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Marginal fit evaluation of implant supported interim fixed partial dentures fabricated using two manufacturing techniques: An *in vitro* study

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Abstract

Aim: This study compared the marginal fit of implant-supported interim fixed partial dentures manufactured using two manufacturing techniques.
Materials and Methods: 3D printed model was constructed with two implants analogues replacing upper first premolar and first molar. Scan abutments, corresponding to CAD/CAM titanium bases, were screwed into implant analogues. The model was then scanned using Primescan AC intraoral scanner and scan file was imported into CAD software as STL file to finalize the design for fabrication of interim implant-supported fixed partial dentures. The CAD file of the designed interim IFPDs was sent to subtractive and additive manufacturing machines to fabricate 24 interim IFPDs, 12 per group. Interim IFPDs were then seated onto ti-bases and marginal gap was evaluated using stereomicroscope. Independent t-tests were performed to analyze data.
Results: Regarding marginal gap, subtractively manufactured interim IFPDs showed statistically significant lower gap values than additively manufactured ones.
Conclusion: The study exhibited a difference between the subtractively and additively manufactured interim IFPDs, showing that subtractively manufactured ones are of reliable marginal fit.

Keywords: Intraoral scanners, marginal fit, additive manufacturing, subtractive manufacturing, interim implant supported fixed partial dentures

Introduction

Implant-supported restorations have recently become a prevalent treatment alternative in the management of missing teeth owing to their proven functional, biological, and mechanical long-term clinical prediction [1].

Likewise, the utilization of interim implant restorations, which are considered transitional treatments, becomes key to achieve preservation of esthetics, phonetics, function, and stability of the peri-implant tissues involved. Importantly, an accurate implant-supported interim restoration provides a better evaluation of the final outcome and anticipation of possible complications with the definitive prosthesis [2].

The execution of computer-aided imaging/computer-aided designing/computer aided manufacturing (CAI/CAD/CAM) technology in dentistry has resulted in more accurate manufacturing of dental restorations, optimizing the quality of restorations [3].

Various techniques are used for the fabrication of interim implant-supported restorations. Improvements in subtractive technologies have permitted construction of dental restorations exhibiting a clinically acceptable fit. However, such technologies present several manufacturing limitations, some of which are wastage of materials, need for replacement of the milling tools after several cycles, inadequate reproduction of surface geometry, and risk of introducing microscopic cracks [4].

Along with the evolution in the manufacturing techniques, additive manufacturing has been introduced to overcome some limitations of subtractive manufacturing. Additively manufactured interim fixed dental restorations and materials have been claimed to have higher mechanical potentials, while CAD-CAM subtractively manufactured interim materials have enhanced physical attributes compared to traditionally manufactured ones.

Multiple studies have been conducted to compare these two parameters, but varied results have been reported [5, 6].
An optimal marginal fit offers better periodontal health and decreases cement dissolution. Poor marginal fit of interim restorations might lead to retention loss, mechanical failure or loosening of the abutment screw; accordingly, the marginal accuracy of implant-supported prosthesis is a key factor for the long-term success of implant restorations [7, 8].
Numerous scales of satisfactory marginal gaps have been testified in the literature, dependent on the used cement type, the restorative material, and the measuring technique. According to the American Dental Association, the clinically acceptable fit for an indirect restoration is between 50 and 100 µm. A marginal gap of no more than 120 micrometers should be obtained for the restoration to be clinically acceptable [9].
Several techniques, ranging from stereomicroscopy, scanning electron microscopy, optical microscopy, and micro-computed tomography were used to evaluate the marginal fit of the restorations prior to clinical acceptance, each with its own set of benefits and downsides [10].
Countless studies have been carried out to investigate the precision of the CAM process in producing lower marginal gap values. It is proved that marginal fit of multi-unit FPD fabricated via digital workflows have been reported to require more studies for clinical reliability [11].
Therefore, the purpose of this study was to assess the efficacy of using two CAD/CAM manufacturing techniques in producing accurate margins in implant supported fixed partial dentures.
The null hypothesis was that there would be no significant difference in marginal fit between subtractively and additively manufactured implant supported IFPDs.

