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Flexural strength comparison of conventional and CAD/CAM additive provisional restorative materials: An *in vitro* study

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Abstract:
Provisional restorations require adequate flexural strength to withstand functional forces during clinical service. Therefore, it is of interest to compare the flexural strength of CAD/CAM additive-manufactured and conventionally fabricated provisional restorative materials using 52 standardized specimens. The additive-manufactured specimens showed significantly higher flexural strength than the conventionally fabricated specimens. Thus, data shows the potential of additive manufacturing as a mechanically advantageous approach for provisional restorations, although further clinical investigations are required to establish its long-term effectiveness.

Keywords: Computer-Aided Design (CAD)/ Computer-Aided Manufacturing (CAM), additive manufacturing, 3d printing, flexural strength, provisional restoration, digital dentistry, fixed prosthodontics

Background:
Provisional restorations play a fundamental role in fixed prosthodontics by protecting prepared teeth, preserving esthetics and occlusal relationships, maintaining periodontal health and allowing evaluation of function and phonetics before placement of the definitive prosthesis **[1]**. The clinical success of these restorations depends not only on marginal adaptation and esthetics but also on their mechanical properties, particularly flexural strength, because they are subjected to continuous tensile, compressive and shear stresses during mastication. Insufficient flexural strength may lead to fracture, loss of function and replacement of the provisional restoration, thereby compromising treatment outcomes **[2]**. Conventional provisional restorative materials, including polymethyl methacrylate, polyethyl methacrylate and bis-acryl composite resins, remain widely used owing to their ease of manipulation, acceptable esthetics and favorable clinical handling. However, these materials are susceptible to polymerization shrinkage, marginal discrepancies and internal porosity and reduced fracture resistance, which may adversely affect their long-term clinical performance **[3]**. Advances in digital dentistry have transformed the fabrication of provisional restorations through computer-aided design and computer-aided manufacturing (CAD/CAM) technologies. Additive manufacturing has emerged as a promising alternative to conventional fabrication because it enables standardized production, minimizes material waste, improves manufacturing efficiency and facilitates fabrication of complex geometries with high dimensional accuracy **[4]**. Furthermore, the controlled manufacturing workflow and industrially polymerized resin systems used in additive manufacturing contribute to improved material consistency and mechanical performance **[5]**. Recent systematic reviews have demonstrated that additively manufactured provisional restorative materials generally exhibit flexural strength comparable with or superior to conventionally fabricated materials, although considerable variability remains due to differences in resin formulations, printing technologies, layer thickness and post-processing procedures **[6]**. Environmental factors, including moisture exposure and oral conditions, may further influence the mechanical behavior of provisional materials and should be considered when evaluating their clinical performance **[7]**. Despite the increasing clinical adoption of CAD/CAM additive manufacturing, inconsistencies among published studies have limited definitive conclusions regarding its mechanical advantages over conventional fabrication techniques **[8]**. Therefore, it is of interest to compare the flexural strength of provisional restorative materials fabricated using CAD/CAM additive manufacturing and conventional techniques.

Materials and Methods:
Study design:
The present investigation was designed as an *in vitro* experimental comparative study conducted at NIMS Dental College and Hospital.
A total of 52 standardized specimens were fabricated and divided equally into two groups (n = 26):
[1] Group 1: CAD/CAM additive-manufactured provisional restorative specimens
[2] Group 2: Conventional Protemp™ 4 provisional restorative specimens
Standardized bar-shaped specimens measuring 25 mm × 2 mm × 2 mm were prepared according to ISO 10477:2018 recommendations for flexural strength testing of polymer-based restorative materials. This design minimized geometric variability and permitted reliable assessment of intrinsic material properties.

