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Original Article

Comparative Evaluation of Flexural Strength of a Milled and Two 3D-Printed Temporary Crown Materials: An *In Vitro* Study

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Abstract

Aim and Objective: The aim of this study was to compare the flexural strength of a milled polymethyl methacrylate (PMMA) material with two 3D-printed resins used for interim dental restorations.

Background and Introduction: Interim restorations are essential for maintaining function, aesthetics, and periodontal health during fixed prosthodontic treatment. The growing use of digital fabrication techniques, including computer-aided design/computer-aided manufacturing (CAD/CAM) milling and 3D printing, necessitates a comparison of mechanical properties – particularly flexural strength – to ensure long-term clinical performance.

Materials and Methods: Sixty standardized rectangular specimens (25 × 2 × 2 mm), fabricated as per ISO 10477:2018, were divided into three groups (n = 20 each): Group A (milled PMMA), Group B1 (3D-printed Freeprint resin), and Group B2 (3D-printed D Tech resin). Specimens were tested using a Universal Testing Machine at a crosshead speed of 1 mm/min with a 20 mm support span. Flexural strength was calculated using the formula $F.S = 3PL/2bd^2$. Statistical analysis included one-way analysis of variance and Tukey's *post hoc* test.

Results: Milled PMMA exhibited the highest mean flexural strength (114.74 ± 5.00 MPa), followed by Freeprint (91.32 ± 3.05 MPa) and D Tech (80.33 ± 5.48 MPa). Significant differences were observed among all groups ($P < 0.001$).

Conclusion: CAD/CAM-milled PMMA demonstrated superior flexural strength compared to both 3D-printed resins, suggesting greater mechanical reliability for interim restorations. Continued innovation in 3D-printed materials is warranted to enhance their clinical applicability.

Key words: 3D printing, Computer-aided design/computer-aided manufacturing, Flexural strength, Interim restorations, Milled polymethyl methacrylate, Universal testing machine

INTRODUCTION

Fixed prosthodontic treatment frequently involves the indirect fabrication of definitive prostheses within dental laboratories, a process that typically spans multiple clinical appointments. During this interim period, provisional restorations play a crucial role in maintaining the integrity and functionality of the oral environment. These temporary restorations are not merely placeholders; they serve multiple essential purposes, including stabilizing prepared teeth, preserving pulpal health, maintaining occlusal relationships, supporting periodontal tissues, and guiding aesthetic and functional outcomes during the diagnostic phase of treatment planning.[1]

To fulfill these roles effectively, interim restorations must demonstrate adequate mechanical strength, particularly

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flexural strength, to withstand the complex and repetitive occlusal forces encountered during mastication.[2] Conventionally, such restorations have been fabricated using polymethyl methacrylate (PMMA) through conventional techniques or computer-aided design/computer-aided manufacturing (CAD/CAM) milling. The latter, involving subtractive manufacturing of PMMA blocks, has gained widespread acceptance due to its reliability, dimensional accuracy, and favorable mechanical properties.[3]

In recent years, the evolution of digital dentistry has introduced additive manufacturing techniques, particularly 3D printing, as viable alternatives for the fabrication of restorations. These methods offer several advantages over milling, including reduced material waste, faster turnaround times, and cost-effectiveness. However, despite these benefits, concerns remain regarding the mechanical performance of 3D-printed resins, especially their ability to resist flexural stress.[4] Given that material failure under masticatory load could compromise the success of interim restorations, it is critical to assess whether 3D-printed materials can match or exceed the mechanical standards set by milled PMMA.

This study, therefore, aims to evaluate and compare the flexural strength of milled PMMA with two commercially available 3D-printed resins. The objective is to determine the suitability of these emerging materials for use in provisional fixed prosthodontic applications, thereby contributing to evidence-based material selection in contemporary restorative dentistry.

MATERIALS AND METHODS

Study Design

This was an *in vitro* experimental study conducted to compare the flexural strength of one milled and two 3D-printed materials used for interim dental restorations.

