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IP Annals of Prosthodontics and Restorative Dentistry

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Original Research Article

A comparative study on the flexural strength of peek-reinforced PMMA for provisional restorations fabricated using 3D printing and traditional methods – An in vitro analysis

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Abstract

Aim: To compare the flexural strength of PEEK-Reinforced PMMA in provisional restorations produced through 3D printing and traditional fabrication methods.

Materials and Methods: A total of 30 tooth-colored PMMA acrylic resin samples, each measuring 65 mm × 10 mm × 2.5 mm, were prepared. These samples were equally divided into three groups, with 10 specimens in each: Group I (Autopolymerized PMMA with 3 wt% PEEK), Group II (Heat Polymerized PMMA with 3 wt% PEEK), and Group III (3D Printed PMMA with 3 wt% PEEK). The flexural strength of the specimens was assessed using a three-point bending test on a universal testing machine. Statistical analysis was performed using one-way ANOVA, followed by intergroup comparisons with the POSTHOC Bonferroni test.

Results: The highest mean flexural strength was observed in Group I (70.96 MPa), followed by Group II (55.27 MPa) and Group III (30.34 MPa). One-way ANOVA indicated a statistically significant difference ($P < 0.05$) among the groups. Pairwise comparisons revealed significant differences ($P < 0.05$) between all groups, except between Group I (Autopolymerized PMMA) and Group II (Heat polymerized PMMA), where no significant difference was observed.

Conclusion: PEEK proves to be a viable reinforcement material for provisional restorations. Autopolymerized PMMA resin enhanced with PEEK offers an alternative treatment option, particularly suitable for patients with significant occlusal forces or those with a history of provisional restoration fractures.

Keywords: 3D printing, Autopolymerized PMMA ,Flexural strength, Heat polymerized PMMA, in vitro study, PEEK, PMMA reinforcement, Polymethylmethacrylate resin PMMA, Post tooth preparation temporary prosthesis, Provisional restorations

Received: 05-06-2025; **Accepted** 16-07-2025; **Available Online**: 22-10-2025

1. Introduction

PMMA resins are widely utilized for creating temporary fixed dental prostheses. Despite their popularity, several challenges persist that require attention to enhance their properties for provisional prosthesis fabrication. A key consideration in designing provisional, temporary, or interim restorations is fulfilling the patient's functional and aesthetic requirements. This becomes particularly crucial in cases where an extended treatment period is needed before the final prosthesis can be placed.

A leading cause of failure in provisional restorations is prosthetic fracture, which can result in patient discomfort and financial burden. Fracture resistance refers to a material's ability to withstand the rapid growth of cracks under stress, particularly in brittle materials, thus preventing catastrophic failure.

Advancements in material science and technology have led to modifications in prosthetic material properties, enhancing the longevity of prostheses. Provisional restorations can be produced using traditional chair-side techniques, laboratory methods on working casts, or, more recently, through digital technologies. The reinforcement of PMMA resin has garnered significant attention within the dental materials community.

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https://doi.org/10.18231/j.aprd.46497.1761127476

Polyetheretherketone (PEEK), a semi-crystalline linear polycyclic aromatic polymer, is commonly used in dentistry for prosthetic frameworks, dental implants, and abutments due to its exceptional mechanical properties. PEEK is available in both granular form and as milled blanks.[1,2]

An important prerequisite for the successful assessment of provisional restoration is its fracture toughness. It is influenced by numerous factors including contact, geometry, micro structural features, load.[2]

The recently introduced additive manufacturing technology, specifically three-dimensional (3D) printing, offers advanced capabilities for fabricating provisional restorations, effectively addressing the limitations of traditional methods.[2]

While extensive research exists on the comparison of different provisional restorative materials and their impact on fracture strength, there is limited data on the flexural strength of PEEK-reinforced PMMA in provisional restorations fabricated through 3D printing and conventional methods. Hence, this study was conducted to compare and evaluate the flexural strength of PEEK-reinforced PMMA for provisional restorations made using both 3D printing and traditional fabrication techniques.

