Journal of Oral Biology and Craniofacial Research 16 (2026) 101405

Contents lists available at ScienceDirect

Journal of Oral Biology and Craniofacial Research

journal homepage: www.elsevier.com/locate/jobcr

Compressive and flexural strength of provisional crown materials fabricated by conventional and 3D printing techniques: An in vitro study ☆

Nandini R.D. *, Nirupama R, Chetan Hegde

Department of Prosthodontics, NITTE Deemed to be University, A B Shetty Memorial Institute of Dental Sciences, Mangalore, Karnataka, India, 575018

ARTICLE INFO

Keywords:
3D printing
GC tempron
Temporary dental prosthesis
Provisional restorations
Flexural strength

ABSTRACT

Purpose: To compare the mechanical properties of the new 3D Accuprint C&B resin against both conventional and other 3D-printed resins to determine its viability for provisional crown fabrication.
Materials and methods: Three materials were selected for comparison: GC Tempron (conventional), 3D Accuprint C&B, and Freeprint Temp (3D-printed resins). Fifteen cylindrical specimens (6 mm × 4 mm) were prepared from each material for compressive strength testing, and fifteen rectangular specimens (25 mm × 2 mm × 2 mm) were fabricated for flexural strength testing as per the manufacturer's instructions. Testing was performed using a universal testing machine. The recorded compressive and flexural strength values were statistically analyzed after confirming normality (Shapiro–Wilk test) and homogeneity (Levene's test). All statistical analyses were conducted using IBM SPSS Statistics software (version 25), with the level of significance set at $p < 0.05$. Data were analyzed using one-way ANOVA with Tukey's HSD test.
Results: Significant intergroup differences were found for both compressive and flexural strength ($p < 0.001$). GC Tempron showed significantly lower values compared with both 3D printed materials ($p < 0.001$). Freeprint Temp and 3D Accuprint did not differ significantly (compressive strength, $p = 0.84$; flexural strength, $p = 0.15$).
Conclusions: 3D Accuprint C&B demonstrated superior mechanical strength compared to GC Tempron and comparable properties to Freeprint Temp. These findings confirm its mechanical viability as a high-performance alternative, making it better suited for durable provisional restorations, particularly in cases involving high resistance to stress, parafunctional habits, or implant-supported prostheses.

1. Introduction

A well-fabricated provisional or interim restoration is crucial in fixed prosthodontics and implantology. It maintains the stability of the abutment tooth and the health of the surrounding soft tissue until a definitive prosthesis is delivered.[1,2] These restorations are essential in various clinical scenarios, such as full mouth rehabilitation, immediate implant loading, and crown lengthening.[1] From a diagnostic perspective, provisional restorations are essential in developing functional, occlusal, and aesthetic parameters. They aid in identifying optimal treatment outcomes and serve as a template for defining tooth contours, aesthetics, proximal contacts, and occlusion.[2]

There are various materials and techniques available for the fabrication of interim restorations. The materials are broadly classified into two groups based on chemical composition: acrylic resins, which include polymethyl methacrylate (PMMA) and polyethyl or butyl methacrylate (PEMA), and composite resins, which consist of materials such as urethane dimethacrylate (UDMA) and bisphenol A-glycidyl dimethacrylate (Bis-GMA).[1,3] The material need varies based on the technique chosen to fabricate the provisional restoration.

The two major factors affecting the durability of a provisional restoration are the compressive and flexural strengths of the restorative material. The average masticatory forces recorded in an adult range from 300 to 500 N (N), placing significant demands on the biomechanical properties of restorative materials.[4] These properties are invariably affected by the setting reaction of the resin material, which

☆ **Institution where the work was performed**: Nitte (Deemed to be University), AB Shetty Memorial Institute of Dental Sciences (ABSMIDS), Department of Prosthodontics, Deralakatte, Mangalore 575018, Karnataka, India

All authors involved in this paper have individually checked and approved the manuscript for the final submission.

* Corresponding author. Department of Prosthodontics, NITTE Deemed to be University, A B Shetty Memorial Institute of Dental Sciences, Mangalore, Karnataka, India, 575018

E-mail address: dr.nandini.dastikop@gmail.com (N. R.D.).

https://doi.org/10.1016/j.jobcr.2026.101405
Received 4 November 2025; Received in revised form 29 November 2025; Accepted 14 January 2026
Available online 27 January 2026

Table 1
Description of the materials utilized in the present study.

