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Original Article

EFFECT OF TWO FABRICATION TECHNIQUES (CAD/CAM AND 3D PRINTING) ON THE INTERNAL FIT, MARGINAL ADAPTATION AND FRACTURE RESISTANCE OF MULTIPLE FUSED PROVISIONAL RESTORATIONS. (IN VITRO STUDY)

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Abstract

Aim: To evaluate the internal fit, marginal adaptation, and fracture resistance of multiple fused provisional crowns fabricated using two digital methods; subtractive, and additive techniques.
Subjects and methods: Typodont model was used, where mandibular first, second premolars, and first molars were prepared to receive 3 fused provisional crowns, fabricated using two techniques; milling (SM group) and 3D printing (AM group) by digital light processing (DLP) (11 samples per group). Silicone replica technique was used to evaluate the internal gap, while the vertical marginal gap (VMG) was evaluated by direct viewing technique using digital microscope before cementation. Cementation of the crowns over duplicated epoxy resin dies was performed under static load (50 N) then fracture resistance was tested using a universal testing machine.
Results: The milled group showed higher internal gap values (102.02 ±11.2 µm) than that of the 3D printed group (100.6 ±13.1 µm) without statistically significant difference. While, the VMG was significantly higher in the SM group (48.58 ± 5.69 µm) than the AM group (43 ± 5.06 µm). Also, the fracture resistance of the SM group (1542.62±214.89 N) was significantly higher than the AM group (774.89 ±170.17 N).
Conclusion: The internal and marginal fit of the 3D printed group were better than that of the milled group. However, the milled provisional restorations showed higher fracture resistance.

Keywords: Internal fit, Marginal adaptation, Provisional restorations, 3D printing, CAD/CAM, Fracture resistance, Fused crowns.

Introduction

Provisional restoration is a mandatory intermediate phase during any prosthodontic treatment. It is important for such restoration to provide adequate biological, mechanical as well as esthetic requirements **Abdullah et al. (2016); Tahayeri et al. (2018).** A variety of methods for fabrication of the provisional restorations have been applied and improved over time, from various conventional methods to digital Computer-Aided Design/Computer-Aided Manufacture (CAD/CAM) methods **Alharbi et al. (2018); Al-Humood et al. (2023).**

The CAD/CAM restorations have become more common owing to overcoming the conventional techniques' drawbacks such as polymerization shrinkage, and heat production. Provisional restorations fabricated by milling approach showed enhanced conversion degree, improved physical and mechanical characteristics **Rosentritt et al. (2017)**. However, the diameter of the milling burs and the motion range of the cutting tools are considered to be limiting factors for the milling process in addition to the material waste when compared to the 3D printing approach **Mai et al. (2017).**

Lately, 3D printing technology has been extremely in demand for its rapid innovation and various applications, as it provides superiority in the manufacturing process owing to its accuracy, speediness, distinctive customization, and less waste making such technology environment-friendly. Additionally, the layering deposition approach precludes stress accumulation within the structure. In our study, Digital light processing (DLP) was employed owing to its ability to cure the whole layer simultaneously without any variance between its sides **Methani et al. (2020); Quan et al. (2020); Chaudhary et al. (2023).**

Assessment of internal fit and marginal adaptation is fundamental for the success and longevity of any dental restoration to achieve a proper long-term prognosis. Since improper marginal fit ends in plaque accumulation, micro leakage with subsequent cement dissolution and periodontal affection. While improper fit impairs adequate seating of the restoration by compromising its retention and resistance **Bhaskaran et al. (2013); Wu et al. (2021). McLean 1971** stated that the marginal discrepancy was considered to be clinically acceptable with a range less than 120 µm for full coverage restorations.