2. Materials and Methods

A total of 30 specimens were prepared, with each group consisting of 10 samples. (**Figure 1**)

The specimens were categorized into three main groups:

1. Group I (n=10) Auto polymerized PMMA3 wt. % PEEK
2. Group II (n=10) Heat polymerized PMMA3 wt. % PEEK
3. Group III (n=10) 3D printed PMMA 3 wt. % PEEK

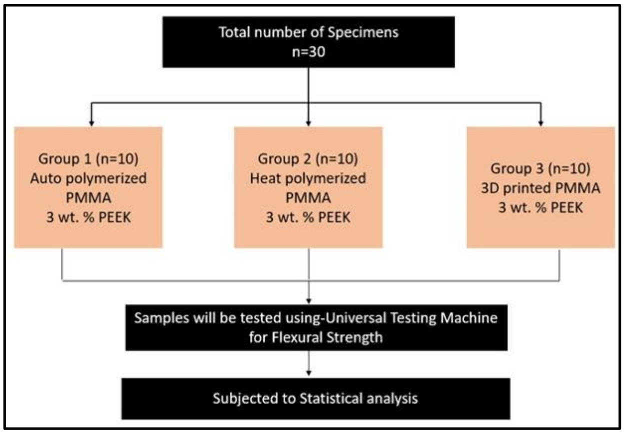

Figure 1: Flowchart depicting distribution of specimens

2.1. Specimen fabrication

For the fabrication of Group I (Autopolymerized PMMA specimens), wax blocks measuring 65 mm × 10 mm × 2.5 mm were created. A vinyl polysiloxane impression material of putty consistency was then used to produce impressions, resulting in 10 samples of autopolymerizing provisional restorative materials (**Figure 2**a). To reinforce these specimens, 3 wt% PEEK was added, and a uniform mixture with PMMA polymer was achieved using a vacuum mixer. The liquid monomer was saturated with the PEEK-reinforced polymer powder. The resin was allowed to reach its plastic stage (1.5–2 minutes after mixing), after which it was inserted into the silicone impression mold using a spatula to produce 10 PMMA specimens (**Figure 2**b).

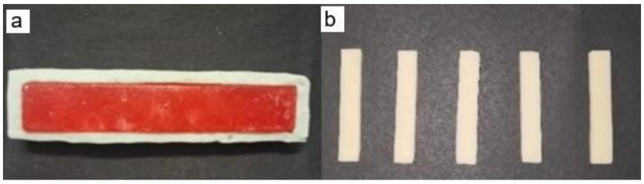

Figure 2: a: Putty index of Wax blocks measuring 65 mm × 10 mm × 2.5 mm; **b:** Auto polymerized PMMA specimens

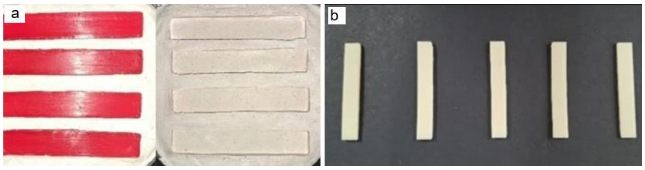

Figure 3: a: Wax blocks positioned for flasking & Mold space created after dewaxing; **b:** Heat Polymerized PMMA specimens