Type of material	Product	Component
Conventional	GC Tempron	Poly methyl methacrylate
3D printing resin	3D Accuprint C&B	Methacrylic Oligomers + Phosphine oxide + Inert nanofillers
	Freeprint Temp	Bis-acrylate resin

becomes a hindrance, particularly when the provisional restoration is required for prolonged duration, or in the cases of parafunctional habits and long-span prostheses.[2] Therefore, these properties play a crucial role in determining the type of material to be incorporated in the fabrication of a provisional restoration.

Conventional direct techniques for fabricating provisional restorations typically utilize traditional self-cured polymethyl methacrylate (PMMA) or bis-acryl resin materials. Although there are several advantages with the conventional technique, namely, the cost-effectiveness, reliability, and ease of fabrication, certain associated drawbacks are the risk of polymerization shrinkage and potential for marginal discrepancies as the material is removed prior to completion of polymerization. The excessive heat generated during the process could induce a reactionary pulpal response as well, thus affecting the pulp status of the abutment tooth.[5]

The introduction of digital technology has revolutionized the field of prosthodontics, creating a significant change to the existing treatment modalities.[5] The 3D printing technique uses a standard tessellation language (STL) file to create a series of cross-sectional slices that are printed in layers, one on top of each other, thus reducing manufacturing time and minimizing raw material waste. As a result, it could be a cost-effective option for fabricating provisional crowns and fixed dental prostheses (FDPs).[2,5] With the availability of newer materials and techniques, understanding the mechanical properties of these materials will help clinicians choose the ideal material and method for provisional restorations.[2] Previous literature has compared the mechanical properties of materials used in conventional techniques with each other and with the CAD/CAM technique, but not with 3D printing.[6,7] However, very few studies have evaluated both the compressive and flexural strength of provisional restorative materials using conventional techniques and 3D printing. Therefore, in this study, we aimed to evaluate the compressive and flexural strengths of GC Tempron (GC Corporation, Tokyo, Japan), a conventional self-cure PMMA-based material, compared to two 3D-printable resins: 3D Accuprint C & B (D-Tech, Pune, India) and FreePrint Temp A3 (Detax GmbH & Co. KG, Ettlingen, Germany). Among the materials selected, 3D Accuprint C & B (D-Tech, Pune, India) was included as it is reported to be the first crown and bridge resin developed in India specifically for 3D printing applications.

This in-vitro study was conducted under the null hypothesis that there would be no statistically significant difference in the compressive and flexural strengths of provisional restorative materials fabricated using 3D printing techniques compared to those fabricated by conventional methods.

2. Material and methods

The materials used in this study were carefully selected based on their relevance to the research objectives and their ability to represent both conventional and 3D printing techniques (Table 1).

Fabrication of Sample Blocks Using the Conventional Technique: A custom metal split mold was fabricated, consisting of a housing and screws for ensuring adequate compression during the fabrication process. The mold was designed in accordance with the ANSI/ADA

