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MARGINAL ASSESSMENT OF PRINTABLE AND MACHINABLE POLYMER-BASED CERAMICS FOR PARTIAL RESTORATIONS. AN IN-VITRO STUDY

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ABSTRACT

Objective: This in-vitro study aimed to assess the impact of margin design and fabrication technique on the marginal adaptation of printable and machinable polymer-based ceramic occlusal veneers.

Materials and methods: Thirty-six extracted human maxillary first premolars were prepared with either a butt or chamfer margin design and randomly assigned to two fabrication groups: 3D printed and milled. The 3D-printed group used ceramic-filled resin material (VarseoSmile Crown plus, Bego, Germany). processed with a DLP printer, while the milled group used Cerasmart (GC America, Inc) blocks and (CEREC MC XL, Dentsply Sirona) milling machine. Marginal gaps were measured at three equidistant points along the restoration using a digital microscope, and the results were statistically analyzed with two-way ANOVA.

Results: There was a significant interaction between margin design and fabrication technique ($p=0.005$). For the butt margin design, there was no significant difference in marginal gap between the 3D printed and milled samples ($p=0.681$). However, the chamfer margin design in the 3D-printed group showed significantly larger marginal gaps compared to the milled group ($p<0.001$). Within the 3D-printed group, chamfer margins resulted in significantly larger gaps than the butt margins ($p=0.002$), whereas the milled group showed no significant difference between the two margin designs ($p=0.365$).

Conclusions: Both margin design and fabrication process affect the marginal adaption of polymer-based ceramic overlays; 3D-printed restorations exhibit noticeably greater marginal gaps than milled restorations. Suggesting that 3D printing technology needs to be improved for intricate patterns like chamfer margins.

KEYWORDS: Polymer-based ceramics, overlays, margin, 3D-printing, milling

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INTRODUCTION

Polymer-based ceramics have evolved broadly over the last decade (1). Hybridization between the traditional resinous polymeric monomers that had been used for decades in direct filling materials with various types and sizes of glass fillers gave raise to special type of materials that have benefits over both the direct dental composites and in-direct available ceramics (2) . The first form of commercially available machinable resin-based material was introduced in early 2000 under the brand name (ParadigmTM MZ100 from 3M) (1) . Dispersed filler resin-based ceramics continued to invade the dental market with variation in industrial polymerization techniques of light, high temperature, and/or high pressure to optimize curing and elimination of uncured monomer release (3) . The primary additional variable that the producer addressed to build its distinct competing product was the modification of the cermic filler type, whether it be silica, zirconia, or barium, and its loading concentration and diameters ranging from 100 nm up to several micrometers (4). Inspired by the concept of glass-infiltrated ceramics, Vita developed a new type of polymer-based ceramics in 2013 called Vita Enamic. This was made possible by the application of another technology. This kind relies on using slip casting or pressing to create a ceramic scaffold or skeleton, which is then further penetrated by the resinous material (1) . The term Polymer-Infiltrated Resin Nanoceramics (PICN) was employed to categorize these materials. Higher mechanical properties than direct composites mainly due to optimum polymerization, ability of indirectly manufactured enables such materials to be the material of choice over direct composites for large cavities with cuspal coverage (5) . Meanwhile despite lower mechanical properties than in-direct ceramics, these materials' modulous of elasticity is closer to that of dentin giving an advantage over ceramic's brittleness and rigidity which was evident by Swain et al (6) comparing PICN to lithium disilicate ceramics. Low cost, ease of manufacturing, less abrasiveness, ease of polishing, modification and intraoral repairability are of the main characteristics that outweigh the selection of such materials (1). These materials are available for both subtractive manufacturing and additive manufacturing. While ceramics are very well established for subtractive machining, additive manufacturing is still under research and not as well recognized as for polymeric nature materials (4). Additive manufacturing offers many advantages over the subtractive one, being economic, decreasing waste, capacity to create intricate designs such as undercuts or complex geometry that aren't millable and giving the ability to customize and hybridize deposited layers according to needed properties (5) . In the realm of tooth conservation and prevention, particularly with the development of bonding technologies, decay-oriented preparations that prevent future loss of healthy tooth structure are being created using newly identified modalities (7) . Occlusal table tops or occlusal overlays are among the new modalities being used for restoring loss of occlusal surfaces instead of full-coverage restorations that were traditionally recommended (8) . This is advantageous in cases of severe tooth attrition, which typically manifest as a short clinical crown in a setting with restricted occlusal space (9). Additionally, in cases where tooth reduction is not essential, hybrid dental materials are recommended as occlusal overlays (10,11) . Different preparation designs were recommended to optimize bonding, restoration fit and marginal seal with no cutting end for the effect of preparation designs on the clinical outcome (12) . While simplicity may recommend butt-margin with no extra preparations, clinical and laboratory studies are found to recommend beveling or surrounding rounded margin finish line to allow optimizing enamel bond, better orientation and some color degradation (13,14,15,16). While numerous machinable polymer-based ceramics were tested in dental literature few numbers of studies to the author's knowledge assessed the printable materials as a permanent restorations (17). According to a study by **Azarbal** and co-workers, (18) machinable PICN restorations surpassed milled lithium disilicate ones in terms of marginal adaptation. On the contrary **Yildirim** and co-authors (19) employed microcomputed tomography scanning to found that while the hybrid materials' adaptability (both machinable and printable) was within a clinically acceptable range, it was noticeably lower than that of the lithium disilicate. This study is designed to assess the difference in marginal adaptation for printable and machinable overlays with different margin designs. The null hypothesis stated that there was no discernible difference in margin adaptation between the margin designs both machined and printed hybrid materials.