Fracture is the most frequent reason for failure of the provisional restorations **Dureja et al. (2018).** That's why the strength of the provisional restoration is of utmost importance, especially in patients with parafunctional habits or extended treatment period **Abad-Coronel et al. (2021)**. Thus, understanding the mechanical properties of a material is essential to evaluate its clinical performance. However, information regarding the quality of the provisional restorations fabricated by 3D printing technique is limited. Thus, our study aimed to evaluate the internal fit, marginal adaptation, and fracture resistance of multiple fused provisional restorations, fabricated using milling approach (*PMMA Telio CAD*) vs DLP 3D printing (*Pro-shape Temp liquid resin*). The null hypothesis was that there was no difference in the internal fit (first null hypothesis), marginal adaptation (second), and fracture resistance (third) of posterior multiple fused provisional restorations fabricated by milling or 3D printing technique.

Subjects and Methods

A. Sample Size Calculation

A power analysis was designed to have adequate power to apply a two-sided statistical test of the null hypothesis. By adopting an alpha level of (0.05) a beta of (0.2) i.e. power=80% & an effect size (d) of (1.30) calculated based on the results of **Mai et al. (2017)**; the predicted sample size (n) was a total of (22) samples i.e. (11) samples per group. Sample size calculation was performed using G*Power version 3.1.9.7.

B. Grouping

According to the sample size calculation, a total of 22 samples were fabricated in this study;11 samples per each group according to the fabrication technique.

Control Group: 11 samples fabricated by milling (SM group).

Intervention Group: 11 samples fabricated by DLP (AM group)

C. Typodont model preparation

Typodont model (*Nissin cast, Nissen dental products incorporation, Nakagyoku, Japan*) **Figure (1)** was used, where first, second premolars, and first molars were prepared to receive full veneer restorations with 1 mm axial reduction, 1.5 mm occlusal clearance, 1 mm rounded shoulder finish line and total convergence angle of 12^0 using tapered stone with rounded end size (TR 13). The preparation was carried out by a single operator. For standardization, depth grooves were done on the occlusal and buccal surfaces. Also, a rubber base putty index was made for each prepared tooth and sectioned buccolingually along with using a graduated periodontal probe to check the amount of reduction.

Figure (1): Prepared teeth of Typodont Model

D. Construction of the provisional crowns

The fabrication of the provisional restorations was performed completely through digital workflow. First, scanning was done using extraoral scanner (*NEWAY, Open technologies, Rezzato, Italy*), then the *Exocad Software (Dental CAD 3.0 Galway, Darmstadt, Germany*) was used to design the provisional restorations **Figure (2)** with cement space adjusted at 60 µm for its proper seating. All the information of the virtual design was saved as STL format which was imported into the software of both; 5 axis milling machine (*Redon GTR milling machine, Dental Direkt, GmbH, Spenge, Germany*) and that of 3D printer (*MicroDent-1 Pro, MOGASSAM, Cairo, Egypt*).

Telio CAD *(Ivoclar vivadent, Liechtenstein, Germany*) was the material of choice for milling (SM group) because of the homogeneity of the material that was allocated for its better load distribution and adequate strength **ALSmail et al. (2022**), while Pro-shape Temp liquid resin; CE Certified Class IIa biocompatible resin (*Proshape, Istanbul, Turkey*) was used for 3D printed group (AM group). In this group, the STL file was sent to Dent-print Software (MOGASSAM, Cairo, *Egypt*) preparing it for printing in which the supporting structures were designed and the printing parameters were adjusted; layer thickness of 50 µm, horizontal printing orientation, and printing cycle of 45 min. The produced 3D printed restorations were washed using 96% 2-propanol (5 min), then post curing (30 min) was done using UV light; LC-3DPrint Box (*Bredent, bre.Lux Power Unit 2, LED Full Range System, Bredent GmbH & Co. KG., Senden, Germany*). After complete construction of all the samples for both groups, the samples were finished and polished then checked for its proper seating using an explorer and magnifying lopes.

