Evaluation of Marginal accuracy / internal fit of interim crowns Fabricated by Conventional, CAD-CAM and 3D Printing Techniques

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Abstract

Purpose: The aim of this study was to compare the marginal accuracy and internal fit of the provisional crowns made with manually fabricated technique, CAD/CAM milling technology, and 3D printing technology. **Materials and Methods**: one mandibular left first premolar (#35) resin tooth was prepared and duplicated using 3D printing technique to produce twenty-one resin dies. Accordingly, a total of (N=21) provisional crowns were constructed. The Constructed provisional restorations were divided into 3 groups according to the method of construction (n=7 for each group), Group 1: Provisional crowns were constructed using conventional manual technique, Group2: Provisional crowns were constructed using CAD/CAM milling technique, Group3: Provisional crowns were constructed using 3D Printing technique. All Provisional crowns were bonded to their corresponding resin dies by using CharmTemp ZONE temporary cement and subjected to thermocycling procedure simulating approximately one month of clinical situations **Results:** Statistical analysis showed that, for marginal gap distance, the highest value was found in conventional group (67.30±11.78), followed by 3D Printing (43.63±5.85), while the lowest value was found in CAD/CAM (27.21±2.80).103.23). ANOVA test showed that there was a significant difference between different groups ($p<0.001$). on the other hand, for total internal gap distance results, the highest mean value was recorded in CAD/CAM group (52.72±3.25), followed by 3D Printing group (52.06±2.65), while the lowest value was recorded in conventional group (39.09±3.41). ANOVA test showed that there was a significant difference between different groups ($p<0.001$). **Conclusion:** Within the limitations of the current study, CAD/CAM constructed provisional crowns have a superior marginal accuracy values compared to 3D Printed and conventional crowns. While regarding to the internal fit, conventional provisional crowns recorded the highest internal adaptation values (occlusal and axial fit) compared to CAD/CAM and 3D Printed crowns.

Introduction

Fabrication of a provisional prosthesis or restoration is an essential procedure for all indirect restoration and an important stage in prosthodontics. A provisional restoration plays an indispensable role in the success of the treatment (1).

Meeting the functional and the esthetic demand is one of the most important aspects of making a provisional restoration. According to Shillingburg this restoration should offer: pulp protection, prevent supra-eruption or tipping of the teeth, serve proper occlusal function for the patient, can be easily

maintainable in a hygienic condition, the material should withstand occlusal forces and should be retentive, be aesthetically pleasing and can be polished so as to prevent plaque accumulation, margins should not intrude the gingival tissues and induce gingival pathosis [(2)].
Likewise, the provisional restoration is important in providing a template for defining tooth contour, esthetics, proximal contacts, and occlusion. It provides an important tool for the psychological management of patients until the final restorations are cemented [(3)].
To encounter these goals, special care should be taken to ensure the fit and shape of such restorations [(3,4)]. The fit of restorations depends largely on the fabrication methods [(5)].
Conventionally, various methods and materials have been introduced to provide a provisional restoration. These materials used for the fabrication of single and multiple unit provisional restorations are mostly resin based [(6)].
A number of materials are available for construction of provisional FDPs [(7)]. The majority of these materials can fit into two main categories based on their composition: Methyl-methacrylate resins and composite resins [(7-9)].
high strength properties, adequate fit at the margins and ease of repair, make polymethyl methacrylate resin (PMMA) the most recurrently used type of resin. Although, PMMA exhibits a release of exothermic heat upon setting, polymerization shrinkage, and low stain resistance. Freshly, it was reported that Bis-GMA composite resin has better esthetics and could overcome the disadvantages of PMMA. [(10)]
the fabrication methods of interim restorations could be either direct or indirect, manual or digital. In turn, there are two kinds of digital manufacturing of interim restorations; subtractive or additive.[(11)]
Digital technologies such as dental scanning and CAD/CAM (computer-aided design and computer-aided manufacturing) technology have developed the process of manufacturing temporary crowns [(12)]. They can improve the quality of temporary crowns and reduce patient chair time by making fabrication times faster and lowering the risk of human errors with manual processes. [(12,13)]
CAD/CAM systems can be subtractive or additive manufacturing methods. The subtractive (milling) method processes an object by trimming a block or disc of material into the desired shape. The additive (3D printing) method builds the object layer-by-layer. [14,15] The additive method has gained acceptance because it uses scarcer materials and processes objects more quickly, also makes complex shapes than the subtractive (milling) method. [(16)] Different 3D printers are currently available in the market for manufacturing temporary crowns. These printers are based on either digital light processing (DLP) or stereolithography (SLA) technologies. [(12, 15, 16)]
Marginal integrity is one of the critical prerequisites of interim prostheses especially for long-term interim restorations in interdisciplinary complex treatments. Good internal fit and marginal seal not only maintain periodontal health but also prevent pulpal irritation, temporary cement washout, bacterial ingress, and secondary caries. [(7)]
Therefore, the aim of this study was to compare the marginal accuracy and internal fit of the provisional crowns made with manually fabricated technique, CAD/CAM milling technology, and 3D printing technology.
The null hypothesis was that there would be no differences in the fit of the provisional crowns manufactured by using the above manufacturing techniques.

