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Original Article

Comparing the accuracy of 3D-printed casts versus plaster casts for tooth-supported and implant-supported restorations

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ABSTRACT

Background: The use of 3D printers in dentistry is expected to increase in the future. However, there is limited information available on the accuracy of dental 3D printers for creating dental and implant models. This study aimed to compare the accuracy of 3D-printed casts and traditional plaster casts for the fabrication of tooth-supported and implant-supported restorations.

Materials and Methods: This *in vitro* study involved a dental model with implant analogs placed at the sites of the right first premolar and molar for an implant-supported bridge and the left first premolar and molar that received preparation for a tooth-supported bridge. Addition silicone impressions were made and poured with dental stone to create 10 plaster casts. The model was scanned using an intraoral scanner, and 20 casts were 3D-printed using digital light processing (DLP) and liquid crystal display (LCD) printers (10 casts for each method). All 30 casts, including the reference model, were scanned using a laboratory scanner, and the obtained Standard Triangle Language files were superimposed in Geomagic software. Data analysis revealed violations of normality and homogeneity of variances. As a result, the Kruskal–Wallis *H* test, a nonparametric method, was employed to compare root mean square (1 RMS = 100 μm) values across three groups. All statistical analyses were performed using SPSS version 27. RMS values were calculated ($P < 0.05$).

Results: The RMS value was significantly lower in the conventional plaster cast group compared to the LCD group ($P = 0.002$). However, there was no significant difference between the LCD and DLP groups ($P = 0.214$) or between the conventional and DLP groups ($P = 0.345$). The interdental distance in the conventional group was significantly lower than that in the 3D-printed groups ($P < 0.05$), but there was no significant difference between the two printing methods ($P = 0.31$). The interimplant distance was lower in the 3D-printed groups compared to the conventional group, and this difference was significant between the DLP and conventional groups ($P = 0.02$).

Conclusion: Although plaster casts demonstrated higher accuracy, 3D-printed casts using additive technology yielded accurate results within the clinically acceptable range (<200 μm).

Key Words: Dental implants, plaster cast, printing, three-dimensional

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INTRODUCTION

Impression making and fabrication of a three-dimensional (3D) cast are crucial steps in the production of prosthetic restorations. Achieving optimal marginal and internal fit for fixed partial dentures (FPDs), as well as a passive fit for implant-supported restorations, is essential for successful and durable restorations. To achieve this, a precise impression and error-free model fabrication are prerequisites.[1-3]

Traditionally, intraoral impressions are made using elastomeric materials and poured with dental stone to create plaster casts. While this technique has been successful, it has drawbacks such as patient discomfort, taste stimulation, impression material distortion, and limitations of plaster models, including volumetric changes, fracture, degradation, wear, loss of surface texture, and contamination from saliva and blood.[4,5]

With technological advancements in intraoral scanners, computer-aided design and computer-aided manufacturing (CAD/CAM) technology have gained popularity in prosthetic restoration fabrication. 3D digital models created using intraoral scanners eliminate the need for conventional impressions and plaster casts. Furthermore, they offer advantages such as permanent data storage and reduced patient discomfort.[6-8]

Intraoral scanning data are saved in Standard Triangle Language (STL) format and used for fabricating 3D models and final restorations.[9] Some restorations can be directly fabricated using digital impressions obtained from intraoral scanners through CAD/CAM technology, eliminating the need for a physical model. However, a physical model is still required for certain applications such as porcelain application, manual waxing for cast restorations, or heat pressing of lithium disilicate ceramic.[9] To fabricate a physical 3D model from digital data, two methods can be employed: subtractive technique using a milling machine or additive technique using 3D printing.[9,10] The milling technique reduces treatment time and offers advantages for dental clinicians, patients, and laboratory technicians. However, it has drawbacks such as material waste, limitations in restoration thickness, and lower accuracy in recording details due to bur size and high equipment costs.[11] On the other hand, the additive technique, also known as rapid prototyping and 3D printing, is based on layer-by-layer material addition. It provides high flexibility in design, accurate recording of details, and minimal material loss.[12-14]