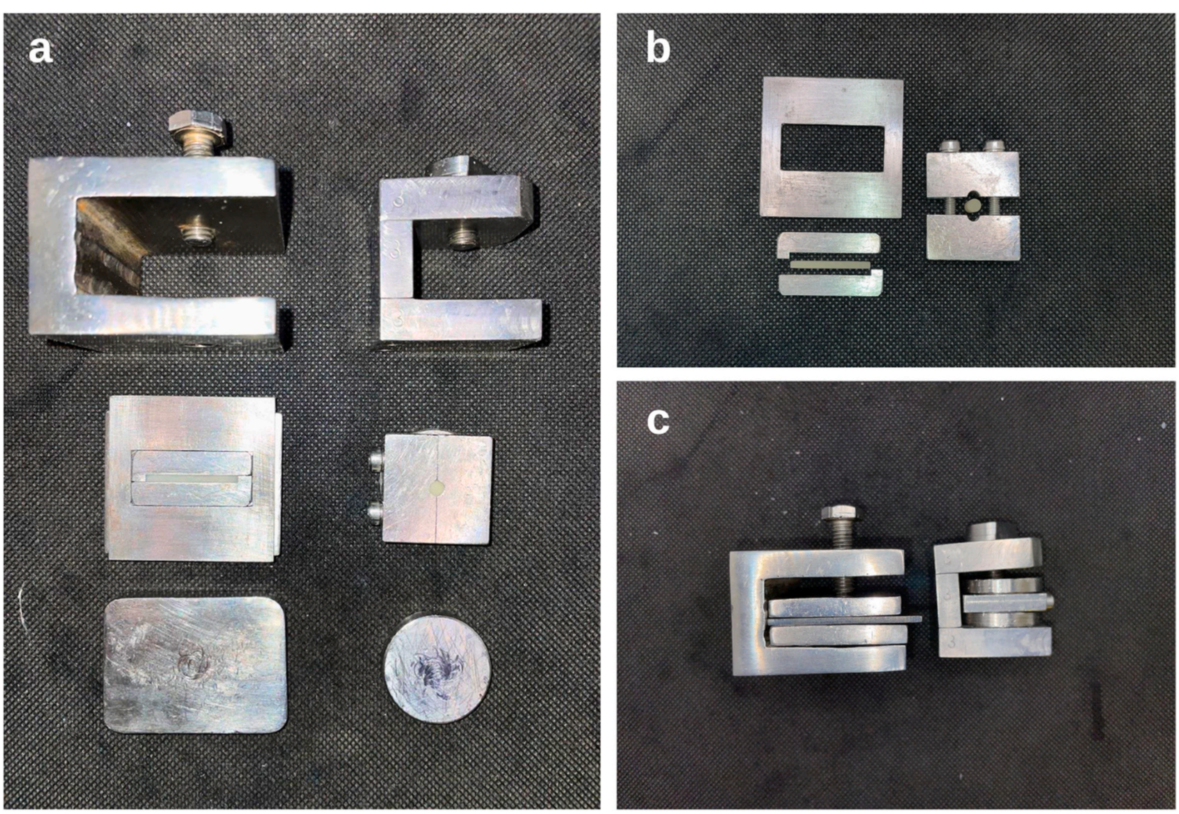

Fig. 1. Customised metal split mold.
1a: Customised metal split mold assembly
1b: Customized metal split mold during fabrication of specimen
1c: Specimen fabricated using conventional resin (GC Tempron).

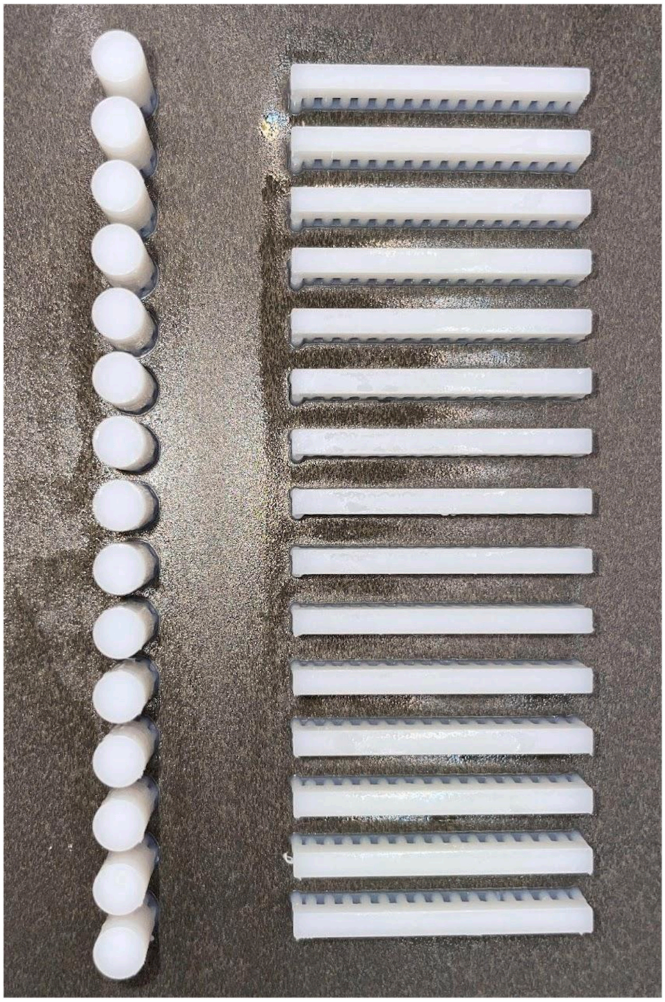

Fig. 2. 3D printed specimen.