MATERIAL AND METHODS

- ***Ethical consideration:***

Ethical approval was obtained from Research Ethics Committee (REC) of the Faculty of Dental Medicine for Girls, Al-Azhar University.

1) Sample size calculation:

A power analysis was designed to have a passable power to apply a statistical test of the null hypothesis that there is no difference between different tested groups regarding marginal and internal adaptation. By adopting an alpha (α) level of 0.05 (5%), a beta (β) level of 0.2 (20%) i.e. power=80% and an effect size (f) (0.738) and (0.811) respectively - calculated based on the results of previous study. [(3)] The predicted sample size (N) was a total of (21) samples i.e. (7) samples per group. Sample size calculation was performed using G*Power version 3.1.9.7. [2]

2) Specimen Preparation

A mandibular left first premolar (#35) resin tooth (Columbia Dentoform Corp., Lan-caster, PA, USA) was selected for this research. an impression for the premolar was taken using PVS material (Cinch, Parkell Inc., Edgewood, NY,USA) before crown preparation and saved to serve as an index for construction of group (1) samples.

This premolar was embedded in the center of plastic cylinder (2cm height and 1.5cm diameter) filled with epoxy resin to make epoxy resin block.

The resin tooth preparation was carried out by using CNC (Computer Numerical Control) with 2mm occlusal reduction, 1.5mm axial reduction, 1mm deep chamfer finish line circumferentially at 1mm above the cementoenamel junction, and a convergence angle of 6 degree.

Then, The Prepared resin tooth #35, was scanned using a model scanner (D2000, 3Shape). The scanned data were manipulated with a CAD software and connected to a 3D printer (Ededn500V, Stratasys Direct, Inc., Valencia CA, USA) to fabricate stereolithographic resin dies (MED690, Stratasys Direct Manufacturing,Valencia, CA, USA).

Based on the data from a pilot study, the sample size (n = 7 per group) was estimated with a power analysis to provide statistical significance (α = 0.05 at 80%), Twenty – one 3D-printed resin dies were constructed accordingly and equally divided into three groups according to the method of construction: (n=7 for each group). Group 1: Provisional crowns constructed using conventional manual technique using Protemp™4 (3M ESPE, Germany), Group2: Provisional crowns constructed using CAD/CAM milling technique using TelioCAD disc (Ivoclar Vivadent, Liechtenstein, Germany), Group3: Provisional crowns constructed using 3D printing technique using NextDent C&B (VertexDental, Netherlands).

