DOI: 10.7860/JCDR/2026/85337.23407

Original Article

Dentistry Section

Comparative Evaluation of Microhardness of CAD/CAM-milled, 3D-printed and Conventional Chairside Interim 3-Unit Fixed Dental Prosthesis: An In-vitro Study

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ABSTRACT

Introduction: Interim Fixed Dental Prostheses (FDP) are essential for maintaining aesthetics, function and occlusal stability during comprehensive dental treatments. The surface microhardness is the key determinant of their durability and resistance to wear.

Aim: To evaluate and compare the *"microhardness"* of fixed dental prosthesis made using traditional techniques, Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM) milling and 3D printing.

Materials and Methods: This in-vitro study was carried out at the Department of Prosthodontics and Crown and Bridge, Bharati Vidyapeeth (Deemed to be University) Dental College and Hospital, Sangli, Maharashtra, India, between October 2024 to December 2024. A total of 30 specimens (N=30) were fabricated using traditional techniques, CAD/CAM machining and 3D printing. The samples were thermocycled for 5,000 cycles in order to simulate the oral condition. Vicker's microhardness test was used to measure microhardness. One-way Analysis of Variance (ANOVA) was used for comparisons between groups (i.e., more than two groups) and the Tukey's post-hoc test was used for comparisons between groups. The p<0.05 was deemed statistically significant.

Results: The 3D-printed group, CAD/CAM group and traditional group had mean microhardness values of 25.70±1.42 HV, 29.90±1.60 HV and 33.80±1.32 HV, respectively. One-way ANOVA test showed f-value=78.2809 and p<0.0001*, which showed that there was statistically significant difference. On pair-wise comparison using Post-hoc Tukey's Honest Significant Difference (HSD) test, highly statistically significant difference was seen between all groups where Conventional showed greater microhardness then followed by CAD/CAM-milled and 3D-printed.

Conclusion: These findings suggest that the *"conventional bis-acryl technique"* provides superior surface microhardness, which may enhance clinical performance and longevity. Additional in-vivo research is required to assess other clinical and mechanical factors.

Keywords: Acrylic resins, Computer-aided design, Computer-aided manufacturing, Composite resins, Surface properties

INTRODUCTION

Interim restoration should satisfy biological, mechanical and aesthetic requirement until final restoration is fabricated. Interim restorations must function in the oral cavity for a longer period of time due to orthodontic or endodontic treatments, temporomandibular joint disorders and during implant osseointegration.

Interim materials microhardness is crucial for long-term use, pulpal protection, periodontal health, occlusal compatibility, maintaining tooth position, protection against fracture, resistance to functional loads, resistance to removal forces, maintaining inter-abutment alignment. Interim restoration should be easily contourable and contour adjacent gingiva, colour stable and have sufficient translucency and function against parafunctional habits [1,2].

A provisional Fixed-Dental Prosthesis (FDP) serves as a diagnostic purpose for defining tooth contour, aesthetics, proximal contacts and occlusion outcome prior to the completion of the definitive prosthesis [1].

They should have good mechanical qualities to withstand the complicated oral environment.

Hardness is one of the mechanical qualities that can be applied to predict the material's wear behaviour [3]. Surface hardness indicates density and suggests that denser materials may be more resistant to wear and surface degradation [4].

Mechanical qualities such as strength and stiffness play significant roles. Interim fixed dental prosthesis should be strong enough to withstand fractures and stiff enough to prevent excessive deformation during functional loading. Material selection significantly impacts the performance of an interim fixed dental prosthesis [5].

There is a scarcity of literature on determining the qualities like flexural strength, marginal gap, hardness, microhardness etc., of interim restorative materials made with modern technologies. The aim of the present in-vitro study was to compare the microhardness of CAD/CAM-milled, 3D-printed and conventional interim three unit prostheses.

