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Effect of Fabrication Technique and Margin Design on the Marginal Fit of Interim Fixed Dental Prosthesis (An In-Vitro Study)

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ABSTRACT

Background: There is limited evidence regarding the effectiveness of various digital manufacturing techniques for producing interim prosthesis with different finish line designs. ***Aim:*** The objective was to evaluate the influence of CAM techniques, 3D printed and milled on the vertical margin gap of interim fixed dental prosthesis using two finish line designs. ***Materials and Methods*****:** Two prepared abutment teeth were designed with finish line designs (shoulder and knife-edge) to receive a 3-unit interim prosthesis (polymethyl methacrylate and microfilled hybrid resin). The reference models were 3D printed (n=28), and an optical impression was performed to design FDPs on CAD software. Group A is milled with a shoulder finish line. Group B is milled with a knife-edge finish line. Group C 3D-printed with a shoulder finish line. Group D 3D-printed with knife-edge finish line. Samples were cemented with long-term temporary cement. Vertical marginal fit was assessed using stereo-optical microscope before and after thermocycling ***Results:*** Marginal gaps in both techniques were influenced by thermocycling. The knife-edge finish line showed a higher gap when milled. Overall gap distance for 3D-printed knife-edge and shoulder finish line before (20-74.8 µm, 17.8-91µm) and after thermocycling (34-103µm, 33-112µm). Overall gap distance for milled knife-edge and milled finish lines before (43-111.8 µm, 17.2-93µm) and after thermocycling (62-141 µm, 27-103µm). ***Conclusion:*** Thermocycling showed a negative effect on vertical marginal adaptation in both techniques. Vertical marginal gap of the interim restorations fabricated by the two techniques was within the acceptable clinical range of ≤120µm.

Keywords: finish line designs; marginal fit; milling method; three-dimensional printing method; tooth-supported FDPs

INTRODUCTION

Replacement of missing teeth aims to restore oral functions and esthetics by using a dental prosthesis. This enhances and maintains the patient’s appearance, comfort,

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physical and psychological health. Various treatment options are available to replace missing teeth, and the choice depends on factors such as the number and condition of the remaining teeth, available space, adequacy of bone support, cost considerations, and the patient's preferences.[1]

The interim fixed dental prosthesis is crucial in fixed prosthodontics treatment, spanning from tooth preparation until the definitive prosthesis is placed. It shares similar biological and biomechanical demands as the definitive prosthesis. Some of the biological requirements include safeguarding the pulp, ensuring cleanability, and achieving pleasing aesthetics. On the other hand, tooth positional stability, resistance to functional/occlusal forces, and proper retention are among the biomechanical requirements.[2]

A variety of interim fixed prosthetic materials are available. The majority of these materials can be classified into two main groups according to their compositions: 1) methacrylate-based materials, and 2) composite resins. It's important to note that no one material or brand is universally suitable for all clinical scenarios. Therefore, understanding the properties of these materials is crucial to determining their limitations, indications, and contraindications for their clinical application.[3]

The properties of those restorations influence their survival rate. One of those properties that affect their long-term success is the fitting accuracy between the restoration and the prepared abutment.[4] The restorations must fit accurately to guarantee durability and mechanical stability, directly affecting the well-being of the surrounding tissues. Insufficient fit can result in several problems, including plaque accumulation, cement leakage, marginal discoloration, compromised aesthetics, increased teeth sensitivity, the possibility of developing caries, and potential periodontal diseases.[5, 6]

In the literature, there is considerable diversity in defining adequate fit and clinically acceptable marginal gap. This variation can be attributed to differences in study designs, such as using various restorative materials, examination methods, finish line designs, and fabrication techniques.[7] Consequently, the variability and distinctiveness of different restoration fabrication techniques significantly impact the final restoration. These diverse fabrication methods can be broadly categorized into direct and indirect methods based on their manufacturing processes.[8] Although the direct method has shown great success for many years due to the fast and straight-forward process, it has disadvantages. Thermal trauma to the tooth pulp may be caused by the exothermic heat released during resin polymerization. Furthermore, the leftover resin monomer may pose a risk to the oral mucosa, potentially leading to lichenoid reactions or oral stomatitis. Additionally, the resin's shrinkage can result in differences in dimensions in the marginal, interproximal, and occlusal areas. As a solution, the indirect method has been implemented to eliminate thermal and chemical risks to the tooth and mucosa. This improved crown adaptation to the tooth is achieved because the polymerization process takes place outside the oral cavity.[9]

