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Assessment of the Effect of Two Different Digital Fabrication Techniques on Marginal and Internal Fit of Interim Fixed Dental Prosthesis

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ABSTRACT

Aim: The aim of that study was to evaluate the marginal and internal fit of a 3-unit, and 6-unit interim fixed dental prosthesis manufactured through milling and 3D printing technologies. ***Materials and Methods:*** Forty-eight interim fixed dental prostheses (FDP) were equally divided into two groups according to the fabrication technique. In group (MT), specimens were fabricated through milling technology while in group (PT), specimens were obtained by 3D printing. Each group was subdivided equally according to the FDP span length into 3-unit FDP (SFDP), and 6-unit FDP (LFDP). Marginal and internal fit were measured through the superimposition of the digital master model data and data of the fitting surfaces of the milled and printed FDPs using the "best-fit" alignment feature of a 3D evaluation superimposition software. The Mann-Whitney U test was used to compare the two fabrication techniques as well as the two span lengths. The significance level was set at $P < 0.05$. ***Results:*** Results showed that 3D printing showed statistically significantly higher overall marginal gap distance (MGD) than the milling technique for the (SFDP) subgroup while milling showed higher overall (MGD) values than 3D printing for the (LFDP) subgroup. For internal fit, 3D printing showed lower overall internal gap distance values than milling. ***Conclusions:*** Milling technology was able to produce restorations with better marginal fit compared to 3D printing only in 3-unit FDPs. However, the opposite was true when the internal fit of the restorations was considered where 3D printing surpassed the milling technique in both the short-span and long-span FDPs. Consequently, 3D printing could be the technique of preference for fabricating provisional restorations especially when it comes to complex long span FDPs.

1. INTRODUCTION

In fixed prosthodontics, an interim restoration is a provisional restoration designed to evaluate the final restoration's functional and esthetic outcomes. It's, additionally, supposed to maintain function for a specific period of time, after which it is discarded and a definitive restoration is fabricated. Hereby, a successful interim restoration should be highly esthetic while at the same time having an adequate fit to preserve the health of the pulp and surrounding periodontal tissues (1-3).

Acknowledging the fact that the long-term success of an interim restoration is highly dependent on the accuracy of fit, both the marginal and internal fit of an interim restoration should be as precise as that of the definitive one(4).

Multiple factors have been reported to have an impact on both the marginal and internal fit of a restoration among which, but not only limited to, are the fabrication technique and the span length (5-7). Additionally, one previous study comparing the fit of straight posterior and curved anterior 4-unit FDP frameworks showed that frameworks with a straight configuration where the pontic and abutment teeth are in one line together displayed better fit(8).

When shedding the light on the variable materials and techniques available in the market for the fabrication of provisional restorations; it could be seen that auto-polymerizing Polymethyl Methacrylate (PMMA), along with other materials such as bis-acryl resin, is deemed as the most commonly used material for direct fabrication technique. However, those materials are associated with high volumetric shrinkage during polymerization that subsequently causes dimensional changes, especially at the marginal area leading to marginal leakage. Additionally, the inclusion of voids and bubbles during the mixing step could considerably affect the mechanical performance of the restoration. With such a multitude of drawbacks, efforts diverted to benefit from the now widely available digital manufacturing techniques(4,6,9-17).

The digital workflow has been introduced in the dental field a couple of decades ago giving the clinician the privilege of simplifying the process of restorations fabrication through the elimination of conventional methods while guaranteeing improved mechanical strength and fit of the restoration. At the time being, most commercially available dental CAD/CAM systems use subtractive manufacturing technology where a restoration is fabricated through milling of a pre-fabricated block or blank. It has gained popularity for multiple reasons, among which are the higher physical and mechanical properties of the material in comparison to those used for directly fabricated restorations (18,19).

Polymethyl methacrylate (PMMA) is one of those materials introduced in the market for the fabrication of interim restorations through milling technology. It is supplied in the form of prefabricated fully polymerized blanks of a homogenous structure, less residual monomers, and porosities, thereby minimizing the polymerization shrinkage and displaying high strength. Consequently, milled PMMA interim restorations have assigned themselves a satisfactory status in the prosthodontics field owing to their superior mechanical properties, optimum fit, and good color stability (20-22)

Despite the multiple perks of the milling technology, it is associated with numerous downsides such as the unnecessary loss of material during milling, the rapid wear of the cutting burs, and poor micro-reproducibility of thin and sharp areas of any design. In an attempt to overcome such limitations, additive technology was introduced where a dental restoration could be fabricated by layering cross-sectional slices through various printing technologies that differ according to the technique of material layering. Stereolithography is considered the most common method of 3D printing where a photosensitive liquid polymer is cured layer by layer following a specific path of the designed model using a laser beam (14,23,24). It has been postulated through previous work that a smaller layer thickness of the material is associated with better dimensional stability and superior accuracy of the printed prosthesis(25). Moreover, one major factor in improving the precision of restorations obtained through stereolithography is the complete polymerization of the full thickness layer of the material thus decreasing the amounts of few monomers resulting in less deformation (26).