MATERIALS AND METHODS

The present in-vitro study was carried out at the Department of Prosthodontics and Crown and Bridge, Bharati Vidyapeeth (Deemed to be University) Dental College and Hospital, Sangli, Maharashtra, India for a period of three months between October 2024 to December 2024 with IEC no BV(DU)MC&H/Sangli/Institutional Ethics Committee (IEC)/D-121/24.

Sample size calculation: Sample size was calculated using G power software with α err prob=0.05 and Power (1-β err prob)=0.95.

Approximately, 10 samples per group were needed in the study.

Study Procedure

A mandibular first molar was removed from the typodont and the adjacent second premolar and second molar were prepared as abutments for an idealised 3-unit fixed dental prosthesis with 1 mm shoulder using flat end tapered fissure diamond bur and the internal line angle was rounded [6]. The occlusal reduction was 1.5 mm with 6 degrees of convergence which was achieved with the help of milling machine. (Paraskop M-Bego, USA). The socket of mandibular 1st molar was filled with modelling wax (Deepti Dental Products of India Pvt. Ltd.,).

Prepared premolar and molar were scanned (Irific NH-100 intraoral scanner) and the master die was fabricated by using a Computer-Aided Designing (CAD) software and 3D printing. (Anycubic-Standard Resin). A total of 30 dies were fabricated [Table/Fig-1].

[Table/Fig-1]: Fabrication of master die.

Over these 30 dies; 30 three-unit FDP were fabricated by various techniques i.e., CAD/CAM-milled, 3D-printed and Conventional i.e., 10 sample per group.

Restorations which had good finish were included for the study.

Restorations which had cracks, incomplete seating, rocking, large pores were excluded.

The die was scanned and digitally designed for the fabrication of CAD-CAM (Ruthinium-PMMA milled) and 3D-printed (Jamg he-C&B-3D-printed resin) interim fixed dental prosthesis. The connector cross-sectional area was designed for Buccolingual (BL) and Mesiodistal (MD) aspects of the 2nd premolar and 1st molar teeth. The connector cross-sectional area for 2nd premolar and 1st molar was BL=3.63 mm and MD=3.77 mm (i.e., 10 mm^2) and for 1st molar and 2nd molar was BL=3.39 mm and MD=4.59 mm (i.e., 12 mm^2). A modified saddle pontic made light buccal contact with the die.

The Standard Tessellation Language (STL) file with scanned data was imported into a CAD-CAM program for the design of the interim prosthesis. Milled FDPs were fabricated from CAD-Temp Poly(methyl methacrylate) (PMMA) blocks.

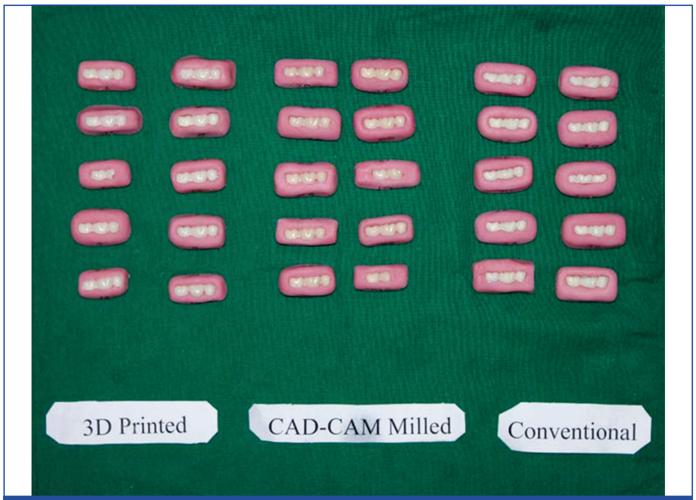
A 3D-Printed specimen was made from a resin material in a 3D Digital Light Processing (DLP) printer at a 90 degree build orientation with a thickness of 1.5 mm.

