temperature of 200°C, build plate temperature of 60°C and 100% infill. Printed casts were allowed to cool before removal from the build platform[9,10,22].

The specifications of the evaluated printers are summarised in Table 1.

Table 1. Printers evaluated and manufacturer specifications.

Printer / Model	Manufacturer	Technology	Build Volume (mm)	Layer Thickness	Material
Aidite EZPRINT T-P1	Aidite, China	DLP	144 × 81 × 130	50 µm	405 nm UV-curable resin
Elegoo Saturn 4 12K	Elegoo, China	LCD	218.88 × 122.88 × 220	50 µm	405 nm UV-curable resin
Bambu Lab H2D	Bambu Lab, China	FDM	350 × 320 × 325	100 µm	PLA filament (1.75 mm)

Dimensional accuracy was evaluated using an optical multisensory coordinate measuring machine (O-INSPECT CMM; Carl Zeiss, Oberkochen, Germany) under controlled environmental conditions (20°C and 50% relative humidity). The STL reference datasets were analysed using ZEISS INSPECT Metrology software with identical anatomical reference points[14,19].



(a) (b)

Figure 2 - Measurement of cast inmultisensorycoordinatemeasuring machine.

Three clinically relevant linear measurements were recorded for both the STL reference models and the printed casts:

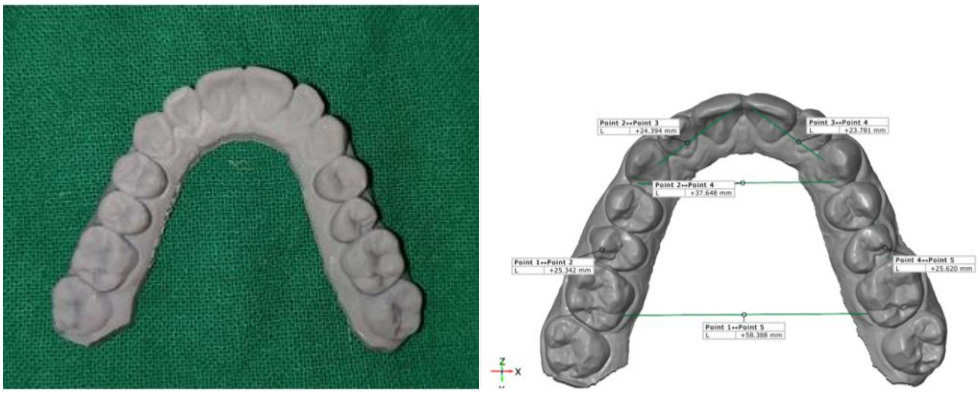
Intermolar width (IMW): Distance between the mesiobuccal cusp tips of the maxillary first molars.

Intercanine width (ICW): Distance between the cusp tips of the maxillary canines.

Arch length (AL): Linear anteroposterior distance between predetermined anterior and posterior reference points (Figure 2).

The examiner was calibrated before data collection, and all measurements were performed by the same investigator to minimise intra-examiner variability.

eISSN: 2583-1194



(a) (b)

Figure 3 : 3D Printed Cast (a) and Digital File with reference measuring points (b)

Statistical analysis was performed using IBM SPSS Statistics Version 22.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated and expressed as mean ± standard deviation, variance, 95% confidence interval, minimum and maximum values. Data normality was assessed using the Shapiro–Wilk test. Intergroup comparisons were performed using one-way analysis of variance (ANOVA). Effect size was determined using eta-squared (η^2) and omega-squared (ω^2). Statistical significance was established at $P < 0.05$.

RESULTS

A total of 14 participants (9 females and 5 males; mean age 28.6 ± 6.4 years) were included in the study. All STL files were successfully acquired and used to fabricate three-dimensional (3D) printed maxillary casts using Digital Light Processing (DLP), Liquid Crystal Display (LCD) and Fused Deposition Modelling (FDM) technologies, resulting in 42 printed models. No printing failures or measurement errors were encountered during the study.

Table 2. Descriptive statistics — Intermolar Width (IMW).

Group	n	Mean ± SD (mm)	Variance	95% CI	Min (mm)	Max (mm)
STL Reference	14	54.36 ± 3.83	14.64	51.37 – 57.34	47.31	60.88
DLP	14	52.26 ± 8.94	79.91	49.27 – 55.24	24.09	60.69
LCD	14	54.30 ± 3.84	14.76	51.32 – 57.29	47.31	60.85
FDM	14	54.61 ± 3.81	14.54	51.63 – 57.59	48.56	61.33

One-way ANOVA: $F = 0.54$, $df = 3/52$, $p = 0.657$, $\eta^2 = 0.03$, $\omega^2 = -0.03$. NS = not statistically significant.