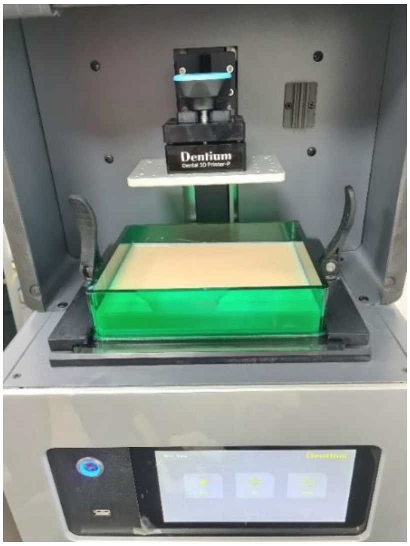

Figure 4: 3D printing of specimens

For the fabrication of Group II (Heat Polymerized PMMA specimens), wax blocks measuring 65 mm × 10 mm × 2.5 mm were prepared and flasked. The specimens were invested in dental flasks and allowed to set for 1 hour. The flasks were then placed in a dewaxing unit for 8 minutes, after which they were opened, and any remaining wax was removed by spraying with hot water (**Figure 3**a). The mold was subsequently coated with a separating medium to facilitate the polymerization process. 3wt% PEEK was taken and uniform mixture of it incorporated in Heat polymerized PMMA in a Vacuum mixer. The monomer methyl methacrylate was added to the mixture in 1:3 ratio by volume, subjected to compression molding technique and processed to obtain heat polymerized PMMA specimens (**Figure 3**b).

For fabrication of Group III 3D printed specimens, specimens of dimensions with 65 × 10 × 2.5 mm were obtained using ResTemp A2 Temporary crown material reinforced with 3wt% PEEK. The resin was poured into a container designed for 3D printing (**Figure 4**) using the Dentium Dental 3D Printed (D3DP) system, and the specimens were then fabricated (**Figure 5**).

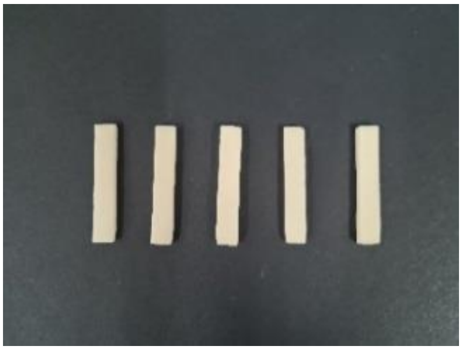

Figure 5: 3D printed specimens

2.2. Three-point bending test

The specimens were subjected to a three-point bending test using a universal testing machine (Instron Corporation, Canton, MA, USA) at a crosshead speed of 2 mm/min to evaluate their flexural strength (**Figure 6**). The peak load (fracture load) for each specimen was recorded and converted into flexural strength using the formula:

$S=3PL/2bd$

Where:

- S = flexural strength (N/mm^2)
- P = load at fracture
- L = distance between jig supports
- b = specimen width
- d = specimen thickness

Figure 6: Specimen under 3 point bending test

3. Results

According to **Table 1**, it showed mean flexural strength was maximum with Auto Polymerized PMMA 3% wt PEEK (70.96 MPa) followed by Heat Polymerized PMMA 3% wt PEEK (55.27 MPa) and 3D printed PMMA 3% wt PEEK (30.34 MPa). The Shapiro-Wilk test for normality showed no significant difference ($p > 0.05$), indicating that parametric tests were appropriate for the analysis. A one-way ANOVA (**Table 2**) was conducted to compare flexural strength among the groups, revealing a significant difference ($p < 0.05$). The POSTHOC Bonferroni test further identified statistically significant differences between the pairwise group comparisons ($p < 0.05$), except for the comparison between Autopolymerized PMMA with 3% wt PEEK and Heat Polymerized PMMA with 3% wt PEEK, where no significant difference was observed ($p > 0.05$).

Table 1: Descriptive details of ‘Flexural Strength’

Flexural strength								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Auto Polymerized PMMA 3% wt PEEK	10	70.96	18.057	5.710	58.0456	83.8804	43.26	112.91
Heat Polymerized PMMA 3% wt PEEK	10	55.27	15.538	4.913	44.1625	66.3935	38.99	93.27
3D Printed PMMA 3% PEEK	10	30.34	6.402	2.024	25.7628	34.9232	17.52	39.51
Total	30	52.19	21.86	3.992	44.0287	60.3606	17.52	112.91

Table 2: Comparison of Degree of Inclination in Class 1 group Using One Way ANOVA

ANOVA					
Flexural strength					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8392.526	2	4196.263	20.688	.000
Within Groups	5476.512	27	202.834		
Total	13869.038	29			

4. Discussion

Provisionalization plays a critical role in the treatment of fixed prostheses. For successful temporization, it is essential to consider biological, mechanical, and aesthetic factors. Over time, various provisional materials have been developed, each offering distinct biological, mechanical, and aesthetic advantages suited to specific clinical situations. Interim restorations serve as temporary solutions between tooth preparation and the final cementation process. The quality of the provisional restoration is vital for the success of the final prosthesis, especially in complex cases such as full-mouth rehabilitations.[2]

Provisional restorations are frequently used for extended durations (6–12 weeks) to assess patient comfort and satisfaction before the final restoration is placed.