MATERIALS AND METHODS

Thirty-six intact human maxillary first premolars were collected. These teeth were recently extracted for orthodontic purposes and their status to be caries free was verified carefully. They had both soft deposits and calculus removed. after which they were kept in a 0.1% thymol solution at room temperature. Subsequently, the roots of the teeth were positioned 2mm apical to cemento enamel junction and secured using autopolymerizing acrylic resin material (Egypoxy) along their long axis inside metal rings. The tooth preparation process involved the use of a 120-degree angled adaptor and a specially designed parallel machine to guide the handpiece. Two silicon indexes were produced for each tooth to evaluate reduction in both directions: the buccolingual and mesiodistal. For all groups, the occlusal reduction had been set at 1 mm. Teeth were randomly divided into two equal groups according to the type of margin preparation intended. For the Butt margin group (n=18), the margin was set at the occluso-buccal line angle, while for the rounded chamfer margin (n=18); the rounded chamfer occluso-buccal margin was created on top of the axial wall (Figure 1). Using a particular stone with a non-cutting guiding tip (6856P 314 018, Komet). Preparations were then polished with a fine stone (8856 P 314 018, Komet). Optical impressions for all specimens were done by the same operator using the intraoral scanner (PrimeScan, Dentsply Sirona, Charlotte, NC, USA) and exported in a surface-tessellation-language (STL) format. With dental CAD software (Exocad DentalCAD, software version 3.0 Galway, Exocad GmbH, Germany), margin detection and insertion path was set, a uniform 60 μm cement space was created. The digital blueprints were produced (Figure 2). Samples were split into two subgroups (n=9) for each group of margin design preparation based on the material and manufacturing technique. For additive manufacturing, A DLP printer (Varseo XS, Bego, Germany) was used to print each specimen, and ceramic-filled resin (Varseo Smile Crownplus A3, Bego, Germany) was used. Each specimen was cleaned for three minutes in an unheated ultrasonic bath using a reusable 96% ethanol solution, and then for two minutes in a fresh 96% ethanol solution to get ready for post-processing. The specimens were cleaned with a brush soaked in a 96% ethanol solution before being flushed out to remove any remaining resin. For the aim of subsequent light-curing, the specimens were put through two stages of 1500 light strikes each in the Bego Otoflash (Bego, Bremen, Germany): a first cycle via the occlusal side and a second step via the intaglio aspect. All subsequent processing phases were completed in accordance with Bego's instructions. Using (CEREC MC XL, Dentsply Sirona)milling machine, the overlays of the two designs were milled for the millable groups using Cerasmart (GC America, Inc) blocks, polished and seated. Each specimen was imaged using a USB digital microscope that has a built-in camera in order to estimate the marginal gaps. The photos were captured using the following image acquisition system:

1. A vertically positioned digital camera (U500x Digital Microscope, Guangdong, China) with a resolution of 3 Mega Pixels was put 2.5 cm away from the samples. The angle formed by the light

sources and the lens's axis is approximately 90 degrees.

2. 8 LED lamps, each with a control wheel for adjustment, were used to create illumination with a color index of about 95%.