Table 3. Descriptive statistics — Intercanine Width (ICW).

Group	n	Mean ± SD (mm)	Variance	95% CI	Min (mm)	Max (mm)
STL Reference	14	37.31 ± 1.71	2.94	36.39 – 38.23	34.43	39.50

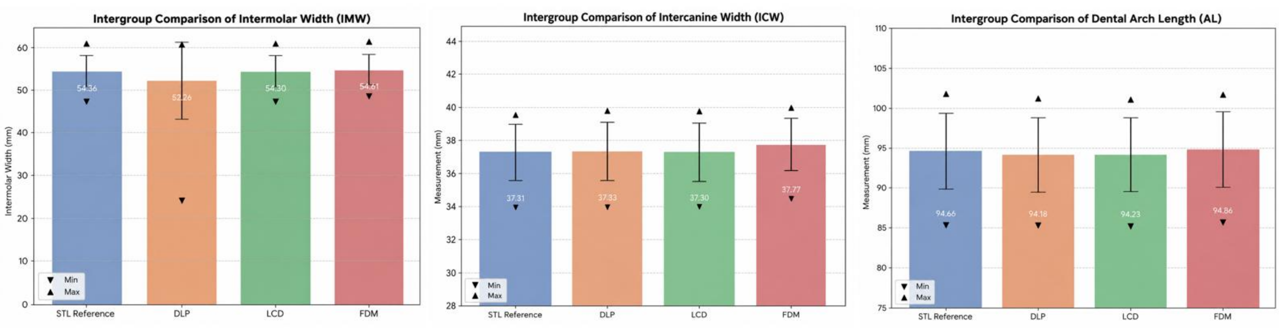
DLP	14	37.33 ± 1.75	3.05	36.41 – 38.25	34.42	39.82
LCD	14	37.30 ± 1.78	3.16	36.38 – 38.21	34.37	39.81
FDM	14	37.77 ± 1.61	2.60	36.85 – 38.69	34.82	40.01

ANOVA: F = 0.25, df = 3/52, p = 0.861, η² = 0.014, ω² = −0.042. NS = not statistically significant.

Table 4. Descriptive statistics — Dental Arch Length (AL).

Group	n	Mean ± SD (mm)	Variance	95% CI	Min (mm)	Max (mm)
STL Reference	14	94.66 ± 4.77	22.75	92.13 – 97.19	86.24	101.84
DLP	14	94.18 ± 4.69	22.03	91.65 – 96.71	86.14	101.24
LCD	14	94.23 ± 4.67	21.83	91.70 – 96.77	85.33	100.98
FDM	14	94.86 ± 4.74	22.51	92.33 – 97.39	86.07	101.70

One-way ANOVA: F = 0.07, df = 3/52, p = 0.976, η² = 0.004, ω² = −0.052. NS = not statistically significant.



(a) (b) (c)

Fig 3: Bar chart for Intermolar Width (IMW) (a) Intercanine Width (ICW) (b) Dental Arch Length (AL) (c)

The mean IMW measurements (Table 2) obtained from the three printing technologies were comparable with the reference Standard Tessellation Language (STL) datasets. Although the DLP group demonstrated greater variability than the other groups, one-way analysis of variance (ANOVA) revealed no statistically significant difference among the evaluated techniques ($F = 0.54$, $P = 0.657$).

Similarly, ICW measurements (Table 3) showed minimal deviation from the STL reference across all groups. The dimensional differences among DLP, LCD and FDM casts were negligible, and statistical analysis demonstrated no significant intergroup difference ($F = 0.25$, $P = 0.861$).

For AL, all three printing technologies produced measurements (Table 4) closely corresponding to the reference datasets. FDM casts exhibited slightly greater numerical deviation than the photopolymerisation-based systems; however, this difference was not statistically significant ($F = 0.07$, $P = 0.976$).

The Shapiro–Wilk test demonstrated that the majority of variables were normally distributed. A deviation from normality was observed only for IMW in the DLP group; however, the remaining datasets satisfied the assumptions for parametric analysis.Effect size analysis revealed very small η^2 values (<0.03) for all three linear measurements, indicating that the choice of printing technology contributed minimally to the observed dimensional variation.