3) Construction of interim crowns:

3-A) construction of conventional manual interim crowns, group (1):

conventional direct technique was used to fabricate the provisional crowns. Protemp™4 was mixed through the self-mixing gun and directly injected into the silicon index (a previously taken impression of the resin tooth before crown preparation), then placed on the prepared resin die and held in place until the mixed material completely set. Seven provisional crowns were fabricated directly according to the above protocol. The crowns were examined to detect any defects then finished and polished using rotary rubber cups (SofLex™ Disc 3M ESPE, Germany) following manufacturer's instructions.

3-B) Construction of CAD/CAM interim crowns, group (2):

Scanning the preparation:3D extra-oral scanner DS MIZAR (.EG solutions, Italy) was used to scan the prepared die to get 3D virtual image.

Designing the restoration:

The Exocad Software, (DentalCAD 3.0 Galway) was used to design a virtual model. Restoration anatomy from dental databases libraries was selected and the cement space was set at 0.05 mm [17]. after the final virtual restoration design had finished, the information sent through STL file to the milling machine.

Milling process: The designed STL file was used to mill the crowns after selecting the type and size of disc for fabrication of provisional crowns. TelioCAD disc (Ivoclar Vivadent, Liechtenstein, Germany), was placed in the spindle of the 5axis milling machine (D15; Yenadent Ltd., Istanbul, Turkey), for milling Seven CAD-CAM provisional crowns.

3-C) construction of 3D printed interim crowns, group (3):

The same CAD/CAM STL file was imported to the CAD software described previously. Seven 3D-printed provisional crowns were constructed with 3D printing material (methacrylate NextDent C&B) (Vertex Dental, Netherlands) and 3D printer (Anycubic Photon SE) (Anycubic Technology Co., Shenzhen, China) which is LCD based using 3D printing technology according to manufacturer's instructions. (Fig.1) After manufacturing, all samples were finished and polished.

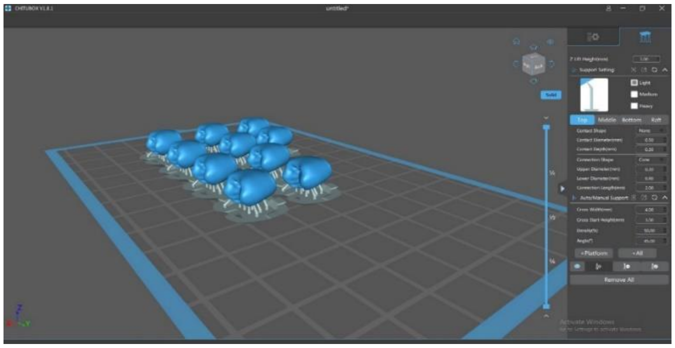

Fig. (1) Crowns design in the Chitubox Pro software in a horizontal direction with ten supporting structures attaching them.

4) Cementation procedure:

CharmTemp ZONE temporary cement (Dentkist, South Korea) was used For crowns cementation on their corresponding resin dies, The cement was mixed according to manufacturer's instructions. The cementation process done by the aid of a specially constructed loading device under a load of 3 kg during the cementation. [18]

5) Thermocycling:

Samples were subjected to 1000 cycles which correspond to approximately one month of service inside the oral cavity. [19] Thermal cycles between the temperature range of 5-55 0C in distilled water (dwell time: 25 seconds with a pause time of 10 sec.). this whole procedure was done by the aid of thermocycling unit.

6) Testing procedures:

6.a. Measurement of marginal gap distance:

To determine the margin accuracy of constructed samples, 7 provisional crowns in each group were examined using USB digital microscope (U500X digital microscope, Guangdong, China). A digital image analysis system (Image J 1.43U, national institute of health, USA) was used to measure and evaluate the gap width between crowns margin and finish line of the die.

Samples were fixed using a specially designed and fabricated holding device. Then each sample was photographed (four shots were taken for each sample one shot for each surface) using USB Digital microscope with a built-in camera connected to a personal computer**.** The images were taken with the following image acquisition system:

- Digital camera with 3 Mega Pixels of resolution, placed vertically at 2.5 cm from the samples. The angle between the axis of the lens and the sources of illumination was approximately 90^{o}.
- Illumination was achieved with 8 LED lamps (adjustable by control wheel), with a color index close to 95 %.

