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EVALUATION OF INTERNAL FIT AND MARGINAL ADAPTATION OF 3D PRINTED VERSUS CAD/CAM MILLED PROVISIONAL ANTERIOR CROWNS (IN-VITRO STUDY)

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ABSTRACT

Aim: This study aimed to evaluate the internal fit and marginal adaptation of 3D printed vs CAD/CAM milled provisional anterior crowns.

Materials and methods: Sixteen 3D printed resin models were fabricated and classified into two groups according to the provisional crown construction technique; group 1: received CAD/CAM milled PMMA crowns (n=8), and group 2: received 3D printed PMMA crowns (n=8). The silicone replica technique was used to evaluate the internal fit, while the vertical marginal gap distance was evaluated using a stereomicroscope. Statistical analysis was performed with SPSS 16 ® (Statistical Package for Scientific Studies). The data for all groups was reported as mean and standard deviation. The provided data was analyzed using the Shapiro-Wilk test and the Kolmogorov-Smirnov test to assess normality. Comparison between different surfaces was performed using the One-Way ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons. Comparison between 2 groups was performed by using an independent t-test.

Results: There was a statistically significant difference between the two groups. The milled group showed a significantly lower internal gap and vertical marginal gap distance than the 3D Printed group (P=0.0001).

Conclusion: The CAD/CAM milled PMMA provisional crowns showed better internal fit and marginal adaptation than the 3D Printed PMMA provisional crowns. Both techniques reported clinically acceptable results.

KEYWORDS: 3D printing, CAD/CAM Milling, PMMA provisional crown, marginal adaptation, internal fit

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INTRODUCTION

The effectiveness of the prosthetic treatment strategy depends on provisional restorations. Numerous purposes can be served by a well-finished and precise provisional restoration, such as pulp preservation, abutment positioning stability, function and esthetics. Moreover, provisional restorations are critical way in evaluating the outcome of the final restoration specially in oral rehabilitation cases. They provide the clinician a valuable diagnostic tool during readjusting of the occlusal scheme specially when there is loss of the vertical dimension. Provisionalization is essential for evaluating both aesthetics and phonetics. Furthermore, it is crucial for achieving success in management of periodontal conditions in cases with impaired esthetic outcomes [1- 4]

Over time, several methods for creating temporary restorations have been employed and improved. Previously, provisional restorations were fabricated conventionally from composite or resin materials. Nowadays, they can be fabricated digitally [5]. Conventionally fabricated provisional restorations have some disadvantages due to the properties of the material being used [6,7]. In order to overcome these drawbacks, digital fabrication techniques had been introduced. Provisional restorations manufactured using digital CAD/CAM technology can be obtained through either additive manufacturing (3D printing) or subtractive manufacturing (milling) [8,9,10,11,12,13].

Provisional restorations fabricated by digital techniques showed better marginal adaptation, better tissue response due to elimination of the free monomer and prevent damage that may occur to the prepared tooth duo to the heat generated during resin polymerization [14,15,16]. 3D printing has recently become a viable alternative for fabrication of provisional restorations [15].

The success of any restoration depends on the accuracy of the margins of the restoration and the precision of fit to the prepared abutments [17,18].

There are three types of marginal misfits: horizontal, vertical, and absolute. The “horizontal marginal discrepancy” represents the horizontal misfit at the edge of the framework, measured at a right angle to the direction of withdrawal. While, the “vertical marginal discrepancy” refers to the vertical misfit measured along the direction of the framework’s removal. [19,20]. However, the term “absolute marginal discrepancy” refers to the angular combination of marginal gap and extension error. [19,21].

Flügge et al[19] found that the clinically accepted value of the vertical marginal gap could be ≤100−120 µm. According to Keerthna et al [22], it is recommended that the marginal gap of restorations is between 25 and 40 µm. The clinically acceptable marginal gap for CAD/CAM restorations is 50–100µm [23]. Nevertheless, increased marginal gap may lead to the exposure of the luting cement to saliva causing dissolution of the cement. This can lead to irritation of the gums, periodontal problems, and recurrent caries [4].

