JFCR
Journal of Fundamental and Clinical Research
https://jfcr.journals.ekb.eg/
ISSN 2735-023X
Vol. 2, No. 1, 29-42, June 2022

Evaluation of Vertical Marginal Fit of Tooth Supported Provisional Dental Prosthesis Fabricated by Three Dimensional Printing Compared to CAD/CAM Milling System. (In Vitro Study)

Marina F. Sidhom[1], Hanaa Zaghloul[2], Ihab El-Sayed Mosleh[3]

ABSTRACT

Background: Different digital fabrication techniques affect the marginal adaptation of tooth supported provisional and final dental prosthesis. However, there is minimal scientific evidence which technique will be effective for producing tooth supported provisional dental prosthesis with predictable marginal fit. ***Aim of the study:*** to evaluate the effect of the two CAM fabrication techniques; milling versus 3D printing on the marginal fit of tooth supported restorations. ***Materials and methods:*** two abutment teeth of a modified typodont with a missing left mandibular first molar were prepared to receive a ceramic FDP. A master reference stone model was then, constructed. An optical impression (STL file) of the reference model was taken. A provisional tooth supported FDP was designed on the CAD software using the STL file of the reference model. Eight Restorations were fabricated by different CAM techniques. The restorations were divided into two groups according to the fabrication method; group A (milled restorations) (n=4) and group B (3D printed restorations) (n=4). Finally, the marginal fit of the provisional dental prosthesis was assessed by a stereo optical microscope on the stone reference model. Mann-Whitney U test was used to compare between the two groups. The significance level was set at $P \leq 0.05$. ***Results:*** the results showed that there was no statistically significant difference between the vertical marginal gap values of the two tested groups. ***Conclusion:*** The vertical marginal gap values of provisional restorations fabricated by the two tested methods of manufacturing were comparable and within the acceptable range of 120 µ.

Keywords: tooth supported FDPs, digital techniques, milling method, three dimensional printing method, marginal fit.

INTRODUCTION

Provisional restorations are crucial for the success of the prosthetic treatment plan. A precisely adapted and well finished provisional restoration has many functions including pulp protection, positional stability of the abutments, restoration of function and esthetics. Moreover, they play a critical clinical role in oral rehabilitation cases, as they provide a prospective simulation of the final restoration. Interim

1.Teaching Assistant, Fixed Prosthodontics Department, Faculty of Oral and Dental medicine, Misr International University, Cairo, Egypt.
2.Professor of Conservative Dentistry (Fixed Prosthodontics) and vice dean of post graduate studies and research affairs, Faculty of Oral & Dental Medicine, Misr International University, Cairo, Egypt.
3.Professor of Fixed Prosthodontics, Faculty of Dentistry, Cairo University, Cairo, Egypt.

restorations present a valuable tool in reorganizing the occlusal scheme in cases with loss of vertical dimension and complicated oral rehabilitation cases as well. Provisionalization plays a significant role for evaluating esthetics and phonetics during the treatment duration for perfecting the definitive restoration. Furthermore, it represents one of the keys of successful periodontal management in compromised esthetic cases.[1–4]

Various techniques of provisional restoration fabrication are employed which have improved over time; starting from the different conventional techniques using resins or composites to digital CAD/CAM fabrication methods either by milling or three dimensional (3D) printing.[5] The conventional techniques of fabrication of the provisional restorations have many drawbacks that are related to the materials' properties and the employment technique.[6,7] Consequently, the digital techniques were introduced aiming to overcome some of these drawbacks.[2]Digital CAD/CAM manufacturing of provisional restorations can be subdivided into subtractive manufacturing technique by milling and the additive manufacturing technique by 3D printing.[8–13] This offered better quality of the restorations by using the pre-cured blocks or resinous 3D printing materials with least patients' discomfort and chair-side time.[2]

Milling/machining technology is a digital technique in which provisional restorations are fabricated by grinding the resin blocks to achieve the desired geometry which is designed by the CAD software.[10] This technique provides frameworks of higher consistency and precision than that of the conventional techniques as the resin blocks were cured under optimal conditions. It also saves time and effort with decreasing the patient's discomfort as well.[9,12] However, this technique has some disadvantages including the unnecessary loss of material during milling, high maintenance cost of the equipment as a result of the rapid wear of the cutting burs, and poor micro reproducibility of thin and sharp areas of any design.[5,8]

