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Original Article

Comparison of marginal and internal adaptation of provisional polymethyl methacrylate restorations fabricated by two three-dimensional printers: An *in vitro* study

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ABSTRACT

Background: Chairside fabrication of provisional restorations using three-dimensional (3D) printers is rising in digital dentistry. The purpose of this research was to compare the marginal and internal adaptation of provisional polymethyl methacrylate (PMMA) restorations fabricated by two different 3D printers.

Materials and Methods: In this *in vitro* investigation, an intact maxillary 1st molar acrylic model was first digitalized by a laboratory scanner. It was then prepared for an all-ceramic restoration and scanned again by the same scanner. The final restoration was designed in Exocad according to the scan files with a 50 µm cement gap. PMMA restorations were printed by two 3D printers; Group 1: Asiga (n = 10) and Group 2: Digident (n = 10). The replica technique was used to assess the marginal and internal fit of the restorations, and one-way ANOVA was used to analyze the data. P <0.05 was regarded as statistically significant.

Results: The mean marginal gap of crowns in Group 1 was significantly lower than that of Group 2 (75 vs. 195 µm, P = 0.001). Regarding internal adaptation, no significant difference was found between the axial gap values in both groups (P > 0.05). The mean occluso-axial gap (90 vs. 140 µm, P = 0.026) and the mean occlusal gap (116 vs. 300 µm, P = 0.001) of crowns in Group 1 were significantly smaller compared to the equivalent values in Group 2.

Conclusion: Provisional PMMA crowns fabricated by the Asiga printer showed significantly higher marginal and internal adaptation than those manufactured by Digident at all points except for the axial surface.

Key Words: Dental marginal adaptation, polymethyl methacrylate, temporary dental restorations, three-dimensional printing

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INTRODUCTION

Fabrication of fixed dental prostheses requires multiple clinical and laboratory procedures.[1] During this period, dentinal tubular exposure makes the tooth more susceptible to pulpal damage. Furthermore, the tooth is more vulnerable to fracture because of the weakened structure.[2] The possibility of tooth

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migration and functional and esthetic concerns are other reasons that necessitate the fabrication of provisional restorations on abutment teeth during this period.[3] Provisional crowns are a temporary solution to provide acceptable esthetics, stability, and function, preserving the occlusal relationship and protecting the dentin-pulp complex and periodontal health until the final restoration is delivered.[4] In addition, temporary restorations are vital diagnostics tools in oral rehabilitation for perfecting the final results by simulating the definitive prostheses, aiding in the recognition and correction of occlusal schemes, determining the proper vertical dimension of occlusion, and evaluating the planned esthetic and phonetic before finalizing the treatment.[5]

Provisional restorations should have optimal contour and adaptation for fulfilling the mentioned goals.[6,7] The absence of optimal marginal adaptation can lead to plaque accumulation, microleakage, cement dissolution, marginal discoloration, poor esthetics, tooth hypersensitivity, dental caries, and periodontal disease development.[2] On the other hand, the higher the internal misfit, the higher the internal stresses at the restoration-tooth interface and the lower the restoration's fracture resistance.[8] The fabrication techniques primarily determine the adaptation of restorations.[4]

A provisional restoration could be made directly (Chairside) or indirectly in a laboratory setting using polymethyl methacrylate (PMMA). The direct method starts with creating an index from the intact tooth/waxed-up model, and then, the provisional restoration is directly made on the prepared tooth. In the indirect process, temporary restorations are made on a stone cast and then transferred to the dental office to be delivered to patients.[9] Despite being quicker, the direct approach demonstrates multiple drawbacks, such as tissue irritation caused by the residual free monomers, which may result in hypersensitivity (allergic stomatitis) or lichenoid reactions,[10] exothermic heat generation irritating the pulpal tissue,[11] and polymerization shrinkage of acrylic resin leading to marginal, interproximal, and occlusal discrepancies.[12] Besides, the mixing procedures may incorporate voids that could adversely affect the restoration's mechanical strength, surface texture, and precise fit. In addition, directly fabricated restorations have a lower flexural strength.[13] The indirect approaches can overcome these limitations, providing higher strength and better marginal and internal adaptations since the polymerization occurs extra-orally on a dental cast.[9,14] In addition, the indirect approach minimizes the potential risks of chemical and thermal damage to the oral mucosa and the prepared teeth.[4] The indirect method, however, requires more procedural steps, is more time-consuming,[9] and could lead to numerous errors due to the involvement of many clinical and laboratory processes,[1] from taking the final impression, pouring the working cast, to the delivery step.[15]