The replica technique can be used for measurement of the internal fit of any restorations. This approach can be employed both in vivo and in vitro studies by filling the area between the crown and the tooth with a light body silicone. Subsequently, the film thickness of the light body is measured with a microscope. Although it’s a relatively simple process, one drawback is that silicone may distort while being examined. [24]

The marginal discrepancies can be assessed using a stereomicroscope. They used a digital camera set up on a tripod to take a 1:1 picture of each of the die’s four sides. The marginal gaps are measured using digital measurement software. While this method is considered as a reliable method, it has certain disadvantage, such as the measurement being affected if the camera angle changes. Since the microscope is positioned perpendicular to the restoration margin, any overhanging in the margin cannot be evaluated because there will be no vertical gap seen in the margin's vertical overlap. [24]

The aim of this study was to evaluate Internal Fit and Marginal adaptation of 3D printed vs CAD/CAM milled provisional anterior crowns. The null hypothesis assumed that there will be no difference between the CAD/CAM milled and 3D printed provisional crowns in terms of internal fit and marginal adaptation.

MATERIALS AND METHODS

Description of research question

P: Population: 3D printed model with all ceramic preparation for a mandibular canine

I: Intervention: 3D printed PMMA crowns

C: Comparator: CAD/CAM milled PMMA crowns

O: Outcomes: 1ry outcome: Internal fit

2ry outcome: vertical marginal gap

S: In Vitro study

Fabrication of the Reference Model

A virtual model was created using Blender for Dental (B4D) software (Blender v 3.6, Blender Foundation, Amsterdam, Netherlands). A virtual die mimicking a prepared mandibular canine to receive an all-ceramic crown was designed [25] (1.5-2mm incisal reduction, 1 mm axial reduction, 1mm chamfer finish line and 8° incisal convergence angle), Figure (1,2). The designed model and separate die were exported as an STL file for printing. Resin models with separate dies were printed using (NextDent Model, Soesterberg,