Study Location

The study was conducted in the Department of Prosthodontics, Pandit Deendayal Upadhyay dental college, Solapur, where sample fabrication was carried out.

Sample Size

A total of 60 specimens were fabricated and equally divided into three groups (n = 20 per group):

- Group A: Milled PMMA (Blooden)
- Group B1: 3D-printed Freeprint resin
- Group B2: 3D-printed D Tech Crown and Bridge resin.

Selection Criteria

Inclusion criteria

- Specimens must have dimensions of 25 mm (length) × 2 mm (breadth) × 2 mm (height)
- Polished surface finish
- Free from visible surface irregularities.

Exclusion criteria

- Presence of surface irregularities or roughness
- Presence of voids, cracks, or fabrication defects.

Specimen Preparation

A standard wax pattern of the specified dimensions was fabricated according to ISO 10477:2018 guidelines. A putty index was created from the wax model, and cold-cure acrylic resin was poured to produce a reference sample. The reference sample was scanned and converted into STL files for digital designing [Figure 1]. These files were used to mill PMMA samples and to 3D print the Freeprint and D Tech specimens using Photon Mono 4K printers [Figures 2-7]. All 3D-printed specimens were post-cured as per manufacturer instructions.

Testing Procedure

Each specimen was tested for flexural strength using a Universal Testing Machine (Model: Unitest 10, ACME Engineers) at a crosshead speed of 1 mm/min. The span between the supports was fixed at 20 mm [Figure 8]. The flexural strength was calculated using the formula:

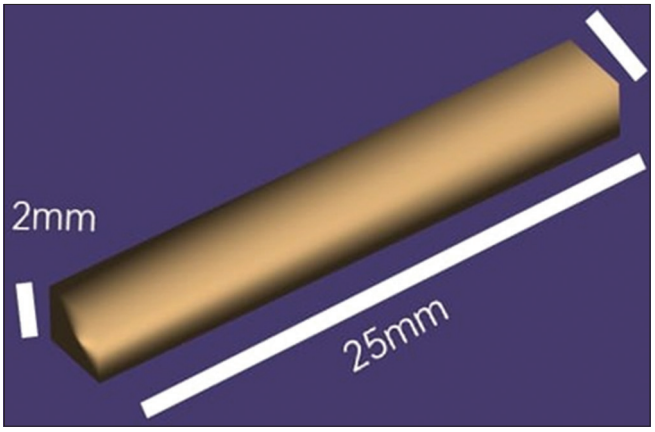


Figure 1: STL file

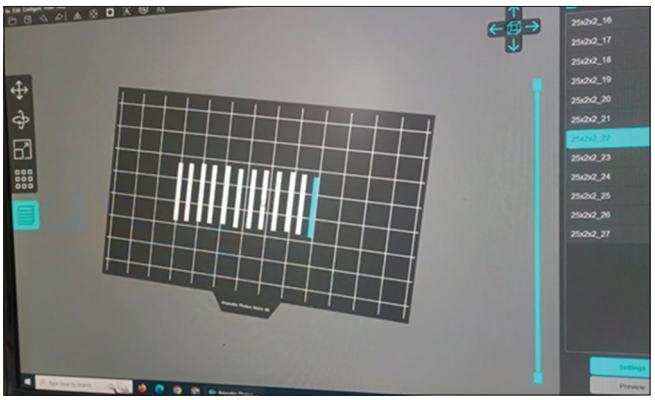


Figure 2: Sample designing

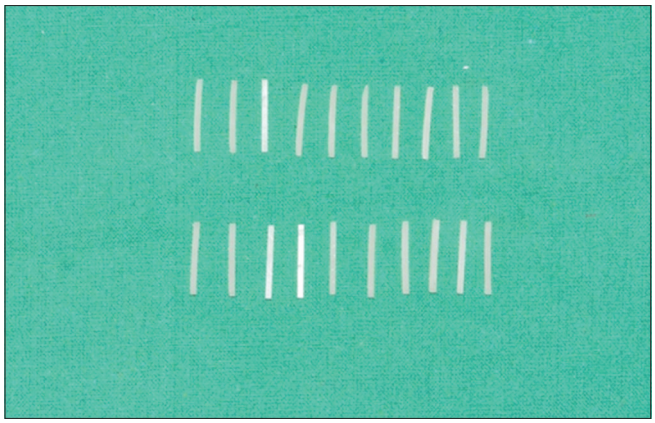


Figure 3: Sample of group A

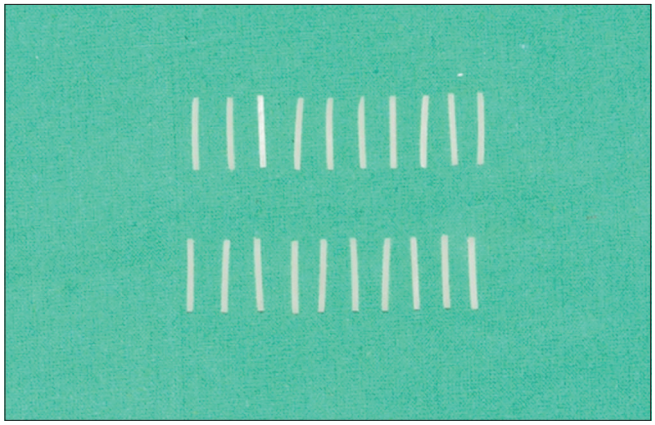


Figure 4: Sample of group B1

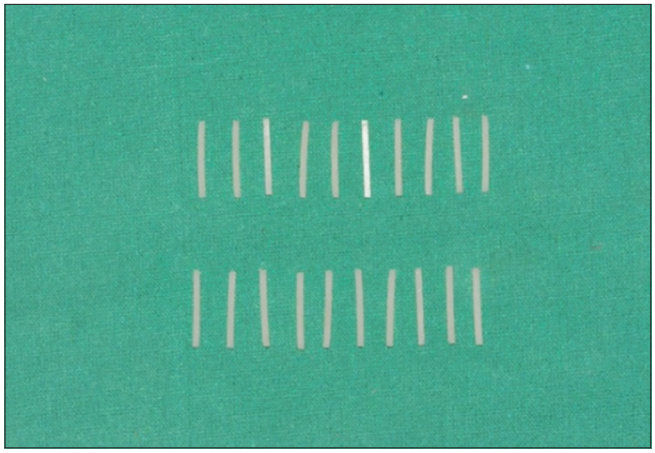


Figure 5: Sample of group B2

$$F.S = (3PL)/(2bd^2)$$

Where,
P = fracture load,
L = span length,
b = specimen width,
d = specimen thickness.