E. Assessment of the internal fit

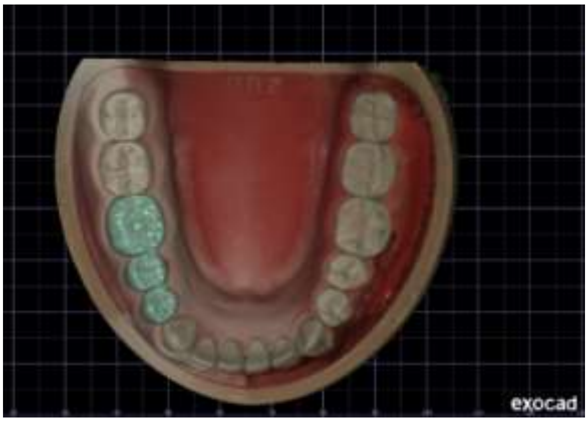

Figure (2): Designing

The internal fit (1st outcome) was assessed using silicone replica technique in which the Light body addition silicone impression material (*Elite HD+, Zhermack, Italy*) was injected into the fitting surface of the crown, and seated on the preparation under a constant load (5Kg) for 10 min **Lee et al. (2017)** by a customized holding device.

After its setting, the provisional crowns with the light body were carefully removed from the preparation and then stabilized using putty body silicone (*Elite HD$^{+,}$ Zhermack, Italy*). Once the putty silicone was set, it was removed from the provisional crowns with the light body attached to it. A surgical blade (no.15c) was used to trim the excess material and section the replica of each tooth into 4 equal segments **Figure (3)**. Two opposite sections were used to measure the internal fit, with 4 points measured on each section: Marginal (M), Axial (A), Occluso-axial (O) and Mid-occlusal (F), yielding 8 points for each one.

Using U500x digital microscope at ×40x magnification, light-body thickness for each replica was measured denoting the distance from the crown's interior surface to the preparation's exterior surface, and a digital image analysis system (*Image J1.43U, National Institute of Health, USA*) was used to measure the thickness **Figure (4)**.

Figure (3): Fabrication of Silicone Replica

F. Assessment of the VMG

The vertical marginal gap (VMG) (2nd outcome) was assessed by direct viewing technique using digital microscope with a built-in camera for capturing each surface. Digital image analysis system (*Image J1.43U, National Institute of Health, USA*) was used to measure the gap's width with 4 predetermined and equally distant points along the surface's circumference (buccal, lingual, mesial, & distal) **Figure (5),** the measurements were repeated 3 times. Then the data obtained was statistically analyzed.

G. Fabrication of the epoxy dies

Epoxy duplicated dies (Elastic Modulus (E)=12.9 GPa) were used as an alternative to natural teeth to assess fracture resistance (3rd outcome) **El Eneen et al. (2019)**. The Nissan cast was placed in a rubber bowl after being cleared from the pink rubbery part (the part simulating the soft tissue), and all the teeth except the prepared ones, and blocked with wax, then it was duplicated using silicone duplicating material (*ALMOTWAKEL A15, Beijing, China*) to create a mold from which the epoxy duplicated dies would be constructed. The area around the teeth imprint in the silicone mold was blocked by wax in order to create a confined area to be filled with epoxy resin (*Kemapoxy 150, CMB, Chemical modern Building international, Egypt*). The full hardness of the epoxy resin was reached after 7 days **Figure (6)**. The crowns were checked for complete seating on the epoxy dies in order to ensure the accuracy of these duplicated dies. There were 11 epoxy dies constructed for each group.

H. Cementation procedure

Charm Temp NE (*Dentkist, Korea*) temporary cement was used according to the manufacturer's instructions in which the samples were cemented to their corresponding dies using a customized loading device under a 5 KG load (10 min) for standardization **Lopes et al. (2019)**.

I. Fracture resistance test

Samples were mounted on a computer-controlled universal testing machine (*Model 3345, Instron Industrial Products, Norwood, MA, USA*), and secured to its lower compartment **Figure (7)**. Fracture test was done by compressive mode of load applied occlusally on the samples using a rectangular metallic rod attached to the upper compartment of the testing machine traveling at crosshead speed of 1 mm/min with a tin foil sheet in-between to achieve homogeneous stress distribution. The load at failure manifested by an audible crack and confirmed by a sharp drop at load-deflection curve on the software, load to fracture was recorded in Newton(N). *Blue-hill Lite Software* (*Instron®, Norwood, MA, USA)* was used to record and gather data.