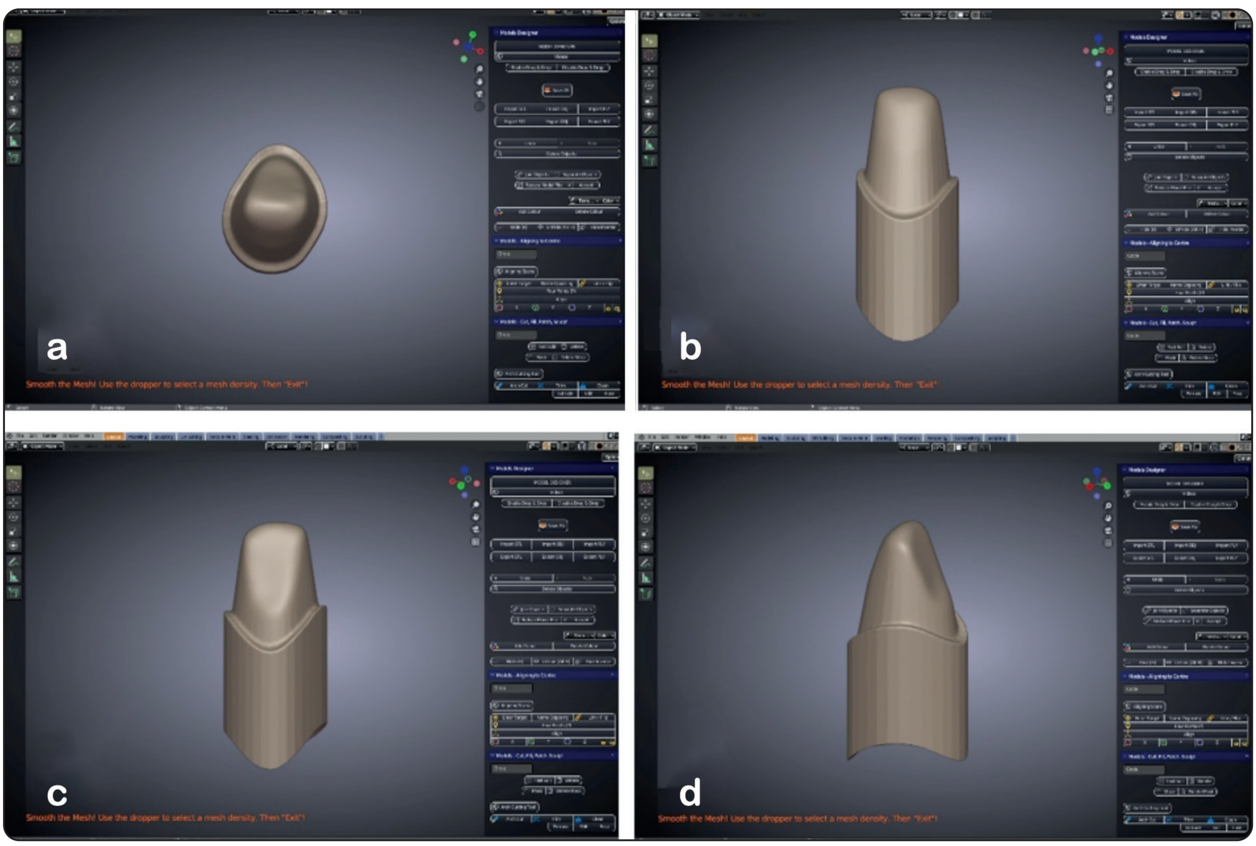

Fig. (1) virtual design of prepared mandibular canine. a) occlusal view, b) buccal view, c) lingual view, d) proximal view

Fig. (2) Virtual model with a separate die

The Netherlands) in a 3D printer (NextDent 5100, Soesterberg, The Netherlands). After completion of the printing process, the printed models were cleaned in ultrasonic cleaner (Codyson, Shenzhen, China) using isopropyl alcohol for 10 min. Then, all models with their separate dies were post-cured for 10 min according to the manufacturer's instruction in an ultraviolet light box (LC-3DPrint Box, Soesterberg, The Netherlands), Figure (3)

Sample Size Calculation

The power analysis focused on internal adaptation (μm) as the primary outcome. The effect size (d = 1.51) was determined using the results of Radwan et al. (2023) [24] in which the milled group recorded (193.78±41.30μm) and the 3D printed group recorded (95.98±41.30 μm). by considering 0.05 alpha level, and 0.2 beta level (power=80%). The actual sample size (n) came to be (8) samples in each group. G*Power Version 3.1.9.7 test was used.

Sample Grouping

Sixteen 3D printed resin models were classified according to the provisional crown construction technique into two groups; group 1 (the comparator group): received CAD/CAM milled PMMA crowns (n=8), and group 2 (the intervention group): received 3D printed PMMA crowns (n=8).

Fabrication of the PMMA provisional crowns:

The working models with the removable die were scanned using a desktop scanner (Ceramill Map 400 Scanner, Amann Girrbach GmbH, Austria) then saved in STL format. The virtual design of the provisional crown was designated using Exocad software (Exocad GmbH, Germany). The software calculated a virtual model from the scanned images and an automatic margin finder was used for margin detection. The cement space was set by the software to be 30 μm [30]. The STL file of CAD design was sent to CAM system

For construction of CAD/CAM milled group, eight PMMA provisional crowns (XT-PMMA disc, China) were milled using five axis milling machine (CORiTEC 150i dry, imes-icore GmbH, Eiterfeld Hessen, Germany). Figure (4)