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology has recently gained great popularity in the fabrication of interim crowns. The digital manufacturing step can be classified into subtractive manufacturing (milling) and additive manufacturing (3D printing). Milling technology represents the prevailing dental CAD-CAM system, where interim crowns are created by mechanically sculpting a resin block using a cutting bur. Due to the high degree of conversion during polymerization of the resin block, interim crowns fabricated through milling demonstrate superior strength and accuracy compared to those made using conventional methods.[9] However, the main drawbacks of the subtractive method are the unnecessary loss of material during milling, high equipment maintenance cost because of the rapid wear of the cutting burs, and poor micro reproducibility in concave, sharp and pointed areas of any design. Consequently, additive technology, specifically 3D printing, began to make inroads into this domain with the aim of addressing certain limitations associated with the milling method..[10, 11]

Additive manufacturing produces precise, accurate prosthesis of complicated geometrical shapes with minimal materials and cost.[12] In addition, multiple restorations can be fabricated at the same time.[10] However, the main drawbacks of this manufacturing technique are the co-occurring dimensional discrepancy that can be manifested in the restoration as different forms of clinical inaccuracies, because of the shrinkage during building and post curing procedure.[13]

Thermocycling is a widely used technique to speed up the aging process of prosthetics, as it attempts to mimic the oral environment to some extent. This method involves subjecting the prosthetics to standardized temperature changes by immersing them in baths ranging from 5 to 55 degrees Celsius for multiple cycles. By employing thermocycling, it becomes possible to predict the longevity of the prosthetics and simulate how the prosthetic material behaves.[14]

Moreover, the type of finish line is among the factors that impact the marginal adaptations of the prosthesis. Several authors have emphasized the significance of assessing the influence of the finish line on the marginal gap of fixed restorations.[15]

Considering the earlier information mentioned, the marginal fit of different manufacturing techniques is still being researched. Hence, the objective of this study is to assess the vertical marginal gap of milled and 3D-printed provisional fixed dental prosthesis with two distinct finish line designs, both before and after thermocycling. Hence, the null hypothesis formulated for this study posited that there would be no discernible difference in the marginal fit of interim restorations produced through 3D printing and CAD/CAM milling, employing two distinct finish line designs, both prior to and following the process of thermocycling.

MATERIALS AND METHODS

A total of 14 provisional fixed dental prosthesis were 3D printed (Vertex-Dental B.V, Soesterberg, Netherlands) and 14 provisional fixed dental prosthesis were milled (Yamahachi Dental MFG, Gamagori, Japan). Each fabrication technique was divided into two equal groups according to the type of finish line design. The marginal fit of 28 provisional tooth-supported dental prosthesis were assessed before and after thermocycling.

1.Fabrication of the Master Model

Two master models were designed from two abutment teeth for a three-unit tooth-supported provisional prosthesis. A digital reference model, featuring a pair of standardized abutments serving as a master die was created digitally using AutoCAD software (Autodesk, USA). This digital model was developed to replicate the preparation of a three-unit all-ceramic Fixed Dental Prosthesis (FDP) for a maxillary first premolar and first molar. The abutments adhered to specific technical specifications, including a height of 5 mm, an occlusal diameter of 4.5 mm for the first premolar, and 7.5 mm for the first molar. The abutments were designed with a six-degree convergence angle for the axial walls, rounded angles, and a level occlusal surface. One of the models was configured with a 1 mm-wide shoulder finish line, while the other received a 0.3 mm wide knife-edge finish line design.[16] The dimensions were checked using a periodontal probe and a caliber to confirm the correct specifications of the abutments.

2.Printing of Master Models

Two working models of shoulder and knife-edge finish line designs were printed using Next Dent Model 2.0 (Vertex-Dental B.V Soesterberg, Netherlands) as shown in **Figure (1)**, following the manufacturer's

Figure (1): 3D printed models on build platform.

instructions using Anycubic Photon S (Shenzhen Anycubic Technology Co., Ltd.), which is a Stereolithography (SLA) 3D printer, this included the following steps as shown in **Figure (2)**.

