Dentistry 3000

Vol 14, No 1 (2026)
ISSN 2167-8677 (online)
DOI 10.5195/d3000/2026.1117

Evaluation of Provisional Restorations

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Abstract

Objective: This study aimed to evaluate and compare the flexural strength, microhardness, surface roughness, and color stability of provisional materials made using 3D printing, CAD/CAM, and conventional techniques. **Materials and Methods**: A total of 168 samples were fabricated and divided into three groups. Group A: 3D-printed at build angles of 0°, 15°, and 45°, Group B: CAD/CAM milled at high and low speeds, and Group C: Conventional self-curing interim resin. All samples were tested for flexural strength, microhardness, surface roughness, and color stability. Data were analyzed using one-way ANOVA and t-tests at a significance level of 0.05. **Results**: Statistical analysis revealed significant differences among groups ($P \leq 0.05$). The 15° 3D-printed group showed the highest flexural strength (149.33 MPa), while the CAD/CAM low-speed group had the lowest (95.83 MPa). The conventional resin showed the highest microhardness (23.7), whereas the 3D-printed 45° had the lowest (11.61). 3D-printed 15° exhibited the highest surface roughness (6.45 µm), while 3D-printed 0° and conventional had smoother surface mean values (0.412, 0.656 µm, respectively). CAD/CAM low-speed demonstrated the best color stability ($\Delta E = 1.18$), while 3D-printed 45° showed the highest discoloration ($\Delta E = 7.42$). **Conclusion**: Fabrication method significantly affects the properties of provisional restorations. While 3D printing offers high strength, it compromises hardness, smoothness, and color stability. Conventional and CAD/CAM methods provide a better balance in clinical performance. **Clinical Significance:** The method used to fabricate provisional restorations significantly influences their mechanical and esthetic properties, which directly affects their clinical performance, durability, and patient satisfaction. 3D Printing (especially at a 15° build angle) yields high flexural strength, making it suitable for load-bearing areas or cases requiring strong interim restorations. However, it has lower microhardness, rougher surfaces, and poorer color stability, which may lead to faster wear, plaque accumulation, and esthetic deterioration over time. Conventional self-curing resins offer higher hardness and smoother surfaces, which are beneficial for wear resistance and patient comfort, but may lack the strength of digitally fabricated options. CAD/CAM materials, particularly those milled at low speeds, exhibit excellent color stability, making them ideal for visible anterior regions where esthetics are critical. However, their lower flexural strength could be a limitation in certain clinical situations.

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Citation: Qasim HH et al. (2026) Evaluation of Provisional Restorations. Dentistry 3000. 1:a001 doi:10.5195/d3000.2026.1117
Received: December 5, 2025
Accepted: December 8, 2025
Published: February 10, 2026

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Vol 14, No 1 (2026) DOI 10.5195/d3000/2026.1117

Introduction

Provisional restorations, also known as interim or temporary restorations, play a crucial role in fixed prosthodontic treatments. They serve to improve esthetics temporarily, provide stabilization, and restore function until the definitive restoration is delivered [1]. These restorations are essential for protecting hard and soft tissues, maintaining patient comfort, and providing a preview of the final prosthesis [2]. Particularly in the anterior region, esthetic performance is critical, and any discoloration or failure may lead to patient dissatisfaction and added clinical costs [3,4].

Provisional materials must withstand intraoral thermal changes and occlusal stresses, especially in long-term or complex treatments such as full-mouth rehabilitation or implant-supported prostheses [5-7]. Thus, their mechanical and physical properties are vital to their clinical success [8]. Traditionally, provisional materials are divided into acrylic-based resins (PMMA, PEMA) and composite-based materials (Bis-GMA, UDMA) [9]. While auto-polymerized PMMA is widely used due to its low cost and ease of use, it suffers from drawbacks such as air entrapment and water sorption, compromising strength [10-13].

Digital technologies, including CAD/CAM and 3D printing, have revolutionized the fabrication of provisional restorations. CAD/CAM milling uses pre-polymerized blocks for improved uniformity and durability [14]. While 3D printing offers customizable, efficient production through technologies like SLA and DLP [15,16]. SLA provides high accuracy but lower strength and durability, whereas DLP is faster and more material efficient [17]. Key 3D printing parameters, such as build orientation, layer thickness, and object positioning, significantly influence the restoration's mechanical behavior and surface characteristics [18,19].

This study aimed to assess and compare the flexural strength (FS), microhardness (MH), surface roughness (Ra), and color stability (Cs) of provisional restorative materials produced by conventional (reflecting a widely practiced conventional method in dentistry), CAD/CAM (to evaluate the impact of milling speed), and 3D printing methods (to examine how printing angle influences material characteristics).