For the fabrication of casts, different photopolymerization techniques, such as VAT polymerization (a type of 3D printing technology that uses a vat of liquid photopolymer resin), specifically stereolithography (SLA) and digital light processing (DLP), can be utilized.[15,16] SLA and DLP printers function similarly, involving the polymerization of a light-sensitive liquid resin.[17] SLA technology employs a single-point laser for polymerization, whereas DLP works through a projector.[18] Casts fabricated using SLA technique exhibit high accuracy, a smooth surface, and excellent mechanical strength. However, this technique is time-consuming, requiring up to 12 h for printing with the highest accuracy. On the other hand, DLP offers the advantage of faster printing as the entire layer is polymerized simultaneously.[18]

Liquid crystal display (LCD) printing technology has gained popularity due to its cost-effectiveness compared to other 3D printers utilizing VAT polymerization. LCD printing does not involve light emission through lenses or other components, thereby avoiding pixel distortion that could affect the results.[19]

The advantages of 3D-printed casts include low weight, reduced risk of fracture, high wear resistance, and the ability to fabricate multiple casts simultaneously.[20] The accuracy of casts produced using additive techniques depends on various factors such as data collection and processing quality, scanner technology, scanning strategy, preparation of tooth or implant scan body, lighting conditions, operator experience, and scanner calibration.[21] In the fabrication process, accuracy can be influenced by additive manufacturing technology, printer calibration, polymer composition, cast design, supporting structure, layer thickness, and fabrication angulation. Finishing processes such as the removal of excess material and supporting structures, final polymerization, and storage can also lead to dimensional changes.[22-26]

Low accuracy of the model would require significant clinical adjustments and result in ill-fitting restorations, compromising clinical outcomes. If the accuracy of 3D models fabricated by 3D printing based on intraoral scanner data is lower than that of plaster casts, the effectiveness of digital treatment may be questioned. However, limited studies have assessed the accuracy of casts produced by intraoral digital scanning, and the reported results regarding the accuracy of casts fabricated using additive manufacturing techniques for FPDs have been conflicting.[27] To address the limitations of previous studies and provide a more comprehensive evaluation, this study aimed to compare the accuracy of 3D-printed casts fabricated using DLP and LCD technologies with traditional plaster casts. By employing a rigorous methodology, including a detailed analysis of both linear and shape measurements, this research seeks to provide a more definitive assessment of the clinical applicability of 3D printing technologies in dentistry. The null hypothesis of the study was that no significant difference would be found in the accuracy of 3D-printed casts fabricated using DLP and LCD technology compared to plaster casts for tooth-supported and implant-supported FPDs.

MATERIALS AND METHODS

This *in vitro* study was approved by the Research Ethics Committee of Shahed University of Medical Sciences, Tehran, Iran (IR.SHAHED.REC.1402.005). This experimental study was conducted *in vitro* using acrylic maxillary models (500A, Nissin) with specific missing teeth: the second premolar on the left and the first and second premolars, as well as the first molar on the right.

Sample size

For the study, the sample size was determined to be 10 per group, totaling 30 participants across three independent groups. This calculation was based on the quantitative nature of the dependent variables, using a one-way ANOVA with an alpha of 0.05, a beta of 0.2, and aiming for a study power of 80%, as per the NCSS PASS 11 software (NCSS, LLC. Kaysville, USA, Utah).

Preparation of the initial model

The right quadrant received two implants at the first premolar and first molar sites to anchor a three-unit implant-supported bridge. Meanwhile, the left quadrant's first premolar and first molar served as abutments for a similar three-unit, tooth-supported bridge.

Conventional impression and plaster model

For the conventional impression, impression copings were secured onto the model and splinted using acrylic resin. To enhance accuracy and offset resin polymerization shrinkage, the splint was bisected with a disc in the center and then reconnected. A gingival retraction cord was placed around the abutment teeth, and a suitable tray, perforated at the implant sites, was chosen. An open-tray, two-step impression was taken using an addition silicone impression material. The impression was then cast with type IV dental stone, and this method was replicated 10 times.

Digital impression and 3D printed model

For digital impression, the scan bodies were tightened with 10 N/cm torque and scanned by an intraoral scanner (TRIOS 3). The STL data were 3D printed by LCD and DLP printers. Thus, three groups (n = 10) were evaluated as follows:

- Conventional group: Conventional impression and plaster model
- DLP group: Digital impression and 3D printed model by DLP printer (Asiga)
- LCD group: Digital impression and 3D printed model by LCD printer (Photon).