Provisional restorations can be fabricated using various techniques. The manual approach is further divided into direct, indirect, and indirect-direct methods. With advancements in technology, additive manufacturing techniques like 3D printing have gained popularity for creating complex structures. This method employs different resins and can produce precise prostheses with minimal material waste. It is often more cost-effective and faster compared to traditional milling. Key 3D printing techniques include stereo lithography, digital light processing, selective laser sintering, and fused deposition modeling.

A key requirement for provisional restorations is their ability to resist deformation under mechanical stresses, including masticatory and parafunctional forces. Despite careful planning to prevent failure, fractures can still occur, leading to patient discomfort and financial burden. The mechanical strength of provisional materials is crucial for clinical success and must be carefully considered. Factors contributing to restoration fractures during function include improper occlusion, bruxism, under-contoured pontics, and traumatic impacts.[3-5]

PEEK is a relatively new material in dentistry, offering mechanical properties comparable to dentin and enamel, including high fracture resistance. However, in its homogeneous form, it can be brittle. PEEK demonstrates outstanding tensile strength and excellent creep resistance. When its flexural and tensile properties are combined, it achieves an optimal balance, enabling the material to withstand high loads over extended periods at elevated temperatures without permanent deformation.[6-9] Its flexural modulus at very high temperatures can be further enhanced through reinforcement with glass or carbon fibers.

Research on the effectiveness of 3D printing for producing temporary restorations is still limited. Eftekhar Ashtiani et al. evaluated the dimensional accuracy of intra-coronal restorations fabricated using digital and conventional methods, finding that the conventional resin pattern technique was more accurate than 3D printing.[10] Several factors can influence the marginal fit of 3D-printed restorations, including the type of printer, resin used, device calibration (considering environmental conditions like moisture and temperature), and the complexity of the restoration's design. Additionally, factors such as restoration preparation design, scanning accuracy, software programs, material properties, and milling reproducibility can affect the precision of temporary restorations. Hence, it is crucial to explore how PEEK reinforcement impacts the properties of 3D-printed resin.

Muhsin et al. investigated the mechanical properties of PEEK polymer as a denture material and found it to be highly resistant to notch concentration. They noted that PEEK dentures with notches at the labial or buccal frenum are less susceptible to fractures under such conditions. In the elastic region, PEEK demonstrates enhanced tensile strength with reduced plastic deformation compared to PMMA.[11] Meanwhile, Sirandoni et al., through a 3D finite element analysis, assessed the biomechanical properties of various framework materials for implant-supported mandibular fixed prostheses. Their study concluded that zirconia was superior to both PEEK and PMMA as a framework material.[12]

In a study by José Manuel Mendes et al., the fracture resistance of three materials used for provisional crowns on implants—polymethyl methacrylate (PMMA), composite resin, and polyether ether ketone (PEEK)—was compared.[13] The results showed that PEEK crowns exhibited the highest fracture resistance, followed by those made with composite resin, while the PMMA crowns had the lowest fracture resistance.

In a study conducted by Mahsa Mohajeri et al., to compare the marginal fit of temporary restorations fabricated by the conventional chairside method, 3D printing, and milling.[14] The results showed Temporary crowns fabricated by the chairside method showed significantly smaller marginal gap; however, the marginal gap of all three groups was within the clinically acceptable range.