Overall, DLP demonstrated the smallest numerical deviation from the STL reference, followed by LCD and FDM. Nevertheless, the dimensional differences among the three additive manufacturing technologies were small and remained within clinically acceptable limits for prosthodontic applications.

Figure 2 illustrates the anatomical reference points used for dimensional measurements, while Table 2, Table 3, Table 4 compares the mean values of IMW, ICW and AL among the study groups.

DISCUSSION

The present clinical observational study compared the dimensional accuracy of maxillary dental casts fabricated using three widely used additive manufacturing technologies—Digital Light Processing (DLP), Liquid Crystal Display (LCD) and Fused Deposition Modelling (FDM)—using patient-derived intraoral scan datasets as the reference standard. The findings demonstrated that all three technologies produced casts with clinically acceptable dimensional accuracy for intermolar width, intercanine width and arch length. Dimensional accuracy is one of the most important determinants of the clinical success of digital prosthodontic workflows because inaccuracies in diagnostic casts may affect prosthesis fit, occlusal relationships and laboratory procedures. The increasing adoption of intraoral scanning and additive manufacturing has therefore generated considerable interest in identifying printing technologies capable of reproducing dental anatomy with high precision while maintaining clinical efficiency and cost-effectiveness.[14,18]

The slightly superior numerical performance of DLP observed in the present study may be explained by its printing mechanism. DLP printers polymerise an entire resin layer simultaneously using a digital light projector, thereby reducing cumulative polymerisation errors and improving dimensional stability. LCD printers also use photopolymerisation but expose the resin through an LCD masking screen, resulting in comparable accuracy with only minor differences attributable to light transmission efficiency and pixel resolution.[7,8] In contrast, FDM fabricates models by sequential deposition of molten thermoplastic filament, making the printed object more susceptible to thermal contraction, layer shrinkage and cumulative deposition errors, particularly over larger dimensions such as the dental arch.[10,23] These manufacturing characteristics probably explain the slightly greater numerical deviation observed for FDM casts, especially in arch length measurements.

The present findings agree with those reported by Nestler et al.,[14] who compared extrusion- and photopolymerisation-based printers and concluded that although photopolymerisation systems demonstrated greater trueness, all evaluated technologies produced models that were clinically acceptable for dental applications. Similarly, Tsolakis et al.[7] observed comparable dimensional accuracy between DLP and LCD technologies, with only minor differences that were unlikely to influence clinical outcomes. Park and Shin[15] also reported excellent reproducibility of printed dental models irrespective of the manufacturing system when standardised printing protocols were followed.

Our findings are also consistent with the systematic review by Etemad-Shahidi et al.,[18] which concluded that contemporary 3D-printing technologies generally produce clinically acceptable full-arch dental models despite differences in manufacturing principles. Likewise, the network meta-analysis by Nemeth et al.[28] suggested that photopolymerisation-based technologies demonstrate marginally greater accuracy than extrusion-based systems; however, the magnitude of these differences is often insufficient to influence routine clinical applications.

Although FDM exhibited the greatest numerical deviation among the evaluated technologies, its measurements remained within clinically acceptable limits. This observation supports the work of Kamio et al.,[22] who demonstrated that modern desktop FDM printers are capable of producing sufficiently accurate dental casts for diagnostic, educational and treatment-planning purposes while offering substantial economic advantages. The comparatively low cost of FDM printers and PLA filament makes this technology particularly attractive for dental schools and institutions where affordability is an important consideration.

An important finding of the present study was the absence of statistically significant differences among the three printing technologies for all evaluated linear measurements. Furthermore, the very small effect sizes indicated that only a minimal proportion of dimensional variability could be attributed to the manufacturing technique itself. These findings suggest that factors such as intraoral scanning accuracy, STL processing, model orientation, post-processing protocols and biological variation among participants may collectively exert a greater influence on the final dimensional outcome than the choice of printing technology alone.[4,19,27]

A major strength of the present investigation is that it evaluated patient-derived intraoral scans rather than standardised laboratory models. Consequently, the study reflects clinical conditions more closely than many previous in vitro investigations. In addition, dimensional measurements were obtained using a high-precision optical coordinate measuring machine, thereby reducing measurement error and improving the reliability of the recorded values.