To overcome these limitations, the application of digital technology in dentistry has been developed due to technological advances and the automation of fabrication processes.[16] Final/temporary restorations can be digitally fabricated using additive (printing) or subtractive (milling)[5] manufacturing techniques.[1] Using computer-aided design and manufacturing (CAD/CAM) digital technology, temporary restorations are manufactured by milling resin blocks into the planned structure as designed by the CAD software.[17] However, CAD/CAM technology has some drawbacks, including the significant waste of raw materials; the fabricated structure's accuracy depends mainly on the size and motion range of the milling machine's cutting burs. In addition, manufacturing large structures frequently wears down the milling burs.[1,18,19]

Therefore, to address some of the shortcomings of the subtractive method, three-dimensional (3D) printing technologies were developed. 3D printers are increasingly used in dentistry to fabricate gingimask (synthetic gingiva fabricated on a dental cast for replicating the gingival tissue), special trays, orthodontic models, and chairside provisional restorations.[20] 3D printers operate based on the layering technique, adding material in cross-sectional layers to form the final product.[21] Time savings and standardized output are two benefits of 3D printing.[6] With this technology, high-wear resistance models can be produced on a large basis, reproducing delicate details like undercuts and intricate internal geometric patterns.[22,23] In addition, compared to the milling technique, this approach makes the most use of raw materials.

In 3D printing, the accuracy, processing duration, and physical properties of printed products are determined by printing parameters, including speed, intensity, angle of laser light, number, and thickness of layers, layer shrinkage, build orientation,[24] hardware, amount and composition of the material, and postfabrication process.[20,25,26] Despite these intervening factors, 3D-printed provisional restorations have yielded optimal results in elastic modulus, flexural strength, fracture strength, wear resistance, peak stress,[26] and adaptation compared to other techniques. The additive pattern of materials applied layer by layer in 3D printing enables the fabrication of complex objects without artificial design modification.[3] Differences in the fabrication mechanism appear to affect the restoration fit, especially at the occlusal area, where 3D printing significantly decreases the internal discrepancy compared to the subtractive method.[27] According to studies, 3D-printed restorations demonstrate better internal and marginal adaptations than milled ones.[20] Mai *et al*.[4] found 3D printing to increase the adaptation of the fabricated temporary restorations, especially at the occlusal surface, compared to milling and compression molding techniques. Lee *et al*.[28] reported a higher internal and marginal fit of provisional restorations in 3D printing than in the milling approach. Peng *et al*.[29] also reported a higher internal adaptation and lower marginal discrepancy of digitally-fabricated provisional restorations made using 3D printing and CAD/CAM.

Stereolithography (SLA), digital light processing (DLP), and material jetting (Multijet and Polyjet) are the methods that can be used for 3D manufacturing prosthetics. These techniques differ significantly in printing mechanism, speed, and resolution.[30] To create the planned structure designed by the CAD program, DLP works by sequentially exposing photopolymerizable liquid monomer layers to ultraviolet (UV) for layer-by-layer material polymerization.[31] Due to its ability to cure an entire layer instantly using a digital mirror device, DLP is quicker than conventional SLA.[32,33] After 3D printing, a postcuring step like UV light irradiation improves the material's mechanical and biocompatibility characteristics.[34] Several factors can affect the accuracy of DLP printers, such as the resolution of the light irradiating plate, the wavelength of irradiated light, duration of radiation, resin type, and the technology of precise controlling of primer along the *Z*-axis.[35]

Due to the novelty of 3D printing technology in dentistry, studies on the accuracy of provisional restorations manufactured by DLP 3D printers are limited.[4,29,36] Considering the significance of optimal marginal and internal adaptation of temporary prostheses, this study aimed to compare the marginal and internal adaptation of provisional PMMA restorations printed by two 3D printers. The null hypothesis was that there would be no discernible difference between the two 3D-printed PMMA temporary crowns regarding their internal or marginal adaptation.