Using a fixed magnification of 40X, the photos were captured at maximum resolution and connected to a suitable personal computer. A resolution of 1280 × 1024 pixels was used to record each image (Figure 3). The gap width was measured and assessed using a digital image analysis system (Image J 1.43U, National Institute of Health, USA). All boundaries, dimensions, frames, and measurable parameters in the Image J software are given in pixels. Consequently, system calibration was carried out in order to translate the pixels into exact real-world units. The Image J software produced a scale, which was compared to an object of known size, in this case a ruler, to achieve calibration. For every specimen, shots of the margins were obtained. Following that, morphometric measurements [three equally spaced landmarks around the circumference of each surface] were made for every image. Every measurement was made three times at each location. After that, the acquired data were gathered, collated, and statistical analysis was performed. For statistical analysis, Values for the mean and standard deviation (SD) were used to present numerical data. Using the Shapiro-Wilk and Levene tests, respectively, and observing the distribution, they were examined for normality and variance homogeneity. The information was homogeneously distributed across variables and had a normal distribution. A two-way ANOVA test was used to assess the data. Using the False Discovery Rate (FDR) method to alter the p-value, the error term of the two-way model was used to compare simple effects. For every test, the significance threshold was set at p<0.05. R statistical analysis software, version 4.4.1 for Windows, was used to conduct the statistical analysis.

RESULTS

A substantial interaction between the two examined factors was revealed by the two-way ANOVA results in Table (1) (p=0.005). Table (2) presents the comparisons of simple effects and demonstrates that there was no significant difference (p=0.681) between the two fabrication procedures for samples with butt-margin preparation. The marginal gap measured in 3D printed samples was, however, substantially greater than that of milled samples (p<0.001) for samples with a chamfer finish line. Samples with chamfer finish line for 3D printed samples had substantially higher gap values than samples with butt-margin (p=0.002). The preparation design's impact was not statistically significant for milled samples (p=0.365). Figures (4), (5) and (6) give summary statistics for various measured variables.

TABLE (1) Two-way ANOVA

Source	Sum of squares (II)	df	Mean square	f-value	p-value
Manufacturing process	441.93	1	441.93	**15.03**	**0.001***
Margin design	113.68	1	113.68	**3.87**	**0.067**
Manufacturing * Margin design	317.21	1	317.21	**10.79**	**0.005***

df degree of freedom, * significant (p<0.05).

TABLE (2) Simple effects comparisons.

Design	Marginal gap (µm) (Mean±SD)		f-value	p-value
	3D printed	*Milled*		
Butt margin	20.06±4.23	18.62±4.11	**0.17**	**0.681**
Chamfer	32.79±8.58	15.43±3.04	**25.64**	**<0.001***
f-value	**13.78**	**0.87**		
p-value	**0.002***	**0.365**		

**** Significant (p<0.05).***

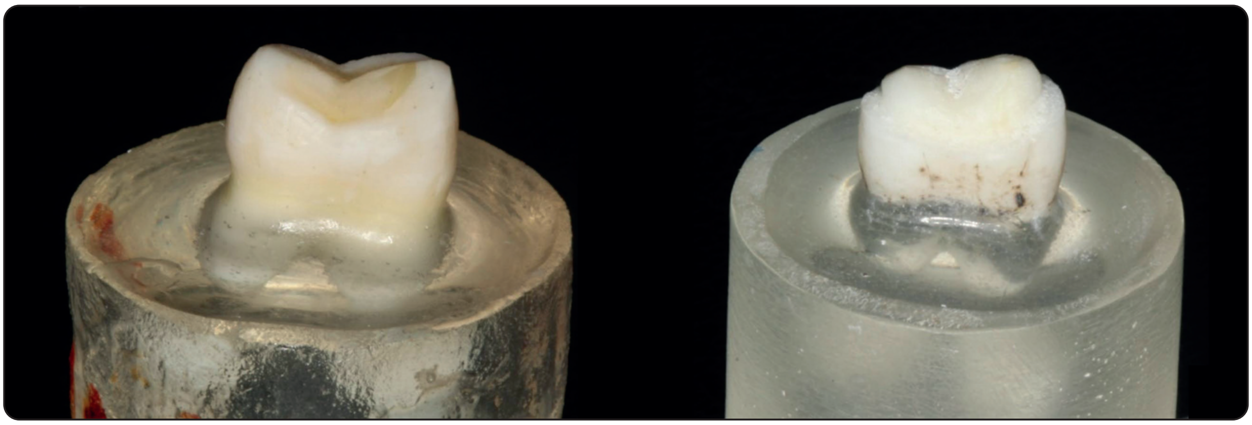


Fig. (1) Preparation of 1mm occlusal reduction (left side) is the butt margin design and (right side) is for chamfer margin design.