With the confusing data between the ability of the milling technology to render an adequate fit as well as superior mechanical properties on one hand, and the capacity of the printing technology to fabricate multi-unit fixed dental prosthesis with high accuracy being still a concern on the other hand, the idea of this study was conceived (22,27). This study aimed to evaluate the marginal and internal fit of a 3-unit, and 6-unit interim fixed dental prosthesis manufactured through milling and 3D printing technologies in order to investigate the potential clinical applicability in the prosthodontic field. The null hypothesis was that there would be no difference in either the marginal or internal fit of the restorations when fabricated with either of the two techniques whether for the short-span or long-span fixed dental prosthesis.

2. MATERIALS AND METHODS

The following study was designed such that forty-eight interim fixed dental prostheses (FDP) were equally divided into two groups according to the fabrication technique; group (MT) where specimens were fabricated through milling technology and group (PT) where specimens were obtained by 3D printing. Each group was further subdivided equally according to the FDP span length into 3-unit FDP (SFDP), and 6-unit FDP (LFDP). A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference between the tested groups. Through adopting an alpha (α) level of 5%, and a beta (β) level of 20% (i.e. power=80%), 24 specimens in each group were found adequate based on the results of previous studies (15,16).

A maxillary typodont model (Nissin Dental Prod. Inc., Japan) was first modified to simulate 2 different clinical situations of edentulous spans ready to receive an FDP. Thus, the upper left 2nd premolar was removed simulating the space for a 3-unit FDP extending from the upper left first premolar to the upper left first molar. Additionally, the upper right lateral incisor, and upper right 1st and 2nd premolars were removed thus mimicking a space for a 6-unit FDP extending from the upper right central incisor to the upper right 1st molar. The model was scanned, with a laboratory desktop scanner (Medit T500, Seoul, Republic of Korea), followed by scanning the mandibular model, as well as the interocclusal relation of the maxillary and mandibular models together. The preoperative virtual scanned model was saved as standard tessellations files (STL) file and was exported to the Exocad library (Exocad GmbH, Germany).

For the preparation of standardized abutment teeth and maintaining the same thickness with minimum reduction, the STL file of the maxillary preoperative scan was exported and edited using Mastercam software (CNC Software, LLC), and the parameters for the preparation designs of both (SFDP) and (LFDP) specimens were set. The abutment teeth were prepared using a computerized numerical control (CNC) (Premium 4820 Laser, Isel, Germany AG, Germany) lathe cutting machine according to the preset preparation designs showing a well-defined circumferential 1mm rounded shoulder finish line, a 2mm occlusal/incisal reduction, 6 degrees axial inclination, and 1.5mm axial walls contouring (28,29). Using a magnifying loop, the prepared teeth were examined carefully for any imperfections, voids, or sharp points, and any tooth that had any defect was discarded.

Following the completion of the abutment teeth preparation, the typodont maxillary model was digitally scanned using the same laboratory desktop scanner and an STL file of the two digital master model was saved. Using the saved preoperative STL file, the 3-unit and 6-unit fixed dental prostheses were designed with the CAD software (Exocad GmbH, Germany). For the (MT) group, twelve 3-unit FDPs and twelve 6-unit FDPs with 60 µm die spacer (17) were milled using a 5-axis wet milling machine (DooWon, Arum 5x40, Daejeon, South Korea from the PMMA blanks (Yamahachi Dental MFG, Gamagori, Japan). On the other hand, for the (PT) group, the same designed STL file generated for the milling was used, and twelve provisional restorations in each sub-group were fabricated from the resin solution (Savoy C&B, China) using a 3D printer (Anycubic: Photon S SLA 3D printer, China) following the manufacturer's instructions. Upon completion, printed restorations were cleaned with by 99% isopropyl alcohol and air dried before post-polymerization was carried out for 2 minutes under ultraviolet light using a light cure unit (Lumamat 100, Schaan, Liechtenstein).

After completion of the milling and printing processes, all milled and printed FDPs were digitally scanned using the same laboratory desktop scanner for the purpose of measurement of both the marginal and internal fit using the 3D evaluation superimposition software (Geomagic Software Control X2022.0.0 3D Q Plus Lab, CA, USA).