Therefore, the 3D printing technique started to invade this field in order to overcome some of the drawbacks of the subtractive technique. It gained a great popularity as it's an additive technique (layer upon layer). And hence, it has the ability to manufacture precise prosthesis with minimal materials waste. It is considered an economical and fast technique. It can produce finer details (undercuts & better anatomy)[1,8,12,14] compared to milling. There are several 3D printing techniques including stereo lithography (SLA), Photopolymer jetting, selective laser sintering (SLS) and fused deposition modelling (FDM).[15–17]

The long term success of tooth supported restorations depends on the accuracy and fit of the framework of the FDPs over the prepared abutments.[14, 15] The marginal misfit can be categorized into vertical, horizontal and absolute marginal misfits. The vertical marginal misfit measured parallel to the path of withdrawal of the framework is called the vertical marginal discrepancy. The horizontal marginal misfit measured perpendicular to the path of withdrawal of the framework is called the horizontal marginal discrepancy.[18,19] However, the absolute marginal discrepancy is the angular combination of marginal gap and extension error. Therefore, it specifically defines the linear distance from the surface finish line of the prepared abutment to the margin of the restoration. Hence, it is the combination of the vertical and horizontal marginal discrepancies according to the perpendicular measurement from the framework or the internal surface of the margin of the crown to the outer edge of the finish line of the tooth.[18]

Mclean and von Fraunhofer[16] reported that the clinically accepted boundary value of the vertical marginal gap is considered to be ≤100-120 μm after a 5-year clinical study of 1000 restoration. Christenson[20] suggested a clinical goal of 25 μm to 40 μm for the marginal adaptation of cemented restorations. For CAD/CAM restorations, the generally acceptable marginal gap discrepancies are between 50 and 100 μm.[21] However, the presence of marginal discrepancies in the restoration can result in exposing the luting cement to the oral environment which leads to increased rate of cement dissolution and permit the percolation of food and microorganisms leading to gingival irritation, periodontal diseases and secondary caries.[4]

One of the most significant factors that affect the fit of the provisional and final restoration is the method of fabrication. By reviewing the literature, many studies[1,14,22–24] compared the fit of the milled or the three dimensional printed restorations and the conventional ones. However, there is lack of knowledge regarding the comparison between three dimensional printed and milled restorations. So, the aim of the present study is to evaluate the effect of these two digital methods of fabrication on the marginal fit of tooth supported provisional dental prosthesis.

MATERIALS AND METHODS

Fabrication of the master cast:

A dentate typodont (El Banna, Cairo, Egypt) was modified by removing mandibular left first molar to simulate a clinical situation of a partially edentulous arch to be restored with a 3-unit tooth supported FDP. The mandibular left second premolar and first molar teeth were prepared to receive a full coverage ceramic 3- unit FDP. The amount of preparation was calibrated by a midsagittal and buccal indices. The amount of preparation was set to be 1.5 mm occlusally and 1.0 mm axially with a deep chamfer margin all round; guided by the rubber base preparation indices and depth grooves. The margins were equi-gingival. Rubber base preparation index was used to confirm preparation thickness and graduated probe for measuring finish line thickness. A PVS (Edge PVS,MDC Dental, Zapopan, Jalisco, México) physical final impression was taken to fabricate the reference model.[25–27] It was then, poured with low expansion stone type IV (GC Fuji Rock EP, GC Europe N.V.Leuven, Belgium). It was used as a control master reference model.[25]

Exporting the standard tessellation language (STL) file:

Digital impression was taken by TRIOS 3 basic (3Shape, Copenhagen, Denmark) to mimic the clinical setting. Following the manufacturer's recommendations, scanning of the reference model, opposing model and a buccal scan of the interarch relationship were carried out. Scans were exported to get the final virtual 3D master model **(Figure 1)**, and they were used to design the provisional dental prosthesis by using CAD/CAM technology.[25,28]

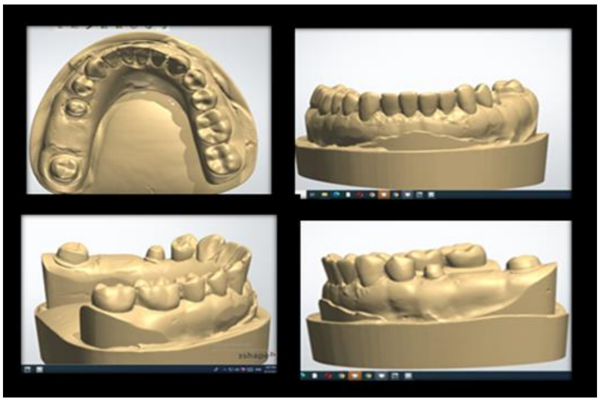

Figure (1): STL scan of the control reference model.