Materials and Methods
Model Preparation
A stone model of a fully dentate maxillary arch was scanned using an extraoral scanner (E2, 3Shape) and exported in standard tessellation language (STL) file format. Upper first premolar, second premolar and first molar were removed from the maxillary arch using CAD software (3 Shape Dental System Premium) to simulate the study design. For prosthetically driven virtual implant planning, teeth set-up restoring upper right first premolar, second premolar and first molar representing the final restoration, was proposed.
Virtual design of two implants replacing upper right first premolar and upper right first molar was planned with parallelism to each other according to designed restoration. Two digital implant analogues (Hybrid Tiologic, Dentaurum), corresponding to implants diameters 3.7 mm for the first premolar and 4.2mm for the first molar, were chosen from the implant library and virtually engaged in the model. The apico-coronal location of implant analogues was adjusted so that the implant platform is inserted 2 mm apical to the cemento-enamel junctions of the adjacent teeth. Final implant positions were then evaluated according to the planned restoration.
The design with virtually placed implant analogues was converted to a model in model builder step. Soft tissue option was selected in the 3Shape Dental System Premium software program and automatically placed around the analogues interface to create a gingival mask and facilitate clearly visible emergence profiles of the upcoming restorations.
The STL file of the model design and gingival mask was transferred into the CAM software to start the fabrication process. The model was fabricated using 3D additively manufactured liquid resin (Proshape Dental Model 3D printing Resin) and printing machine (Creality Halot-One resin).
Via light crystal display (LCD) printing technology, the manufacturer instructions post-processing procedures were followed. The model and the gingival mask were put in a bath consisting of 96% isopropyl alcohol for 4 minutes to remove any residual unpolymerized resin. After the removal of the residual resin, the model was placed in a UV-light polymerization device (MP100, Hephzibah) for final curing and to remove the stickiness on the printed pieces. Finally, the supporting structures were also removed.
Implant analogues corresponding to implants diameters 3.7 mm and 4.2 mm, with length 12 mm were screwed into their planned positions, using the corresponding screwdriver until final tightening was done. Scan abutments, corresponding to CAD/CAM titanium base abutments, were seated on and screwed into implant analogues. After placing scan abutments, the acquisition of the model was performed by an intraoral scanner (Cerec Primescan AC, Dentsply, Sirona) to generate (STL) files to start fabrication process.

Interim implant-supported fixed partial dentures fabrication
The 3D printed model was scanned using Primescan AC intraoral scanner. The scanning method was consistent for all scans as per the manufacturer's instructions to be continuous, 2-3mm away from the tooth's surface, starting from the occlusal surface of the upper right second molar, moving towards the incisal surface of the anterior teeth, then rotating the camera (which was automatically positioned at a 60° angle) to capture the palatal and interproximal regions and then rotating it once again to record the buccal surface of the arch.
The upper jaw, upper jaw with gingival mask, and upper jaw with scanbodies attached were required to be scanned. Model was created after rendering the acquisition phase then scan file was exported to 3Shape Dental System Premium software program.
The previously designed restoration used for the prosthetically driven implant analogues placement was used as a pre-operative scan to replicate and finalize the design for the interim fixed partial denture.
The software generated an initial suggestion for teeth placement. Using smile library, the teeth shape and size were managed to match those of the adjacent teeth and proper teeth alignment was guaranteed.
Ti-base abutment option was selected, and the emergence profile was shaped according to the gingival mask scan that was imported. Control points of the emergence profile at the required level in relation to the gingival margin were positioned, which is usually about 1 mm below the gingival level. The last step was the assembly step, where bridge and abutments were combined and screw holes with their proposed angulations were created.
A power analysis was designed to have acceptable power to apply a two-sided statistical test of the null hypothesis that there is no difference would be found between different tested groups regarding manufacturing technique. By adopting an alpha (α) level of (0.05), a beta (β) of (0.2) (i.e., power=80%), and an impact size (d) of (1.197) calculated based on the results of a previous study [12]; the total required sample size (n) was found to be (24) samples. Sample size calculation was performed using G*Power version 3.1.9.7. Samples were further divided according to the technique of fabrication of interim supported fixed prosthesis into two groups: group S=

Subtractive manufacturing (milling) (n=12), and group A= additive manufacturing (3D printing) (n=12).

Ti-bases were screwed into the implants' analogues, for the manufactured fixed partial dentures to be placed on. The STL file of the designed fixed partial denture was exported to CAM software (vhf-dental CAD software) of the milling machine (VHF, S5). PMMA discs (Yamahachi PMMA YAP) were used for subtractive manufacturing of 12 fixed partial dentures using a dry milling machine. The IFPDs were finished and polished to get a perfectly smooth restoration.

The STL file of the designed fixed partial denture was also exported to CAM software (3D Sprint Software) of the 3D printer (NextDent) for additive manufacturing of 12 fixed partial dentures using 3D printer resin (NextDent C&B MFH) following the manufacturer recommendations.

After the printing procedure, removal of the supports was done, then the restorations were introduced in 90% isopropyl alcohol for 20 minutes to remove the uncured resin then dyring. Following that, 30-minutes UV-light curing using ultraviolet curing unit was accustomed to maintaining dimensional accuracy and biocompatibility. Post cured IFDPs were polished using felt wheel bur (Moleroda, Roda) and pumice polishing paste (Universal Polishing Paste) to have a perfectly smooth FDPs. The seating and adaptation of the subtractively and additively manufactured interim fixed partial dentures were then checked on the printed model.