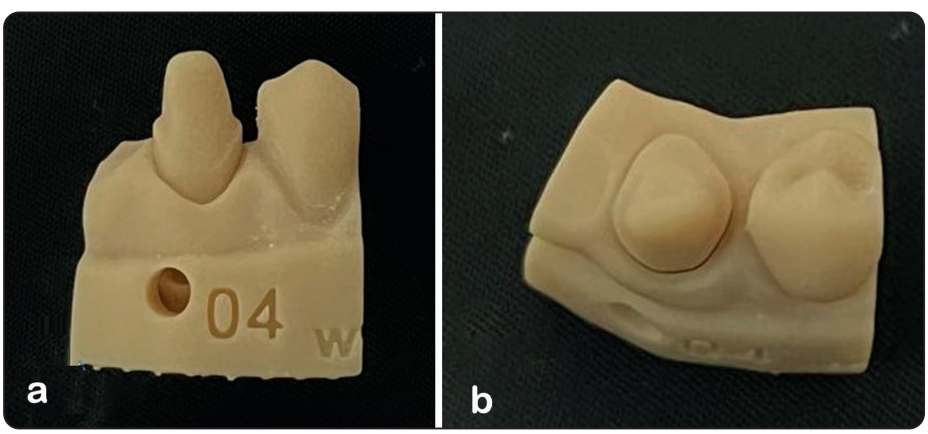

Fig. (3) 3D printed resin model
a) buccal view,
b) occlusal view

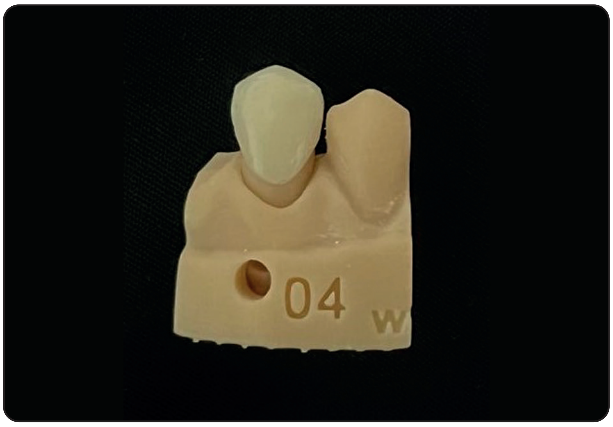

Fig. (4) Milled PMMA crown

For construction of 3D printed group, 3D printer (NextDent 5100 - Soesterberg, Neitherland) was used to produce eight PMMA provisional crowns. A Next Dent C&B resin liquid especially for provisional crown was used (NextDent - Soesterberg, Neitherland). After complete printing, the resultant restorations were cleaned in ultrasonic cleaner (Codyson, Shenzhen, China) using isopropyl alcohol for 10 min. After that, all the printed crowns were post-cured for 30 min according to the manufacturer's instructions under ultraviolet light box (LC-3DPrint Box, Soesterberg, The Netherlands) to ensure that all the crowns are fully polymerized obtaining high mechanical properties. Figure (5)

Fig. (5) 3D printed PMMA crown

Internal fit evaluation (Replica technique)

The internal fit was assessed using the replica technique, in which a light body silicone impression material (FLEXCEED light, GC, India) was injected into the crown's fitting surface. Each crown was placed onto its corresponding die till complete seating, then the material was left to set completely following the manufacturer's instructions. After that, the crown removed, while the silicone replica was left on the fitting surface of the crown reflecting the thickness of the cement gap. A putty silicone material (FLEXCEED putty, GC, India) was used to support the light body silicon replica. After complete setting, it was removed and divided into four sections using a surgical blade no.15 (Kiato, Kher surgical private limited, India). The sections were made in both the bucco-palatal and mesio-distal directions.