The images were taken at maximum resolution (2272× 1704 pixels) and connected with an IBM compatible personal computer using a fixed magnification of 40X. The images were recorded with a resolution of 1280 × 1024 pixels per image.

Then morphometric measurements were done for each shot (three equidistant landmarks along the circumference for each surface). Measurement at each point was repeated three times.

6.b. Measurement of Internal fit:

The same samples which marginal fit were measured were sectioned mesio-distally with a low-speed diamond saw (Top Dent, Edenta Golden, Swiss) under water spray, standardization of the cutting place in all samples done by measuring the distance between cusp tips of each sample with a digital caliper and drawing a mesio-distal line in the midway of this distance on each sample where sectioning is done through. The samples were rinsed in running water and then dried with compressed air.

The internal gap along the crown-tooth interface was assessed with USB Digital microscope (Portable LCD Digital Microscope) at 25× magnification in which the image was captured and transferred to a computer equipped with the image analysis software program.
The gap along the veneer-tooth interface were measured in (µm). The internal fit was evaluated in terms of occlusal and axial fit. The measuring points were illustrated in the following schematic diagram **figure (2)**, in which 7 points were measured (1,2,3) representing occlusal fit while (4,5,6,7) representing axial fit. The site of each measuring point was fixed in each sample.

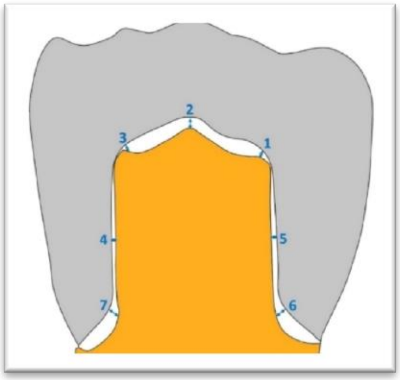

Figure (2): Schematic representation illustrating the measuring points

7. Statistical Analysis:

Quantitative data were statistically analyzed for significance using One Way ANOVA and post hoc test, and presented as numbers and percentages. While qualitative data were analyzed using Chi-Square test, and presented as mean and standard deviation.
The confidence interval was set to 95% and the margin of error accepted was set to 5%. So, the p-value was considered significant as the following: P > 0.05: Non significant, P < 0.05: Significant, P < 0.01: Highly significant.

RESULTS

The results of the Marginal gap distance values (µm) shows that; There was a significant difference between different groups (p<0.001). The highest value was found in conventional group (67.30±11.78), followed by 3D Printing (43.63±5.85), while the lowest value was found in CAD/CAM (27.21±2.80). Post hoc pairwise comparisons showed different groups to have significantly different values from each other (p<0.001). **table (1)**

Table (1): Mean and standard deviation (SD) values of gap distance (µm) for different groups (A)

Fit	Group	N	Mean	SD	95% Confidence interval		f-value	p-value
					Lower	Upper		
Marginal	Conventional	7	67.30^{A}	11.78	58.58	76.02	47.19	<0.001*
	CAD/CAM	7	27.21^{C}	2.80	25.14	29.29		
	3D Printing	7	43.63^{B}	5.85	39.30	47.96		

Different superscript letters indicate a statistically significant difference within the same vertical column and measurement *; significant (p ≤ 0.05) ns; non-significant (p>0.05), SD= Standard deviation

The results of the internal adaptation values (µm) displays that; *For Occlusal gap distance (µm):* There was a significant difference between different groups (p=0.002). The highest gap value was found in 3D Printing (59.45±9.57), followed by CAD/CAM (56.80±10.08), while the lowest value was found in conventional group (40.10±7.05). Post hoc pairwise comparisons showed conventional group to have a significantly lower value than other groups (p<0.001). table (2)