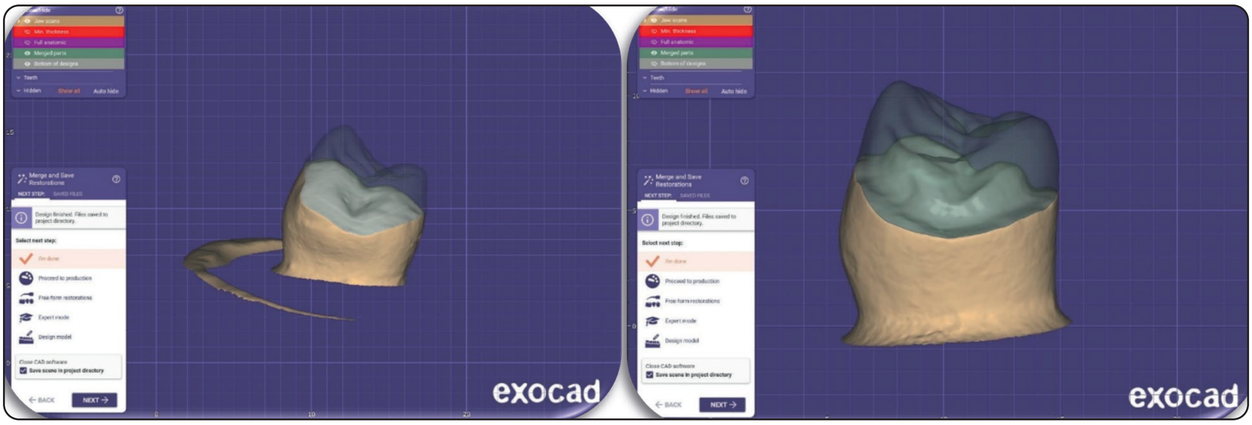
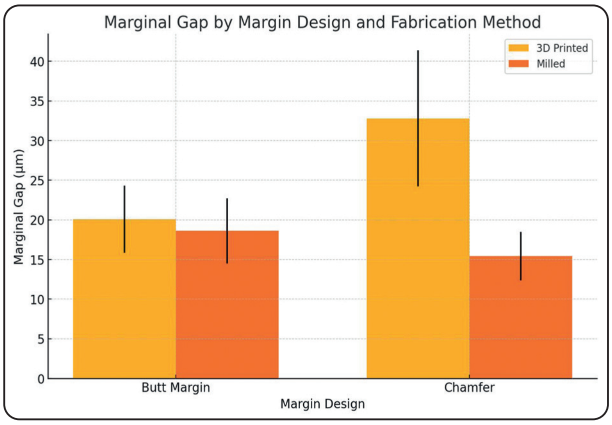


Fig (2) Blue prints for both margin designs; (right side) chamfer margin design, (left side) butt margin design.

Fig (3) Microscopic picture of the overlay-tooth margin, top layer is the occlusal overlay (restoration), bottom layer is the tooth structure.



Fig(4) Bar Chart with Error Bars This shows the marginal gap (in μm) for both margin designs (butt and chamfer) across the two fabrication methods (3D printed and milled).

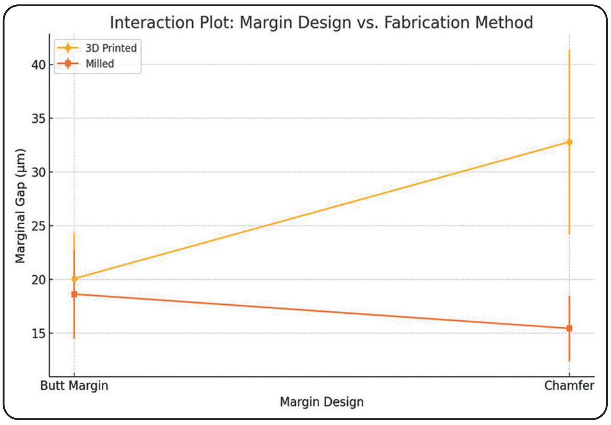


Fig. (5) Interaction Plot highlights the interaction between margin design and fabrication method showing how the marginal gap varies for 3D printed and milled samples with different margin design.