J. Statistical analysis

Normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) were used to examine the data distribution in which the data was presented as mean, and standard deviation. Student t-test was used to compare the values between both groups at each surface. One-way analysis of variance was performed followed by Tukey's post-hoc test if it showed significance. Two-way ANOVA compared the effect of each factor (fabrication method and surface). The significance level was set at power (P) ≤ 0.05 and a 95% confidence level. The statistical analysis was done using Graph Pad Instat software.

Results

For internal fit, the milled group (SM) recorded statistically non-significant higher gap mean value (102.02 ± 11.22 µm) than that of the 3D printed group (AM) (100.6± 13.1 µm) as proven with two-way ANOVA test ($p = 0.7916 > 0.05$), detailed results are shown in **Table (1)**.

For VMG, the (SM) group recorded statistically significant higher gap mean value (48.58 ± 5.69 µm) than that of the (AM) group (43.003 ± 5.06 µm) as proven with two-way ANOVA test ($p = 0.0248 < 0.05$), detailed results are shown in **Table (2)**.

The (SM) group showed statistically significant higher mean value for the fracture resistance (1542.62±214.89 N) than that of (AM) group (774.89 ±170.17 N) as demonstrated by t-test ($t=9.3$, $P=<0.0001 < 0.05$) as shown in **Figure (8).**

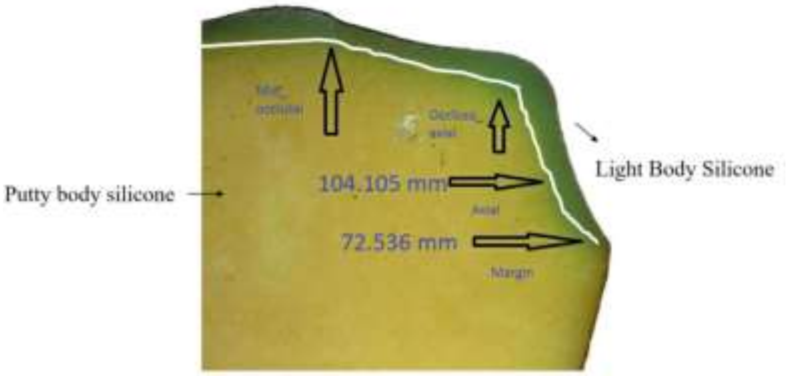

Figure (4): Section of the Silicone replica under microscope

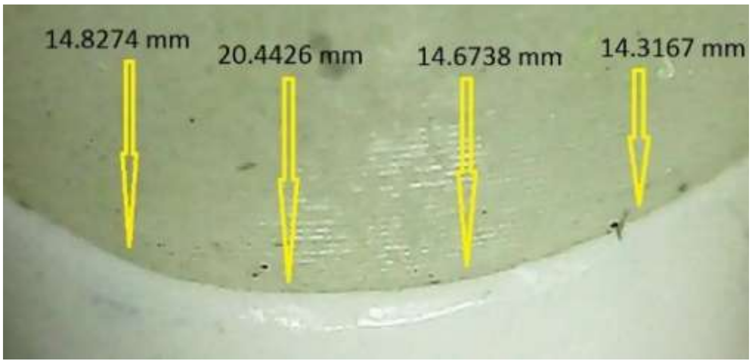

Figure (5): Measuring VMG under the microscope
(4 points on the buccal surface of second premolar)

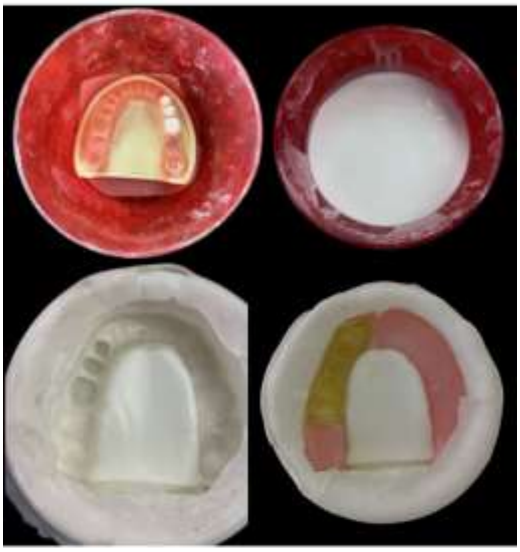

Figure (6): Fabrication of Epoxy Die

Figure (7): Sample in Universal Testing Machine

Table (1): Comparison of the internal gap results between both groups at different measurement sites