For evaluation of the marginal fit, a total of twelve points were chosen and distributed along the marginal area of each retainer. They were distributed such that there were two points on each axial surface, and one point on each of the mesio-buccal, mesio-palatal, disto-buccal, and disto-palatal line angles (Figure 1). On the other hand, for internal fit evaluation, each FDP was measured along the bucco-palatal (B-P) and mesio-distal (M-D) directions at eighteen points distributed such that there were three points on the occlusal/incisal surface (1 mid occlusal/incisal and 2 axio-occlusal/ axio-incisal), and three points on each axial surface (cuspal/incisal, mid-axial, and margin) (Figures 2,3).

In order to superimpose the data, the digital master model data and data of the fitting surfaces of the milled and printed FDPs were automatically aligned using the "best-fit" alignment feature of the 3D evaluation superimposition software. However, for the sake of attaining a precise superimposition, all data sets outside the areas of interest were eliminated by removing all areas below the margin. Subsequently, the software automatically calculated the Gap Distance in µm and the data were recorded for statistical analyses. A color map representing visual deviation was created and the maximum and minimum tolerance limits were set from -100 µm (dark blue) to +100 µm (red) (Figure 4).

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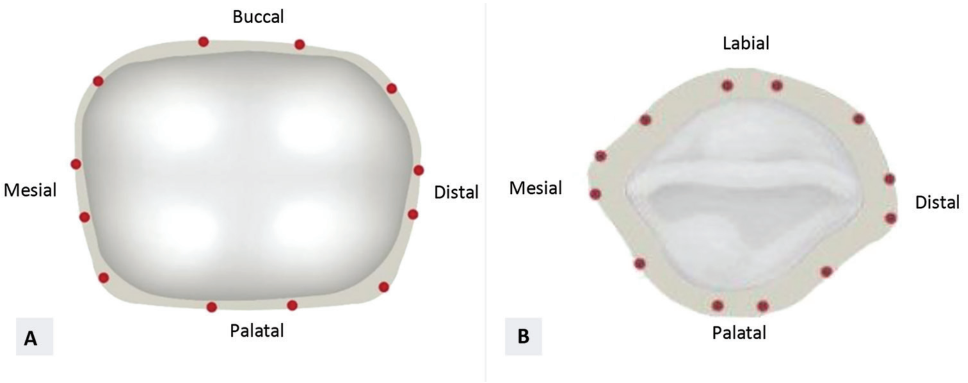

Figure (1) — (A): Diagrammatic drawing representing a posterior retainer showing the points selected for marginal fit measurement.(B) Diagrammatic drawing representing an anterior retainer showing the points selected for marginal fit measurement

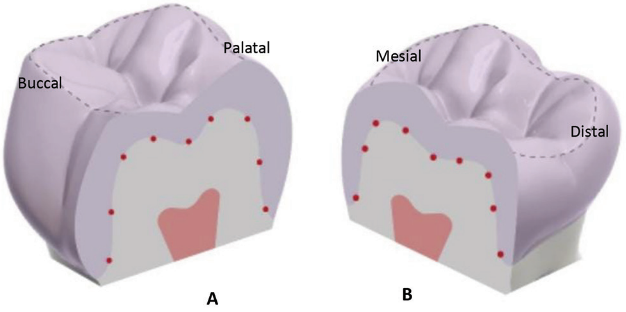

Figure (2) — Diagrammatic drawing representing a posterior retainer showing 18 points selected for internal fit measurement. (A) Bucco-palatal direction (B) Mesio-distal direction

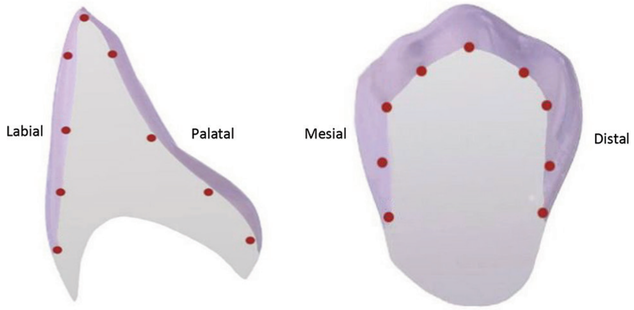

Figure (3) — Diagrammatic drawing representing an anterior retainer showing 18 points selected for internal fit measurement. (A) Labio-palatal direction (B) Mesio-distal direction

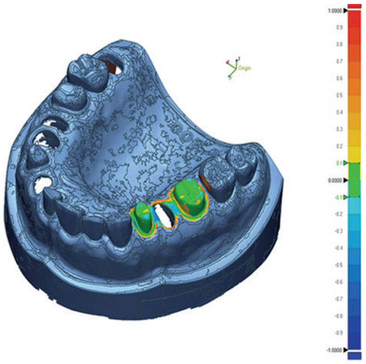

Figure (4) —Color difference maps of marginal and internal discrepancies. Color map was set from -100 (dark blue) to +100 µm (red).