A total of 30 specimens were fabricated (n=10). Conventional prostheses were made from Putty index of already fabricated prosthesis with putty and light body (Avue-Dental Avenue). The interim restorative material (Protemp 4 TM -bisacrylic composite) was injected into putty index and allowed to set completely according to manufacturer's instructions. The prostheses were finished and polished using rotary rubber cups using a handpiece at a speed of 2000 to 5000 rpm and then examined around for any defect [Table/Fig-2].

[Table/Fig-2]: Fabrication of prostheses over dies.

All specimens were thermocycled for 5,000 cycles in distilled water (5°C and 55°C, transfer time of 10 seconds and dwell time of 60 seconds) in a digitally controlled water-bath chamber (Bio-Technics India) to represent six months of oral environment.

The specimens were used to determine the surface hardness. They were embedded in acrylic resin as a measure to secure in place for microhardness testing [Table/Fig-3].



[Table/Fig-3]: Specimens fabricated by 3D printing, CAD/CAM milling and conventional methods.

All specimens were subjected to the Vicker`s micro-indentation test under a load of 50g for 15 sec contact time. Indentation diagonals were used to calculate surface hardness [Table/Fig-4].

[Table/Fig-4]: Specimens subjected to Vicker`s micro-indentation test.

STATISTICAL ANALYSIS

Data obtained was compiled on a Microsoft (MS) office excel sheet and was subjected to statistical analysis using Statistical package for social sciences {Statistical Package for Social Sciences (SPSS) v 26.0, IBM}. Descriptive statistics like Mean and SD for numerical data have been depicted. Normality of numerical data was checked using Shapiro-Wilk test; it was found that the data followed a normal curve; hence parametric tests were used for comparisons Intergroup comparison (i.e., >2 groups) was done using One-way ANOVA followed by pair-wise comparison using Tukey's Post-hoc test. For all the statistical tests, $p<0.05$ was considered to be statistically significant, keeping α error at 5% and β error at 5%, thus giving a power to the study as 95%.

RESULTS

On microhardness analysis, cumulative mean and standard deviation for CAD/CAM-milled group was 29.90 and 1.60, for 3D-printed group it showed 25.70±1.42 and for Conventional group it was 33.80±1.32. One-way ANOVA test showed f-value=78.2809 and $p<0.0001^*$, which showed that there was statistically significant difference [Table/Fig-5].

Groups	Mean (HV)	Std. Dev.	Std. Err.	95% CI for mean		f-value	p-value
				Lower	Upper		
3D-printed	25.70	1.42	0.45	24.69	26.71	78.2809	0.0001*
CAD-CAM	29.90	1.60	0.50	28.76	31.04		
Conventional	33.80	1.32	0.42	32.86	34.74		

[Table/Fig-5]: Cumulative mean and standard deviation of hardness value for three groups and comparison of three groups by One-way ANOVA.
*$p<0.05$

On pair-wise comparison using Post-hoc Tukey's HSD test, highly statistically significant difference was seen between all groups where Conventional showed greater microhardness followed by CAD/CAM-milled and 3D-printed. On comparison between 3D and CAD-CAM, CAD-CAM showed to have greater microhardness than 3D-printed and between 3D and conventional methods, conventional had greater microhardness than 3D-printed. On comparison with CAD-CAM and conventional, conventional had greater microhardness than CAD-CAM [Table/Fig-6].

(I) Group	(J) Group	Mean difference (I-J)	Std. error	p-value	95% Confidence interval	
					Lower bound	Upper bound
3D-printed	CAD-CAM	-4.20	0.6475	0.0001*	-5.81	-2.59
	Conventional	-8.10	0.6475	0.0001*	-9.71	-6.49
CAD-CAM	Conventional	-3.90	0.6475	0.0001*	-5.51	-2.29

[Table/Fig-6]: Pair wise comparison of hardness value for three groups using Tukey's Post-hoc test.
*$p<0.05$