Figure (2): Any cubic Photon S SLA 3D printer.

3. Designing and Fabricating the Tooth-Supported Provisional Dental Prosthesis

3.1. Restoration Design

Digital impressions of both models were taken by using a Medit T500 lab scanner to mimic clinical situations. Then the scans were exported as STL files and will be used to design the provisional dental prosthesis using CAD/CAM technology. On the EXOCAD software (Exocad GmbH, Darmstadt, Germany), the finish lines were traced on the two abutment teeth. Then the design of the full anatomic crown for the maxillary first premolar and first molar was selected. In contrast, the design for the full anatomic pontic was chosen for restoring the maxillary second premolar from the Exocad software library and connected.

The spacing for cement application was established for both abutments: a cement gap of 0.03 mm and an additional cement gap of 0.060 mm.[17] The design was saved, and ready for the CAM step by either milling or 3D printing.

3.2. Milling the Tooth-Supported Provisional Dental Prosthesis (Group A, B)

After placing the FDPs in the preferred orientation within the material blank, the STL file was transmitted to the milling machine. This was followed by using the CAM 5-S1 impression milling machine software. The

PMMA disc (Yamahachi Dental MFG, Gamagori, Japan) was fixed to the machine holder. Then, the order was given to mill and get the final end product of the milled provisional FDPs, as shown in **Figure (3)**.

Subsequent to the milling process, the supporting sprues were detached, and the FDPs underwent the final steps of finishing and polishing. Fourteen FDPs were milled and assessed for proper fit. Seven FDPs had shoulder finish lines (n=7), while the remaining seven had knife-edge finish lines (n=7).

Figure (3): 28 FDPs on 3D printed master dies.

3.3. 3D Printing Tooth-Supported Provisional Dental Prosthesis (Group A, B)

The fabrication of 14 tooth-supported provisional dental prostheses was conducted through 3D printing, utilizing the Anycubic Photon S 3D printer. For this process, the Next Dent C&B resin tank (Vertex-Dental B.V, Soesterberg, Netherlands) along with the build platform, was set up within the printer. The material chosen was Next Dent microfilled hybrid, a biocompatible Class IIa substance intended for the creation of durable temporary crowns and bridges over extended periods.

A printing task was prepared using Chitubox software by importing the stored design of the dental restoration STL file.

The files were positioned horizontally, aligning the occlusal plane with the build platform, followed by the generation of supports. Subsequently, the print job was transmitted to the printer, initiating the printing process. A total of seven FDPs with shoulder finish lines and seven FDPs with knife-edge finish lines were 3D printed (n=14).

The printed FDPs were cleaned with ethanol (>90%) for three minutes to remove any excess material, with the aid of a sealed wash container. Then rinsed again with clean ethanol (>90%) for two minutes and left to air dry completely.[17] Post-cured FDPs were polished using Felt wheel bur and pumice polishing paste for a perfectly smooth finish and visually checked.

4. Cementation of Tooth-Supported Fixed Dental Prosthesis

Cementation of FDP samples was done following the manufacturer's recommendations using DentoTemp (Itena, Villepinte, France), which is a long-term temporary cement, to simulate the clinical scenario. FDPs were placed under a static load of 3 Kg for two minutes according to the manufacturer's instructions while setting the cement to ensure complete seating of the restorations on the dies using a custom-made loading device.[18]

5. Measuring the Marginal Fit of the Test Groups Before Thermocycling

The vertical marginal gap distance for each cemented FDP was measured using stereomicroscope from the restoration margin to the finish line, as shown in **Figure (4)**. Images of the margins were captured using a handheld digital microscope equipped with an integrated camera, mounted on a precise microscope stand, and connected to an IBM-compatible personal computer.

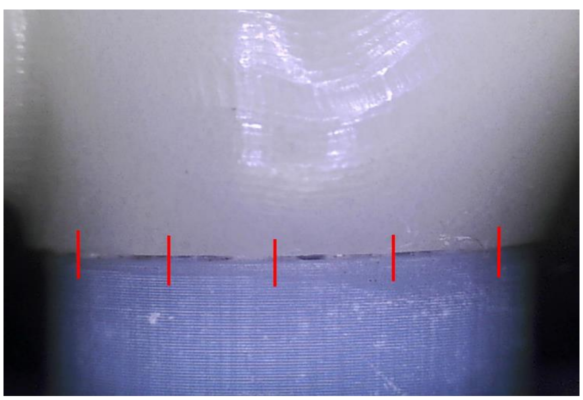

Figure (4): Stereomicroscope of 5 equidistant measurements**.**

The fixed magnification used for capturing the images was set at 50X. Stereomicrographs were captured on predetermined marks on each surface. The measuring points were standardized equidistantly using the ruler of the stereomicroscope.