Material and Methods

Materials used in the study are presented in Table 1. In this study, a total of 168 provisional restorative materials samples were prepared and divided into three groups according to methods of fabrication as follows:

- Group A: 3D printing at build angles of 0°, 15°, and 45°.
- Group B: CAD/CAM by milling prefabricated resin blocks under two protocols: a high-speed process (5–8 minutes) and a low-speed process (8–15 minutes)
- Group C: Conventional self-curing PMMA, fabricated using the traditional flasking procedure.

Specimen Preparation

3D Printed Specimens

The 3D printed samples were produced using a DLP 3D printer (Creality LD-006, China, Figure 1) with FREEPRINT® temp resin. STL files were processed with HalotBox slicer software, applying build angles of 0°, 15°, and 45°, each with a layer thickness of 100 µm. After printing, the specimens were washed in 99% isopropyl alcohol for 4 min, followed by a 30-minute post-curing cycle under UV light (405 nm) using a Creality post-curing machine.

CAD/CAM Specimens

Specimens were milled from pre-polymerized PMMA blocks (Dental Direct polyX ML, Figure 2) using a 5-axis milling machine (Zahndent, China). The virtual designs were created with GO2dental CAM software, exported as STL files, and milled using burs of 2.5, 1-, and 0.5-mm diameters. Two milling speeds were applied: low-speed (8–15) min and high-speed (5–8 min).

Conventional Specimens

Conventional specimens were produced using the conventional self-curing PMMA powder/liquid technique. Resin patterns were invested in a two-part brass flask with die stone and separated using a medium (Zhermack®, Italy). The acrylic resin was prepared at a 2:1 powder-to-liquid ratio and packed into the mold. Polymerization was carried out in an Alvomet unit (DIKAN 105) under regulated pressure and temperature. After completion, the flask was allowed to bench-cool before deflasking. All specimens were then finished and polished before testing.

Flexural Strength Testing [4]

Forty-two bar-shaped specimens for each test (25 × 2 × 2 mm, Figure 3A) were prepared following ISO 4049:2000 standards. Flexural strength was tested using a universal testing machine (China, Figure 4A) with a three-point bending setup (support span: 50 mm, cross-head speed: 5 mm/min). Flexural strength (σ, MPa) was calculated using the formula:

1. flexural strength = $3FL/2bd^2$
2. Where:
3. • F = maximum load at fracture (N)

• L = support span (mm) • b = specimen width (mm) • d = specimen thickness (mm)

Vickers Microhardness Testing

Forty-two disc-shaped specimens (9 mm height × 3 mm thickness, Figure 3B) [20] were fabricated for the microhardness test. A Vickers microhardness tester (HV-1000, China) with a diamond indenter applied a 50 g load for 15 seconds (Figure 4B). Three indentations were made per specimen, and the mean value was recorded. The Vickers hardness number (VHN) was calculated using the formula:

4. VHN = 1.8544L /D2.
5. Where L = applied load (Kg). D = mean diagonal length (mm).

Surface Roughness Testing

Forty-two disc-shaped specimens (10 mm diameter × 2 mm thickness, Figure 3C) [21] these were used for surface roughness evaluation. Measurements were performed using a surface profilometer (AMT220, China) with a diamond stylus tip radius of 2.5 µm and a scan length of 0.8 mm (Figure 4C). Three readings per specimen were taken at 120° intervals, and the mean surface roughness (Ra, µm) was recorded for each sample.

Color stability testing

Forty-two disc-shaped specimens (10 mm diameter × 2 mm thickness, Figure 3C) were assessed at two time points: baseline and after staining, using a 3nh D65 Colorimeter (3nh, China, Figure 4D). Baseline measurements were taken after polishing and storing the specimens in distilled water for one week, recording the L1, a1, and b1 values. Subsequently, the specimens were immersed in a coffee solution for staining. The staining solution was prepared by dissolving 2 g of 100% pure agglomerated instant coffee (Coffee Break, Jordan) in 200 ml of hot water, and it was replaced daily over 7 days. The solution was left to reach ambient temperature (~25°C) before specimen immersion. After 7 days, specimens were rinsed with distilled water for 20 seconds and gently blot-dried. Post-staining color readings were then recorded as L2, a2, and b2, and the color difference (ΔE) was calculated using the formula: $\Delta E = \sqrt{[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]}$.

The L* value indicates the brightness of an object, a* describes the color levels between red and green, while b* describes the color levels between yellow and blue.