The study nevertheless has several limitations. The sample size was relatively small, and only maxillary arches were evaluated. In addition, one representative printer from each manufacturing technology was investigated; therefore, the findings cannot be generalised to all commercially available systems. Only linear dimensional accuracy was assessed, whereas volumetric accuracy, surface trueness, colour deviation, marginal adaptation, mechanical properties and long-term dimensional stability were beyond the scope of the present investigation. Future multicentre clinical studies involving larger sample sizes, different printer systems and comprehensive three-dimensional analyses are recommended to establish evidence-based guidelines for selecting additive manufacturing technologies in prosthodontics.

Overall, the findings indicate that DLP, LCD and FDM technologies are all capable of producing clinically acceptable dental casts for contemporary prosthodontic practice. While DLP demonstrated the highest numerical accuracy, the absence of statistically significant differences suggests that the selection of a printing technology should be based not only on dimensional accuracy but also on clinical indication, production efficiency and economic considerations.

CONCLUSIONS

Within the limitations of this clinical observational study, all three additive manufacturing technologies evaluated—Digital Light Processing (DLP), Liquid Crystal Display (LCD) and Fused Deposition Modelling (FDM)—produced maxillary dental casts with clinically acceptable dimensional accuracy. Although DLP demonstrated the smallest numerical deviation from the reference STL datasets, no statistically significant differences were observed among the three printing technologies for intermolar width, intercanine width or arch length. These findings suggest that each technology can be incorporated into contemporary digital prosthodontic workflows according to clinical requirements. DLP may be preferred for procedures demanding greater dimensional precision, whereas LCD and FDM offer cost-effective alternatives for diagnostic, educational and routine clinical applications. Further multicentre clinical studies with larger sample sizes and comprehensive three-dimensional accuracy analyses are required to validate these findings.

Clinical Significance

All three evaluated 3D printing technologies produced clinically acceptable dental casts for prosthodontic applications. DLP demonstrated the highest numerical accuracy, whereas LCD and FDM provided acceptable accuracy with potential economic advantages, supporting their selection according to the precision requirements and cost considerations of individual clinical situations..

REFERENCES

[1] Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent Mater J. 2009;28(1):44–56.

[2] Dawood A, Marti BM, Sauret-Jackson V, Darwood A. 3D printing in dentistry. Br Dent J. 2015;219(11):521–529.

[3] Revilla-León M, Özcan M. Additive manufacturing technologies used for processing polymers: current status and potential application in prosthetic dentistry. J Prosthodont. 2019;28(2):146–158.

[4] Güth JF, Edelhoff D, Schweiger J, Keul C. A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. Clin Oral Investig. 2016;20(7):1487–1494.

[5] Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent. 2013;109(2):121–128.

[6] Osman RB, Alharbi N, Wismeijer D. Build angle: does it influence the accuracy of 3D-printed dental restorations using digital light-processing technology? Int J Prosthodont. 2017;30(2):182–188.

[7] Tsolakis IA, Papaioannou W, Papadopoulou E, Dalampira M, Tsolakis AI. Comparison in terms of accuracy between DLP and LCD printing technology for dental model printing. Dent J (Basel). 2022;10(10):181.

[8] Batarseh S, Goldsberry N, Handysides C, et al. Comparison of volumetric change in objects printed with LCD and DLP 3D printers. J Calif Dent Assoc. 2023;51(1):2271641.

[9] Javaid M, Haleem A. Additive manufacturing applications in medical cases: a literature based review. Alexandria J Med. 2018;54(4):411–422.

[10] Kristiawan RB, Imaduddin F, Ariawan D, Ubaidillah, Arifin Z. A review on the fused deposition modeling (FDM) 3D printing: filament processing, materials, and printing parameters. Open Engineering. 2021;11(1):639–649.

[11] Tian Y, Chen C, Xu X, et al. A review of 3D printing in dentistry: technologies, affecting factors, and applications. Scanning. 2021;2021:9950131.

[12] Mahato M, Hota S, Jain A, et al. Comparison of conventional and digital workflows in the fabrication of fixed prostheses: a systematic review. Cureus. 2024;16(6):e62000.

[13] Jin SJ, Jeong ID, Kim JH, Kim WC. Accuracy (trueness and precision) of dental models fabricated using additive manufacturing methods. Int J Comput Dent. 2018;21(2):107–113.

[14] Nestler N, Wesemann C, Spies BC, Beuer F, Bumann A. Dimensional accuracy of extrusion- and photopolymerization-based 3D printers: in vitro study comparing printed casts. J Prosthet Dent. 2021;125(1):103–110.

[15] Park ME, Shin SY. Three-dimensional comparative study on the accuracy and reproducibility of dental casts fabricated by 3D printers. J Prosthet Dent. 2018;119(5):861.e1–861.e7.