And, for Axial gap distance (µm): There was a significant difference between different groups (f=14.84, p<0.001). The highest value was found in 3D Printing (50.97±0.46), followed by CAD/CAM (46.93±5.55), while the lowest value was found in conventional group (38.43±5.19). Post hoc pairwise

comparisons showed conventional group to have a significantly lower value than other groups (p<0.001). table (2)
*Accordingly, the results of total Internal gap distance (µm) (*occlusal and axial internal adaptation values of each sample) demonstrate that: There was a significant difference between different groups (p<0.001). The highest mean value was recorded in CAD/CAM group (52.72±3.25), followed by 3D Printing group (52.06±2.65), while the lowest value was recorded in conventional group (39.09±3.41). table (2) Post hoc pairwise comparisons showed conventional group to have a significantly lower value than other groups. While there was no significant difference between CAD/CAM and 3DPrinting group, (p<0.001).
Table (2): Mean and standard deviation (SD) values of gap distance (µm) for different groups (B)

Fit	Group	N	Mean	SD	95% Confidence interval		f-value	p-value
					Lower	Upper		
Occlusal	**Conventional**	7	40.10^{B}	7.05	34.88	45.33	**9.51**	**0.002***
	CAD/CAM	7	56.80^{A}	10.08	49.33	64.27		
	3D Printing	7	59.45^{A}	9.57	52.36	66.54		
Axial	**Conventional**	7	38.43^{B}	5.19	34.59	42.27	**14.84**	**<0.001***
	CAD/CAM	7	46.93^{A}	5.55	42.82	51.04		
	3D Printing	7	50.97^{A}	0.46	50.63	51.31		
Internal	**Conventional**	7	39.09^{B}	3.41	36.56	41.62	**42.43**	**<0.001***
	CAD/CAM	7	52.72^{A}	3.25	50.31	55.13		
	3D Printing	7	52.06^{A}	2.65	50.10	54.03		

Different superscript letters indicate a statistically significant difference within the same vertical column and measurement *; significant (p ≤ 0.05) ns; non-significant (p>0.05), SD= Standard deviation

DISCUSSION

The information regarding the marginal accuracy, internal adaptation and of 3D Printed interim restorations with those obtained using subtractive CAD/CAM technique and conventional manual technique, is still lacking.
Therefore, the present study was carried out to compare the marginal accuracy and internal fit of the provisional crowns made with manually fabricated technique, CAD/CAM milling technology, and 3D printing technology.
Marginal accuracy evaluated through measuring the vertical space between the crown margin and the die finish line, internal adaptation evaluated through measuring the horizontal space between the internal surface of the crown and the outer surface of the die at different points.
In the current study, it was hypothesized that there would be no significant differences in the marginal adaptation and internal fit between provisional crowns fabricated using either digital technology (CAD/CAM and 3D Printing) or manually fabricated technique.
However, the null hypothesis was partially accepted since the results showed a significant different between CAD/CAM (group 2) and the other two groups regarding marginal gab as milled provisional crowns had lower marginal gab than 3D Printed and conventional crowns.
Also, there is a significant difference between Conventional (group 1) and the other groups regarding internal fit as conventional provisional crowns had better internal fit (occlusal and axial fit) than CAD/CAM and 3D Printed crowns.
In the present study to achieve standardization, the extra-oral scanner of the same manufacturer was used for scanning the dies. All the fabricated provisional restorations were designed by Exocad software and the same STL file was used for both techniques (CAD/CAM and 3D Printing). In the present study; the cement space was adjusted for all samples to be 0.05mm [(17)].
In the present study the CAD/CAM group recorded the statistically significant lowest mean marginal gab distance (the best marginal adaptation) followed by 3D Printing and finally the Conventional group, **table (1)**.

Which in agreement with Yao et al [20] as they concluded that CAD/CAM interim materials had better marginal accuracy properties than bis-acryl materials, especially after thermal cycling.
Also, Abdullah et al [21] they concluded that CAD/CAM provisional crowns demonstrated superior marginal fit compared to the direct provisional crowns.

