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ORIGINAL RESEARCH **OPEN ACCESS**

Flexural and compressive strength of bis-acryl, polymethyl methacrylate, and 3D-printed provisional resins: a comparative in vitro study

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ABSTRACT

Background: Provisional restorations must maintain adequate mechanical integrity during treatment, particularly when subjected to bending and occlusal forces. **Objective:** To compare the flexural and compressive strengths of a bis-acryl resin, an autopolymerizing polymethyl methacrylate (PMMA) resin, and a 3D-printed provisional resin. **Methods:** A comparative experimental in vitro study was conducted using 54 specimens, with 18 specimens assigned to each material. For each group, nine specimens were evaluated for flexural strength and nine for compressive strength. After storage in distilled water at 37 °C for 24 hours, flexural strength was assessed using a three-point bending test and compressive strength by axial loading in a universal testing machine. **Results:** Significant differences were found among the materials for flexural strength ($F = 6.104$; $p = 0.007$) and compressive strength ($F = 20.750$; $p = 0.000$). The bis-acryl resin showed the highest mean flexural strength (69.46 ± 7.70 MPa), followed by the 3D-printed resin (60.92 ± 3.54 MPa) and PMMA (57.04 ± 10.36 MPa). It also showed the highest mean compressive strength (82.25 ± 14.79 MPa), followed by the 3D-printed resin (75.96 ± 5.62 MPa) and PMMA (51.30 ± 9.89 MPa). Flexural strength differed significantly between the bis-acryl resin and both PMMA and the 3D-printed resin, whereas compressive strength differed significantly between PMMA and the other two materials. **Conclusion:** Under the conditions of this study, the bis-acryl resin demonstrated the most favorable overall mechanical performance, while the 3D-printed resin showed compressive strength comparable to that of the bis-acryl resin.

Keywords: Dental Materials; Polymethyl Methacrylate; Composite Resins; Flexural Strength; Compressive Strength.

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Introduction

Provisional restorations are an essential component of fixed prosthodontic treatment because they protect prepared teeth and periodontal tissues while maintaining function, occlusal stability, esthetics, and patient comfort until the definitive prosthesis is delivered [1,2]. Although intended for temporary use, these restorations may remain in service for several weeks or months, particularly during complex oral rehabilitation, implant-supported treatment, or periodontal and esthetic assessment. They may be fabricated using direct, indirect, direct–indirect, or computer-aided techniques; regardless of the fabrication method, provisional restorations must provide adequate dimensional stability and mechanical integrity throughout the treatment period [3,4].

Polymethyl methacrylate (PMMA) and bis-acryl composite resins are among the most commonly used conventional materials for provisional fixed restorations. Their mechanical behavior depends on their chemical composition, polymerization mechanism, and fabrication procedure. Idrissi et al. compared cold-polymerized PMMA, heat-polymerized PMMA, an autopolymerizing bis-acryl composite, and a urethane dimethacrylate resin, reporting the highest flexural strength for heat-polymerized PMMA [5]. More recently, additive manufacturing has enabled provisional restorations to be produced layer by layer from digitally designed models, offering advantages such as standardization, reproducibility, and reduced material waste. Nevertheless, the available evidence shows variable mechanical performance of 3D-printed provisional resins compared with conventionally fabricated and milled materials [6]. The behavior of computer-aided interim resins may also be influenced by surface treatment and manufacturing conditions [7], while the flexural strength of PMMA is affected by its copolymer composition and polymerization characteristics [8].

Previous investigations have attempted to improve the mechanical properties of resin-based materials through different reinforcement strategies. Glass-fiber incorporation has been evaluated in bis-acryl provisional restorations [9], whereas the flexural strength and load-bearing capacity of PMMA may be modified by fiber placement [10], polyetheretherketone or zirconium oxide nanoparticles [11], glass or polyethylene fiber meshes [12], repair procedures and thermocycling [13], and the incorporation of graphene and silver nanoparticles [14]. Fiber-reinforcement techniques have also been shown to influence the flexural behavior of composite resins [15]. However, these studies mainly evaluated modified or reinforced materials and therefore do not directly represent the behavior of unmodified provisional resins. Furthermore, studies assessing both flexural and compressive strength have frequently focused on resin-based core build-up materials rather than provisional prosthodontic materials [16]. Consequently, direct evidence simultaneously comparing the flexural and compressive strengths of unmodified bis-acryl, autopolymerizing PMMA, and 3D-printed provisional resins under standardized experimental conditions remains limited.