Variable		**Fabrication method**								**Statistics**
		3D Printed				**Milled**				
		Mean	*± SD*	*95% CI*		*Mean*	*± SD*	*95% CI*		*t-test*
				Low	*High*			*Low*	*High*	P value
Measurement site	***Margin***	76.11^{B}	14.8	67.34	84.87	78.91^{B}	11.1	72.4	85.44	0.6202 ns
	Axial	87.02^{B}	10.8	80.66	93.38	100.5^{B}	11.5	93.7	107.2	0.0103*
	Occluso_axial	114^{A}	23.3	100.2	127.7	119.6^{A}	17.3	109	129.8	0.5276 ns
	Mid_occlusal	125.4^{A}	15.1	116.5	134.3	109.1^{AB}	27.6	92.8	125.4	0.1007 ns

Different letters in same column indicating significant differences between groups ($p<0.05$)

*; significant ($p<0.05$) _ ns; non-significant ($p>0.05$) _ SD: standard deviation _ CI: Confidence Interval _ P: Power

Table (2): Comparison of the marginal gap results between both groups at different measurement surfaces

Variable		**Fabrication method**								**Statistics**
		3D Printed				**Milled**				
		Mean	± *SD*	*95% CI*		*Mean*	± *SD*	*95% CI*		*t-test*
				Low	*High*			*Low*	*High*	P value
Measurement surface	***Buccal***	22.65^{C}	0.97	21.68	23.22	29.5^{D}	1.17	28.34	30.19	<0.0001*
	Mesial	83.7^{A}	13.8	69.94	91.84	76.21^{A}	10.3	65.93	82.28	0.1633 ns
	Lingual	22.88^{C}	0.82	22.06	23.37	38.48^{C}	0.71	37.77	38.9	<0.0001*
	Distal	42.78^{B}	4.66	38.11	45.54	50.12^{B}	10.6	39.56	56.35	0.0477*

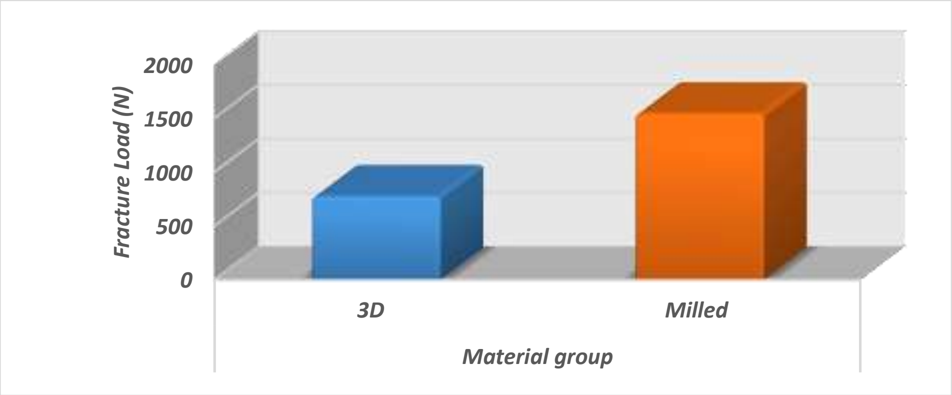

Figure (8): Column chart showing the mean values of the fracture resistance for both groups

Discussion

Long term provisional restorations are needed in certain clinical situations such as full mouth rehabilitation, and cases including periodontal treatment. Provisionalization plays a crucial role in the assessment of esthetics, function, and phonetics **Astudillo-Rubio et al. (2018)**; **Abad-Coronel et al. (2021).** The survival rate for the interim material would range from 6 months up to 2 years according to **Bauer et al. (2020).**