To assess the accuracy, the reference model and all obtained models were scanned using a laboratory scanner (Open Technology), and the STL files were digitized and compared. Geomagic Control X (version 2020.1; 3D Systems) was used for the comparison [Figure 1]. Mathematical algorithms were applied to align each STL file with the reference file, and the variance between the test file and the reference

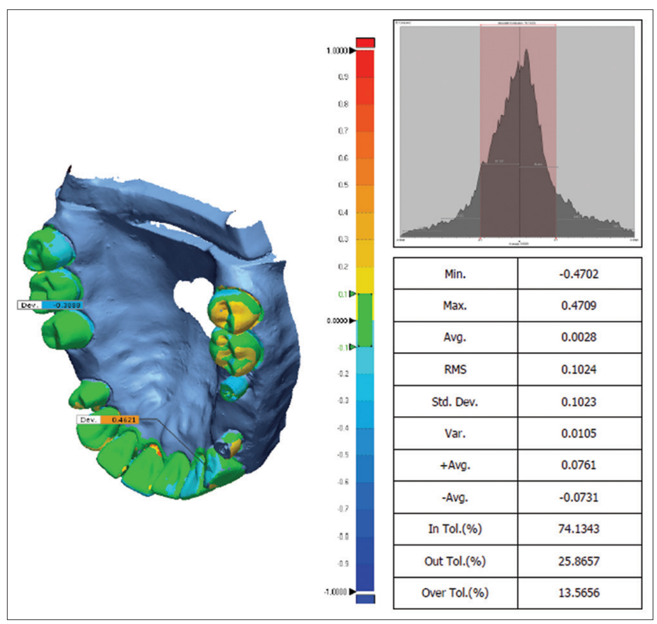

Figure 1: Superimposition of Standard Triangle Language files in Geomagic software.

file was calculated using the superimposition of the STL files. The root mean square (RMS) value was calculated at four positions for the difference between the reference and scanned STL files (1 RMS = 100 µm).

To further analyze the accuracy, shape (deformation) and distance (linear measurement) analyses were performed. For linear measurements, two hypothetical points were selected on tooth abutments and scan bodies, and the distance between them was measured and compared in the three groups [Figure 2]. For shape analysis, a curve was considered on the teeth in the buccolingual direction, and the groups were compared at 11 points [Figure 3].

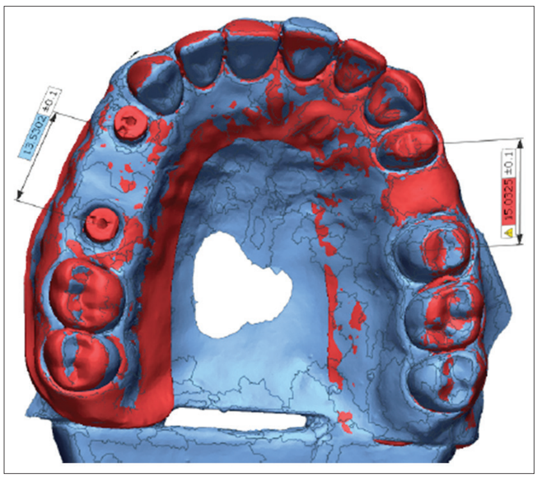

Figure 2: Comparison of interdental and interimplant linear measurements.

Statistical analysis

The statistical analysis was conducted using the Shapiro–Wilk test to analyze the normality of data distribution and the Levene's test to assess the homogeneity of variances. Since the data showed a non-normal distribution and nonhomogeneity of variances, the Kruskal–Wallis H test was applied to compare the RMS values among the three groups. All statistical analyses were performed using SPSS version 27 (IBM, Armonk, NY, USA) ($P < 0.05$).

RESULTS

The study findings indicate that the RMS value was highest in the LCD group and lowest in the conventional group, with a significant difference between the conventional and LCD groups ($P = 0.002$). However, no significant differences were observed between the LCD and DLP ($P = 0.214$) or DLP and conventional ($P = 0.345$) groups [Table 1].