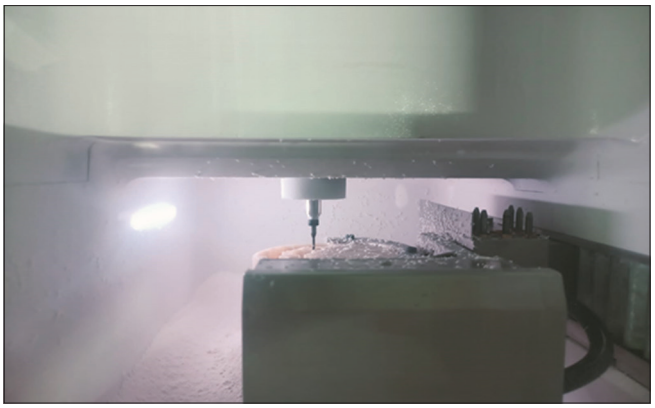


Figure 6: Close view of sample milling polymethyl methacrylate sample

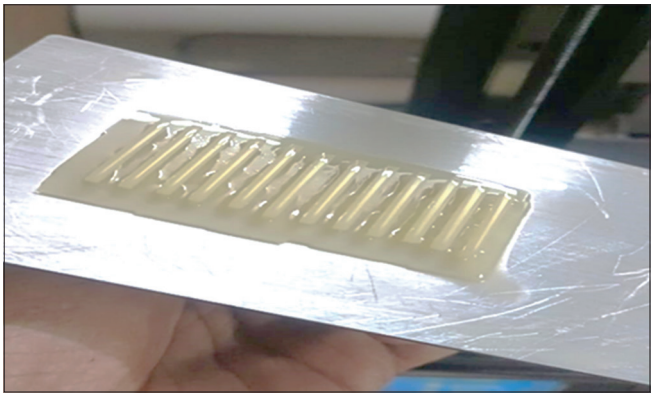


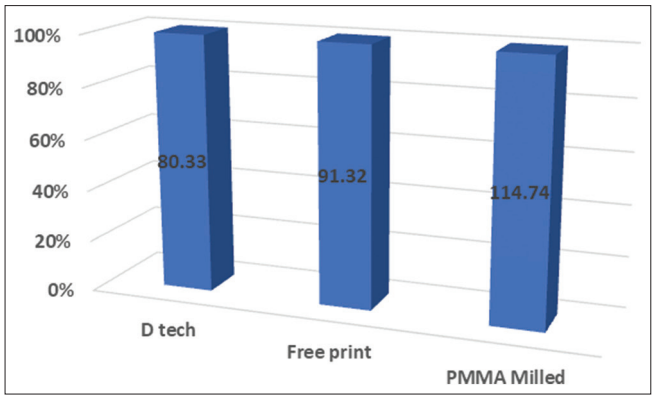
Figure 7: 3D Sample printing for group B1

Figure 8: Sample testing in universal testing machine

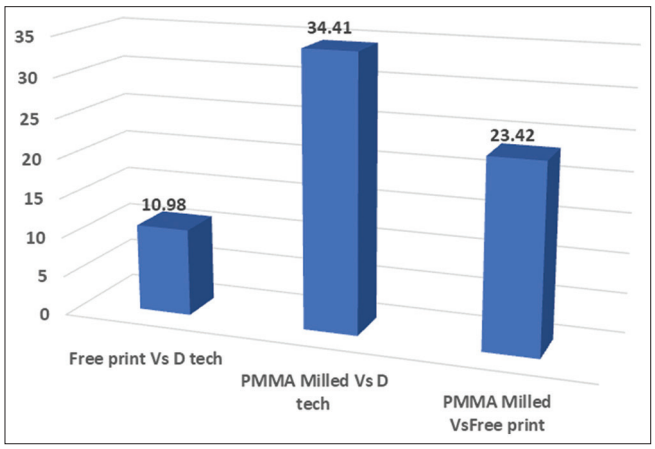
RESULTS

Statistical Analysis

Descriptive statistics were calculated for each group, including mean, standard deviation (SD), and range. One-way analysis of variance (ANOVA) was used to assess differences among the groups, and Tukey's *post hoc* test was performed for pairwise comparisons. $P < 0.05$ was considered statistically significant.



Graph 1: Flexural strength of three materials



Graph 2: Mean difference in the flexural strength

- Table 1 summarizes the descriptive statistics, including mean, standard deviation, and range of flexural strength for the three materials.
- Table 2 presents the one-way ANOVA results comparing flexural strength among the three groups.
- Table 3 shows the pairwise comparison (Tukey's post hoc test) of flexural strength values between the materials.
- Graph 1 illustrates the comparative flexural strength of the three materials.
- Graph 2 depicts the mean difference in flexural strength among the groups.