The fit of the provisional crown is closely related to its fabrication method as mentioned by **Wu et al. (2021).** Also, **Alharbi**

the finish-line design in either milling or 3D printing technique**.**

In the current study, two fabrication techniques (milling vs 3D printing) were tested in the term of internal fit, marginal adaptation, and fracture resistance of provisional restorations. Multiple fused provisional crowns were employed as fused crowns were used for splinting of periodontally compromised dentition **Mosedale (2007)**,

The internal fit was assessed using silicone replica technique because of its simplicity, accuracy, and reliability. Also, it is affordable, non-invasive and can be repeated without precision loss **Abdullah et al. (2016).**

According to **Boitelle et al. (2014)**, the

Figure (2): Comparison between swaps from two groups during follow up time

on the fit of the provisional crowns than that of

ranged from 68 to 280 µm occlusally, for the axial gap from 9 to 140 µm and 20 to 80 µm for the marginal gap**.**

Regarding the results of our study**,** the first null hypothesis failed to be rejected as there was no statistically significant difference between groups in which the mean value of the internal gap was slightly higher in the milled group (SM) (102.02 ±11.2 µm) than the 3D printed group (AM) (100.6 ±13.1 µm). Although the values were clinically accepted for both tested techniques, such reduced values for the milled restorations might be allocated to flaws induced from the cutting burs' tolerance as described by **Alharbi et al. (2018)**.

These results were in agreement with **Lee et al. (2017)** who found that the mean ± SD values of the internal gap were higher in the milled group, fabricated from PMMA Vipi block (171.6± 97.4 µm), compared to both 3D printed groups, fabricated from VeroGlaze MED620 & ZMD-1000B printing resins. Also, **Alharbi et al. (2018)** found that the 3D printed group (SLA Temporis® hybrid resin material) showed lower internal gap values (110 ±33 µm) than that of the milled group (PMMA-based acrylate resin Polycon®) (151±39 µm). In addition, **Falahchai et al. (2022)** recorded that the mean gap values of the DLP group (NextDent C&B) was less than that of milled group (PMMA Ceramill TEMP blocks) at all points.

On the other hand, our findings were in disagreement with **Kang et al. (2018)** who showed that the accuracy of the provisional crowns produced by subtractive technique (PMMA VipiBlock) was greater than that of the additive technique (PMMA Zmd1000B, Dentis). This was allocated to use a stereo-lithographic (SLA) printer in which an error from light diffraction occurred leading to poor representation of the printed surface.

Vertical marginal discrepancy was evaluated by direct viewing technique through a high powerful digital microscope. It is one of the highly applied approaches to detect VMG because it is affordable, and less time consuming than other techniques with less probability of error accumulation **Habib. (2018)**. The measurement of VMG was performed without cementation to preclude the impact of the cementation technique variance **Gonzalo et al. (2019).** Although in our study, the number of the measurement points (8 for middle retainer and 12 for mesial & distal retainers) might be considered inadequate for each retainer separately, **Groten et al. (2000)** stated that a larger number of crowns per sample could compensate for such inadequacy. There were 32 points of measurements per sample in our study. It was suggested that 20 to 25 measurements per sample could be used sufficiently for measuring the marginal gap **Shoukry et al. (2023).**

Beuer et al. (2009) mentioned a range of 100 -150µm for the marginal gap to be accepted, while **Boitelle et al. (2014)** reported that the CAD-CAM prostheses showed marginal discrepancies values less than 80 µm.

The second null hypothesis was rejected as the AM group (43.003 ± 5.06 µm) had lower statistically significant VMG than that of the SM group (48.58 ± 5.69 µm). The higher VMG of the milled group could be assigned to the cutting burs' size in relation to the surface details that were smaller than the bur's diameter; thus, some surfaces details would not be properly reproduced. In addition to the motion range of the milling machine which was also considered as a limiting factor resulting in better marginal fit for 3D printing technique as explained by **Lee et al. (2017), Alharbi et al. (2018)** and **Sidhom et al. (2022).** Moreover, **Elfar et al. (2018)** attributed such better restoration fit to the incremental layering strategy of the 3D printing technique which enabled perfect details' reproduction with higher precision. However, these outcomes concurred with **Alharbi et al. (2018)** who recorded that the marginal gap values were lower in the 3D printed group (22±8 µm) than that of the milled group (33±15 µm). In the present study, the marginal gap values of the proximal surfaces were higher than that of the axial surfaces and this may be attributed to the difference in the surface contour between them.