Designing and fabricating the tooth supported provisional dental prosthesis:

Designing of the restorations:

On the 3 shape software (3Shape, Copenhagen, Denmark), interim FDP was designed.[2,5] The finish lines of the two abutments were traced, then, a design of a full anatomic bridge was set **(Figure 2).**

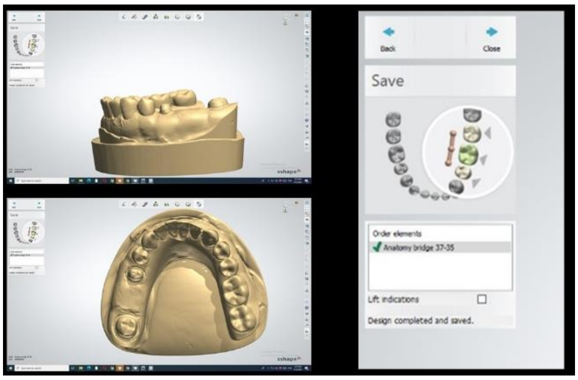

Fig. (2): selection of design.

The cement space was set up for both abutments; cement gap: 0.03 mm, extra cement gap: 0.06 mm and finish line thickness: 1mm.[1,29,30] Finally, the occlusal and proximal contacts of the FDP were adjusted **(Figure 3).** The design was saved,

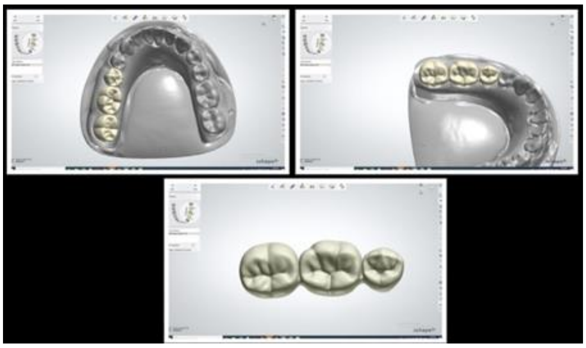

Figure (3): Finished FDP design.

ready for the CAM step either by milling or 3D printing.

Milling the tooth supported provisional dental prosthesis:

The saved STL file was sent to the 5 axis milling machine (CAM 5-S1 impression milling machine software, 3Shape, Copenhagen, Denmark) after positioning of the FDPs in the desired position in the blank. The provisional material disc (The Tempo-CAD PMMA discs, On dent, Bornova, Turkey) was fixed to the machine holder. Then, the order was given to mill and get the final end product of the milled FDPs.

After milling, the supporting structures were removed and the FDPs were finished and polished **(Figure 4).**

Figure (4): Milled provisional restorations.

3D printing the tooth supported provisional dental prosthesis:

3D Printing of four tooth supported provisional dental prosthesis was carried out using Formlabs 3D printer (Formlabs Inc, Somerville, Massachusetts, USA.)

The resin tank (Formlabs temporary CB, Formlabs Inc, Somerville, Massachusetts, USA) was inserted into the printer. A print job using Preform software was prepared by importing the saved dental restoration STL file. The files were oriented horizontally with the occlusal plane facing the build platform.

After the end of the printing procedure, using the Form Wash unit (Formlabs Inc, Somerville, Massachusetts, USA.), the FDPs were washed with clean IPA (≥99%) for 3 minutes. The post curing procedure was done in two steps using the form cure unit (Formlabs Inc, Somerville, Massachusetts, USA.). The printed FDPs were cured in the Form Cure unit at 60°C (140°F) for 20 minutes. The FDPs were sandblasted and finished. Finally, they were placed again in the Cure unit for an additional 20 minutes. At the end, Post cured FDPs were polished **(Figure 5).**

Figure (5): 3D printed provisional restorations.

Measuring the marginal fit of the two test groups:

The vertical marginal gap distance for each FDP was measured using stereomicroscope (Euromex, Microscopen BV, Arnhem, The Netherlands). Images for the margins were captured with a specified camera in the microscope with magnification 10X. Five Equidistant measurement points were taken from each surface (buccal, lingual, mesial and distal) with a total of 20 points for each retainer of the FDP.[31] **(Figure 6)**

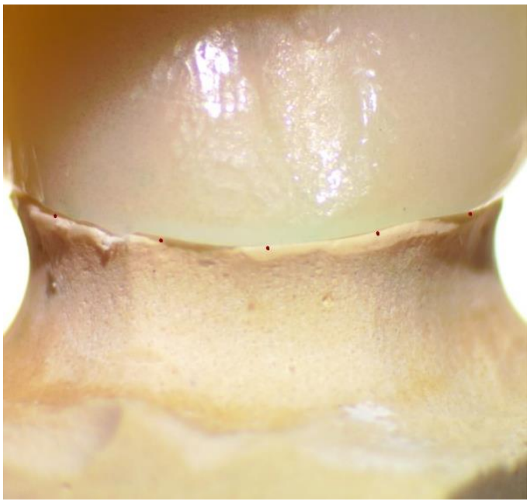

Figure (6): Equidistant points of measurements on stereomicroscope.