Standard No. 27 for polymer-based restorative materials (Fig. 1a).[8] A thin layer of petroleum jelly was applied to the mold using a brush. GC Tempron was mixed as per the manufacturer's instructions (1.0 g powder/0.5 mL liquid; 20–30 s mixing time) and poured into the mold.[9] The screws incorporated into the metal housing were tightened to ensure adequate packing and removal of excess material (Fig. 1b). The specimens were retrieved from the split mold, and any excess material was trimmed (Fig. 1c).

A total of 15 cylindrical blocks, each measuring 6 mm in length and 4 mm in diameter, were fabricated to evaluate compressive strength. Additionally, 15 rectangular blocks, each measuring 25 mm in length, 2 mm in width, and 2 mm in height, were fabricated to assess flexural strength. All specimens and samples were fabricated in accordance with ANSI/ADA No. 27 (Fig. 1c).[8]

Fabrication of Sample Blocks from 3D Printing: The STL file was designed using Composer software (v1.2.11) and printed with an Asiga Max 3D printer, which utilizes the Digital Light Processing (DLP) technique, as per the recommended dimensions (Fig. 2).[8] The printed specimens were detached from the build platform and cleaned using isopropyl alcohol in two steps: a dirt wash for 1 min and 30 s, followed by a clean wash for 1 min and 30 s. This was followed by a 15-min post-curing process as per the manufacturers' instructions.

Testing of samples: Both compressive and flexural strengths were measured using a Universal Testing Machine (UTM) [FIE Make, Model: UTN-10]. To measure the compressive strength, the specimens were mounted on the UTM and compressive force was applied at a crosshead speed of 0.75 mm/min (Fig. 3a and b), with the values recorded at load failure.

Flexural strength was evaluated by performing a three-point bending test in accordance with ISO-178, using a UTM [10 kN]. Specimens were positioned on two support rollers with a center-to-center span of 20 mm. Load was applied at a crosshead speed of 0.75 mm/min until fracture occurred (Fig. 4a and b). The maximum load at failure was recorded for each specimen. Flexural strength (MPa) was calculated using the following formula:

$$\sigma = 3FL/2bh^2$$

where F represents the maximum load exerted on the specimen (N), L is the distance between supports (mm), b is the width of the specimen at the center (mm), and h is the height of the specimen at the center (mm), with all dimensions measured immediately prior to testing.

Statistical analysis: The recorded flexural strength values were statistically analyzed to evaluate differences among the groups. The normality and homogeneity were assessed using the Shapiro-Wilk test and Levene's test, respectively. A One-way Analysis of Variance (ANOVA) was performed to detect statistically significant differences in mean flexural strength across the experimental groups. Subsequently, Tukey's Honestly Significant Difference (HSD) post hoc test was applied for multiple pairwise comparisons to identify which specific groups differed significantly while controlling for the family-wise error rate. All statistical analyses were conducted using IBM SPSS Statistics software (version 25), with the level of significance set at $p < 0.05$.

3. Results

The mean compressive strengths recorded for the GC Tempron, 3D Accuprint and Freeprint Temp groups were 266.65 ± 18.78, 347.07 ± 40.25, and 354.47 ± 42.83, respectively. The difference in mean compressive strength between the three groups was found to be statistically significant ($P < 0.001$) (Table 2). Multiple comparisons of the mean differences between all three groups demonstrated that the GC Tempron group had significantly lower mean compressive strength compared to the 3D Accuprint and Freeprint Temp groups ($P < 0.001$) (Table 3). However, no significant difference was observed in mean compressive strength between the 3D Accuprint and Freeprint Temp groups ($P = 0.84$).

The mean flexural strengths for the GC Tempron, 3D Accuprint and Freeprint Temp groups were 115.69 ± 21.95, 151.60 ± 21.22, and 167.67 ± 26.28, respectively. A statistically significant difference was observed in mean flexural strength between the three groups ($P < 0.001$) (Table 4).