MATERIALS AND METHODS

This *in vitro* study was approved by the Research Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.DENTISTRY.REC.1400.135). Using the one-way ANOVA Power Analysis feature of Power Analysis and Sample Size (PASS)11 software, the sample size was determined to be 10 in each group following a study by Kim *et al*.,[37] assuming $\alpha = 0.05$, $\beta = 0.2$, the mean of standard deviation for the marginal, occlusal, and axial gap to be 55, 89, and 82 μm, and effect size of 0.51, 2.1, and 2.1, respectively.

An acrylic right maxillary 1st molar model (Nissin Dental Prod. Inc., Tokyo, Japan) was mounted on a metal stub with auto-polymerizing acrylic resin to 2 mm to the cementoenamel junction. Next, it was scanned by a laboratory scanner (Shape Lab Scanner D3; Denmark), and the data were saved in the standard tessellation language (STL) format. The tooth was prepared using a high-speed handpiece and a round-end tapered bur (Jota, Ruthi, Switzerland) under water irrigation for an all-ceramic restoration. The final preparation had a chamfer finish line with a 1.2 mm width circumferentially, 2 mm occlusal reduction, 1 mm axial reduction, and a convergence angle of 6°.[28] [Figure 1a].

After preparation, the tooth was scanned again by the same laboratory scanner. The two STL files of the intact and prepared model were transferred to Exocad 2016 software (Exocad GmbH, Darmstadt, Germany). The final restoration was designed according to the scan files considering a 50 μm cement gap. A single clinician performed preparation and design.

The final file was then transferred to two DLP printers: Asiga (Asiga MAX UV, Asiga, Sydney, Australia) and Digident 3D (Ario Salamat, Tehran, Iran); the crowns were printed using PMMA resin (Detax GmbH, Germany). Each printer printed ten restorations [Figure 1b]. The printer settings were as follows: printing layer thickness: 50 µm; projector: UV light-emitting diode 405 nm; projector resolution: 1280 × 800; printing size: 90 mm × 56 mm × 130 mm, product size: 450 mm × 410 mm × 900 mm; XY resolution: 25–100 µm, and *Z* resolution: 1 µm. The fabricated provisional crowns were immersed in a digital ultrasonic cleaner (Skymen, China) containing 70% ethyl alcohol for 180 s to eliminate unpolymerized resins. Postcuring was performed for 10 min in a curing unit at 405 nm wavelength (Light Zone II DS-310, Denstar, South Korea). A single qualified technician performed all fabrication procedures.

The replica technique measured fabricated restorations' marginal and internal adaptation. For this purpose, a light-body silicone material (Charmflex, Dentkist, South Korea) was injected into the intaglio surface of each restoration. Restorations were placed on the acrylic model applying mild manual pressure from the occlusal surface to simulate the clinical settings. The pressure continued until the impression material was polymerized as instructed by the manufacturer. The crown was then cautiously removed to leave the thin layer of the light body material on the tooth surfaces. Then, a heavy-body silicone impression material (Charmflex, Dentkist, South Korea) was poured into a stellar-shaped mold and placed on the prepared tooth. Five minutes were allowed for its polymerization, according to the manufacturer. Next, the silicone was removed [Figure 1c], sectioned perpendicular to the occlusal surface with a #15 surgical scalpel, and divided into 4 segments with mesiodistal and buccolingual cross-sectional incisions. Heavy-body and light-body silicone materials had two different colors and were easily distinguishable. The heavy-body silicone was used to reinforce the replica segment during sectioning to prevent distortion. In cross-sectional assessment, only the diameter of light-body silicone was necessary for measurement analyses. Samples were coded, and all measurements were performed by a blinded prosthodontist (S.H).

Each replica section was inspected under a stereomicroscope (Leitz GmbH, Oberkochen, Germany) under × 10 [Figure 1d]. The diameter of the light-body silicone was measured at the occlusal surface as the occlusal gap at the axial surface as the axial gap, at the occluso-axial point angle as the occluso-axial gap, and at the finish line as the marginal gap [Figure 2]. The values were recorded in micrometers [Figure 3].