Numerical data were then explored for normality by checking the data distribution using Kolmogorov-Smirnov and Shapiro-Wilk tests. Gap distance data showed non-parametric distribution and consequently, data were presented as median, range, mean, and standard deviation (SD) values. The Mann-Whitney U test was used to compare the two fabrication techniques as well as between the two span lengths. The significance level was set at P <0.05. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

3. RESULTS

Marginal Fit

Through tables (1-5), it was observed that the effect of the manufacturing technique varied between the (SFDP) and (LFDP) subgroups where 3D printing showed statistically significantly higher overall marginal gap distance (MGD) than the milling technique ($P < 0.05$) for the (SFDP) subgroup. At the molar retainer, the statistically significantly higher (MGD) values for the (PT) group were recorded at the mesial, mesio-buccal, and mesio-palatal sites while at the premolar retainer, 3D printing showed statistically significantly higher (MGD) ($P<0.05$) than milling technique at the disto-buccal, distal, and disto-palatal points. On the other hand, milling showed higher overall (MGD) values than 3D printing for the (LFDP) subgroup specimens which were statistically significant only at the central incisor and canine retainers ($P < 0.05$). The significantly higher values of the milling technique were recorded at the mesial, mesio-buccal, palatal, and mesio-palatal points of the canine retainer as well as the mesial, and mesio-buccal points of the central incisor retainer.

(SFDP) specimens always showed lower (MGD) values than those of (LFDP) which was statistically significant ($P < 0.05$) only in the milled groups (Table 6).

Table (1)

Descriptive statistics and results of Mann-Whitney U test for comparison between marginal gap distances (µm) at the molar retainers in 3-unit FDPs fabricated by 3D printing and milling techniques

Site	**3D printing**	**Milling**	***P*-value**
Mesial			
Median (Range)	98.1 (60 – 115.7)	45.5 (11.9-65.9)	0.006*
Mean (SD)	96.5 (19.8)	43 (20.3)	
Mesio-Buccal			
Median (Range)	88 (81.3 – 88.7)	26.5 (2.1-51)	0.045*
Mean (SD)	86 (4.1)	26.5 (24.5)	
Buccal			
Median (Range)	45.5 (31.7 – 66.2)	33.8 (1.3-84.3)	0.522
Mean (SD)	46.6 (12.7)	38.7 (32.5)	
Disto-Buccal			
Median (Range)	13.7 (10.7 – 26.4)	21.8 (6-41.3)	0.827
Mean (SD)	16.9 (8.3)	23 (17.7)	
Distal			
Median (Range)	32.5 (1.3 – 88.3)	18.9 (4.1-58.2)	0.631
Mean (SD)	36.6 (30.1)	23.3 (20.2)	
Disto-Palatal			
Median (Range)	20.2 (18.4 – 107.2)	20.8 (12.4-100.5)	0.827
Mean (SD)	48.6 (50.8)	44.6 (48.6)	
Palatal			
Median (Range)	38.1 (29.3 – 68.2)	19.6 (3.4-99.7)	0.150
Mean (SD)	42.5 (15)	31.4 (35.5)	
Mesio-Palatal			
Median (Range)	79.2 (61.3 – 105)	30.6 (10-46.8)	0.045*
Mean (SD)	81.8 (22)	29.1 (18.4)	
Overall			
Median (Range)	50.7 (1.3-115.7)	27.7 (1.3-100.5)	0.002*
Mean (SD)	56.5 (32.9)	33 (26.8)	

**: Significant at P < 0.05*

Table (2)

Descriptive statistics and results of Mann-Whitney U test for comparison between marginal gap distances (µm) at premolar retainers in 3-unit FDPs fabricated by 3D printing and milling techniques