Multiple comparisons of the mean differences between all three groups showed that the GC Tempron group exhibited significantly lower mean flexural strength compared to the 3D Accuprint and Freeprint Temp groups ($P < 0.001$) (Table 5). However, no significant difference was observed in mean flexural strength between the 3D Accuprint and Freeprint Temp groups ($P = 0.15$) (Table 5).

4. Discussion

A provisional restoration plays a pivotal role in maintaining the physiological health of the abutment tooth until the placement of the final prosthesis. Therefore, such restorations must be composed of materials with sufficient compressive and flexural strength to withstand the pressures of mastication and/or additional shear stress associated with parafunctional habits, if present.[10] GC Tempron (GC Corporation, Tokyo, Japan) and FreePrint Temp A3 (Detax GmbH & Co. KG, Ettlingen, Germany) were chosen based on their well-established mechanical and clinical properties. 3D Accuprint C & B (D-Tech, Pune, India), India's first 3D-printed resin specifically designed for temporary restorations, was included in this study due to its novelty and the limited literature available on its properties and clinical performance.[11]

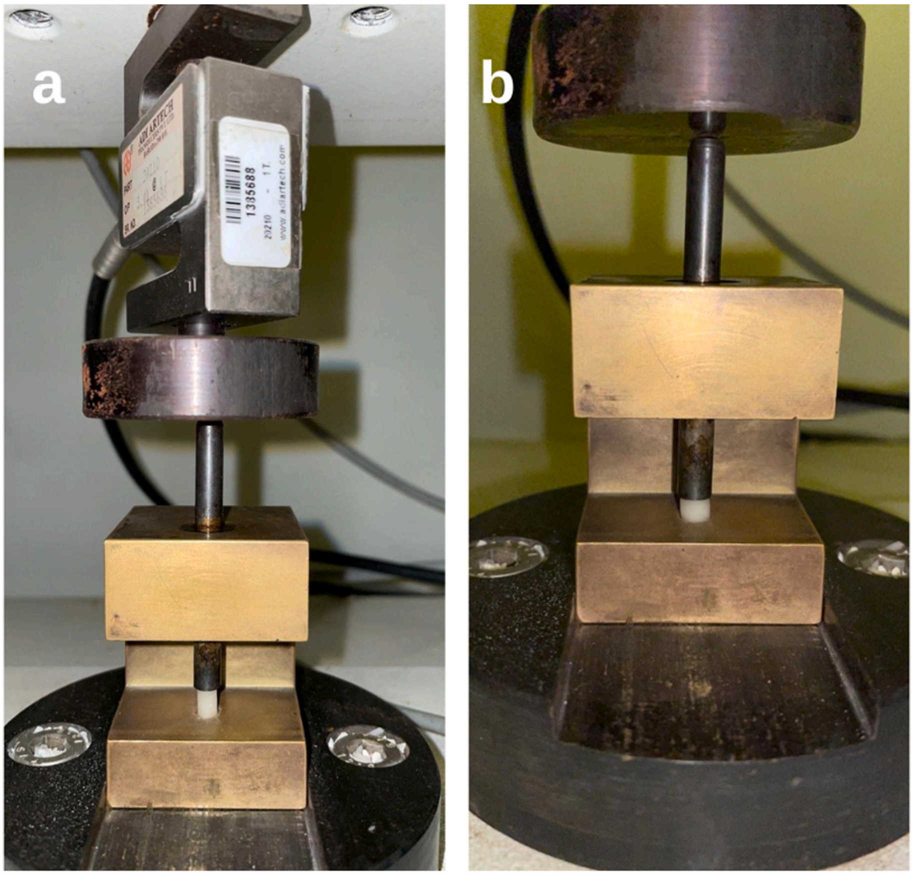

Fig. 3. Compressive strength evaluation
3a: Mounted specimen on UTM machine for evaluation of compressive strength
3b: Specimen on compressive load application.