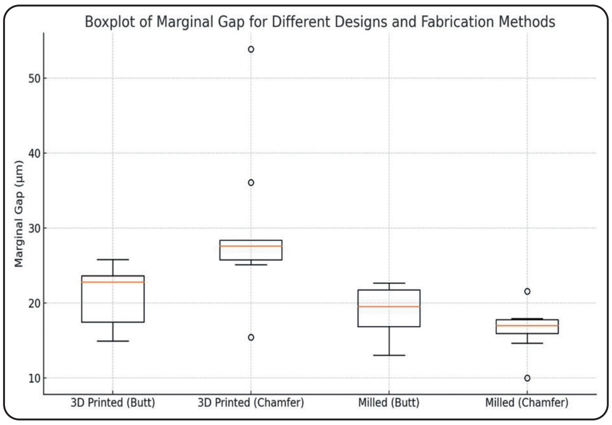


Fig. (6) Boxplot Comparison shows the distribution of marginal gaps for each combination of margin design and fabrication method providing insight into the spread of the data.

DISCUSSION

The results of this study revealed important insights into the impact of margin design and fabrication techniques on the marginal adaptation of polymer-based ceramic occlusal veneers. Subtractive milling is currently a choice for the majority of hybrid ceramics utilized as restorative materials (20). Known as a "flexible nanoceramic," Cerasmart is a high-density resin composite material made of millable polymer-based ceramics that contains 71% wt filler particles(20) . Though there aren't many 3D-printed hybrid materials accessible for single, long-term, or fixed restorations,(17) Varseosmile Crown plus, a revolutionary 3D-printable hybrid material, was introduced recently. It was additively manufactured using digital light processing (DLP) technology(21). According to the producer, this material has outstanding aesthetics along with strong flexural strength, modulus, and dimensional stability. One of the main indicators of the clinical efficacy of fixed prosthetic restorations is the marginal adaptation (22) .

Cement breakdown, restorative fracture secondary caries, or microleakage could result from a substantial marginal or internal disparity. Preventing secondary problems hence requires aiming for the optimal adapting of indirect restoration to preparation (23) . The intrinsic accuracy of a system and its proportionate impact on marginal fit could not be determined from measurements taken only after cementation (24) . The majority of investigators also found that it was more convenient to perform measurements without cementing the crown. Consequently, this investigation was carried out prior to cementing in order to ignore the influence of the luting cement properties (24) . Less than 100–120 μm is regarded as an acceptable marginal gap in terms of the optimal and clinically acceptable marginal adaptation(24) .

This investigation yielded clinically acceptable mean values for marginal discrepancy ranging from 15.43±3.04μm to 32.79±8.58μm for both manufacturing procedures and margin designs employed. One possible explanation for the low marginal gaps observed could be the design's simplicity as an occlusal overlay with minimal cement gap settings. In CAD design, the cement space setting typically adheres to the International Organization for Standardization (ISO) 4049:2019 standard for polymer-based filling, restorative, and luting materials mixing ratio of base and catalyst, where the critical cement thickness is set at 50µm(25) . Thus, it was just set by the CAD process at 60 µm. In 2019, Dauti and colleagues(26) assessed the impact of minor cement space settings variations of 50 and 80 µm on the internal and marginal adaptation of hybrid ceramic crowns. Their findings indicated that both virtual spacer settings may be employed in the manufacturing process with negligible variations. Greater luting material thickness resulted in higher tensile stress in the crown's core, which increased the degree of crown flexure and failure even if the cement thickness served as a cushion between the crown and abutment(26). Consequently, the thinnest possible cement gap settings was used in this investigation. In 2022, Maneenakarith and coworkers(27) also discovered that thinner resin cement space had a stronger cement-zirconia shear bond than thicker one. Regardless of the margin design, the milled samples in this investigation had smaller marginal gap values than the 3D printed ones. This contrasted with numerous previous research that found that 3D printed restorations had superior marginal adaptation than milled restorations. (28,29,30)

In 2022, Kakinuma et al (31) discovered that, in comparison to milled crowns made from Cerasmart blocks, 3D-printed resin-composite crowns showed improved precision and fewer marginal gaps. According to a 2022 study by Donmez et al, (32) implant-supported 3D-printed definitive composite crowns (Saremco Print, Crowntec) exhibited superior marginal adaption in comparison to crowns made with three distinct milled materials—among them Cerasmart, the same material we employed in our work—fabricated via a milling approach. Furthermore, Suksuphan P and colleagues (25) found that when they used a variety of materials, including both materials we investigated, 3D printed crowns had a higher marginal adaptability than milled ones. They gave the explanation that additive manufacturing can create undercuts and intricate structures more easily than milling.