Likewise, Angwarawong et al [22] agree with our study as they concluded that the interim crowns fabricated with the Brylic Solid (CAD/CAM technique) and the Freeprint Temp (3D Printing technique) had a smaller marginal gap than those fabricated with Unifast Trad and Protemp 4 (Conventional technique), both before and after aging.
These results could be attributed to the fact that, the fabrication process has a more significant influence on the marginal gap of interim restorations than the materials themselves, Polymerization shrinkage is one cause of the dimensional changes that can adversely affect marginal gap and occurs with directly made interim restorations. This problem has greater impact with PMMA resin, while it is comparatively lower but still observable with bis-acryl resin [22].
On the other hand, Polymerization shrinkage is less of a problem with CAD-CAM interim restorations, either because the high-density CAD-CAM PMMA block was pre-polymerized during the industrial fabrication process or because the CAD-CAM-printed resin was completed layer by layer by cross-sectional polymerization in the controlled conditions of a 3D printer. This may be why CAD-CAM milled and 3D printing interim materials exhibited much smaller marginal gap compared with conventionally fabricated materials [22].
While both Lee et al[23] and Alharbi et al [24] disagree with our results as they concluded that provisional restorations fabricated using 3D-printing techniques exhibited lower marginal gap (superior marginal adaptation) than restorations fabricated using CAD/CAM techniques.
These results could be explained by the difference in 3D printing machines and different photocuring techniques which affect the marginal accuracy of the restoration. Alharbi et al[24] used SLA 3Dprinting photocuring technique, with good precision to print objects with complex structure and fine size by using laser beam. While in the current study LCD photocuring technique with Anycubic photon SE printer was used. The LCD machine has a short service life and needs to be replaced regularly, the light intensity of LCD 3D is very weak, because only 10% of the light could penetrate from the LCD screen and 90% of light is absorbed by the LCD screen. This in turn results in a prolonged time of printing and low conversion degree. [25] thus, the produced provisional crowns would be affected.
Also, in this study Conventional (group1) recorded the highest internal adaptation values compared to both; CAD/CAM and 3D Printed groups. The second null hypothesis was therefore rejected as the fabrication technique affected the internal adaptation of provisional crowns.
Kang et al [26] agree with our study regarding internal fit as the internal fitness of the resin crown made using a DLP 3D printer and subtractive manufacturing system showed no statistically significant differences, and clinically acceptable results.
While, Lee et al [23] disagree with our results as they concluded that internal fit of the interim restoration is more outstanding in 3D printing method than the CAD/CAM milling method. Lower values recorded with 3D printing technique compared to the results of the present study could be explained based on the type and technique of the printing process.
Additionally, Reich et al [27] reported that CAD/CAM systems which depend on optical impression, experience problems with rounded edges and positive error which simulates virtual peaks near the edges and so called over shooters. The anatomical occlusal reduction design followed in the present study rather than a flat occlusal reduction may have produced more occlusal gaps duo to the inaccuracies created during the scanning process. This assumption can be validated as areas of least adaptation are curved where scanning is less accurate.
This study had some limitations because it was carried out in vitro on specimens. This didn't really replicate the in vivo trials that used actual dental crowns. Future studies are needed to assess the aging process, color stability, porosity, and additional mechanical measurements of temporary crown materials. In addition, further characteristic studies could be conducted on different parameters of 3D printing technology for

temporary crowns. These parameters include building orientation, post-processing, and layer thickness. Finally, clinical studies should be conducted to investigate the clinical performance of 3D-printed temporary crowns.

CONCLUSION

Within the limitations of the current study, CAD/CAM constructed provisional crowns have a superior marginal accuracy values compared to 3D Printed and conventional crowns. While regarding to the internal fit, conventional provisional crowns recorded the highest internal adaptation values (occlusal and axial fit) compared to CAD/CAM and 3D Printed crowns.

Declaration of Conflict of Interest

The authors declare that they have no conflict of interest.

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