Data were analyzed using the one-way ANOVA using the SPSS software (IBM SPSS Statistics 24, IBM SPSS Inc., Chicago, IL, USA) at a 0.05 significance level. The statistician who analyzed the data was also blinded to the obtained data.

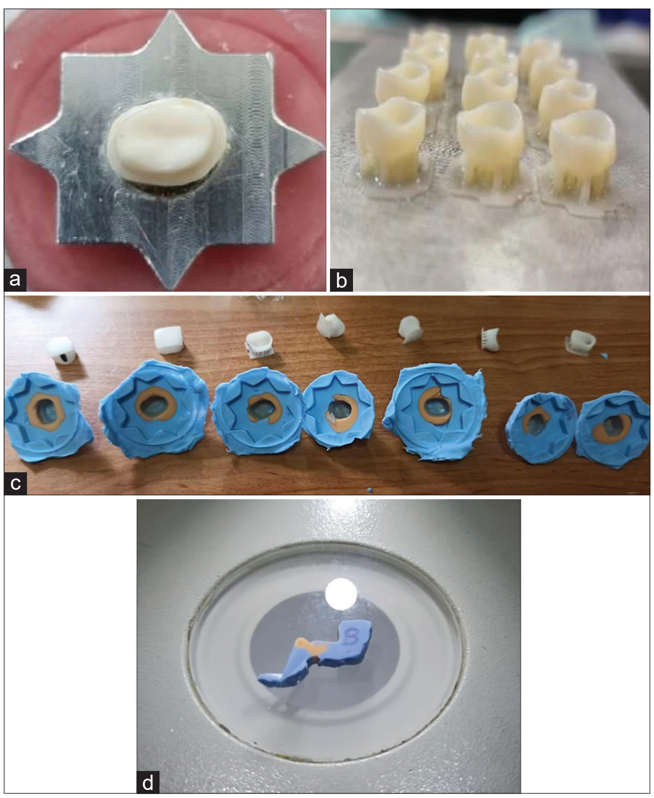

Figure 1: (a) The prepared acrylic tooth model. (b) Printed temporary restorations. (c) Silicone indexes taken for evaluations with the replica technique. (d) A sectioned silicone segment under the stereomicroscope.

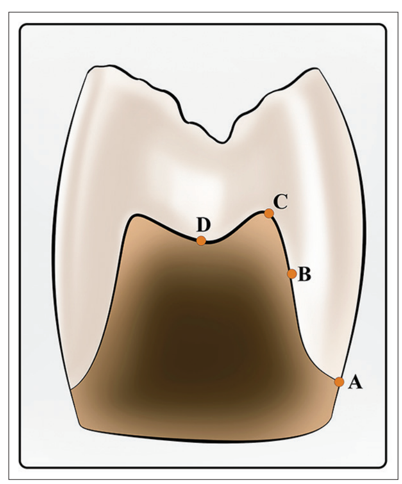

Figure 2: Marginal and internal fit measurement positions are shown schematically for the replica method. (A) Marginal gap. (B) Axial gap. (C) Occluso-axial gap. (D) Occlusal gap.

RESULTS

Table 1 and Figure 4 present the marginal, axial, occlusogingival, and occlusal gap values in provisional restorations printed by the Asiga and Digident 3D printers. The mean marginal gap of crowns printed by the Asiga printer was significantly lower than that of the Digident printer (75 vs. 195 µm, $P = 0.001$). Regarding internal adaptation, no significant difference was found in the axial gap of the crowns produced by the two printers ($P = 0.763$). The mean occluso-axial gap of crowns printed with Asiga was significantly lower than those printed with Digident (90 vs. 140 µm, $P = 0.026$). The mean occlusal gap of crowns printed with Asiga was significantly lower than those fabricated with the Digident printer (116 vs. 300 µm, $P = 0.001$). According to standard deviation values, which indicate data dispersion, the Asiga printer produced substantially more homogeneous gap values. In other words, the measured values in different provisional crowns fabricated by the Asiga printer were close, showing a higher precision; however, the data dispersion in temporary crowns fabricated by the Digident printer was higher.