Considering the degree of simplicity in our design linked to the nature of restoration could be the true reason for the findings changing in favor of the milling method instead of the 3D printing approach. For the butt margin, this variation was negligible, but for the chamfer design, it was clearly significant. Given that both manufacturing methods utilize distinct polymer-based ceramic materials, it has been proposed that the marginal adaptation of CAD/CAM restorations varies depending on the material (33,34) .

Additionally, the specificity of each material's chemical and microstructural properties affects the CAD/CAM production's accuracy and precision. These results may therefore be material dependent(35). Regardless of the manufacturing method, the overall butt margin showed lower marginal gap values for the margin design effect than the chamfer design. This was barely noted for the milled group but was significantly evident in the samples from 3D printing. Our findings thus indicated that, in terms of marginal precision, additive manufacturing—that is, 3D printing—seemed more susceptible to variations in margin design. Dimensional errors may be introduced by the 3D printing process, especially when dealing with intricate margin designs like the chamfer (18).

This was further supported by Azarbal et al 2021, (18) who found that while the differences were within clinically acceptable bounds, 3D-printed restorations had marginal gaps that were somewhat greater than those of milled restorations. According to Yildirim et al.in 2018, (19) milled restorations shown better marginal adaption than hybrid materials generated with 3D printing; however, the current investigation demonstrated that this distinction is only noteworthy for specific margin designs (namely, chamfer). This raises questions about whether the inherent properties of the fabrication method or the complexity of the margin design are the primary drivers of these discrepancies.

It is possible that the intricate geometries involved in chamfer margins, which require precise layer-by-layer deposition in 3D printing, are more prone to inaccuracies compared to the more straightforward butt margin. In contrast, milling may offer better control and precision, particularly for detailed margin designs. The lack of significant differences between printed and milled restorations with the butt margin design is noteworthy and suggests that simpler margin designs may be less susceptible to the limitations of 3D printing technology. This finding is consistent with previous research, such as the study by Al-Akhali et al in 2018, (10) revealed that, in cases where restorations are made using straightforward designs, small differences in the fabrication process have little effect on the strength and longevity of polymer-based ceramics. However, Yildirim et al (19) have pointed out that the wider gaps seen in 3D-printed samples with chamfer edges may be related to the constraints of the additive manufacturing process in managing the fine details of complicated geometries (19). The characteristics of each manufacturing technique and variable factorial elements inherited through each procedure might explain the gained results. Marginal accuracy of the milled restorations may be impacted by the following factors during the milling process: abutment preparation design, cement spacing setting, hardness of the milled materials, and burs diameter and sharpness (36). In contrast, a number of printing characteristics, including build orientation, layer thickness, x-y resolution, light exposure duration, post-processing, and printing materials, may have an impact on the accuracy of restorations produced by 3D printing (37). Only a few studies have varied these factors and comparatively investigated the marginal adaptation of 3D-printed crowns. Therefore, further studies on the factors associated with 3D printing techniques are required. In this investigation, the marginal gap was measured by direct microscopic inspection. The direct microscopic examination of the gaps around the crown edges is the most often utilized technique(24) . However, there are significant drawbacks to this approach, including the possibility of difficult-to-prove reference locations that create projection mistakes (32). It may be useful to employ other techniques, such as the triple scan protocol or micro computed tomography (micro-CT), (19) to corroborate findings and obtain additional insights on 3 dimensional internal and marginal fit.

CONCLUSION

1. No significant difference in marginal adaptation between 3D printed and milled restorations with the butt margin design.
2. Chamfer margin design resulted in a significantly larger marginal gap for 3D printed restorations compared to milled ones.
3. For 3D printed restorations, chamfer margins had significantly larger gaps than butt margins.
4. Milled restorations showed no significant difference in the marginal gap between chamfer and butt margins.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval

“Research Ethics Committee of Faculty of Dentistry Ain Shams University FDASU-REC” waived ethical approval for this study due to being an In-vitro study with no patients, animal experiments or living tissues included. Exemption no: FDASU-Rec ER092403.

Conflict of interest

The authors declare that they have no conflicts of interest.

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