The mechanical performance of provisional materials is clinically relevant because deformation or fracture may compromise mastication, esthetics, occlusal stability, patient comfort, and continuity of prosthodontic treatment. Flexural strength reflects a material's ability to withstand bending stresses, whereas compressive strength represents its capacity to resist forces generated during occlusal loading. Therefore, the objective of this in vitro study was to compare the flexural and compressive strengths of a bis-acryl resin, an autopolymerizing PMMA resin, and a 3D-printed provisional resin. This research is justified by the need to provide standardized comparative evidence to support the selection of provisional restorative materials according to their mechanical performance, with direct implications for evidence-based prosthodontic practice. The null hypothesis was that there would be no statistically significant differences in flexural or compressive strength among the three provisional resin materials

Materials and methods

Study design and reporting guideline

This comparative experimental in vitro study evaluated the flexural and compressive strength of three provisional restorative materials. Specimen preparation and mechanical testing were performed in Lima, Peru, during September 2024 at an independent mechanical testing laboratory. The laboratory identity and institutional identifiers are withheld from the anonymized manuscript to preserve confidentiality and will be provided directly to the journal's editorial office if requested. The study was reported in accordance with the Checklist for Reporting In-vitro Studies (CRIS) [17]. Because no human participants, animals, biological samples, or clinical interventions were involved, STROBE, CONSORT, PRISMA, CARE, STARD, and COREQ were not applicable.

Materials, population, and sample

The study population consisted of specimens fabricated from three commercially available provisional restorative materials: an autopolymerizing bis-acryl resin (Protemp 4, shade A1; 3M), an autopolymerizing polymethyl methacrylate resin (Alike, shade 59; GC), and a 3D-printable provisional crown resin (Temporary Crown, shade Ivory; IFUN). These materials constituted the three independent experimental groups.

The sample size was estimated using parameters obtained from a previous in vitro investigation of resin-based materials, with a significance level of 5% and a statistical power of 95% [18]. The final sample comprised 54 specimens, with 18 specimens assigned to each material group. Mechanical testing was completed in two laboratory batches comprising 24 and 30 specimens, respectively. The number of specimens analyzed for each mechanical outcome is reported with the corresponding results. A nonprobability convenience sampling method was used because the specimens were intentionally fabricated under standardized laboratory conditions.

Specimens were included when they were fabricated from one of the three selected materials, corresponded to the specified shade, complied with the required dimensions, had undergone the same finishing and polishing protocol, and showed no visible structural defects. Specimens presenting cracks, pores, air bubbles, inclusions, surface irregularities, contamination, inadequate storage, or relevant dimensional deviations were excluded before mechanical testing. A measurement was excluded only when a documented technical failure, equipment malfunction, or deviation from the testing protocol prevented valid assessment. No result was removed solely because it was statistically extreme, and fracture during mechanical testing was considered the expected experimental endpoint rather than an exclusion criterion.

Specimen preparation

Bar-shaped specimens measuring 25 mm × 2 mm × 2 mm were fabricated for the flexural strength test, whereas cylindrical specimens measuring 4 mm in diameter and 10 mm in height were prepared for the compressive strength test. All dimensions were standardized according to the corresponding laboratory testing procedures.

The specimens made from Temporary Crown resin were initially produced using three-dimensional printing. Digital models with the required dimensions were processed using the printing and post-curing parameters recommended for the selected resin system. After printing, the specimens were cleaned, support structures were removed, and post-curing was completed according to the manufacturer's instructions.

Dimensionally verified printed specimens were used as master patterns to prepare silicone molds for the conventional materials. The internal surfaces of the molds were covered with a thin layer of petroleum jelly applied using a microbrush. Protemp 4 bis-acryl resin was dispensed into the molds using its automixing system, whereas Alike PMMA resin was mixed and inserted according to the powder-to-liquid ratio and polymerization time recommended by the manufacturer.