In terms of interdental and interimplant linear measurements, differences were noted compared to the reference model. The interdental distance was significantly smaller in the conventional group compared to the printed groups ($P = 0.01$ and $P = 0.02$), whereas no significant difference was found between the two printing groups ($P = 0.31$). In addition, the interimplant distance was smaller in the printed group than in the conventional group, with a

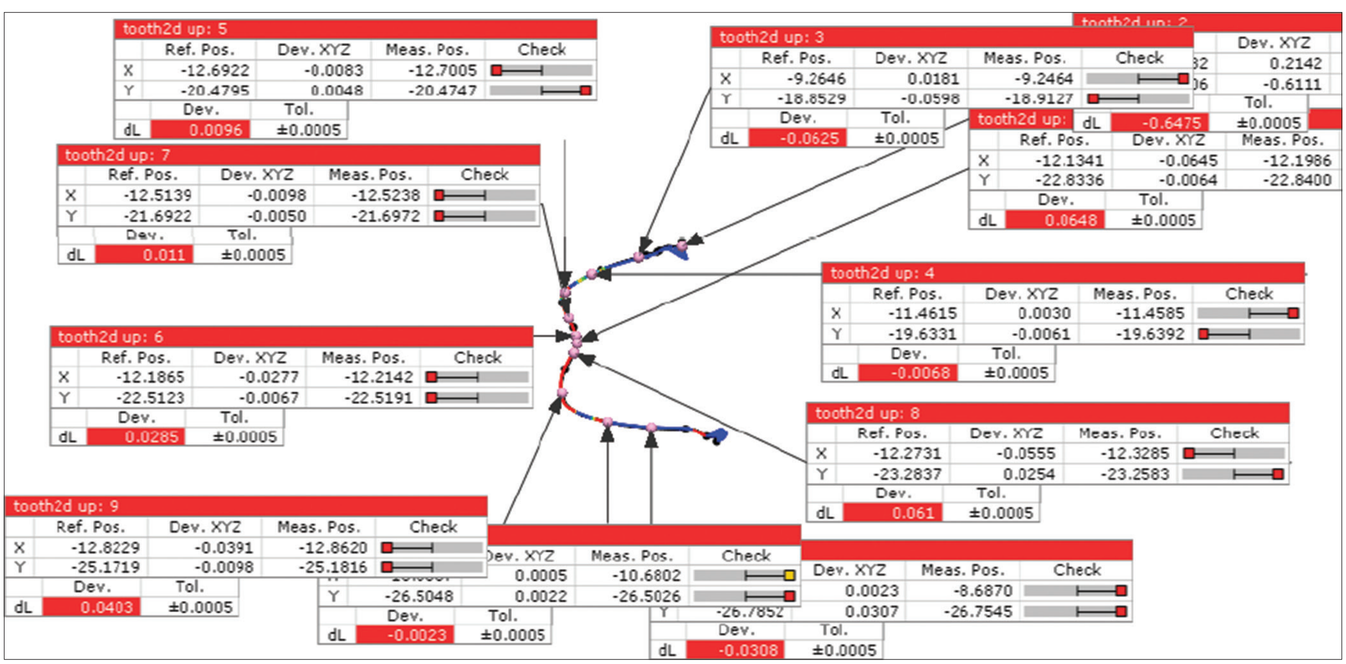

Figure 3: Assessment of tooth curvature (deformation).

significant difference observed between the DLP and conventional group ($P = 0.02$).

The deformation analysis indicated that tooth type (premolar and molar) did not have a significant impact on accuracy ($P > 0.5$). When comparing interdental and interimplant areas, the conventional group exhibited the highest deformation, whereas the DLP group showed the lowest deformation. Significantly different deformations were observed in the interdental area among the three groups ($P < 0.05$), whereas no significant differences were found in the interimplant area ($P > 0.05$). Across all groups, deformation in the interdental area was notably greater than in the interimplant area ($P = 0.000$). Pairwise comparisons of maximum differences in interdental and interimplant areas are detailed in Table 2.

DISCUSSION

This study compared the accuracy of 3D-printed casts using DLP and LCD technology with plaster casts for making dental prostheses. Plaster casts were found to be more accurate, rejecting the null hypothesis. However, 3D-printed casts still showed clinically acceptable accuracy (<200 μm) and can be used for making prostheses, as supported by previous research.[28] Abdeen *et al.*[29] also found that despite some deviations, the 3D-printed casts were within an acceptable clinical range.