Marginal gap evaluation

A new model was additively manufactured as previously described without contact teeth for the marginal fit evaluation at the proximal surfaces of the FPD retainers. The analogues were then screwed in designed places. FPDs were then seated onto Ti-bases and marginal gap evaluation was then performed. The vertical distance between the Ti-base margin and the retainer's margin represents the marginal gap. The vertical marginal gap distance for each interim IFPD was measured using stereomicroscope (Nikon SMZ745T). Images for the margins were captured with a specified camera (DX-230, 1080, 60FPS 2300 W) in the microscope with magnification 50X. (Figure 1)

Four equidistant measurement points were taken along the cervical circumference for each surface (buccal, lingual, and mesial/distal) with a total of 12 points for each retainer of the IFDP with a microscope camera connected to an image analysis software program (Omnimet, Buehler). Using this software, the measured parameters are expressed in pixels. Then, system calibration was done to convert the pixels into absolute units. Data obtained was collected, tabulated, and subjected to statistical analysis. (Figure 2)

Statistical analysis

Numerical data were presented as mean with 95% confidence intervals (CI), standard deviation (SD), minimum (min) and maximum (max) values. They were checked for normality using Shapiro-Wilk test. Data were normally distributed and analyzed using independent t-test. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.3.1 for Windows.

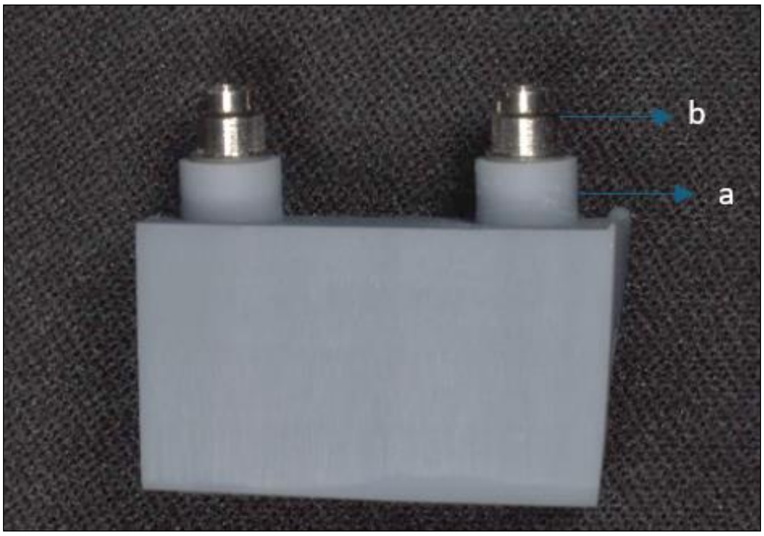

Fig 1: Ti-base screwed into the additively manufactured model. A: implant analogues housings B: Ti-base screwed into implant analogue

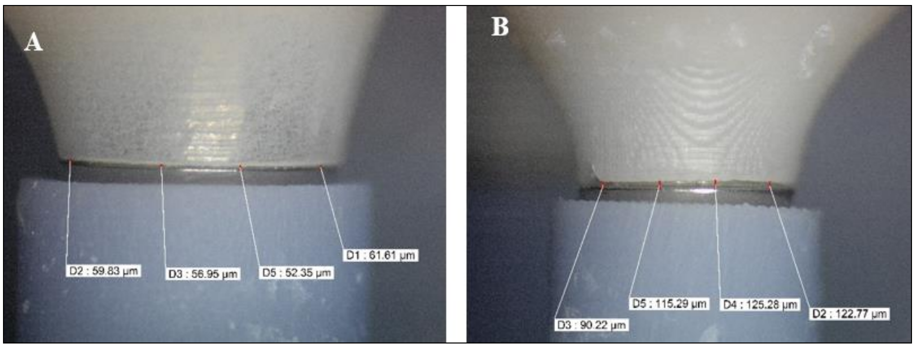

Fig 2: Stereomicroscope images representing the marginal gap of manufacture interim IFPD of molar retainers in buccal view. A: subtractively manufactured interim IFPD. B: additively manufactured IFPD

Results

For marginal gap of fabricated interim IFPDs, statistically significant variance in the marginal gap was found in premolar and molar retainers, where additively manufactured fixed partial dentures (100.79±7.84) and (85.30±8.08) showed statistically significant higher values of gap distance than subtractively manufactured fixed partial dentures (43.07±5.87) and (42.08±2.97) respectively (p<0.001) (Table 1).