Measurements were recorded in microns. The mean of the twenty points was recorded for statistical analysis. A digital image analysis software (Image J 1.43U image analysis software), was used to measure and evaluate the gap. Using this software, the measured parameters are expressed in pixels and converted to microns. Standardization was made by comparing an object of known size (a ruler in this study) with a scale generated by the software.

Data analysis:

Marginal gap distance data showed non-parametric distribution. Mann-Whitney U test was used to compare between the two groups. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

In **table (1)** and **figure (7)**, with regards to the distal retainer, at the buccal, lingual, distal as well as mesial surfaces; there was no statistically significant difference between the marginal gap distances of the two groups (P-value = 0.149, Effect size = 1.187), (P-value = 0.248, Effect size = 0.894), (P-value = 0.564, Effect size = 0.417) and (P-value = 0.386, Effect size = 0.643), respectively. As regards the overall gap distance regardless of surface; there was also no statistically

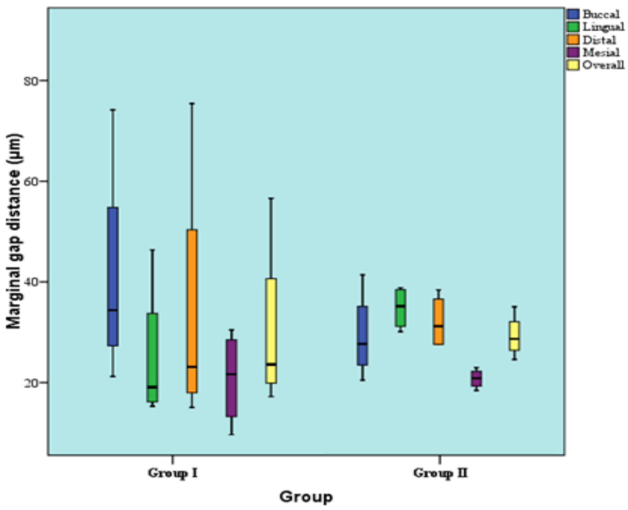

Figure (7): Box plot representing median and range values for the marginal gap distances in the two groups (Molar).

Table (1): Descriptive statistics and results of Mann-Whitney U test for comparison between marginal gap distances (µm) in the two groups (Molar).

Surface	*Group I (n = 4)*	*Group II (n = 4)*	*P-value*	*Effect size (d)*
Buccal				
Median (Range)	41.1 (27.9-80.9)	28.3 (21.2-42)	0.149	1.187
Mean (SD)	47.7 (23)	30 (8.8)		
Lingual				
Median (Range)	25.7 (22-53)	35.8 (30.8-39.5)	0.248	0.894
Mean (SD)	31.6 (14.5)	35.5 (4.3)		
Distal				
Median (Range)	29.8 (21.7-82.1)	31.9 (28.2-39.1)	0.564	0.417
Mean (SD)	40.8 (27.8)	32.7 (5.4)		
Mesial				
Median (Range)	28.3 (16.3-37.1)	21.5 (19.1-23.6)	0.386	0.643
Mean (SD)	27.5 (9.4)	21.4 (1.9)		
Overall				
Median (Range)	30.3 (23.9-63.3)	29.3 (25.2-35.7)	0.773	0.205
Mean (SD)	36.9 (17.9)	29.9 (4.3)		

**: Significant at $P \leq 0.05$*

significant difference between the marginal gap distances of the two groups (P-value = 0.773, Effect size = 0.205).

For the mesial retainer, at the buccal, lingual, distal as well as the mesial surfaces; there was no statistically significant difference between the marginal gap distances of the two groups (P-value = 0.248, Effect size = 0.894), (P-value = 0.386, Effect size = 0.643), (P-value = 0.149, Effect size = 1.187) and (P-value = 0.386, Effect size = 0.643), respectively. As regards the overall gap distance regardless of surface; there was also no statistically significant difference between the marginal gap distances of the two groups (P-value = 0.773, Effect size = 0.205) as shown in **table (2)** and **figure (8)**.

Figures (9) and **(10)** demonstrates representative stereomicroscopic images of both the mesial and distal retainers; showing the difference in marginal fit of both milled and 3D printed groups.