A comparison of additive manufacturing techniques in the study showed lower RMS values for 3D printing using DLP, indicating higher accuracy compared to LCD printing, which was in agreement with the results of Moon *et al.*[30] and Ciocan *et al.*[31]

Differences between DLP and LCD printers include lighting duration, light wavelength, and supply volume. LCD printers use liquid crystal for polymerization, offering high resolution but may have slight light leakage affecting accuracy.[32] Light intensity is a key difference between DLP and LCD printing, impacting print speed and polymerization degree.[33] While LCD printers are cost-effective with good resolution, they have a shorter lifespan and require frequent maintenance due to low light intensity causing potential resin polymerization issues.[33]

The clinically acceptable marginal fit for FPDs ranges from 90 to 200 μm.[34,35] Several researchers believe that an optimal marginal fit is 120 μm.[34] For the proximal contacts, 50 μm is usually considered an optimal fit.[36] A linear deviation of up to 200 μm is deemed acceptable due to measurement errors in plaster casts.[37]

Tsolakis *et al.*[19] compared LCD and DLP 3D printers for dental model printing, finding higher

Table 1: Pairwise comparisons of the groups regarding the root mean square (1 root mean square=100 μm)

RMS	Test statistic	SE	Standard test statistic	Significant	Adjusted significant[a]
Conventional-DLP	−6.200	3.935	−1.576	0.115	0.345
Conventional-LCD	−13.300	3.935	−3.380	0.001	0.002
DLP-LCD	7.100	3.935	1.804	0.071	0.214

[a]Significant values were adjusted by the Bonferroni correction for multiple tests. SE: Standard error; RMS: Root mean square; LCD: Liquid crystal display; DLP: Digital light processing

Table 2: Pairwise comparisons of the groups regarding maximum difference in interdental and interimplant areas regarding the root mean square (1 root mean square=100 μm)

Dependent variable	Group (I)	Group (J)	Mean difference (I−J)	SE	*P*
Maximum difference in interdental area	Conventional	LCD	0.60309000	0.10982986	0.000
		DLP	0.76711000	0.10588081	0.000
	LCD	Conventional	−0.60309000	0.10982986	0.000
		DLP	0.16402000	0.06382651	0.049
	DLP	Conventional	−0.76711000	0.10588081	0.000
		LCD	−0.16402000	0.06382651	0.049
Maximum difference in interimplant area	Conventional	LCD	0.04702200	0.03916486	0.480
		DLP	0.02495700	0.03915485	0.804
	LCD	Conventional	−0.04702200	0.03916486	0.480
		DLP	−0.02206500	0.00992454	0.094
	DLP	Conventional	−0.02495700	0.03915485	0.804
		LCD	0.02206500	0.00992454	0.094

LCD: Liquid crystal display; DLP: Digital light processing; SE: Standard error accuracy with DLP for dental casts. Both printer types were deemed suitable for orthodontic appliance fabrication, which was in agreement with the present results.

In vitro, studies showed acceptable accuracy for additive technology and plaster casts in implant- and tooth-supported restorations. Deviations in 3D-printed casts and conventional methods were noted, with factors like operator experience affecting plaster cast accuracy.[28] Interdental area deviations in 3D-printed casts were attributed to complex anatomy, whereas interimplant area accuracy was influenced by cast topography, the accurate position of implant analog, and polymer flexibility.[38]

Tan *et al*.[1] and Banjar *et al*.[39] and Gagnon-Audet *et al*.[40] indicated linear distortion due to resin shrinkage could affect analog seating. For parallel implants, the 3D linear distortion of resin models printed by the DLP printer was similar to that of conventional plaster casts. Alshawaf *et al*.[41] found higher distortion levels in resin 3D-printed casts based on implant angulation. Chia *et al*.[42] found no significant difference in 3D linear distortion of virtual models of parallel and angulated implants. Thus, additional accumulated distortion for angulated implants can be due to photopolymer resin shrinkage and distortion of the site of digital analogs.

According to the present results, conventional methods showed higher interdental area accuracy, while 3D printing excelled in the interimplant area. Future research on restoration fabrication and fit assessment is recommended.

CONCLUSION

Although plaster casts had higher accuracy, 3D-printed casts by the additive technology also yielded accurate results. The accuracy of 3D-printed casts at the interimplant area was higher than that at the interdental area. Furthermore, 3D-printed casts by the DLP technology showed higher accuracy than those printed by the LCD monitor.

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Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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