Table 1: Descriptive statistics for marginal gap of fabricated IFPDs (mm)

FPD	Retainer	Mean	95% CI		SD	Min.	Max.	P-value
			Lower	Upper				
Additive manufacturing (Group A)	Premolar	100.79	80.93	115.65	7.84	95.10	120.28	<0.001*
	Molar	85.30	82.29	100.31	8.08	80.45	113.68	
Subtractive Manufacturing (Group S)	Premolar	43.07	39.43	46.71	5.87	35.64	54.68	
	Molar	42.08	40.25	43.92	2.97	36.62	45.89	

*; Significant (p< 0.05) ns; non-significant (p>0.05)
CI: confident interval. SD: standard deviation

Discussion

Dental implants may be the optimal selection to replace a single or more missing teeth due to their high certainty, appliance survival rate, and patient's fulfillment [13]. Importantly, an accurate implant-supported interim restoration provides a better assessment of the final outcome and anticipation of possible problems with the definitive prosthesis [14].

Achieving precise and ideal restoration has been the goal of dental clinicians. Long-term success of interim implant restorations is dependent essentially on its marginal fit. An optimal marginal fit between the implant abutment and the interim restoration offers better periodontal health and reduces cement dissolution. Hence, the possibility of a discrepancy may result in retention loss, mechanical failure, and bacterial accumulation followed by an inflammatory response around the preimplant tissue [15, 9, 8, 16, 17].

The usage of a CAD/CAM (computer-aided design–computer-aided manufacture) systems can prevent certain processing inaccuracies (mixing, dosage, and material states) that can be role of a direct technique of fabrication. Digital manufacturing techniques involve the use of quality-controlled materials, a higher degree of consistency, and elimination of the obstacles of traditional techniques [18].

Furthermore, several computer-aided manufacturing (CAM) methods have been developed to fabricate resin-based implant-supported interim prostheses. These methods are subdivided into subtractive manufacturing technique by milling and additive manufacturing technique by 3D printing, offering enhanced quality of the restorations by using the pre-cured blocks for milling or resinous 3D printing materials with least patients' discomfort and chair-side time [19].

Abundant studies have been performed to compare these two CAM techniques in producing accurate marginal fit of implant supported restorations, but they have reported varied studies [20-23].

The null hypothesis of the outcome was rejected, since additively manufactured IFPDs had a significantly higher gap values than subtractively manufactured ones.

This may be attributed to manufacturing defects in additively manufactured IFPDs resulting in poor margin quality. The findings of thisaccuracyurred with other reports in the literature, like Mahsa Mohajeri *et al*. in 2021 [24] who agreed in her study that mean marginal gap values for milled restorations was lower than that of the printed. This was attributed to the milling technology, where the final protheses were milled out from pre-polymerized blocks, thus, no polymerization shrinkage occurred. In contrast to milling technology, printing technology involves post-processing shrinkage affecting the accuracy and the fit of the restoration and consequently the marginal gap.

In addition, Anca Igreț *et al*. in 2023 [6] compared the marginal adaptation of discrete types of provisional fixed dental restorations, fabricated using 3D printing technology versus milling CAM technology using stereomicroscope. The 3D printed group, reported the highest marginal gap values with a median value of 316.5 µm, therefore eliminating the possibility of clinical use. This was attributed to the limited accuracy and material properties of currently available 3D printing resins.

However, Thakare, Akshay *et al*. in 2022 [25] compared and evaluated the internal and marginal fit of interim crowns fabricated by CAD/CAM milling and two dissimilar 3D printing systems and concluded that 3D printing manufactured crowns with improved marginal and internal fit than CAD/CAM milling. This was justified by the errors caused by bur diameter, high cutting speed, and the dimensional distortions caused by insufficient cooling that may produce excessive vibrations and put thermal and mechanical tension on the work piece.

The limitations of this study may include that it is an *in vitro* study. Further studies are required to justify the results in this study, the practicality of marginal fit *in vivo* studies and to assess if results from *in vitro* studies are comparable and clinically applicable.

The findings of the present study are limited to a particular printing technology, printer type, printing parameters, materials, and post-processing procedures used. Thus, results may not be generalized to all AM technologies, as any changes in the parameters, such as build angle, printing layer thickness, laser intensity, and laser speed, may yield different results. Regarding the marginal gap evaluation, the calculations for marginal differences were made in an image analysis software programs using a calibrated grid leaving room for possible errors [26].

Conclusion

Within the limitations of this study, the following could be concluded

1. The marginal accuracy of implant supported IFPDs is affected by CAM technique. Subtractively manufactured implant supported IFPDs showed lower marginal gap values compared to additively manufactured ones.
2. The marginal gap values of all tested groups were within the clinically acceptable values.

Clinical Relevance

The use of subtractive manufacturing technology is recommended for the production of accurate marginal fit of interim implant-supported fixed partial dentures.

Conflict of Interest

Not available

Financial Support

Not available

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