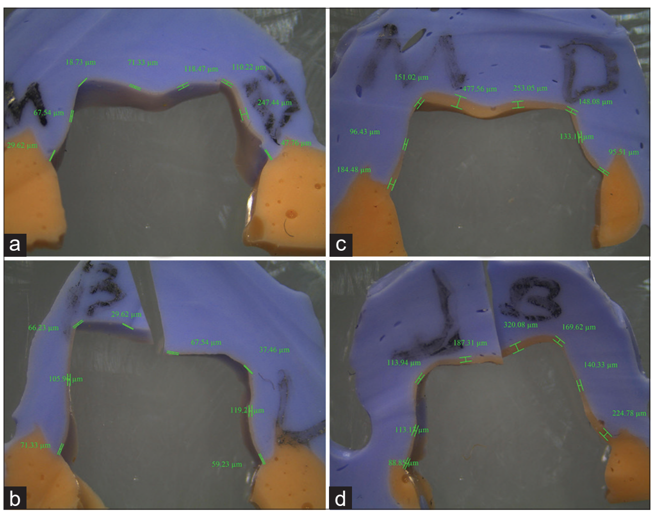

Figure 3: Measuring the marginal, axial, occlusogingival, and occlusal gaps using the replica technique for temporary crowns printed by the Asiga (left column) and the digident (right column) from mesiodistal (a and c) and buccolingual (b and d) views.

DISCUSSION

Given the importance of fabricating provisional restorations with optimal fit, this study compared the marginal and internal adaptation of temporary PMMA restorations printed using two 3D printers. Compared to the Digident printer, the Asiga fabricated crowns with a significantly lower mean marginal gap. Despite the insignificant differences in the internal adaptation between the two printers in the axial misfit, the mean occluso-axial and occlusal misfit of crowns printed with Asiga was significantly lower. The null hypothesis was therefore rejected.

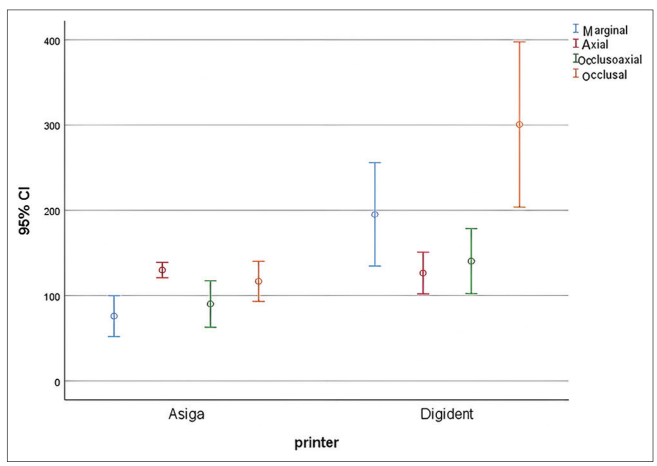

Figure 4: Mean and 95% CI regarding measured gap values for both 3D Printers. CI: Confidence interval.

Table 1: Marginal, axial, occluso-axial, and occlusal gap values (µm) in provisional crowns fabricated by the Asiga and Digident three-dimensional printers

Variable	Printer	Mean±SD	95% CI		Minimum	Maximum	*P*
			Lower bound	Upper bound			
Gap marginal	Asiga	75±33	51	99	42	153	0.001
	Digident	195±84	134	255	95	373	
Axial gap	Asiga	129±12	120	138	110	154	0.763
	Digident	126±34	101	150	78	170	
Occluso-axial gap	Asiga	90±37	63	117	49	177	0.026
	Digident	140±53	102	178	58	240	
Occlusal gap	Asiga	116±32	93	140	67	171	0.001
	Digident	300±135	203	397	80	503	

SD: Standard deviation; CI: Confidence interval

In line with the present findings, the higher marginal and internal adaptation of provisional crowns fabricated using the Asiga printer was reported in the literature. Alenezi and Yehya[38] employed the replica technique to compare the marginal gap of three types of restoration fabricated using 3D printers (Asiga and Formlab) and a milling machine (Sirona). They reported the marginal gap of crowns printed using Asiga as 70–80 µm, consistent with the present results. Nestler *et al*.[25] reported the acceptable accuracy of two extrusion-type and three photo-polymerization-type 3D printers. They found the highest accuracy associated with the Asiga in all distance measurements, which agreed with the current study's findings.