Site	3D printing	Milling	*P*-value
Mesial			
Median (Range)	33.2 (4.8–72.7)	12.2 (4-49.5)	0.262
Mean (SD)	38.1 (29.8)	18.5 (17.4)	
Mesio-Buccal			
Median (Range)	19.1 (12.1–25.3)	20.8 (8-30.9)	0.827
Mean (SD)	18.8 (6.6)	19.9 (11.5)	
Buccal			
Median (Range)	30.3 (8.7–75.6)	34.2 (8.4-52.8)	0.873
Mean (SD)	35.7 (25.1)	30.9 (18.6)	
Disto-Buccal			
Median (Range)	95.5 (95.4 – 106.3)	30 (13.5-42.4)	0.045*
Mean (SD)	99.1 (6.3)	28.6 (14.5)	
Distal			
Median (Range)	70.6 (48.5–106.8)	23.6 (2.7-63.5)	0.016*
Mean (SD)	74.8 (26.8)	26.4 (22.2)	
Disto-Palatal			
Median (Range)	112.8 (111.6–114)	27.2 (6.8-91.5)	0.004*
Mean (SD)	112.8 (1.2)	41.8 (44.2)	
Palatal			
Median (Range)	83 (40.5– 97.1)	64 (23.8-85.6)	0.262
Mean (SD)	75.1 (22.8)	60.3 (22.7)	
Mesio-Palatal			
Median (Range)	26 (21.3 – 37.2)	82.9 (60.2-112.2)	0.006*
Mean (SD)	28.2 (8.2)	85.1 (26.1)	
Overall			
Median (Range)	53 (4.8-114)	30.5 (2.7-112.2)	0.009*
Mean (SD)	58.8 (35.6)	37.3 (28.6)	

**: Significant at P < 0.05*

Table (3)

Descriptive statistics and results of Mann-Whitney U test for comparison between marginal gap distances (µm) at molar retainers in 6-unit FDPs fabricated by 3D printing and milling techniques

Site	3D printing	Milling	*P*-value
Mesial			
Median (Range)	58 (22.7 – 71)	47.6 (26-97.5)	1
Mean (SD)	49.3 (20.6)	51 (26.5)	
Mesio-Buccal			
Median (Range)	78.6 (76.8 – 116.3)	118 (31.6-184.7)	0.513
Mean (SD)	90.6 (22.3)	111.4 (76.8)	
Buccal			
Median (Range)	135.3 (110.5 – 166.6)	128.4 (103.9-189.6)	0.749
Mean (SD)	132.8 (20.7)	135.3 (32.7)	
Disto-Buccal			
Median (Range)	67.3 (63.7 – 105.3)	89.1 (32.8-135.6)	0.827
Mean (SD)	78.8 (23)	85.8 (51.5)	
Distal			
Median (Range)	15.8 (1.6 – 57.6)	48.6 (13.5-92.4)	0.020*
Mean (SD)	23.4 (25.1)	46.1 (28.8)	
Disto-Palatal			
Median (Range)	62.9 (61.5 – 151.5)	101.2 (38.7-121)	0.827
Mean (SD)	92 (51.6)	87 (43)	
Palatal			
Median (Range)	80.1 (67.3 – 94.7)	72.7 (48.4-86.3)	0.109
Mean (SD)	82.4 (10.6)	70.4 (13.2)	
Mesio-Palatal			
Median (Range)	29.1 (18.9 – 87.8)	111 (24.4-115.7)	<0.001*
Mean (SD)	45.3 (37.2)	83.7 (51.4)	
Overall			
Median (Range)	69.2 (1.6-166.6)	76.5 (13.5-189.6)	0.597
Mean (SD)	73.5 (42.3)	81.1 (46)	

**: Significant at P < 0.05*

Table (4)

Descriptive statistics and results of Mann-Whitney U test for comparison between marginal gap distances (µm) at canine retainers in 6-unit FDPs fabricated by 3D printing and milling techniques

Site	3D printing	Milling	*P*-value
Mesial			
Median (Range)	22.1 (13.7 – 56.7)	90.6 (5.9-150.8)	0.015*
Mean (SD)	30.5 (19.5)	77.8 (56.3)	
Mesio-Buccal			
Median (Range)	13.1 (10.1 – 57)	79.4 (58.5-94.4)	0.023*
Mean (SD)	26.7 (26.3)	77.4 (18)	
Buccal			
Median (Range)	32.5 (1.2 – 58.1)	59.4 (13.6-83.4)	0.149
Mean (SD)	31.9 (27.5)	52.4 (27.7)	
Disto-Buccal			
Median (Range)	15.5 (9.3 – 43.5)	46.6 (2-65.8)	0.513
Mean (SD)	22.8 (18.2)	38.1 (32.7)	
Distal			
Median (Range)	57.6 (52 – 69.4)	54 (11.3-142)	0.748
Mean (SD)	59.5 (7.4)	68.1 (55)	
Disto-Lingual			
Median (Range)	23 (8 – 114.5)	60.4 (49.1-169.7)	0.275
Mean (SD)	48.5 (57.6)	93.1 (66.6)	
Lingual			
Median (Range)	48.7 (31 – 91.1)	110.4 (78.8-144)	0.006*
Mean (SD)	53.4 (20.9)	112.3 (24.3)	
Mesio-Lingual			
Median (Range)	31.2 (10.3 – 60)	112.8 (86.3-113.5)	0.001*
Mean (SD)	33.8 (25)	104.2 (15.5)	
Overall			
Median (Range)	44.5 (1.2-114.5)	79.1 (2-169.7)	<0.001*
Mean (SD)	40.2 (26.3)	77.8 (44.4)	