Ethical considerations:

The study protocol was reviewed and approved by the Institutional Ethics Committee of NIMS University Rajasthan, Jaipur Approval No. IEC/P560-/2024

Sample size calculation:
The sample size was calculated using the following formula:

$$n = [(Z_{\alpha/2} + Z_{1-\beta})^2 \times (\sigma_1^2 + \sigma_2^2)] / \Delta^2$$

Using a confidence level of 95%, study power of 80% and expected differences derived from previous literature, the required sample size was calculated as 25.9 specimens per group and rounded to 26 specimens per group.
Therefore:
[1] Group 1 = 26 specimens
[2] Group 2 = 26 specimens
Total sample size = 52 specimens.

Inclusion criteria:
[1] Properly cured and polished specimens
[2] Uniform dimensions and thickness
[3] Absence of visible defects
[4] Storage in artificial saliva for 15 days at 37°C
[5] Compliance with ISO 10477:2018 specifications

Exclusion criteria:
[1] Distorted specimens
[2] Specimens exhibiting porosity
[3] Uneven thickness
[4] Visible cracks or defects

Randomization:
All fabricated specimens were assigned identification numbers and randomized before testing using a computer-generated random sequence to minimize allocation bias.

Calibration:
The Universal Testing Machine was calibrated according to the manufacturer's instructions before commencement of testing.

Fabrication of CAD/CAM additive-manufactured specimens:
Specimens were digitally designed using Chitubox Basic Version 2.3 software according to ISO 10477:2018 specifications. A standardized virtual template measuring 25 mm × 2 mm × 2 mm was created and exported as Standard Tessellation Language (STL) files. The STL files were printed using an ELEGOO Saturn 3 Ultra Digital Light Processing (DLP) 3D printer (ELEGOO, Shenzhen, China) with Orikam Neo 3D photopolymer resin. Printing was performed using a layer thickness of 50–100 µm and manufacturer-recommended exposure settings. Following printing, specimens were washed in isopropyl alcohol to remove uncured resin, support structures were carefully removed and post-curing was performed in a UV-curing unit according to the manufacturer's recommendations. Final finishing and polishing were completed using sequential silicon carbide abrasive papers.

Fabrication of conventional specimens:
Conventional specimens were fabricated using Protemp™ 4 bis-acryl composite resin within a custom-made stainless-steel split mould measuring 25 mm × 2 mm × 2 mm. The material was dispensed using an automixing dispensing gun to minimize air incorporation and ensure uniform consistency. After polymerization, specimens were retrieved from the mould, finished, polished and dimensionally verified using a digital Vernier caliper.

Storage protocol:
All specimens were immersed individually in artificial saliva (pH 6.9) and stored at 37°C for 15 days to simulate oral environmental conditions.

Flexural strength testing:
Following storage, all specimens were subjected to a three-point bending test using a WDW 5 kN Universal Testing Machine (Banbros, Taiwan).

Testing parameters included:
[1] Testing method: Three-point bending
[2] Crosshead speed: 0.75 mm/min
[3] Outcome measure: Flexural strength (MPa)

Flexural strength was calculated using the formula:
$FS = 3FL / 2bd^2$
Where:
[1] FS = Flexural strength (MPa)
[2] F = Maximum fracture load (N)
[3] L = Span length (mm)
[4] b = Specimen width (mm)
[5] d = Specimen thickness (mm)

Statistical analysis:
Data were analyzed using Statistical Package for the Social Sciences (SPSS) software. Normality of data distribution was assessed using the Shapiro–Wilk test. Mean, standard deviation and standard error were calculated for both groups. Homogeneity of variance was evaluated using Levene's test. Intergroup comparison was performed using the Independent Samples t-test. Statistical significance was established at $p < 0.05$.

Results:
The CAD/CAM additive-manufactured provisional restorative material demonstrated a higher mean flexural strength (291.71 ± 13.15 MPa) compared with the conventionally fabricated Protemp™ 4 material (268.14 ± 10.69 MPa) **Table 1.** The findings indicate superior resistance to bending forces in the CAD/CAM additive group. Levene's test demonstrated homogeneity of variance between the groups ($p = 0.258$). Independent Samples t-test revealed a statistically significant difference in flexural strength between the two groups ($p < 0.001$). The CAD/CAM additive-manufactured specimens exhibited a mean flexural strength that was 23.56 MPa greater than that of the Protemp™ 4 specimens. Therefore, the null hypothesis was rejected **Table 2**.