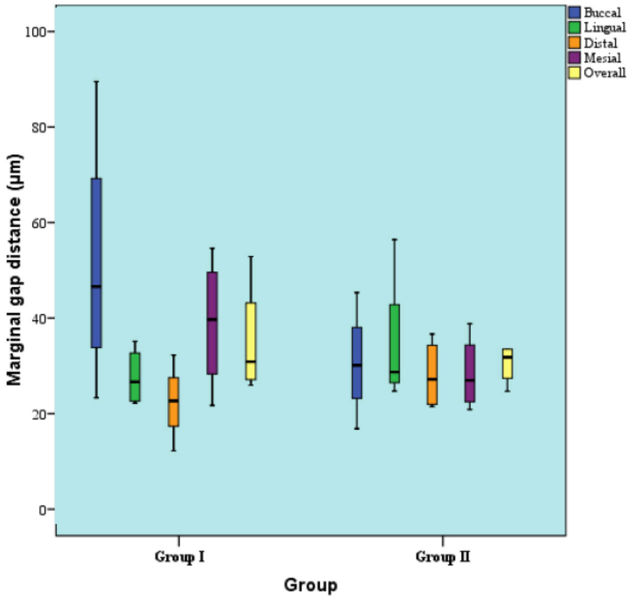

Figure (8): Box plot representing median and range values for marginal gap distances in the two groups (Premolar).

Table (2): Descriptive statistics and results of Mann-Whitney U test for comparison between marginal gap distances (µm) in the two groups (Premolar).

Surface	*Group I (n = 4)*	*Group II (n = 4)*	*P-value*	*Effect size (d)*
		Buccal		
Median (Range)	45.9 (22.9-89.3)	30.8 (17-46.5)	0.248	0.894
Mean (SD)	50.9 (27.9)	31.3 (12.1)		
		Lingual		
Median (Range)	25.8 (21.3-34.4)	29.3 (25.1-58)	0.386	0.643
Mean (SD)	26.8 (6.2)	35.4 (15.2)		
		Distal		
Median (Range)	21.8 (11.2-31.5)	27.7 (21.8-37.5)	0.149	1.187
Mean (SD)	21.5 (8.3)	28.7 (7.7)		
		Mesial		
Median (Range)	39 (20.8-54)	27.5 (21.2-39.8)	0.386	0.643
Mean (SD)	38.2 (14.2)	29 (8.2)		
		Overall		
Median (Range)	30 (25.1-52.3)	32.5 (25.1-34.3)	0.773	0.205
Mean (SD)	34.4 (12.4)	31.1 (4.3)		

**: Significant at $P \leq 0.05$*

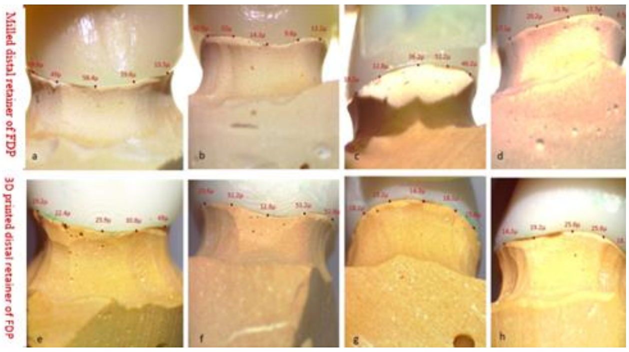

Figure (9): Stereomicroscope images of milled and 3D printed provisional restoration (molar) at different surfaces: a, b, c, d; milled and e, f, g, h; 3D printed (buccal, lingual, mesial and distal).

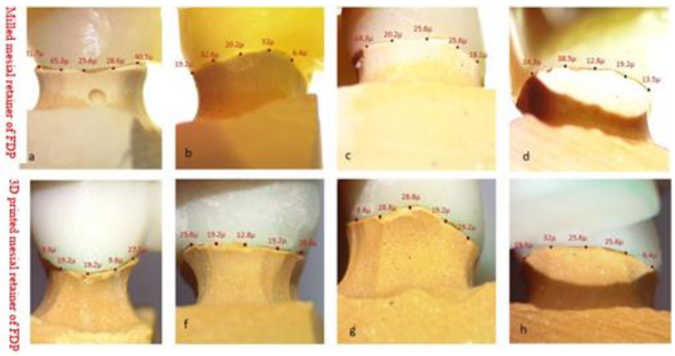

Figure (10): Stereomicroscope images of milled and 3D printed provisional restoration (premolar) at different surfaces: a, b, c, d; milled and e, f, g, h; 3D printed (buccal, lingual, mesial and distal).