**: Significant at P < 0.05*

Table (5)

Descriptive statistics and results of Mann-Whitney U test for comparison between marginal gap distances (µm) at central incisor retainers in 6-unit FDPs fabricated by 3D printing and milling techniques

Site	3D printing	Milling	*P*-value
Mesial			
Median (Range)	52.5 (29.4 – 98.7)	194.7 (99.2-221.7)	0.004*
Mean (SD)	62.3 (30.2)	178.7 (45.7)	
Mesio-Buccal			
Median (Range)	73.5 (68.3 – 73.5)	172.3 (110.2-178.9)	0.016*
Mean (SD)	71.8 (3)	153.8 (37.9)	
Buccal			
Median (Range)	53.5 (40.7 – 67.2)	50.3 (37.8-131.6)	1
Mean (SD)	54.9 (10.6)	70.6 (40.6)	
Disto-Buccal			
Median (Range)	24.1 (20.1 – 38.2)	37.8 (9.4-52.2)	0.825
Mean (SD)	28.8 (8.1)	33.1 (21.8)	
Distal			
Median (Range)	109.4 (99.4 – 112.4)	166.3 (68.6-214.4)	0.335
Mean (SD)	107.1 (6.3)	146.9 (53.7)	
Disto-Palatal			
Median (Range)	50 (49.7– 115.3)	110.7 (52.4-149.9)	0.275
Mean (SD)	71.7 (37.8)	104.3 (49.1)	
Palatal			
Median (Range)	84.9 (62.7 – 102.3)	67 (40.7-100.2)	0.199
Mean (SD)	81.7 (13.8)	67.5 (22.9)	
Mesio-Palatal			
Median (Range)	26.3 (15.9 – 60.9)	63 (31.4-115.9)	0.127
Mean (SD)	34.4 (23.6)	70.1 (42.7)	
Overall			
Median (Range)	66.6 (15.9-115.3)	99.7 (9.4-221.7)	0.012*
Mean (SD)	68.2 (29.3)	107.4 (61.6)	

**: Significant at P < 0.05*

Table (6)

Descriptive statistics and results of Mann-Whitney U test for comparison between overall marginal gap distances (µm) in 3-unit and 6-unit FDPs fabricated by each technique

Fabrication technique	6-unit FDP	3-unit FDP	*P*-value
3D printing			
Median (Range)	58.1 (1.2-166.6)	51.7 (1.3-115.7)	0.643
Mean (SD)	60.6 (36.1)	57.7 (34)	
Milling			
Median (Range)	84.3 (2-221.7)	29 (1.3-112.2)	<0.001*
Mean (SD)	88.8 (52.5)	35.1 (27.6)	

**: Significant at P < 0.05*

Internal Fit

Results of Mann-Whitney U test comparing the effect of the manufacturing technique on internal gap distance (Tables 7,8) revealed that 3D printing showed lower overall internal gap distance values than milling which was statistically significant ($P < 0.05$) in the (B-P) direction of both (SFDP) and (LFDP) specimens as well as the (M-D) direction of the (LFDP) specimens. In (SFDP) subgroup, there was no significant difference between milling and 3D printing when measurements were made along the (M-D) direction of both the molar and premolar retainers, as well as the (B-P) direction of the premolar retainer ($P>0.05$).On the other hand, 3D printing showed significantly lower ($P<0.05$) internal gap distance than milling technique with measurements made along the bucco-palatal direction of the molar retainer. As for (LFDP) subgroup; there was no significant difference between milling and 3D printing when measurements were made along the (M-D) direction of the molar ($P=0.473$), and canine ($P=0.084$) retainers, as well as along the (B-P) direction of the central incisor retainer ($P=0.174$).

Table (7)

Descriptive statistics and results of Mann-Whitney U test for comparison between gap distances (µm) in 3-unit FDPs fabricated by 3D printing and milling techniques

Retainer	Direction	3D printing	Milling	*P*-value
Molar	B-P			
	Median (Range)	23 (2 – 99.1)	40.6 (12.9 – 100.7)	0.010*
	Mean (SD)	28.5 (24.2)	43.1 (21.9)	
	M-D			
	Median (Range)	42 (1.9 – 105.1)	48.2 (1.1 – 94.7)	0.604
	Mean (SD)	47.8 (29.6)	43.5 (27.3)	
Premolar	B-P			
	Median (Range)	41.2 (1 – 118.4)	70.5 (5.6 – 145.9)	0.092
	Mean (SD)	49.4 (31.5)	65.6 (36.8)	
	M-D			
	Median (Range)	39.1 (6.5 – 114.3)	46.8 (3.1 – 242.2)	0.397
	Mean (SD)	46.3 (32.8)	62.6 (52.9)	
Overall	B-P			
	Median (Range)	33 (1 – 118.4)	50.4 (5.6 – 145.9)	0.007*
	Mean (SD)	39 (29.7)	54.4 (32.1)	
	M-D			
	Median (Range)	40.6 (1.9 – 114.3)	47.5 (1.1 – 242.2)	0.715
	Mean (SD)	47.1 (31)	53 (42.8)	