Despite a lack of clinical or evidence-based consensus on the acceptable marginal discrepancy threshold, a marginal gap <120 µm would be clinically justifiable.[39] Euán *et al*.,[40] Jalali *et al*.,[41] and Martins *et al*.[42] reported marginal and internal gaps as 50–200 µm for ceramic crowns. Despite the lack of evidence for the efficacy of 3D printing in fabricating temporary restorations, a marginal gap of 120–172 µm would be acceptable.[43] As a result, the marginal gap of 75 µm for the temporary crowns printed with the Asiga printer in the current research was acceptable. However, the marginal gap of 195 µm obtained for Digident was marginally acceptable. The present study measured the gap after placing the fabricated crowns on the tooth model without any adjustment. The gap of provisional crowns printed using Digident might therefore be clinically acceptable after adjustments.

Similar to the present research, the results of the replica technique in a study by Ryu *et al*.[44] reported clinically acceptable marginal and occlusal gaps of 58–113 and 75–152 µm for the temporary PMMA crowns fabricated in different build directions using DLP 3D printing. The measured occlusal gap was 2.5–5 times >30 µm cement space. Their reported axial gap (52–69 µm) below the occlusal and cervical gap values was explained by errors in STL file splitting, which needed axial wall cement space increased to improve the fit. In another study, Chou *et al*.[45] compared the internal fit of 3D-printed metallic single crowns with milling and conventional casting methods. Their results fell within the 120 µm range, which was considered clinically acceptable; while the lowest mean value for the printed restorations was at the axial wall (100.59 ± 9.26 µm), the mean value for the marginal discrepancy was higher (111.3 ± 12.3 µm). The mean internal fit value (marginal + central fossa + cusp tip + axial values) was 111.85 µm. It should be noted that in addition to using another type of 3D printing technology (metal printer), the abovementioned study reported the marginal and internal gap of permanent 3D-printed metallic restorations, while the present study evaluated provisional PMMA crowns.

No standardized methods have been developed for measuring marginal and internal gaps.[46] Therefore, variations in the investigative techniques can account for the discrepancy in findings. The methods of measuring a prosthesis fitness include direct measurement after cementing the restoration on the tooth model[47] and examining the internal part of restoration using X-ray micro-computed tomography.[48] To evaluate prosthesis adaptation before cementation, the present study employed the cross-sectional replica technique and a stereomicroscope to measure discrepancies at four points designated in the mesiodistal and buccolingual segments of the sectioned silicone.[49] The different results reported with different accuracy in literature can also be explained by variations in the fabrication method, e.g., CAD/CAM and 3D printing, printer brand, printer settings such as radiation angle, type of supporting structure, the material used to fabricate the crowns, scanning accuracy, software program, dental model, restoration design, finish line design, cement gap, and cementation technique.

Mohajeri *et al*.[36] compared the marginal adaptation of fabricated provisional implant restorations using the conventional approach, 3D printing, and CAD/CAM. In contrast to the present findings, a marginal gap of 91.40 µm was obtained using another brand of a DLP 3D printer. Sidhom *et al*.[1] evaluated the effect of 3D printing and CAD/CAM milling on the marginal fit of PMMA provisional fixed partial denture (FPD). They reported statistically-insignificant differences between the two groups and an overall marginal gap of 31.1 ± 4.3 µm at the mesial retainer. In addition to their different study design, they evaluated the marginal gap in a 3-unit FPD, and their measurements were based on the images acquired using a stereomicroscope and a digital image analyzer without using the replica technique.