Dhivya priya et al., conducted a study to compare the flexural strength of autopolymerizing poly methyl methacrylate resins (PMMA) resin, CAD/CAM milled PMMA and CAD/CAM milled poly ether ether ketone (PEEK) when used as provisional restorative materials for long span situations in full mouth rehabilitation after aging and thermocycling.[15] The mean flexural strength of PEEK was statistically significant than the other two materials tested and hence can be recommended for use as a provisional restorative material for long span situations in full mouth rehabilitation. However, the mean flexural strength of PEEK reduced approximately by 44% when subjected to further aging.

Jayaprakash et al., conducted a study to comparatively evaluate the wear resistance of two different materials used as provisional implant supported restorative Prosthesis. Milled PEEK exhibited a marginally smoother surface compared to Milled PMMA. Milled PMMA showed significantly higher wear as compared to milled PEEK indicative of least wear resistance.[16]

While there is extensive literature comparing various provisional restorative materials and their impact on fracture strength, there is limited information on the comparison of flexural strength in PEEK-reinforced PMMA for provisional restorations produced through 3D printing and conventional methods. Therefore, this study was conducted to compare and evaluate the flexural strength of PEEK-reinforced PMMA in provisional restorations fabricated using both 3D printing and traditional techniques.

In this study, to improve the mechanical bonding between PEEK and PMMA, the powders were blended at a speed of 400 rpm for 30 minutes. This process ensured a uniform distribution of PEEK within the acrylic powder, enhancing the bonding strength and minimizing the tendency for agglomeration. As a result, it helped reduce stress concentration points within the material.

The mean flexural strength (**Table 1**) was highest in Group I (70.96 MPa), followed by Group II (55.27 MPa) and Group III (30.34 MPa). The Shapiro-Wilk test for normality showed no significant difference ($p > 0.05$), allowing the use of parametric tests for analysis. A one-way ANOVA revealed a significant difference in flexural strength (**Table 2**) among the groups ($p < 0.05$). Pairwise comparisons indicated significant differences ($p < 0.05$) between all groups, except between Group I (Autopolymerized PMMA) and Group II (Heat Polymerized PMMA), where no significant difference was observed. The POSTHOC Bonferroni test confirmed statistically significant differences between the pairwise group comparisons ($p < 0.05$), as detailed below.

Auto Polymerized PMMA 3% wt PEEK vs 3D Printed PMMA 3% PEEK (P0.05). The Mean Flexural strength Reported Is as Given Below 3D Printed PMMA 3% PEEK < Heat Polymerized PMMA 3% wt PEEK < Auto Polymerized PMMA 3% wt PEEK. The reinforcement of PEEK into the 3D printed resin led to a material with elastic consistency but also a reduction in fracture strength. The reinforcement of PEEK into the 3D printed resin might have improved some of the material's flexibility or toughness but at the cost of reduced resistance to fracture under high loads. This kind of trade-off is important to consider when designing materials for applications that require both strength and flexibility.

A limitation of the present study is that it was conducted in vitro, which, while useful for predicting material behavior in clinical settings, does not fully replicate the complexities of the oral environment. Incorporating thermo-cycling would have provided a more accurate simulation of oral conditions. Future research should focus on in vivo studies or more advanced in vitro models to evaluate the performance of this material under realistic conditions. Additionally, studies using scanning electron microscopy are recommended to examine surface characteristics, the distribution of nanoparticles within the mixture, and to identify porosities or agglomerates at fracture sites, which could influence the mechanical and physical properties of provisional restorations.

5. Conclusion

PEEK demonstrates potential as an effective reinforcement material for provisional restorations. Auto polymerized PMMA resin reinforced with PEEK offers a viable alternative for patients experiencing heavy occlusal forces or those with a history of provisional restoration fractures. To confirm the findings of this study, further research is needed, particularly focusing on fatigue testing and cyclic loading to assess the long-term performance of this material combination under simulated clinical conditions.

6. Source of Funding

None.

7. Conflict of Interest

None.

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Cite this article: Jayyarapu D, Mamidi D, Gandavaram NK, Jinka S, Gontu S. A comparative study on the flexural strength of peek-reinforced PMMA for provisional restorations fabricated using 3D printing and traditional methods – An in vitro analysis. *IP Ann Prosthodont Restor Dent*. 2025;11(3):236-241.