The light body's thickness was assessed by the use of a stereomicroscope (Wild Leica MZ6, Leica Mikrosysteme, Wetzlar, Germany) in conjunction with a digital camera (Leica Mikrosysteme, Wetzlar, Germany) at a magnification of 40X. The thickness of the light body silicone was measured at 9 different points, these points were mesial-cervical (M-C), mesial-axial (M-A), distal-cervical (D-C), distal-axial (D-A), buccal-cervical (B-C), buccal-axial (B-A), lingual-cervical (L-C), lingual-axial (L-A) and incisal (I). Figure (6). Each point was measured using Image tool software (Image J 1.43U, National Institute of Health, USA).

Vertical Marginal gap distance evaluation

The marginal gap was evaluated using a stereomicroscope (Wild Leica MZ6, Leica Mikrosysteme, Wetzlar, Germany) with a digital camera (Leica DFC 420 C, Leica Mikrosysteme, Wetzlar, Germany) at 40X magnification, Image tool software (Image J 1.43U, National Institute of Health, USA) was used to measure the marginal gap. The vertical marginal gap was defined by

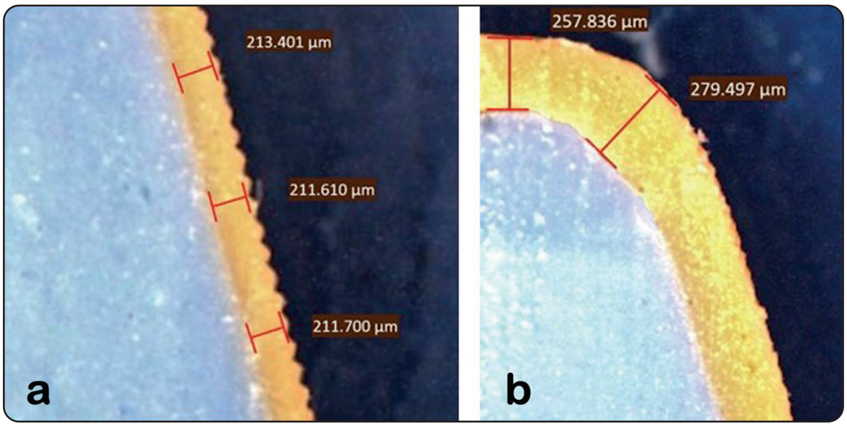

Fig. (6) Internal fit measurement, a) axial, b) incisal

Holmes et al. [20] as the distance between the edge of the finish line of the prepared tooth and the crown margin. To ensure standardization, the axial wall was divided into three equal parts. At each section, three measurements were taken for the marginal gaps. This resulted in a total of 12 measurements for each axial wall. These measurements were then averaged to provide a single measurement for each axial wall. Figure (7)

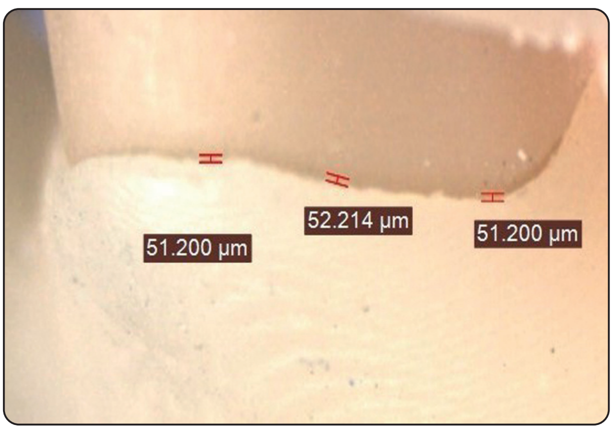

Fig. (7) Vertical Marginal gap distance measurement

RESULTS

Statistical analysis

Statistical analysis was conducted using SPSS 16® software package designed for scientific studies. The data for all groups were reported as means and standard deviations. The provided data was analyzed using the Shapiro-Wilk test and the Kolmogorov-Smirnov test to assess normality. The results indicated that all the data followed a normal distribution. Accordingly, comparison between different surfaces was performed using One Way ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons. Comparison between the two groups was performed by using Independent t - test.