DISCUSSION

The results of the present in-vitro study demonstrated that the conventional bis-acrylic group achieved the highest microhardness values (33.80±1.32 HV), followed by the CAD/CAM-milled group (29.90±1.60 HV) and the 3D-printed FDP group (25.70±1.42 HV). A one-way ANOVA revealed a statistically significant difference between these fabrication techniques ($f = 78.28$, $p<0.0001$). The superior microhardness observed in the conventional group is primarily attributed to the chemical composition of bis-acrylic composite resins, which contain multifunctional monomers such as bisphenol A-glycidyl methacrylate (Bis-GMA) and Triethylene Glycol Dimethacrylate (TEGDMA). As noted by Savabi O et al., these monomers facilitate an extensive cross-linking density that enhances the overall mechanical strength and surface resistance [3]. Furthermore, the incorporation of inorganic fillers in bis-acryl composites helps reduce polymerisation shrinkage and improves abrasion resistance compared to traditional monomethacrylate-based resins [4,7].

The findings of the present study are consistent with those of Wechkunanukul N et al., who reported significantly higher microhardness for conventional resins compared with the milled and 3D-printed materials ($p<0.05$) [8]. Farina AP et al., similarly suggested that optimised polymerisation cycles can increase monomer conversion [9], thereby enhancing surface hardness and reducing the plasticising effect of residual monomers. However, these results contrast with research by Mukherjee B et al. and Mukherjee S et al. and Jain A et al., which indicated that CAD-CAM milling produced superior hardness due to industrial pre-polymerisation under high pressure [10-12]. In the present study, while CAD/CAM-milled PMMA performed better than 3D-printed resins, it did not surpass the bis-acrylic composite. The high density and minimal porosity of industrially polymerised CAD-Temp PMMA blocks remain a significant advantage for long-term functional stability [7,13].

In contrast, 3D-printed FDPs exhibited the lowest microhardness. According to Yıldırım M, this deficit may stem from variations in printer settings, such as build orientation and layer thickness, which affect the material's internal structural integrity [14,15]. The layer-by-layer additive manufacturing process can lead to decreased polymer density and higher interfacial porosity compared to milled or conventional materials [15,16]. While authors like Digholkar S et al. and Revilla-León M et al., have suggested that 3D printing can achieve high mechanical properties [1,17], recent studies by Chen M et al. and Korsel AM and Al-Zord M emphasise that 3D resins are highly technique-sensitive and often require intensive post-curing to approach the hardness levels of subtractive methods [18,19]. Clinically, microhardness is a vital predictor of wear behaviour and plaque resistance; materials with higher hardness offer smoother, denser surfaces that resist bacterial colonisation [1,20,21]. Although this study provides valuable data, future research should incorporate aging protocols and in-vivo conditions to further assess the long-term performance of these materials [22].

Limitation(s)

The present study was conducted under in-vitro conditions, which may not fully replicate the complexities of clinical scenarios. Furthermore, only a single material was assessed for each fabrication technique, thereby limiting the generalisability of the findings across other materials or methods. In addition, other relevant mechanical properties- such as surface roughness, flexural strength and marginal adaptation- were not evaluated, which restricts the comprehensiveness of the conclusions.

CONCLUSION(S)

When microhardness was compared across several manufacturing methods, the traditional bis-acryl approach demonstrated the highest microhardness, followed by the CAD/CAM-milled and 3D-printed groups.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]

- Plagiarism X-checker: Jan 06, 2026
- Manual Googling: Jan 14, 2026
- iThenticate Software: Jan 17, 2026 (8%)

ETYMOLOGY: Author Origin

EMENDATIONS: 6

AUTHOR DECLARATION:

- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? Yes
- Was informed consent obtained from the subjects involved in the study? No
- For any images presented appropriate consent has been obtained from the subjects. No

Date of Submission: **Nov 11, 2025**
Date of Peer Review: **Jan 08, 2026**
Date of Acceptance: **Jan 20, 2026**
Date of Publishing: **May 01, 2026**