DISCUSSION

Provisional restorations play an indispensable critical role in the success of the treatment plan. The need for long term provisionalization especially in complex cases necessitates having a precise highly biocompatible restoration.[32] This was adequately achieved by using the CAD/CAM fabrication techniques that offered restorations of better quality.[32,33]

Marginal fit is one of the most significant criteria in evaluating FDPs and in their success. While, any marginal discrepancy between the margin of the indirect restoration and the tooth is considered to be one of the main causes of their failure.

Vertical marginal gap was assessed by using a stereomicroscope. It is a non-destructive method for measurement according to Romeo et al [34] in 2009. Also, Yucel et al[35] 2013 stated that direct imaging technique under a microscope with image analysis software permits a non-destructive multiple measurements.

In the current study, a total of 20 reference points were measured for each retainer of the FDP to cover the margin circumferentially. It was supported by a study conducted by Groten et al[36] 2000. They claimed that a range of 20 - 25 measurements per crown should be measured to achieve an accurate evaluation close to 50 measurements per crown (optimum number). Therefore, this study ensured obtaining adequate information about the gap size and assure a statistical accuracy of the results.

During measuring the vertical marginal fit in the present study, the dies were positioned in holding jig machine to hold the tested FDP on the die with a standardized force for all the specimens for accurate standardized measurements. Marginal gap measurement was done without cementation to exclude the effect of cementation technique variations.[37]

The vertical marginal gap values of the milled and 3D printed FDPs were within the clinical acceptance range as per McLean et al[38]which is less than 120 µm. The results of the present study showed that the 3D printed FDPs showed statistically insignificant better marginal adaptation and less marginal discrepancy. The insignificant difference may be attributed to the high precision and the continuous innovations in the CAM whether for milling or 3D printing. While the better vertical marginal fit of the 3D printed group over the milled one could be attributed to the fact that the smallest bur used in the milling process was 1mm. This limited the accurate reproduction of areas that were less than 1 mm. A less than 1 mm bur could not be used on milling PMMA resin as it is easily heated. This would have caused the resin to be melted and interlock in the flutes of the bur and fracturing the bur in the process.[8,39]

This result was in agreement with the studies performed by Haddadi et al[40] 2021 who found that there is no statistically significant difference in the value of the vertical marginal gap between the provisional crowns fabricated by milling and that fabricated by 3D printing. They concluded that 3D printing can effectively replace milling in the fabrication of provisional restorations.

On the other hand, several studies[1,5,41–43] concluded that 3D printing offers better marginal adaptation compared to milling. Park et al[41] 2016 and Lee et al[5] 2017 attributed the decreased marginal fit of milled implant supported restoration to the milling bur diameter. They reported that the curved parts of the provisional restoration margin were more precisely fabricated by 3D printing compared to milling as a result of the limitations of motion of the milling machine axes and bur diameter. Moreover, Elfar et al[43] concluded that the higher accuracy of the 3D printing was attributed to the incremental layering process during fabrication that allows for accurate reproduction of all details, adequate compensation of the polymerization shrinkage and better marginal fit compared to milling. Lastly, Alharabi et al[1] accredited the higher vertical marginal gap of the milled restorations to the tolerance of the milling burs and their wear. They claimed that any surface detail less than the diameter of the milling bur will be over-milled and lead to loose inaccurate restoration.

Contradicting results were reported by Savencu et al[44] 2020. They found that the best vertical marginal gap values were obtained for the milled metal copings followed by the 3D printed ones. They pointed out that the decreased accuracy of the 3D printed copings is due to the accumulation of errors at different stages of fabrication; the segmentation of the design by the printing software, processing, and during the printing process itself. Also, the shrinkage during building and post curing was claimed to lead to the larger marginal discrepancy.

The limitations of this study includes; failing to fully reproduce clinical situations; saliva, patient movement, and anatomical features (tongue, lips, and cheeks) during scanning and designing. Also, the present study was limited to the analysis of the fit of 3 unit FDPs. Moreover, the present study investigated the accuracy of SLA 3D printing technology only. Therefore, further research should be conducted under different oral environmental and clinical factors. Moreover, investigating the fit of long span FDPs and oral rehabilitation cases is recommended. Finally, 3D printing technologies other than the tested SLA technology should be tested in the upcoming studies.

The final outcome of this study is that during the digital workflow, additive 3D printing technology can replace its subtractive counterpart during the construction of provisional restorations for its maximum accuracy, precise fit and cost effectiveness.