Five equidistant measurement points were taken from three surfaces (buccal, lingual, and mesial for the first premolar and buccal, lingual, and distal for the first molar), in which 2 of these points were at the line angles of the pontic.[16] This is a total of 15 points for each retainer of the FDP. Digital image analysis software (Image J 1.49d, National Institute of Health, USA), which was used to measure and evaluate the gap. The measured parameters were expressed in pixels and converted to microns. Measurements was recorded in microns, and the mean of the fifteen points were recorded for statistical analysis. Hence, a process of system calibration was carried out to translate the pixel measurements into real-world units. This calibration involved a comparison between a known-sized object (a ruler in this case) and a scale generated using Image J software.[17]

6. Thermocycling

Thermocycling was carried out for 5,000 cycles after cementing the 28 samples on the model dies. [19] Thermocycling included the temperature of 5, as shown in **Figure (5A)** and 55 degrees Celsius, as shown in **Figure (5B)**, with dwelling times of 60 seconds, and

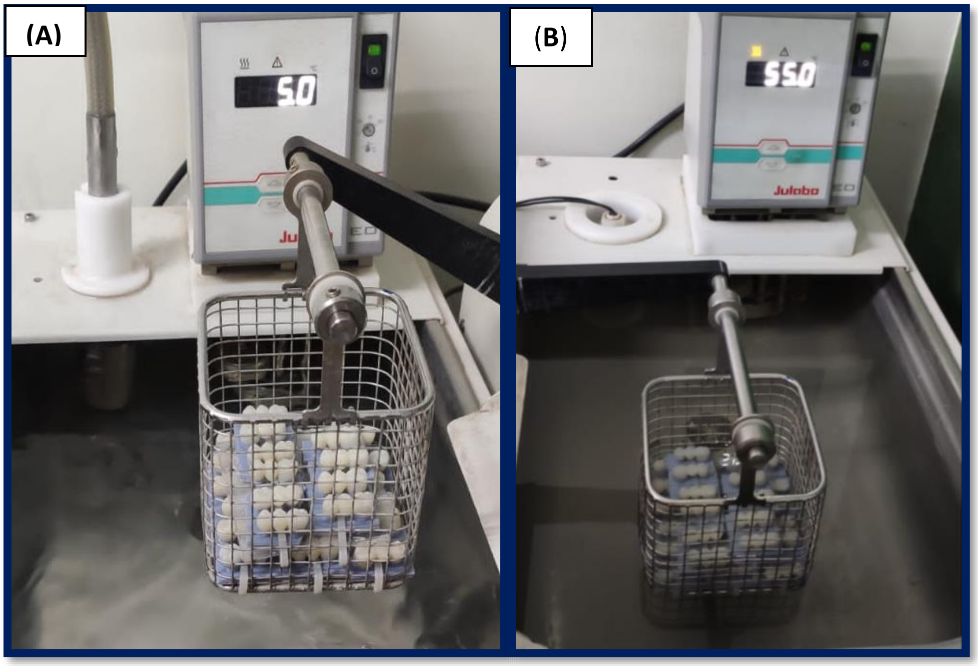

Figure (5): (A) 5.0 degrees Celsius bath. **(B)** 55.0 degrees Celsius bath.

transfer time s of 15 seconds, to represent 6 months in the oral environment (Julabo GmbH, Germany). [19]

7. Measuring the Marginal Fit of the Test Groups After Thermocycling

After the samples have been thermally cycled. Stereomicrographs were captured on predetermined marks on each surface. All 28 provisional FDP have been measured to assess the vertical marginal gap in the exact manner as measurements before thermocycling. Then the data obtained were collected, tubulated, and then subjected to statistical analysis.

Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Gap distance data showed non-normal (non-parametric) distribution. Data were presented as median and range values. Mann-Whitney U test was used to compare the two techniques and the two finish line types. Wilcoxon signed-rank test was used to compare between marginal gap before and after thermocycling. The significance level was set at $P \leq 0.05$.