Table 1: Descriptive distribution of flexural strength

Group (n=26)	Mean ± SD (MPa)	SEM
CAD/CAM Additive	291.71 ± 13.15	2.58
Protemp™ 4	268.14 ± 10.69	2.10

Table 2: Intergroup comparison of flexural strength

Variable	F	p	t	df	Mean Difference	95% CI	p-value
Flexural Strength	1.31	0.258	7.089	50	23.56	16.88–30.24	<0.001

Discussion:

Mechanical durability is an essential requirement for provisional restorative materials because these restorations are expected to withstand functional and parafunctional occlusal forces throughout the provisional phase of treatment. Among the various mechanical properties, flexural strength is considered one of the most clinically relevant indicators of fracture resistance and restoration longevity **[2]**. The present investigation demonstrated that CAD/CAM additive-manufactured provisional restorations exhibited significantly greater flexural strength than conventionally fabricated Protemp™ 4 restorations, resulting in rejection of the null hypothesis. The superior performance observed in the additive-manufactured group agrees with previous evidence demonstrating enhanced mechanical characteristics of digitally fabricated interim restorative materials **[5, 9]**. Controlled photopolymerization during additive manufacturing promotes a higher degree of monomer conversion and formation of a dense cross-linked polymer network, thereby improving resistance to deformation and fracture **[8, 10]**. In addition, industrially manufactured photopolymer resins exhibit greater compositional homogeneity and fewer internal defects than conventionally mixed materials, further contributing to improved mechanical performance **[5]**. Post-processing procedures also play a critical role in determining the final mechanical properties of printed restorations. Washing protocols eliminate residual uncured resin, whereas appropriate post-curing enhances polymerization, increases cross-link density and improves dimensional stability **[11–13]**. Consequently, optimization of post-processing procedures is essential for achieving consistent mechanical behavior and maximizing the clinical performance of additively manufactured provisional materials. Printing parameters represent another important determinant of flexural strength. Previous investigations have showed that build orientation, layer configuration and printing strategy significantly influence stress distribution, interlayer bonding and fracture resistance of printed restorations **[14–16]**. Appropriate optimization of these variables may further improve the mechanical reliability of CAD/CAM additive-manufactured provisional restorations. To better simulate the oral environment, all specimens in the present study were stored in artificial saliva before mechanical testing. Despite this environmental exposure, the additive-manufactured specimens maintained significantly higher flexural strength than conventionally fabricated restorations. Similar findings have been reported following artificial aging, thermocycling and hydrothermal degradation, indicating that modern CAD/CAM resin materials maintain favorable mechanical stability under simulated clinical conditions **[7, 17–26]**. The findings of the present study are further supported by recent systematic reviews, which concluded that contemporary 3D-printed provisional restorative materials generally show favorable flexural strength and may provide mechanical performance equal or superior to conventional provisional materials **[6, 21]**. These observations suggest that CAD/CAM additive manufacturing may be particularly advantageous for long-span provisional restorations, implant-supported prostheses, full-mouth rehabilitation and patients with increased occlusal loading, where enhanced fracture resistance is clinically desirable. The present study has certain limitations. As an *in vitro* investigation, it could not fully reproduce the complex oral environment, including cyclic fatigue, thermal fluctuations, pH variations, enzymatic degradation and long-term functional loading. Future studies incorporating thermocycling, fatigue testing, wear analysis and randomized clinical trials are necessary to establish the long-term clinical performance and durability of CAD/CAM additive-manufactured provisional restorative materials.