[16] Al-Imam H, Gram M, Benetti AR, Gotfredsen K. Accuracy of stereolithography additive casts used in a digital workflow. J Prosthet Dent. 2018;119(4):580–585.

[17] Camardella LT, de Vasconcellos Vilella O, Breuning H. Accuracy of printed dental models made with 2 prototype technologies and different designs of model bases. Am J Orthod Dentofacial Orthop. 2017;151(6):1178–1187.

[18] Etemad-Shahidi Y, Qallandar OB, Evenden J, Alifui-Segbaya F, Ahmed KE. Accuracy of 3-dimensionally printed full-arch dental models: a systematic review. J Clin Med. 2020;9(10):3357.

[19] Lin LH, Granatelli J, Alifui-Segbaya F, et al. A proposed in vitro methodology for assessing the accuracy of three-dimensionally printed dental models and the impact of storage on dimensional stability. Appl Sci. 2021;11(13):5994.

[20] Nagata K, Muromachi K, Kouzai Y, et al. Fit accuracy of resin crown on a dental model fabricated using fused deposition modeling 3D printing and a polylactic acid filament. J Prosthodont Res. 2023;67(1):144–149.

[21] Taczała J, Czepułkowska W, Konieczny B, et al. Comparison of 3D printing MJP and FDM technology in dentistry. Arch Mater Sci Eng. 2020;101(1):32–40.

[22] Kamio T, Iwata H, Kawai T. Challenges and solutions for cost-effective and practical dental cast fabrication with a desktop fused deposition modeling (FDM) 3D printer. Cureus. 2024;16(11):e73147.

[23] Wickramasinghe S, Do T, Tran P. FDM-based 3D printing of polymer and associated composite: a review on mechanical properties, defects and treatments. Polymers. 2020;12(7):1529.

[24] Kessler A, Hickel R, Reymus M. 3D printing in dentistry — state of the art. Oper Dent. 2020;45(1):30–40.

[25] Dimitrova M, Vlahova A, Kalachev Y, et al. Recent advances in 3D printing of polymers for application in prosthodontics. Polymers. 2023;15(23):4525.

[26] Thongthammachat S, Moore BK, Barco MT, et al. Dimensional accuracy of dental casts: influence of tray material, impression material, and time. J Prosthodont. 2002;11(2):98–108.

[27] Patzelt SB, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. Clin Oral Investig. 2014;18(6):1687–1694.

[28] Nemeth A, Vitai V, Czumbel ML, et al. Clear guidance to select the most accurate technologies for 3D printing dental models — a network meta-analysis. J Dent. 2023;134:104532.

[29] Chen Y, Wei J. Application of 3D printing technology in dentistry: a review. Polymers. 2025;17(7):886.

[30] Ersöz E, Mosaddad SA, Molinero-Mourelle P, et al. Evaluation of time-dependent dimensional changes in dental casts fabricated from polylactic acid using fused filament fabrication additive manufacturing. Digital Dentistry J. 2026;100066.

[31] Jun MK, Kim JW, Ku HM. Three-dimensional printing in dentistry: a scoping review of clinical applications, advantages, and current limitations. Oral. 2025;5(2):24.

[32] Schubert O, Edelhoff D, Güth JF, Schweiger J. Advances in 3D printing for removable prosthetics — insights and perspectives. J Esthet Restor Dent. 2026 Jan 6.

[33] Vandenberghe B. The digital patient — imaging science in dentistry. J Dent. 2018;74:S21–S26.

[34] Al Mortadi N, Alzoubi KH, Alzoubi M. Comparison of dental arch measurements between 3D-printed, digital, and stone casts. Future Sci OA. 2026;12(1):2602761.

[35] Jeong YG, Lee WS, Lee KB. Accuracy evaluation of dental models manufactured by CAD/CAM milling method and 3D printing method. J Adv Prosthodont. 2018;10(4):245–251.

[36] Batarseh S, Goldsberry N, Handysides C, et al. Volumetric stability comparison between LCD and DLP 3D-printed dental objects. J Calif Dent Assoc. 2023;51:2271641.

[37] Vlasa A, Bocanet VI, Muntean MH, et al. Accuracy of three-dimensional printed dental models based on SLA vs. DLP. Appl Sci. 2023;13(4):2664.

[38] Doh RM, Choi WI, Kim SY, Jung BY. Mechanical properties of a polylactic 3D-printed interim crown after thermocycling. PLoS One. 2025;20(1):e0318217.