RESULTS

1. Comparison between Construction Techniques

1.1. Knife-edge Finish Line

With a knife-edge finish line, whether before or after thermocycling, 3D printing showed statistically significantly lower gap distance than milling at the buccal, lingual, distal and mesial surfaces. As regards the overall gap distance (regardless of the surface), 3D printing showed a statistically significantly lower gap distance than milling with values 20-74.8 µm before thermocycling and 34-103 µm after thermocycling as shown in **Figure (6)**.

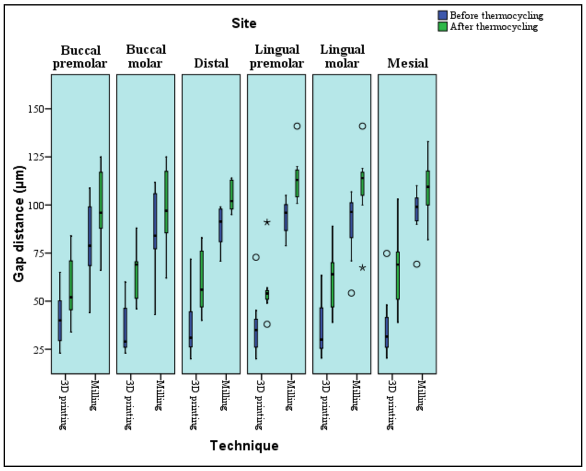

Figure (6): Box plot representing median and range values for gap distance of the construction techniques with knife-edge finish line (Circles and stars represent outliers).

1.2. Shoulder Finish Line

With the shoulder finish line before thermocycling, there was no statistically significant difference between the two techniques at the buccal, lingual, distal and mesial surfaces. As regards the overall gap distance (regardless of surface), there was no statistically significant difference between the two techniques with range values of 43-111.8 µm as shown in **Figure (7)**.

After thermocycling, there was no statistically significant difference between the two techniques at the buccal, lingual, distal and mesial surfaces, while for the overall gap distance (regardless of the surface), 3D printing showed statistically a significantly higher median gap distance of 60.5 µm than milling.

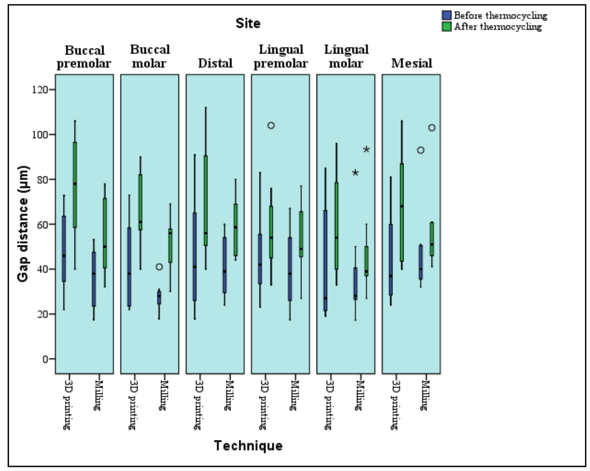

Figure (7): Box plot representing median and range values for gap distance of the construction techniques with shoulder finish line (Circles and stars represent outliers).

2. Comparison between Finish Line Types

2.1. 3D Printing

In case of 3D-printing technique whether before or after thermocycling, there was no statistically significant difference between the two finish line types at the buccal, lingual, distal and mesial surfaces. As regards the overall gap distance (regardless of the surface), there was no statistically significant difference between the two finish line types.

2.2. Milling

With the milling technique, whether before or after thermocycling, the knife-edge finish line showed a statistically significantly higher median gap distance than the shoulder finish line at the buccal, lingual, distal and mesial surfaces. As regards the overall gap distance, the knife-edge finish line showed a statistically significantly higher median gap distance than the shoulder finish line, with a value of 109.7 µm.

3. Effect of Thermocycling

3.1. 3D Printing

As regards the 3D-printing technique, whether with knife-edge or shoulder finish lines, there was a statistically significant increase in median gap distance after thermocycling at the buccal, lingual, distal and mesial surfaces. As regards the overall gap distance (regardless of the surface), there was a statistically significant increase in median gap distance after thermocycling with values of 56.5 µm and 60.5 µm as shown in **Table (1)**.