Conclusion:

CAD/CAM additive-manufactured provisional restorative materials showed significantly higher flexural strength than conventional Protemp™ 4 bis-acryl resin. The superior performance may be attributed to improved polymerization, enhanced material homogeneity and reduced internal defects associated with additive manufacturing. Thus, data shows that CAD/CAM additive-manufactured provisional materials offer improved mechanical reliability and may serve as a suitable alternative for provisional restorations subjected to increased functional demands.

Ethical approval:

Institutional Ethics Committee, NIMS University Rajasthan
Approval No.: IEC/P560-/2024.

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Author contributions:

All authors contributed to the conception and design of the study, data collection, analysis and interpretation of data, manuscript preparation, critical revision of the manuscript and approved the final version for publication.

References:

[1] https://www.scribd.com/document/445292875/Provisional-Restorations-in-Fixed-Prosthodontics

[2] Haselton DR *et al. J Prosthet Dent*. 2002 **87**:225. [PMID: 11854681]
[3] Al-humood H *et al. Materials (Basel)*. 2023 **16**:1996. [PMID: 36903109]
[4] Tian Y *et al. Scanning*. 2021 **2021**:9950131. [PMID: 34367410]
[5] Revilla-León M *et al. J Esthet Restor Dent*. 2019 **31**:51. [PMID: 30367716]
[6] Yildırım Ö *et al. BMC Oral Health*. 2025 **25**:82. [PMID: 39825379]
[7] Alzaid M *et al. Eur J Dent*. 2023 **17**:234. [PMID: 35820440]
[8] Park SM *et al. Materials (Basel)*. 2020 **13**:3970. [PMID: 32911702]
[9] Saini RS *et al. BMC Oral Health*. 2024 **24**:66. [PMID: 38200473]
[10] Alshamrani AA *et al. Biomed Res Int*. 2022 **2022**:8353137. [PMID: 35237691]
[11] Hwangbo NK *et al. Polymers (Basel)*. 2021 **13**:4410. [PMID: 34960960]
[12] Pagac M *et al. Polymers (Basel)*. 2021 **13**:598. [PMID: 33671195]
[13] Kang MJ *et al. Materials (Basel)*. 2022 **15**:6889. [PMID: 36234230]
[14] Alharbi N *et al. J Prosthet Dent*. 2016 **115**:760. [PMID: 26803175]
[15] Mudhaffer S *et al. J Prosthet Dent*. 2025 **133**:1345. [PMID: 39366837]
[16] Kaiahara FH *et al. Polymers (Basel)*. 2025 **17**:265. [PMID: 39940468]
[17] Kato Y *et al. J Prosthodont Res*. 2026 [PMID: 42036345]
[18] Abou-Obaid AI *et al. Open Access Library Journal*. 2024 **11**:1. [DOI: 10.4236/oalib.1111959]
[19] Abdullah HA *et al. Braz Dent Sci*. 2024 **4**:e4368. [DOI: 10.4322/bds.2024.e4208]
[20] Tavuz KA *et al. J Mech Behav Biomed Mater*. 2025 **161**:106817. [PMID: 39571468]
[21] Alqarni AI *et al. World J Adv Res Rev*. 2024 **23**:2890. [DOI: 10.30574/wjarr.2024.23.2.2431]
[22] Sree MD *et al. IOSR Journal of Dental and Medical Sciences.* 2026 **25**:66. [DOI: 10.9790/0853-2505026670]
[23] Pallis D *et al. J Esthet Restor Dent*. 2025 **37**:2011. [PMID: 40296335]
[24] Karthikeyan *et al. Biosc.Biotech.Res.Comm.* 2020 **13**:187 [DOI: 10.21786/bbrc/13.8/134]
[25] Al-Dwairi ZN *et al. J Prosthodont*. 2020 **29**:341. [PMID: 29896904]
[26] Idrissi HA *et al. Children*. 2023 **10**:380. [DOI: 10.3390/children10020380]

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