Once polymerization was complete, the specimens were carefully removed from the molds. Excess material and surface irregularities were eliminated, and all specimens were finished and polished using the same sequence of Sof-Lex polishing discs (3M). Each specimen was visually inspected under magnification to identify bubbles, cracks, pores, or other manufacturing defects. The final dimensions were verified using a 200-mm Mitutoyo digital vernier caliper with a resolution of 0.01 mm.

All accepted specimens were immersed in distilled water and stored at 37 °C for 24 hours before mechanical testing. The preparation, polishing, inspection, dimensional verification, and storage procedures were standardized across the three material groups.

Flexural strength assessment

Flexural strength was evaluated using a three-point bending test in accordance with ISO 4049:2019 [19]. Each bar-shaped specimen was centered on the supporting device of an LG CMT-5L universal mechanical testing machine. A vertical load was applied at the midpoint of the specimen at a crosshead speed of 0.5 mm/min until fracture occurred.

The maximum load at fracture was recorded in newtons with a force resolution of 0.001 N. Flexural strength was expressed in megapascals and calculated from the maximum fracture load, distance between the supports, specimen width, and specimen thickness, in accordance with the calculation procedure established by ISO 4049.

Compressive strength assessment

Compressive strength was assessed in accordance with ISO 3597-3:2003 [20]. Each cylindrical specimen was positioned vertically and centered on the lower platform of the universal mechanical testing machine. The compressive load was applied along the longitudinal axis of the specimen at a crosshead speed of 0.5 mm/min until structural failure or the maximum supported load was reached.

The maximum load was recorded in newtons, and compressive strength was expressed in megapascals. The value was determined from the maximum load supported by the specimen and its initial cross-sectional area following the standardized laboratory procedure. The mechanical tests were conducted under controlled environmental conditions. The temperature ranged from 19.8 °C to 20.7 °C, and relative humidity ranged from 64% to 68% during the two testing sessions.

Measurement instruments and quality control

The primary outcomes were flexural strength and compressive strength, both recorded in megapascals. Mechanical loading was performed using an LG CMT-5L universal testing machine with a force resolution of 0.001 N, and specimen dimensions were verified using a Mitutoyo digital vernier caliper with a resolution of 0.01 mm. Measurement quality was supported by the use of standardized specimen dimensions, internationally recognized mechanical testing procedures, consistent storage conditions, the same measuring equipment, and uniform loading speed for all groups. The same finishing, polishing, visual inspection, and dimensional verification procedures were applied to all specimens before testing. Because the outcomes were objective physical measurements rather than scores from a multi-item scale, assessment of internal consistency using Cronbach's alpha was not applicable.

Statistical Analysis

Data were recorded in a structured data collection form and analyzed using IBM SPSS Statistics, version 27.0. Flexural and compressive strength were analyzed separately. Quantitative variables were summarized using the mean and standard deviation and, when appropriate, the median, interquartile range, minimum, and maximum values.

The distribution of the data within each material group was assessed using the Shapiro–Wilk test because of the number of specimens included in each comparison. Homogeneity of variances was evaluated using Levene's test. When the assumptions of normality and homogeneity of variances were satisfied, differences among the three materials were analyzed using one-way analysis of variance, followed by Tukey's post hoc test. When the data were normally distributed but variances were unequal, Welch's analysis of variance and the Games–Howell post hoc test were applied. When the normality assumption was not met, the Kruskal–Wallis test was used, followed by pairwise comparisons with adjustment for multiple testing. All statistical tests were two-sided, and the significance level was set at 5%.

Ethical considerations

The research project was reviewed and approved by the institutional bioethics committee of the affiliated university in accordance with its regulations for scientific research. Authorization to conduct the mechanical tests was also obtained from the independent laboratory responsible for the experimental procedures. To preserve confidentiality during blinded peer review, the committee's name, institutional affiliation, and approval identifier have been withheld from the anonymized manuscript and will be submitted directly to the journal's editorial office when required. Because this was an in vitro study involving only dental resin specimens and no human participants, animals, biological samples, or identifiable personal information, informed consent was not applicable. The study was conducted without commercial influence on material selection or interpretation of the results, and laboratory waste was managed in accordance with institutional biosafety and waste-disposal regulations.