3.2. Milling

Similarly, for the milling technique, whether with knife-edge or shoulder finish lines, there was a statistically significant increase in median gap distance after thermocycling at the buccal, lingual, distal and mesial surfaces. As regards the overall gap distance (regardless of the surface), there was a statistically significant increase in

Table (1): Descriptive statistics and results of Wilcoxon signed-rank test for comparison between gap distance (µm) before and after thermocycling with 3D printing technique.

Finish line	Surface	Before thermocycling (n = 7)		After thermocycling (n = 7)		*P*-value	*Effect size (d)*
		Median	Range	Median	Range		
Knife-edge	Buccal (Premolar)	40	23-65	52	34-84	0.018*	4.039
	Buccal (Molar)	29	23-60	69	46-88	0.018*	4.039
	Distal	31	20-71.8	56	40-83	0.018*	3.966
	Lingual (Premolar)	35	20-72.8	54	38-91	0.018*	4.039
	Lingual (Molar)	30	20.4-63.4	64	39-89	0.018*	3.966
	Mesial	31.6	20.4-74.8	69	39-103	0.018*	4.039
	Overall	33.3	20-74.8	56.5	34-103	<0.001*	3.136
Shoulder	Buccal (Premolar)	46	22-72.8	78	40-106	0.018*	3.966
	Buccal (Molar)	38	22-73	61	40-90	0.018*	3.966
	Distal	41	17.8-91	56	40-112	0.018*	3.966
	Lingual (Premolar)	42	23-83	54	33-104	0.017*	4.11
	Lingual (Molar)	27	19-85	54	33-96	0.017*	4.155
	Mesial	37	24-81	68	40-106	0.018*	4.039
	Overall	41	17.8-91	60.5	33-112	<0.001*	3.554

**: Significant at P ≤ 0.05.*

median gap distance after thermocycling with values of 109.7 µm and 50 µm, as shown in **Table (2)**.

carried out, involving subtractive methods like milling or additive methods like 3D printing.

Table (2): Descriptive statistics and results of Wilcoxon signed-rank test for comparison between gap distance (µm) before and after thermocycling with milling technique.

Finish line	Surface	Before thermocycling (n = 7)		After thermocycling (n = 7)		*P*-value	*Effect size (d)*
		Median	Range	Median	Range		
Knife-edge	Buccal (Premolar)	78.8	44-108.8	96	66-125	0.018*	4.074
	Buccal (Molar)	84	43-111.8	97	62-125	0.018*	4.074
	Distal	91.4	70.8-99	102	95-114	0.018*	3.966
	Lingual (Premolar)	96	78.8-105	113	100.8-141	0.018*	4.039
	Lingual (Molar)	96.4	54.2-106.8	114	67.4-141	0.018*	3.966
	Mesial	99	69.2-110	109.4	82-133	0.018*	3.966
	Overall	95.5	43-111.8	109.7	62-141	<0.001*	3.552
Shoulder	Buccal (Premolar)	38	17.4-53.2	50	32-78	0.018*	3.966
	Buccal (Molar)	28	17.8-41	56	30-69	0.018*	4.074
	Distal	39	24-60	58.6	44-80	0.018*	4.074
	Lingual (Premolar)	38	17.4-67	49	27-77	0.018*	4.074
	Lingual (Molar)	28	17.2-83	39	27-93.4	0.017*	4.11
	Mesial	40	32-93	51	41-103	0.016*	4.415
	Overall	32.5	17.2-93	50	27-103	<0.001*	3.568

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

DISCUSSION

Digital fabrication techniques (milling and 3D printing) have recently gained great popularity and competently substituted the conventional ones, and 3D printing has been an area of digital technology growth. These methods enable the creation of dental restorations on digital models and replicas through CAD software, eliminating the requirement for a physical model. Subsequently, digital production (CAM) is

Likewise, interim restorations play a significant role in the success of the treatment plan for complex cases.[20] Long-term provisionalization of these cases necessitates having a highly precise biocompatible restoration.[21] CAD/CAM fabrication techniques achieved this by offering restorations of better quality.[20, 22] Thus, this laboratory-based study examined the impact of fabrication methods in two digital workflows: 3D-printing versus milling, along with the evaluation of two finish line designs (shoulder and knife-edge) on the marginal fit of 3-unit interim FDPs.