Internal Fit

Mean and standard deviation of internal gap in both groups at different points, incisal, and overall were presented in table (1) and figure (8).

Comparison between groups was performed by using independent t test which revealed that internal gap of CAD/CAM group was significantly lower than Printed group as P=0.0001.

Comparison between different points was performed using One WAY ANOVA test which revealed that there was a significant difference between the points in both groups in which the CAD/CAM group showed better internal fit than the 3D printed group as P=0.0001, followed by Tukey Post Hoc test for multiple comparison which revealed that there was insignificant difference between B-C (110.76±2.63) and B-A (113.7±1.99) in cad cam group, and there was insignificant difference between M-C (124.0±3.31) and M-A (122.61± 2.86) in printed group.

TABLE (1) Mean and standard deviation of internal gap at different points, in both groups:

	Group				**Difference**				
	CAD/CAM crowns		**Printed crowns**		95% Confidence Interval of the Difference				P value
	Mean	Standard Deviation	Mean	Standard Deviation	Mean Difference	Sta. Error Difference	Lower	Upper	
M-C	35.50 ^{a}	1.68	124.00 ^{a}	3.31	88.50	1.31	-91.32	-85.69	0.0001*
M-A	40.54 ^{b}	1.82	122.61 ^{a}	2.86	82.07	1.20	-84.64	-79.49	0.0001*
D-C	43.75 ^{c}	1.65	237.18 ^{b}	1.79	193.43	0.86	-195.28	-191.59	0.0001*
D-A	48.70 ^{d}	2.06	178.54 ^{c}	2.51	129.85	1.15	-132.31	-127.39	0.0001*
B-C	110.76 ^{e}	2.63	197.94 ^{d}	3.77	87.18	1.62	-90.66	-83.69	0.0001*
B-A	113.70 ^{e}	1.99	210.99 ^{e}	3.58	97.29	1.45	-100.39	-94.18	0.0001*
L-C	105.51 ^{f}	2.52	143.22 ^{f}	1.53	37.71	1.04	-39.94	-35.47	0.0001*
L-A	87.90 ^{g}	2.91	116.20 ^{g}	2.18	28.30	1.29	-31.06	-25.54	0.0001*
Incisal	158.79 ^{h}	3.00	264.28 ^{h}	1.29	105.49	1.16	-107.97	-103.01	0.0001*
Overall	82.79	0.69	177.22	1.12	94.43	0.47	-95.42	-93.43	0.0001*
P value	***0.0001****		***0.0001****						

***Significant difference at P<0.05.**

Means with different superscript letters at the same row were significantly different (P<0.005).

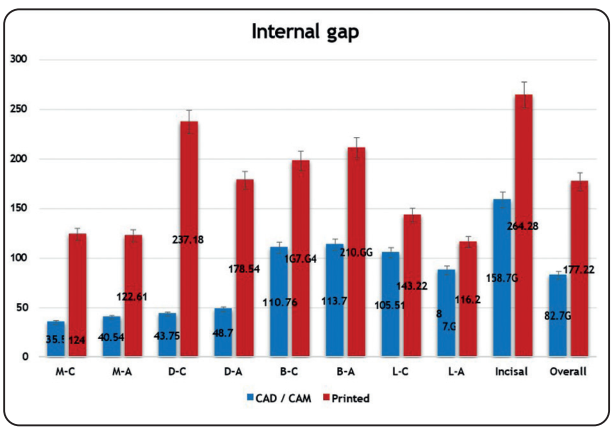

Fig. (8) Bar chart representing internal gap in CAD/CAM and printed groups.

Vertical marginal gap:

Intergroup comparison:

Comparison between CAD/CAM and printed groups were presented in table (2) and figure (9), Independent t- test was performed and revealed that CAD/CAM group showed significantly lower vertical marginal gap distance than Printed group (P=0.0001) regarding buccal, mesial, distal, lingual, while in overall p=0.01.