*: *Significant at $P < 0.05$*

Table (8)

Descriptive statistics and results of Mann-Whitney U test for comparison between gap distances (µm) in 6-unit FDPs fabricated by 3D printing and milling techniques

Retainer	Direction	3D printing	Milling	*P*-value
Molar	B-P			
	Median (Range)	31.9 (10.1 – 77.5)	62 (8.8 – 158)	0.002*
	Mean (SD)	38.2 (21.5)	71.4 (41.6)	
	M-D			
	Median (Range)	55.2 (3.1 – 162.5)	72.3 (2.4 – 174.6)	0.473
	Mean (SD)	66.3 (45.8)	76.5 (48)	
Canine	B-P			
	Median (Range)	24.9 (1.3 – 49.6)	55.4 (12.8 – 140.3)	<0.001*
	Mean (SD)	23.7 (13.2)	62.5 (28.6)	
	M-D			
	Median (Range)	49.6 (6.8 – 139)	68.8 (12.8 – 186.2)	0.084
	Mean (SD)	57.1 (36.3)	75.9 (42.1)	
Incisor	B-P			
	Median (Range)	64.2 (13.9 – 108.4)	75.7 (12.3 – 214.4)	0.174
	Mean (SD)	59.7 (33.5)	86.3 (59.1)	
	M-D			
	Median (Range)	71.6 (1.5 – 159)	126.4 (7.2 – 225.1)	0.002*
	Mean (SD)	63.4 (42.7)	120.8 (65)	
Overall	B-			
	Median (Range)	31.9 (1.3 – 108.4)	59.8 (8.8 – 214.4)	<0.001*
	Mean (SD)	40.5 (28.2)	73.4 (45.4)	
	M-D			
	Median (Range)	56.3 (1.5 – 162.5)	82.6 (2.4 – 225.1)	0.002*
	Mean (SD)	62.3 (41.5)	91 (56.1)	

*: *Significant at $P < 0.05$*

When considering the effect of the span length on internal gap distance with different manufacturing techniques, it was observed that (SFDP) specimens showed significantly lower internal gap values ($P < 0.05$) compared to those of (LFDP) in both (B-P) and (M-D) directions when the milling technique was used (Table 9).

Table (9)

Descriptive statistics and results of Mann-Whitney U test for comparison between overall gap distances (µm) in 6-unit and 3-unit FDPs fabricated by each technique

Fabrication technique	Direction	6-unit FDPs	3-unit FDPs	*P*-value
3D printing	B-P			
	Median (Range)	31.9 (1.3 – 108.4)	33 (1 – 118.4)	0.736
	Mean (SD)	40.5 (28.2)	39 (29.7)	
	M-D			
	Median (Range)	56.3 (1.5 – 162.5)	40.6 (1.9 – 114.3)	0.051
	Mean (SD)	62.3 (41.5)	47.1 (31)	
Milling	B-P			
	Median (Range)	59.8 (8.8 – 214.4)	50.4 (5.6 – 145.9)	0.017*
	Mean (SD)	73.4 (45.4)	54.4 (32.1)	
	M-D			
	Median (Range)	82.6 (2.4 – 225.1)	47.5 (1.1 – 242.2)	<0.001*
	Mean (SD)	91 (56.1)	53 (42.8)	

*: *Significant at $P <0.05$*

4. DISCUSSION

The purpose of this study was to evaluate the marginal and internal fit of short-span and long-span interim fixed dental prostheses manufactured by two different technologies. Multiple methods, that are based on either 2D analysis such as the silicone replica technique, or alternatively on 3D analysis as micro-computed or optical coherence tomography, have been implemented in literature for the analysis of the marginal and internal fit. Though such 2D analysis-based techniques could be simple to carry out, they suffer from the limitations of damaging the specimens or worse lacking essential data about the third dimension thus resulting in deficient measurements. Consequently, the authors in the current study chose to use a 3D-based technique that relies on superimposing the scanned 3D data of the master model along with the fitting surface of the restoration using 3D analysis software. Consequently, it has the paramount advantage of being a non-invasive method that allows the examination of multiple cross-sections, as well as checking the marginal and internal fit of the restoration before intraoral placement (30-32).