Results

A total of 54 specimens were analyzed, with nine specimens from each material included in each mechanical test. Statistically significant differences were observed among the three provisional resin materials for both flexural strength ($F = 6.104$, $p = 0.007$) and compressive strength ($F = 20.750$, $p = 0.000$). The bis-acryl resin exhibited the highest mean flexural strength (69.46 ± 7.70 MPa), followed by the 3D-printed resin (60.92 ± 3.54 MPa) and PMMA (57.04 ± 10.36 MPa). The same order was observed for compressive strength, with mean values of 82.25 ± 14.79 MPa for the bis-acryl resin, 75.96 ± 5.62 MPa for the 3D-printed resin, and 51.30 ± 9.89 MPa for PMMA (Table 1).

Table 1. Flexural and compressive strength among a bis-acryl resin, a polymethyl methacrylate resin, and a printed resin.

Strength	Resin	N	Mean	SD	95% CI	F	p
Flexural	PMMA	9	57.04	10.36	49.1–64.9	6.104	0.007**
	Bis-acryl	9	69.46	7.70	63.5–75.4		
	Printed resin	9	60.92	3.54	58.2–63.6		
Compressive	PMMA	9	51.30	9.89	43.7–58.9	20.750	0.000**
	Bis-acryl	9	82.25	14.79	70.9–93.6		
	Printed resin	9	75.96	5.62	71.6–80.3		
Total		54					

***N:** Number; SD: Standard deviation; CI: Confidence interval; F: ANOVA test. *Statistically significant at $p < 0.05$ using one-way ANOVA.

Table 2. Flexural strength of bis-acryl, polymethyl methacrylate, and printed resin specimens.

Strength	Resin groups	DSE	DESP	K	p
Flexural	G1–G2	3.74	0.65	10.22	0.006**
	G1–G3	3.72	2.73	2.44	0.514
	G2–G3	3.74	2.079	7.78	0.038**

*G1: PMMA resin; G2: Bis-acryl resins; G3: Printed resins; DSE: Error deviation; DESP: Test statistic deviation; K: Kruskal–Wallis test. *Statistically significant at $p < 0.05$.

Table 3. Compressive strength of bis-acryl, polymethyl methacrylate, and printed resin specimens.

Strength	Resin groups	DSE	DESP	K	p
Compressive	G1–G2	3.74	3.95	14.78	0.000**
	G1–G3	3.72	2.64	9.89	0.025**
	G2–G3	3.74	1.31	4.89	0.574

*G1: PMMA resin; G2: Bis-acryl resins; G3: Printed resins; DSE: Error deviation; DESP: Test statistic deviation; K: Kruskal–Wallis test. *Statistically significant at $p < 0.05$.

For flexural strength, pairwise comparisons revealed statistically significant differences between PMMA and the bis-acryl resin ($p = 0.006$) and between the bis-acryl and 3D-printed resins ($p = 0.038$). In contrast, no statistically significant difference was observed between PMMA and the 3D-printed resin ($p = 0.514$) (Table 2).

For compressive strength, statistically significant differences were identified between PMMA and the bis-acryl resin ($p = 0.000$) and between PMMA and the 3D-printed resin ($p = 0.025$). No statistically significant difference was found between the bis-acryl and 3D-printed resins ($p = 0.574$) (Table 3).

Discussion

The present study identified statistically significant differences in flexural and compressive strength among the three provisional resin materials, leading to rejection of the null hypothesis. Bis-acryl resin exhibited the highest mean values for both mechanical properties, whereas PMMA showed the lowest values. Nevertheless, the pairwise comparisons differed according to the type of loading. Bis-acryl resin showed significantly greater flexural strength than both PMMA and the 3D-printed resin, while PMMA and the 3D-printed material did not differ significantly. For compressive strength, PMMA differed significantly from the other two materials, whereas bis-acryl and 3D-printed resins presented comparable values. These results indicate that the mechanical behavior of provisional materials depends on the type of stress applied and should not be assessed using a single mechanical property.