CONCLUSION

Within the limitations of the present study, the following points could be concluded:

1. The vertical marginal gap values of provisional restorations fabricated by the two tested methods of manufacturing (milling and 3D printing) were within the acceptable range of 120 microns.
2. The 3D printed provisional restorations showed comparable marginal fit to that of the milled ones.

FUNDING: This research received no external funding.

CONFLICTS OF INTEREST: The authors declare no conflict of interest.

REFERENCES

1.Alharbi N, Alharbi S, Cuijpers VM, Osman RB. Three-dimensional evaluation of marginal and internal fit of 3D-printed interim restorations fabricated on different finish line designs. J Prosthodont Res. 2017;62:218-26.

2.Dureja I, Yadav B, Malhotra P, Dabas N, Bhargava A, Pahwa R. A comparative evaluation of vertical marginal fit of provisional crowns fabricated by computer - aided design / computer - aided manufacturing technique and direct (intraoral technique) and flexural strength of the materials : An in vitro study. J Indian Prosthdont Soc 2018;18:314-20.

3.Heboyan AG. Marginal and internal fit of fixed prosthodontic constructions: A literature review. Int J Dent Res Rev. 2019;2:1-8.

4.Singla M, Padmaja K, Arora J.Provisional Restorations in Fixed Prosthodontics. Int J Dent Med Res.2014;1:148-51.

5.Lee W, Lee D, Lee K. Evaluation of internal fit of interim crown fabricated with CAD / CAM milling and 3D printing system. J Adv Prosthodont 2017;9:265-70.

6.Patras M, Naka O, Doukoudakis S, Pissiotis A. Management of provisional restorations’ deficiencies: A literature review. J Esthet Restor Dent. 2012;24:26-38.

7.Tom TN, Uthappa MA, Sunny K, Begum F, Nautiyal M, Tamore S. Provisional restorations: An overview of materials used. J Adv Clin Res Insights. 2016;3:212-4.

8.Jeong Y, Lee W, Lee K. Accuracy evaluation of dental models manufactured by CAD / CAM milling method and 3D printing method. J Adv Prosthodont 2018;10:245-51.

9.Gabriella A, Presotto C, Ricardo A. Dimensional precision of implant-supported frameworks fabricated by 3D printing. J Prosthet Dent.2019;122:38-45.

10.Bds TFA, Cam CAD. ScienceDirect Advancements in CAD / CAM technology : Options for practical implementation. J Prosthodont Res. 2016;60:72-84.

11.Abduo J, Lyons K, Bennamoun M.

Trends in Computer-Aided Manufacturing in Prosthodontics : A Review of the Available Streams. Int J Dent 2014;2014:15-30.

12. Jain R, Takkar R, Jain G, Takkar R, Deora N, Jain Professor R. CAD-CAM the future of digital dentistry: A review. Ann Prosthodont Restor Dent. 2016;2:33-6.

13. Abdullah AO, Muhammed FK, Zheng B, Liu Y. An Overview of Computer Aided Design / Computer Aided manufacturing(CAD/CAM) in restorative dentistry.J Dent Mater Tech2018;7:1-10.

14. Homsy FR, Özcan M, Dent M, Khoury M. Marginal and internal fit of pressed lithium disilicate inlays fabricated with milling , 3D printing , and conventional technologies. J Prosthet Dent.2018;119:783-90.

15. Quadri S, Kapoor B, Singh G, Tewari RK. Rapid prototyping : An innovative technique in dentistry. Int J S Res2017;9:96-102.

16. Dawood A, Marti BM, Darwood A. 3D printing in dentistry. Br Dent J 2015;219:521-9.

17. Zaharia C, Gabor A, Gavrilovici A, Stan AT, Idorasi L, Negruțiu M. Digital Dentistry 3D Printing Applications. J. Interdiscip. Med.2017;2:50-3.

18. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1984;6:405-8.

19. Khaledi AAR, Vojdani M, Farzin M, Pirouzi S, Orandi S. the effect of sintering time on the marginal fit of zirconia copings. J Prosthodont. 2019;28:e285-9.

20. Keerthna M, Nallaswamy D, Bennis MA. Assessment of Marginal Discrepancies In Zirconia Fixed Dental Prosthesis Fabricated Using Various Cad Cam Milling Systems–A Systematic Review.J Dent Med Sci 2020;19:28-39.

21. Akbar JH, Petrie CS, Walker MP, Williams K, Eick JD. Marginal adaptation of Cerec 3 CAD/CAM composite crowns using two different finish line preparation designs. J Prosthodont. 2006;15:155-63.