Marginal fit is one of the most significant criteria in evaluating of FDPs and their success.[23] In addition, a marginal discrepancy is considered to be one of the main causes of failure of indirect restorations.[16, 24, 25]

The assessment of the vertical marginal gap was conducted using a stereomicroscope, which is a non-invasive measuring approach according to Romeo et al.[26] Additionally, Yucel et al.,[27] pointed out that utilizing a direct imaging method under a microscope along with software for image analysis facilitates the acquisition of numerous non-destructive measurements.

In the present research, 15 distinct reference points were assessed for every retainer comprising the FDP to encompass the margin line. Five equidistant measurement points were taken from three surfaces using the stereomicroscope ruler (buccal, lingual, and mesial for the first premolar and buccal, lingual, and distal for the first molar), in which 2 of these points were at the line angles of the pontic site. The mesial and distal surfaces of the pontic area were not included owing to the difficulty in recording this area by stereomicroscope due to inaccessibility. This approach finds support in the research carried out by Groten et al., [28] were relying on only 4 to 12 measurements per crown could potentially lead to misleading outcomes. Consequently, this current study opted for more than 12 measurements for each abutment to guarantee comprehensive insights into the gap dimensions and to ensure the statistical precision of the findings. The measurement of the marginal gap took place subsequent to the cementation of all samples, mirroring real-world clinical situations.

Based on the results, the null hypothesis of this study was partially rejected. Regarding the construction techniques, the results of the present study showed that 3D printing showed a statistically significant lower gap distance than milling before and after thermocycling with knife-edge finish line, while there was no difference between the two techniques before thermocycling with the shoulder finish line. On the other hand, 3D-printing showed a higher gap distance after thermocycling with the shoulder finish line.

The vertical marginal gap measurements for both the milled and 3D printed Fixed Dental Prostheses (FDPs) were found to fall within the clinically acceptable range of 120 microns, in line with the criteria defined by McLean et al.[29] An exception was observed for the knife-edge milled FDPs, which exhibited a gap exceeding the clinically acceptable range after undergoing thermocycling. The enhanced vertical marginal fit of the 3D printed group compared to the milled group can be attributed to the fact that the milling process employed the smallest bur size of 1 mm, limiting the precise replication of areas smaller than 1 mm.

Furthermore, Elfar et al.,[30] concluded that the heightened accuracy of 3D printing could be attributed to the incremental layering approach during fabrication. This method ensures the precise reproduction of intricate details, effective compensation for polymerization shrinkage, and a superior marginal fit compared to the milling technique.

Conversely, the increased gap distance observed in 3D-printed FDPs might be ascribed to residual stress arising from water absorption and temperature variations. These factors can lead to debonding between the layers in the 3D printing process, potentially triggering crack formation and eventually leading to structural failure over time.[31]

In this study, a higher vertical marginal gap was found after thermocycling than before thermocycling, whether 3D printed or milled in both finish line groups. The reason behind this is the fluctuations in temperature, causing the resin to expand and contract, particularly at the thin margin region. This phenomenon can initiate and propagate cracks through the areas with weaker or porous resin, potentially leading to an increase in the marginal gap.[19, 31] Additionally, the presence of moisture in the environment can result in the leaching of residual monomer, leading to a higher concentration of voids at the margin area and an increased risk of fracture. This finding is consistent with a study by Thidarat et al.,[19] which emphasized the considerable impact of the aging process on the marginal gap of interim restorations.

Nevertheless, it is essential to exercise caution when generalizing the results. This study focused solely on one clinically available material and one system for each fabrication method. It remains to be investigated whether the conclusions drawn from this study can be extended to different materials and systems, particularly considering that a definitive restoration will follow interim restorations.

CONCLUSION

Based on the finding of this in vitro study and within its limitation, the following points were concluded:

1. Thermocycling negatively affected t-

he vertical marginal adaptation of interim restorations.

2. Interim restorations with knife-edge finish line constructed by 3D printing showed better vertical marginal adaptation values than those constructed by milling.

3. Using 3D-printing seems to be a suitable technique for construction of 3-unit interim prosthesis.

4. All interim restorations showed clinically acceptable vertical marginal adaptation of ≤120µm.

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