The greater flexural strength observed for the bis-acryl resin differs from the findings of Idrissi et al., who reported that heat-polymerized PMMA achieved the highest flexural strength among the provisional materials evaluated [5]. This discrepancy may be related to differences in polymerization method, material formulation, specimen preparation, storage conditions, and testing protocol. The PMMA evaluated in the present study was autopolymerizing, whereas heat-polymerized acrylic resins may develop a more homogeneous polymer structure and a higher degree of conversion [8]. Research involving conventional and bulk-fill composites has also demonstrated that material composition and repair procedures can affect flexural performance [21]. Similarly, the flexural behavior of resin-based core materials and resin cements has been associated with their formulation and structural characteristics [22,23]. Although these materials are not directly equivalent to provisional resins, their findings

support the influence of polymer composition and processing conditions on resistance to bending.

For compressive strength, bis-acryl resin exhibited the highest numerical mean, followed by the 3D-printed resin, with no statistically significant difference between these two materials. Conversely, PMMA showed significantly lower compressive strength than both groups. Malhotra et al. reported differences in compressive and flexural strength among conventional, resin-modified, and hybrid glass-ionomer materials [24], while Jayakumar et al. identified significant mechanical differences among resin-based core materials and an alkasite restorative material [25]. Although those studies evaluated different material categories, they similarly indicate that chemical formulation and processing directly influence mechanical resistance. The performance of the 3D-printed resin in the present study is also consistent with previous evidence showing that additively manufactured provisional materials may achieve mechanical properties comparable to those of conventional alternatives [6]. However, their behavior can vary according to resin composition, printing orientation, layer configuration, surface treatment, and post-curing protocol [7].

From a clinical perspective, the higher flexural strength of bis-acryl resin suggests that it may be advantageous for provisional restorations subjected to bending stresses, particularly in posterior regions, extended spans, or prolonged treatment periods. The absence of a significant compressive difference between bis-acryl and 3D-printed resins also indicates that the printed material may represent a suitable alternative within digital restorative workflows. Nevertheless, PMMA should not be considered clinically unsuitable solely because it exhibited lower values in this experiment. Material selection also depends on reparability, handling, cost, esthetics, restoration design, treatment duration, and occlusal conditions. Surface finishing and polishing can influence the roughness of resin-based materials [26], while exposure to staining solutions and subsequent polishing may affect their optical behavior [27]. Polymerization dynamics may also influence the final structural properties of resin systems [28]. Therefore, mechanical strength should be considered together with surface quality, color stability, dimensional accuracy, and clinical manageability.

The principal strengths of this study were the standardized specimen dimensions, uniform storage conditions, objective mechanical testing, and simultaneous evaluation of two clinically relevant properties. However, several limitations must be acknowledged. The in vitro design did not reproduce thermal variations, saliva, pH changes, cyclic fatigue, dietary exposure, or multidirectional occlusal forces. Previous evidence indicates that immersion in acidic beverages can alter the flexural strength of resin-based materials [29], suggesting that the values obtained under controlled laboratory conditions may differ from those observed after clinical aging. In addition, only one commercial product from each material category was evaluated, and each mechanical test included nine specimens per group, limiting generalization to other resin systems.

Potential differences associated with chemical composition and exposure to resin components should also be considered when assessing the broader biological and occupational behavior of polymeric materials [30]. Future studies should evaluate several commercial brands, different printing orientations and post-curing protocols, thermocycling, prolonged water storage, cyclic loading, fracture patterns, and Weibull reliability. Clinical investigations are also required to determine whether the observed mechanical differences translate into differences in fracture incidence, restoration survival, or treatment-related complications

Conclusions

The bis-acryl resin exhibited the highest flexural strength and was significantly stronger than both PMMA and the 3D-printed resin. It also showed the highest compressive strength, with a significant difference compared with PMMA but not with the 3D-printed resin. Under the conditions of this in vitro study, the bis-acryl resin demonstrated the most favorable overall mechanical performance among the materials evaluated.

Author Contributions Statement (CrediT)

VS: Conceptualization, Methodology, Writing – Original Draft, Supervision, Formal analysis, Data curation, Validation, Visualization, Resources, Project administration, Funding acquisition, Writing – Review & Editing.

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Conflict of Interest

The authors declare that they have no financial, institutional, commercial, or personal conflicts of interest that could have influenced the design, conduct, analysis, interpretation, or publication of this study.

Data Availability

The datasets generated and analyzed during this in vitro study, including the raw flexural and compressive strength measurements, are available from the corresponding author upon reasonable request.

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