Intragroup comparison:

Comparison between different surfaces was performed by using One Way ANOVA test which revealed that there was a significant difference between them as P=0.0001 regarding CAD/CAM and printed groups. Table (3) and figure (10) Tuky's Post Hoc test for multiple comparisons was performed and demonstrated that:

In CAD/CAM milled group: buccal (20.09±1.08) and lingual surfaces (22.62±3.54) showed significantly the least vertical marginal gap with insignificant difference between them, then mesial surface (37.76±3.09), while distal surface (70.45±4.14) demonstrated significantly the highest vertical marginal gap distance.

In 3D Printed group: buccal (29.72±1.77) and lingual surfaces (31.49±3.61) showed significantly the least vertical marginal gap with insignificant difference between them, then mesial surface (47.36±3.97), while distal surface (51.83±2.73) demonstrated significantly the highest vertical marginal gap

TABLE (2) Mean and standard deviation of vertical marginal gap at different surfaces and overall, in both groups:

	Group				**Independent - t**				P value
	CAD/CAM crowns		**Printed crowns**		95% Confidence Interval of the Difference				
	Mean	Standard Deviation	Mean	Standard Deviation	Mean Difference	Sta. Error Difference	Lower	Upper	
Buccal	20.10	1.08	29.72	1.77	9.62	0.73	-11.19	-8.05	0.0001*
Mesial	36.76	3.09	47.36	3.97	10.60	1.78	-14.41	-6.79	0.0001*
Distal	70.45	4.14	51.83	2.73	18.63	1.75	14.86	22.39	0.0001*
Lingual	22.62	3.54	31.49	3.61	8.87	1.79	-12.70	-5.03	0.0001*
Overall	37.48	2.04	40.10	1.62	2.62	0.92	-4.59	-0.64	0.013*

Significant difference as P<0.05.

TABLE (3) Mean and standard deviation of vertical marginal gap at different surfaces and overall, in both groups:

	Buccal		**Mesial**		**Distal**		**Lingual**		**P value**
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
CAD/ CAM	20.09 [a]	1.08	36.76 [b]	3.09	70.45 [c]	4.14	22.62 [a]	3.54	0.0001*
Printed	29.72 [a]	1.77	47.36 [b]	3.97	51.83 [c]	2.73	31.49 [a]	3.61	0.0001*

**Significant difference as P<0.05.*

Means with different superscript letters at the same row were significantly different at P<0.005.

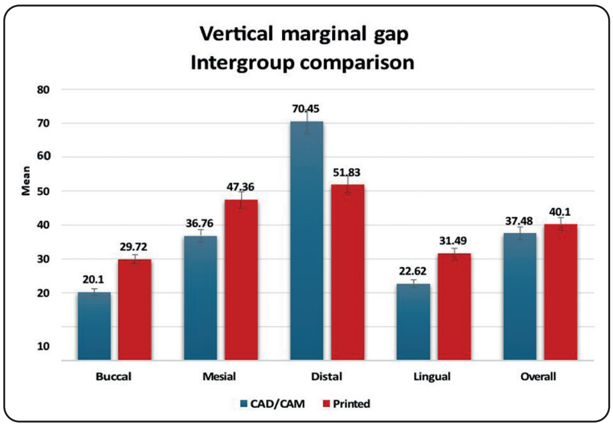

Fig. (9) Bar chart representing vertical marginal gap comparison between CAD/CAM and printed groups.