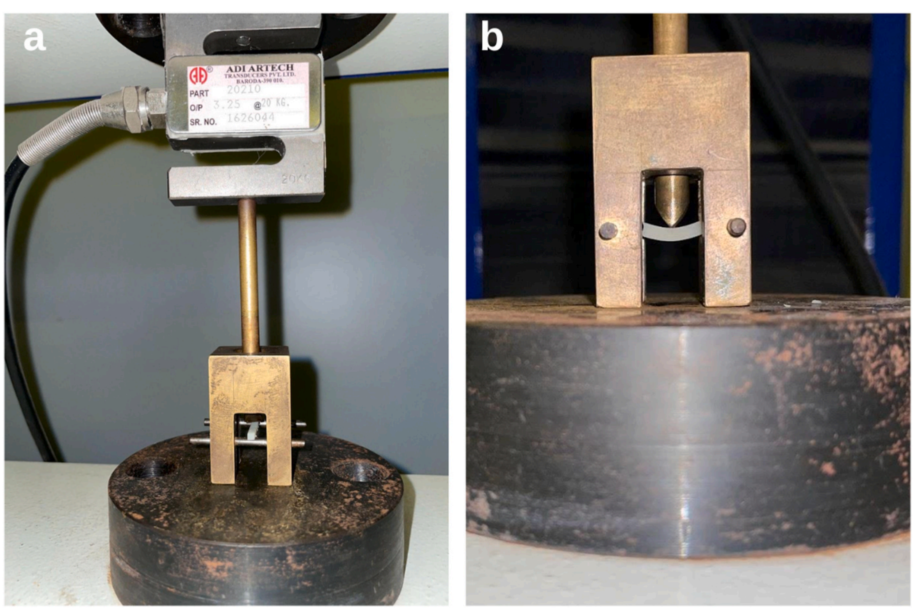

Fig. 4. Flexural strength evaluation
4a: Mounted specimen on UTM machine for evaluation of flexural strength
4b: Specimen on flexural load application.

Digital technology is currently shaping the future of dentistry, with various advancements being introduced into the ever-evolving field of clinical practice.[3] The two-photon digital light processing (DLP) printing technique was reported to be the most frequently employed method, possibly due to its efficiency, speed, and superior resolution.[12] We utilized a high-resolution DLP printer (Asiga Max UV 3D printer) and

Table 2
Comparison of mean Compressive Strength (in Mpa) between conventional and 3D printing techniques using One-way ANOVA Test.

Groups	N	Mean	SD	Min	Max	*p*-value
GC Tempron	15	266.65	18.78	243	304	<0.001*
3D Accuprint C&B	15	347.07	40.25	280	410	
Freeprint temp	15	354.47	42.83	270	418	

*p < 0.05 - Statistically Significant.

Table 3
Multiple Comparisons of mean difference in the Compressive Strength between groups using Tukey's post hoc Test.

I) Groups	(J) Groups	Mean Diff (I-J)	95 % CI		*p*-value
			Lower	Upper	
GC Tempron	3D Accuprint C&B	−80.413	−112.020	−48.810	<0.001*
	Freeprint temp	−87.813	−119.420	−56.210	<0.001*
3D Accuprint C&B	Freeprint temp	−7.400	−39.000	24.200	0.84

*p < 0.05 - Statistically Significant.

strictly adhered to manufacturer-recommended post-curing protocols. This rigorous standardization ensures that the observed mechanical properties are true material characteristics and not artifacts of sub-optimal processing. By evaluating both compressive and flexural strength, our study offers a more robust characterization of these materials, addressing the different types of forces encountered during mastication.

In the present study, the mean compressive strength of GC Tempron resin was significantly lower than that of the 3D-printed materials ($P < 0.001$). No statistically significant difference was observed between the two 3D-printed groups, indicating that additively manufactured provisional materials possess comparable mechanical performance under compressive loading conditions. These findings suggest that conventional PMMA-based materials may be less suitable for clinical scenarios involving high occlusal stress or parafunctional habits, where greater resistance to compressive forces is required. The results are in alignment with those reported by Pantea et al.[13] and Vally et al.,[4] both of whom demonstrated that 3D-printed resins exhibited superior compressive and flexural properties relative to conventional materials used in provisional restorations. The improved mechanical behaviour of the 3D-printed resins may be attributed to enhanced structural homogeneity, precise layering, and a higher degree of polymer cross-linking achieved during the photopolymerization process, all of which contribute to increased material strength and dimensional stability.