However, paying a look at our results, it could be seen that the null hypothesis was rejected, as both the manufacturing technique as well as the span length had a significant effect on the marginal and internal fit.

Since a good marginal seal is a crucial factor in the success and longevity of any dental restoration, McLean et al. (33) claimed that 120 µm is the maximum clinically accepted margin gap while Boening et al. (34) considered the marginal gap ranging between 100 µm and 200 µm as being in the clinically accepted range. Accordingly, values for the (MGD) in our study have been deemed within the clinically acceptable range whether for the 3D printed or milled groups in both (SFDP) and (LFDP) subgroups.

Nevertheless, the effect the manufacturing technique had on the (MGD) values varied among both the (SFDP) and (LFDP) subgroups. While the milling technique resulted in significantly lower (MGD) values in the (SFDP) subgroup, the opposite was true for the (LFDP) one. Looking back in the literature, authors found contradicting results regarding the effect of both milling and 3D printing. Several studies have reported less marginal discrepancy for the 3D printed restorations compared to milled ones (13,15,16,35,36). Lee et al. (16) claimed that the milling axes limitation of motion as well as the large diameter of the milling bur could render less precise fabrication of the marginal area of the restoration. Additionally, Alharabi et al. (35) stated that the wear, as well as the tolerance of the milling bur could result in loose restorations and high marginal discrepancies.

On the other hand, Wu J et al. (17) and Savencu et al. (37) reported higher marginal discrepancies for 3D printed restorations compared to milled ones. Savencu et al. (37) suggested that the limited accuracy of the 3D printing could be reverted to the cumulative errors in different stages of fabrication such as the shrinkage during building and post-curing that could have led to high marginal discrepancy.

A myriad of factors could have contributed to such variations in findings between different studies as well as between our study and previous studies such as the printers used, printed layer thickness, shrinkage between layers, the orientation of the printed parts, as well as the size of the milling bur used(5,15,38-40).

However, paying a look at the impact of the span length on the marginal fit, results revealed that there was no significant difference in the overall (MGD) of the 3-unit FDPs fabricated through 3D printing and that of the 6-unit FDPs fabricated by the same technology. This could be validated through the enhanced printing accuracy subsequent to the use of decreased resin layer thickness of 50 μm that is well compatible with the laser intensity of the SLA printer implemented in our study thus leading to better polymerization (25,41). Dikova et al. (26) have shown in their study that the polymerization of the full thickness of the resin layer has resulted in minimum amounts of free monomers and consequently higher printing accuracy and fewer deformations. On the contrary, there was a significant difference in the (MDG) values between the 3-unit and 6-unit FDPs when the milling technique was used with values being significantly higher in the 6-unit FDPs. Such results are quite rational referring to the conclusions drawn by Komine et al. (8) in a previous study affirming that FDPs with a straight configuration where pontics are in the same line with the abutment teeth displayed superior fit compared to curved FDPs.

On the other hand, when considering the effect of the two manufacturing techniques implemented in our study on the internal fit, 3D printing technology proved to allow better overall internal fit in both (SFDP) and (LFDP) subgroups which was found to coincide with multiple previous studies (15,16,17,35). This could be attributed to errors resulting from the tolerance of milling burs where the limited size and angle of the burs could probably impose some limitations when milling the fitting surface of the restorations (14,42).

Additionally, it was obvious through our results, that the span length had an effect on the internal gap values when the milling technique was used. It was shown that milling caused significantly higher internal gap values in the 6-unit FDPs than the 3-unit ones in both (B-P) and (M-D) directions. Our results are well-justified based on what Komine et al. (8) have earlier inferred.

With the great interest in 3D printing technology and the tremendous progress happening in that field, the results of our study show its superior performance over the milling technology, especially in complex long span restorations. However, this study evaluated only a single material type and a single system for each fabrication method which raises a question regarding the explication of our findings to other materials and systems in the market. Further studies are needed using different materials, systems, and preparation designs. Additionally, clinical trials are still needed considering the fact that this in vitro study has omitted the effect of factors such as saliva, gingival crevicular fluid, as well as limited accessibility; all of which are reasons that could impede the intra-oral scanning process and give rise to inaccuracies regarding the fit of the restorations.

5. CONCLUSIONS

Within the limitations of this study, it was clear that milling technology was able to produce restorations with better marginal fit compared to 3D printing only in 3-unit FDPs. However, the opposite was true when the internal fit of the restorations was considered where 3D printing surpassed the milling technique with both the short-span and long-span FDPs. Consequently, 3D printing could be the technique of preference for fabricating provisional restorations especially when it comes to complex long span FDPs.

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