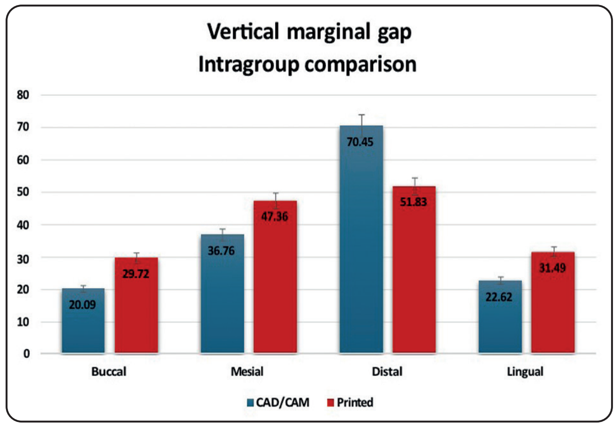

Fig. (10) Bar chart representing vertical marginal gap comparison between different surfaces in CAD/CAM and printed groups.

DISCUSSION

Many factors play role in the long-term success while restoring complex cases, one of these factors is the fabrication of a well finished and highly precise provisional restorations [29]. Digital fabrication techniques can efficiently achieve long-term success specially in oral rehabilitation cases [28,29].

Due to the rapid advancement of digital technology, it is now feasible to create provisional restorations by virtually designing and producing them using either subtractive or additive technologies. Even while subtractive technology is the "gold standard" of the digital era, it has many limitations regarding the intaglio surface of milled restorations and the ability of milling of complex structures because of restrictions on the orientations, angles, and milling tools used. However, compared to subtractive manufacturing, additive manufacturing technology exhibits more effective material use and sophisticated structure production. [9,24,30]

The precise fit of any restoration is crucial for the crown's resistance and retention forms. The occurrence of a marginal gap, especially when employing new technologies, is a highly significant aspect to consider when choosing a fabrication technique. There is always a space between the end point of the tooth that has been prepared and the edge of a full coverage restoration, even if the preparation is done very carefully. According to the literature, the clinically accepted marginal gap is 120 µm or less, while the recommended range for the incisal and occlusal gap is 250 - 300 µm. [23, 27]

There are many techniques to evaluate the precision of any restoration such as, replica technique, microcomputed tomography, profile projection, laser videography, and cross-sectioning method [24]

In this study, the internal gap was evaluated using of the replica technique. The replica technique had been proved by many authors to be a reliable and nondestructive method for evaluation of the internal fit and showed low risk of restoration damage during evaluation [5,24,26,27]. The silicon replicas were cut into four parts. After that all the parts were checked under a stereomicroscope with the magnification of 40x.

The vertical marginal gap was evaluated and measured using a stereomicroscope as it is considered a dependable and non-invasive measuring instrument [27,31]. In addition, Yucel et al. [32] claimed that the utilization of a microscope equipped with image analysis software enables non-destructive multiple measurements through the direct imaging technique.

The results of the presented study showed a significant higher internal fit and decreased vertical marginal gap for the CAD/CAM milled PMMA provisional crowns when compared to the 3D printed PMMA provisional crowns. So, the null hypothesis of the presented study was rejected.

These results were consistent with previous studies, as reported by Savencu et al. [33]. They reported that the metal coping fabricated by milling technique had the most optimal vertical marginal gap values, than those fabricated by 3D printing. They declared that errors accumulated at several stages of manufacturing, design segmentation by printing software, processing, and printing itself may lead to the decreasing accuracy during 3D printing. There was a greater marginal discrepancy as a result of the shrinkage that occurred during constructing and after curing.

In addition, Refaie et al [27] revealed that the average marginal gap of the milled restorations was significantly smaller compared to the 3D printed ones. This may be attributed to excessive polymerization of the material during the production process, resulting in light scattering and causing more material to harden than anticipated.

The internal gap and vertical marginal gap values of the CAD/CAM milled and 3D printed PMMA provisional crowns were within the clinical acceptance range as stated in the literature [19,22,23,24,27]

CONCLUSIONS

Within the limitation of this study, the milled PMMA provisional crowns showed better internal fit marginal adaptation than 3D Printed PMMA provisional crown. Both techniques reported clinically accepted results.

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