Regarding the fracture resistance, the third null hypothesis was rejected in which the SM group exhibited higher mean value compared to the AM group. These findings were in accordance with **Abad-Coronel et al. (2021)** who reported that the milled FDPs, fabricated from PMMA VipiBlock (1663.57 ± 130 N), recorded a greater fracture resistance than that of the 3D printed FDPs (hybrid resin, PriZma 3D Bio Prov) (1437.74 ± 73 N). Also, **Nold et al. (2021)** reported that the milled FDPs, fabricated from InCoris PMMA blanks, showed the highest fracture strength value (1060 ± 89 N) with all the samples withstanding the dynamic loading compared to the 3D printed FDPs (Rigid, Formlabs) (931.7 ±151 N).

Moreover, **Sakr et al. (2022)** revealed that the fracture resistance of the milled crowns (Telio-CAD) showed greater mean value (910.2 ± 118 N) than that of the 3D printed crowns (Next-Dent C&B) (720.8 ± 129N). **Bhambhu et al. (2023)** reported that the fracture resistance of 3-unit provisional FDPs was higher in the CAD/CAM group (Ceramill TEMP PMMA) (2510.3 N), compared to the 3D printed group (micro-hybrid resin) (2182.9 N). These findings could be explained by the industrial manufacturing operation of the milled structures guaranteeing superior conversion degrees and enhanced reticular compaction of PMMA, providing higher resistance to fracture as mentioned by **Abad-Coronel et al. (2021).**

On the contrary, **Suralik et al. (2020**) showed that the 3D printed provisional FDPs, fabricated from SLA Freeprint Temp, had significantly greater fracture resistance (408.49 N) than that of the milled FDPs, (PMMA Zirlux Temp) (294.64 N). Also, **Ibrahim et al. (2020**) reported that the 3D printed crowns (Nextdent C&B) recorded statistically higher fracture resistance (1226.4±48 N) compared to the milled crowns (Telio CAD) (933.4±104 N). These higher values for the 3D printed group could be assigned to the vertical orientation of printing, and the chemical bonding among the layers created by the layering approach. **Falahchai et al. (2022)** results were opposite too, where the fracture resistance of DLP fabricated FDPs (727 ± 134 N) was greater than that of the milled FDPs (648 ± 166 N), this difference in the results may be attributed to the different study designs and materials used. Furthermore, it emphasized that the mechanical properties of the 3D printed structures are not only influenced by the material but also by the parameters of the printing process.

Since the resistance against masticatory forces is fundamental for the clinical longevity of the restorations. It was noteworthy that the results obtained for both groups were still higher than the physiologic occlusal forces applied on the posterior teeth ranging from 400 N to 800 N **Falahchai et al. (2022); Martín-Ortega et al. (2022)**.

The limitations of our study were that the experiment was conducted under in vitro conditions and the restorations were tested under static and not dynamic load. Therefore, it is recommended that there will be further investigations and studies for the clinical performance of the 3D printed restorations considering other mechanical and physical properties.

Conclusions

1. Provisional crowns fabricated by DLP showed better internal fit than the milled provisional crowns without significant difference.
2. 3D printed crowns reported statistically significant lower VMG than the milled crowns, both groups were within the clinically accepted range.
3. The provisional crowns constructed using milling approach showed higher fracture resistance compared to the 3D printed crowns
4. Both fabrication methods could be used successfully for producing provisional restorations. While in case of strong biting forces clinically, the milled provisional restorations would offer better resistance to the occlusal loads

Conflict of Interest:

The authors declare no conflict of interest.

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Ethics:

This study protocol was approved by the ethical committee of the Scientific Research of the Faculty of Dentistry, Cairo University. The approval number was (9-3-21).

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