Descriptive Statistics

The flexural strength of three different materials – D-Tech, Freeprint, and PMMA Milled – was evaluated using 20 samples from each group. The descriptive statistics, including mean, SD, minimum, and maximum values, are presented in the table below:

The results indicate that PMMA milled samples exhibited the highest flexural strength, with a mean value of 114.74 MPa and a SD of 5.00 MPa. The range of flexural strength for this group was from 105.67 MPa to 123.75 MPa. The Freeprint group demonstrated a mean flexural strength of 91.32 MPa with a lower SD of 3.05 MPa, suggesting more consistent results across the samples, with values ranging from 84.59 MPa to 97.98 MPa. D-Tech samples showed the lowest flexural strength, with a mean of 80.33 MPa and a SD of 5.48 MPa, with values ranging from 71 MPa to 89.9 MPa.

Table 1: Evaluation of the flexural strength of three materials

Group	*n*	Mean (MPa)	Standard deviation	Min (MPa)	Max (MPa)
D-Tech	20	80.33	5.48	71	89.9
Freeprint	20	91.32	3.05	84.59	97.98
Polymethyl methacrylate milled	20	114.74	5.00	105.67	123.75

Table 2: Comparison of the flexural strength of three materials

Source of variation	Sum of squares	df	Mean square	F	*P*-value
Between groups	12352.251	2	6176.126	287.859	<0.001
Within groups	1222.958	57	21.455		
Total	13575.210	59			

Table 3: Pairwise comparison of the flexural strength of three materials

Comparison	Mean difference (MPa)	*P*-value
Freeprint versus D-Tech	10.98	<0.001
PMMA versus D-Tech	34.41	<0.001
PMMA versus Freeprint	23.42	<0.001

PMMA: Polymethyl methacrylate

A one-way ANOVA was conducted to compare the mean flexural strength among the three groups. The analysis yielded an F-value of 287.859 and $P < 0.001$, indicating a highly significant difference in flexural strength between the groups.

To determine which specific groups differed significantly, a *post hoc* Tukey test was performed. The pairwise comparisons revealed significant differences between all three groups: These results demonstrate that PMMA milled samples had significantly higher flexural strength than both Freeprint and D-Tech. In addition, Freeprint exhibited significantly better flexural strength compared to D-Tech.

DISCUSSION

The introduction of digital manufacturing technologies such as CAD/CAM and 3D printing has revolutionized

the fabrication of temporary dental restorations. Among the popular additive manufacturing technologies, digital light processing (DLP) and Stereolithography (SLA) offer precise, rapid, and reproducible methods for creating dental prostheses from photopolymer resins. DLP, in particular, enables layer-by-layer construction of restorations with high accuracy, directly from CAD designs, significantly reducing fabrication time compared to conventional methods. While the use of acrylic-based composites is well established in dentistry, the integration of 3D printing has enabled the in-office production of intricate interim restorations within 30 min – broadening clinical options and improving efficiency.

Despite these advantages, the success of temporary restorations is highly dependent on their mechanical properties, particularly flexural strength, which must be adequate to withstand occlusal and masticatory forces. In this study, a direct comparison was made between CAD/CAM-milled PMMA (Bloomden) and two commercially available 3D-printed crown and bridge resins (Freeprint and D-Tech) to assess their suitability for use as interim prostheses. The results revealed that milled PMMA exhibited the highest flexural strength among the tested materials, followed by Freeprint and then D-Tech. These findings align with those of Rejikumar *et al*.,[5] who demonstrated the superior mechanical performance of CAD/CAM PMMA resins over 3D-printed alternatives. The enhanced strength of milled PMMA is attributed to its high polymer cross-linking density and industrial curing under controlled conditions, which reduce residual monomer content and porosity.

In comparison, Souza *et al*.[6] evaluated the flexural strength and Vickers hardness of 3D-printed materials and noted inferior performance compared to milled PMMA, echoing our observations. They emphasized the need for optimization in resin formulation and post-processing protocols to improve clinical viability.

Further supporting evidence is found in the study by Digholkar *et al*.,[7] who compared manufacturing techniques and found that CAD/CAM-milled specimens showed higher flexural strength and lower porosity than 3D-printed counterparts. Similarly, Shenoy *et al*.[8] observed milled PMMA to have significantly higher flexural strength (128.32 ± 0.35 MPa) than 3D-printed PMMA (80.06 ± 0.95 MPa), reinforcing the argument for PMMA's suitability in load-bearing provisional restorations.