The findings of the present study demonstrated that both 3D-printed materials—3D Accuprint C&B and FreePrint Temp A3—exhibited significantly higher flexural strength than the conventional PMMA-based material, GC Tempron. This indicates that additively manufactured provisional resins possess superior resistance to flexural stress, rendering them more suitable for clinical situations demanding enhanced mechanical durability. While FreePrint Temp A3 recorded the highest mean flexural strength, the difference in performance compared to 3D Accuprint C&B was not statistically significant, suggesting that both materials provide comparable and clinically acceptable flexural properties. These results further support the increasing preference for 3D-printed materials in prosthodontics, particularly for long-span fixed dental prostheses (FDPs) or cases involving parafunctional loading, where resistance to deformation and fracture is critical. It is well established that long-span FDPs are more susceptible to flexural failure than short-span prostheses, especially at high-stress regions such as connectors or areas with material voids.[14,15] Thus, the use of high-strength 3D-printed materials may enhance the longevity and clinical reliability of provisional restorations in such demanding scenarios.

Although additive manufacturing offers superior mechanical properties, it requires additional equipment, specialized knowledge, and has a learning curve for handling digital platforms. In contrast, conventional methods are relatively easy to use, inexpensive, and require less time to fabricate. Therefore, the choice of material should be guided by factors such as the span of the prosthesis, the magnitude of occlusal forces involved, the duration the material must withstand these forces, and the patient's financial considerations. Various factors such as the printing techniques, composition of resins, printing layer thickness, post printing conditions and printing directions impact the material properties of the additive manufacturing process.[1,16]

This study provides the first comparative mechanical characterization of the novel 3D Accuprint C&B resin, specifically assessing its viability for provisional crown and bridge fabrication. While our study presents a potential alternative product with promising results, the limitations of our research should be taken into consideration while assessing the clinical implications. This study was limited by its in vitro design, which does not fully replicate the complex conditions of the oral environment. The sample size was relatively small, and only a short-term mechanical evaluation was performed without assessing ageing or fatigue behaviour. Additionally, a limited range of materials was tested, which may restrict the generalizability of the findings to other provisional restorative products. Further studies assessing the impact of these factors on mechanical properties are essential to develop an optimal 3D printing protocol which can be followed. The usage of 3D Accuprint C&B resin for provisional restorations could be recommended with further clinical research.

5. Conclusion

The mechanical properties of the newly introduced 3D Accuprint C&B resin were thoroughly evaluated and found to be significantly greater than the conventional PMMA-based material (GC Tempron) in both compressive and flexural strength. Furthermore, it demonstrated mechanical properties that are comparable to the commercially successful 3D-printed resin (Freeprint Temp). These results indicate that 3D Accuprint C&B is a strong, viable alternative to existing provisional materials and may be particularly beneficial for long-term restorations and in patients with high occlusal demands.

Table 4
Comparison of mean Flexural Strength (in Mpa) between conventional and 3D printing techniques using One-way ANOVA Test.

Groups	N	Mean	SD	Min	Max	*p*-value
GC Tempron	15	115.69	21.95	88	165	<0.001*
3D Accuprint C&B	15	151.60	21.22	120	201	
Detax -Freeprint	15	167.67	26.28	119	228	

*p < 0.05 - Statistically Significant.

Table 5
Multiple Comparisons of mean difference in the Flexural Strength between groups using Tukey's post hoc Test.

(I) Groups	(J) Groups	Mean Diff (I-J)	95 % CI		*p*-value
			Lower	Upper	
GC Tempron	3D Accuprint C&B	−35.91	−56.54	−15.28	<0.001*
	Freeprint temp	−51.98	−72.61	−31.35	<0.001*
3D Accuprint C&B	Freeprint temp	−16.07	−36.70	4.56	0.15

*p < 0.05 - Statistically Significant.

Patient/guardian's consent

Not applicable as this is an in-vitro study design.

Author contributions

N.D., N.R., C.H conceived the idea. N.D. acquired the data for analysis. N.R. and C.H analyzed and interpreted the data. C.H and N. D led the writing, drafting and revision of the article. All authors approved the final version.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publily available due to privacy or ethical restrictions.

Ethics approval statement

Study was approved by the Institution's ethics committee of AB Shetty Memorial Institute of Dental Sciences (Cert. No. ABSM/EC/233/2022).

Funding statement

This research has not received any financial or non-financial benefits.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

Acknowledgements

We have no significant contributors other than the authors.

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