22. Homsy F, Bottin M, Özcan M, Majzoub Z. Fit Accuracy of Pressed and Milled Lithium Disilicate Inlays Fabricated From Conventional Impressions or a Laboratory-Based Digital Workflow. Eur J Prosthodont Restor Dent. 2019;27:18-25.

23. Tahayeri A, Morgan M, Fugolin AP, et al. 3D printed versus conventionally cured provisional crown and bridge dental materials. Dent Mater. 2018;32:192-200.

24. Johnson R, Verrett R, Haney S, Mansueto M, Challa S. Marginal Gap of Milled versus Cast Gold Restorations. J

Prosthodont. 2017;26:56-63.

25. Alshawaf B, Matthew HW, Khaled F, Yukio R, Panos K. Accuracy of printed casts generated from digital implant impressions versus stone casts from conventional implant impressions : A comparative in vitro study. Clin Oral Implants Res 2018;29:835-42.
26. Buda M, Bratos M, Sorensen JA. Accuracy of 3-dimensional computer-aided manufactured single-tooth implant definitive casts. J Prosthet Dent. 2018;120:913-8.
27. Kim W. Accuracy of dental models fabricated by CAD / CAM milling method and 3D printing method . J Oral Res 2018;7:127-33.
28. Khng KYK. An in vitro evaluation of the marginal integrity of CAD/CAM interim crowns compared to conventional interim resin crowns. J Prosthet D ent 2016;115:617-23.
29. Kale E, Seker E, Yilmaz B, Özcelik TB. Effect of cement space on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns. J Prosthet Dent. 2016;116:890-5.
30. Ibrahim A, El-Shehawy D, El-Naggar G. Fracture resistance of interim restoration constructed by 3D printing versus CAD / CAM technique (In vitro study). AS J Dent Sci, 2020; 19: 13-20.
31. Hassan RH, Mokhtar AH, Zaghloul H. Evaluation of marginal fit and microleakage of monolithic zirconia crowns cemented by bio-active and glass ionomer cements: In vitro study. Brazilian Dent Sci. 2020;23:1-11.
32. Rayyan MM, Aboushelib M, Sayed NM, Ibrahim A, Jimbo R. Comparison of interim restorations fabricated by CAD/CAM with those fabricated manually. J Prosthet Dent. 2015;114:414-9.
33. Suralik KM, Sun J, Chen C, Lee SJ. Eff ect of Fabrication Method on Fracture Strength of Provisional Implant-Supported Fixed Dental Prostheses. Prosthesis2020;2:325-32.
34. Romeo E, Iorio M, Storelli S,Camandona M, Abati S.Marginal adaptation of full coverage CAD/CAM restorations:invitro study using non destructive method. Minerva Stomatol 2009;58:61-72.
35. Yucel MT, Aykent F, Avunduk MC. In vitro evaluation of the marginal fit of different all-ceramic crowns. J Dent Sci. 2013;8:225-30.
36. Groten M, Ayman D, Probster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in vitro testing. J Prosthet Dent.2008;83:40-9.
37. Gonzalo E, Suárez MJ, Serrano B, Lozano JFL. A comparison of the marginal vertical discrepancies of

zirconium and metal ceramic posterior fixed dental prostheses before and after cementation. J Prosthet Dent. 2009;102:378-84.

38. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J. 1971;131:107-11.
39. Choi JW, Ahn JJ, Son K, Huh JB. Three-dimensional evaluation on accuracy of conventional and milled gypsum models and 3D printed photopolymer models. Materials. 2019;12:1-10.
40. Haddadi Y, Ranjkesh B, Isidor F, Bahrami G. Marginal and internal fit of crowns based on additive or subtractive manufacturing. Biomater Investig Dent. 2021;8:87-91.
41. Park JY, Jeong il Do, Lee JJ, Bae SY, Kim JH, Kim WC. In vitro assessment of the marginal and internal fits of interim implant restorations fabricated with different methods. J Prosthet Dent. 2016;116:536-42.
42. Wu J, Xie H, Sadr A, Chung KH. Evaluation of Internal Fit and Marginal Adaptation of Provisional Crowns Fabricated with Three Different Techniques. Sensors 2021; 21 :1-15.
43. Elfar, M., Korsel, A.M., & Kamel, M. (2018). Marginal fit of heat pressed lithium disilicate crowns fabricated by three-dimensional printed and subtractive CAD/CAM wax patterns. Tanta Dent J. 2018;15:91-8.
44. Savencu CE, Şerban C, Porojan L. Adaptability evaluation of metal-ceramic crowns obtained by additive and subtractive technologies. Appl Sci. 2020;10:5563.