The inclusion of nanoparticles, such as zirconia and silver-immobilized halloysite nanotubes, as proposed by Darbandi and Amin,[9] is an emerging strategy to enhance the mechanical and antibacterial properties of 3D-printed resins. Their study demonstrated that fillers significantly improved flexural strength and hardness, suggesting a promising direction for future material development.

Contrasting perspectives are presented by Park *et al*.,[10] who noted that SLA-based 3D-printed specimens exhibited flexural strengths between 135 and 149 MPa – higher than some conventional methods – indicating that print technology, material type, and post-processing play critical roles in determining final properties. In addition, Othman *et al*.[11] found no significant differences in fracture strength between 3D-printed and milled anterior crowns, though molar crowns favored milling.

Surface roughness, an important factor in plaque accumulation and esthetics, was explored by Rizzante and Bueno,[12] who reported comparable or superior microhardness in 3D-printed materials, though flexural strength remained lower. These results support the potential use of 3D-printed resins as cost-effective interim options, particularly when adjusted for processing quality.

Lastly, Simoneti *et al*.[13] and Jeong *et al*.[14] further validated the mechanical superiority of milled PMMA through fracture toughness comparisons, though they highlighted the challenge of standardizing 3D printing materials due to their diversity in composition and production parameters.[15] AQ3

The marginal fit and internal adaptation of provisional restorations are critical parameters influencing their longevity, esthetic success, and resistance to secondary caries. In this context, recent advancements in digital workflows, particularly three-dimensional (3D) printing, have significantly transformed the fabrication process of interim restorations.

Arora *et al*.[16] demonstrated that cobalt-chromium copings fabricated using 3D-printed resin patterns exhibited significantly superior marginal accuracy (mean 82.21 ± 15.26 μm) compared to those fabricated using milled PMMA patterns (106.75 ± 12.76 μm). The improved adaptation in the 3D-printed group was attributed to the additive layering process, which enables more precise reproduction of fine internal and marginal contours with reduced distortion.

Daghrery *et al*.[17] further corroborated these findings by comparing 3D-printed and milled laminate veneers. Their results showed that 3D-printed veneers achieved statistically smaller internal gaps and overall discrepancies, indicating better internal adaptation – an essential factor for

preventing microleakage and ensuring restoration longevity.

Several clinical advantages of 3D-printed provisional materials were consistently evident:

- Enhanced marginal and internal fit, improving sealing ability and clinical outcomes.
- Superior ability to reproduce complex geometries, such as undercuts and internal line angles.
- Reduced material waste with recyclability rates approaching 96%, making the process environmentally favorable.
- Minimal tool wear and heat generation, reducing fabrication errors due to material deformation.
- Faster turnaround times, enabling efficient chairside fabrication and patient-specific customization.

Although CAD/CAM-milled PMMA still exhibits superior mechanical properties, particularly for long-span or posterior restorations subjected to higher occlusal loads, 3D-printed resins have shown significant progress. Modern formulations consistently surpass the clinical flexural strength threshold of 50 MPa, making them suitable for short- to medium-term provisional crowns and bridges. Emerging advancements such as nanocomposite reinforcement, improved curing protocols, and optimized print orientations continue to enhance the structural reliability of these materials.

In conclusion, while milled PMMA remains the gold standard for high-strength provisional restorations, the evolving capabilities of 3D-printed materials make them a promising and clinically acceptable alternative – especially in esthetically demanding, time-sensitive, and digitally integrated workflows.

CONCLUSION

CAD/CAM-milled PMMA demonstrated the highest flexural strength, making it ideal for long-term temporary restorations. Among the 3D-printed materials, Freeprint performed better than Dtech but still exhibited lower strength compared to milled PMMA. Continued advancements in 3D printing technology are necessary to enhance the mechanical performance of printed restorations.

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