Due to the luting agent's ability to close the marginal gap, its biomechanical behavior should also be evaluated. The degree of leakage may be influenced by the cement's potential to seal when subjected to the oral environment at the marginal gap.[50] The nature of the cement material also affects physical characteristics, resistance to functional stresses, and the extent of leakage.[51] The cement may prohibit the prosthesis from being fully seated and having the margin sealed.[51] Stappert *et al*.[52] reported an increase in the marginal gap of metal-ceramic FPDs after cementation (from 53 µm to 63 µm). Wolfart *et al*.[50] also noted that after cementation, the marginal gap values of restorations increased from 96 µm to 130 µm. Therefore, the present study excluded the effects of cementation by measuring marginal and internal gaps without cementation.[53]

The marginal and internal gaps are also determined by the tooth type (canine/premolar/molar).[46] In contrast to the present results for a molar tooth, Alharbi *et al*.[3] reported an incisal gap of 169 µm for 3D-printed anterior temporary restorations, twice the designated cement space. Their reported axial gap was 41 µm, less than the specified cement space of 60 µm. This finding was significant; even though the taper degree and chamfer margin are consistent across all tooth types, each tooth has a unique surface characteristic and appearance.

Several factors also affect the accuracy of DLP printers, such as (I) The resolution of the light irradiation plate, which was full HD for both printers in the present study, (II) The irradiated wavelength of light, which was 405 nm in both printers used in this study, (III) Duration of radiation, which is calibrated by the manufacturer, (IV) Resin type, which was the same in both printers used in this study, and (V) Calibration. Resin 3D printers such as SLA and DLP printers provide the highest resolution along the *Z*-axis, enabling the operator to select a thickness between 25 and 300 µm. With an increase in the thickness of each layer, printing speed is expedited, but attention to detail decreases. Thus, the operator should select a thickness to balance speed and recording details.[54] The pixels of different printers have different forms, so they cannot be easily compared. Although the resolution is a quantitative, measurable parameter, it cannot be stated with certainty that it affects the accuracy and quality of the printer. Calibration is also critical.[3] Aside from the calibration performed by the manufacturer, the operator should also calibrate the device and adjust the manufacturing settings, such as layer thickness and curing time.[55] Depending on the material used, a top-notch 3D printer can produce a broad range of outcomes. Different resin materials demand different types of adjustments and calibrations. Resins that have not been previously used with a specific 3D printer may not yield optimal results.[54]

The two printers evaluated in this study appear the same in general parameters. However, the Asiga printer benefits from a technology that constantly monitors printing quality and assesses the related parameters. The main difference between the Asiga and Digident printers is the incorporated system for precise control of the platform in the vertical direction, which is present in the Asiga printer, such that after printing each layer, the printer checks the magnitude of displacement of the platform with encoder sensors and waits until the platform moves up by the thickness of one layer, and then performs the curing.[56] This property prevents cumulative errors in a high number of layers. Another difference between the two printers is the internal radiometer incorporated in the Asiga printer. This radiometer constantly measures the wavelength of the irradiated light to ensure that the same wavelength of light is irradiated to all layers.[56] It should be noted that the absolute precision of a printed object does not depend on the capability of the printer to create a precise layer; instead, it depends on the reproducible capacity of the printer to develop exact layers over and over again. In total, it may be stated that reaching a decision regarding the accuracy of a printer based on its mechanical properties alone is almost impossible, and the best technique would be to test it in function.

Compared to clinical research, *in vitro* investigations on the adaptation of provisional restorations often overestimate the obtained values.[57] The present study's limitation included its *in vitro* design. Oral variables such as patient movements, saliva, blood, and a limited working area might further decrease the accuracy and contribute to the marginal misfit of restorations. This study also evaluated only two types of printers. Although manual sectioning in the replica technique was carefully performed, potential human errors might have caused the overestimation or underestimation of the adaptation.

It is recommended that further studies be conducted on the marginal and internal adaptation of temporary restorations fabricated using different types of 3D printers, including photopolymer jetting, SLA, and DLP printers, using various resins. Future studies can quantify the internal and marginal gaps using micro-computed tomography and triple scan protocol. Future studies can also evaluate the adaptation of 3D-printed multi-unit restorations. Further clinical trials must confirm the results and evaluate the biomechanical, esthetic, and financial viability of 3D printing fabrication methods.

CONCLUSION

Provisional PMMA restorations printed by the Asiga printer demonstrated significantly higher marginal and internal adaptation than those manufactured by Digident at all points except for the axial surface.

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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 nonfinancial in this article.

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