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Statistical analysis

Statistical analyses were performed using SPSS software (version 23, Statistical Package for the Social Sciences). The statistical analysis included Descriptive Statistics, the Shapiro-Wilk test was used for normality, Independent-Samples T-Test, One-way ANOVA, and Duncan multiple comparison test.

Results

The mean, standard deviation (SD) of the flexural Strength, microhardness, Surface Roughness, and ΔE for the tested materials are listed in (Table 2). According to method of fabrication and type of provisional restorative materials, Analysis of variance One-way (ANOVA) shows that there is significant difference ($P \leq 0.05$) in the mean values of the flexural strength, microhardness, surface roughness, and color stability between the 3D printed groups fabricated with different build angles of 0, 15, and 45 degrees, CAD/CAM fabricated at different times of the milling procedure (low and high speed) and conventional groups.

One-way (ANOVA) showed that there is no significant difference ($P > 0.05$) in the mean value of the flexural strength, while there is a significant difference ($P \leq 0.05$) in the mean value of the microhardness, surface roughness, and color stability for the different orientations at build angles of 0, 15, and 45 degrees of the 3D-printed provisional restoration groups (Figure 5 A, B, C, and D). Independent Samples T test for quality of mean (Table 3) demonstrates that there is a significant difference ($P < 0.05$) in the mean value of the flexural strength, surface roughness, and color stability. There is no significant difference ($P > 0.05$) in the mean value of the microhardness between the two groups of CAD/CAM that were fabricated at different times of the milling procedure (low and high speed).

Duncan's test (Table 2) showed that the 3D-printed at a 15° orientation showed the highest mean value (149.33 MPa) of flexural strength, while the CAD/CAM low-speed displayed the lowest mean value (95.83 MPa). The conventional PMMA demonstrated the highest mean value (23.7) of microhardness, while 3D-printed 45° specimens had the lowest mean value (11.61). The 3D-printed 15° showed the highest mean value (6.45 μm) of surface roughness, while the conventional and 3D-printed 0° groups had smoother surface mean values (0.66, 0.41 μm), respectively. In terms of color stability, low milling speed CAD-CAM had the lowest mean value (1.18), while the 3D-printed at 45° orientation showed the highest discoloration mean value (7.42) among groups.

Dicussion

The present study was designed to evaluate and compare the flexural strength, microhardness, surface roughness, and color stability of provisional restorative materials fabricated using 3D printing, CAD/CAM, and conventional techniques. The null hypothesis of the present research was rejected based on the results obtained. Although laboratory tests cannot fully replicate actual clinical conditions, conducting them in a controlled environment provides a reliable means to compare different materials.

Flexural strength represents a key mechanical property of provisional restorative materials. Its importance increases particularly when restorations are required for long-term use, in patients with parafunctional habits, or in cases involving multi-unit provisional bridges.

The current study demonstrated that 3D-printed provisional restorative materials exhibited superior flexural strength compared to both CAD/CAM-milled and conventionally fabricated groups. (Table 2). Within the 3D Printed build angles (0°, 15°, and 45°) groups, there was no statistically significant difference in flexural strength, indicating that the tested build angles did not notably influence this property. This explains that additive manufacturing via 3D printing, irrespective of the build angle (0°, 15°, 45°), produces materials with superior resistance to bending forces. This superior performance may be attributed to the layer-by-layer fabrication process that allows for more homogeneous deposition of resin, reduced porosity, and the ability to optimize build orientation and resin formulations, all of which contribute to enhanced mechanical performance.

For the CAD/CAM groups, the CAD/CAM high-speed group showed significantly higher flexural strength than the low-speed group (Table 3). Interestingly, the conventional group demonstrated higher flexural strength than the CAD/CAM low-speed group but was comparable to the CAD/CAM high-speed group. A possible explanation is that the self-cured acrylic used in the conventional method polymerizes as a bulk mass without the introduction of milling-related stresses or surface microcracks, which may weaken the CAD/CAM specimens at lower processing speeds. On the other hand, the high-speed CAD/CAM milling reduced such defects, leading to a flexural strength more closely aligned with the conventional group.

This can be explained by the effect of milling parameters, as higher milling speed reduces the contact time between the bur and the material, thereby minimizing heat generation, internal stresses, and microcrack formation. As a result, the structural integrity of the material is better preserved, leading to superior flexural resistance compared with the low-speed milling group, where prolonged cutting may induce more defects. These findings contradict those of Digholkar et al [22] reported that CAD/CAM materials showed the highest flexural strength, followed by conventionally fabricated and self-cured resins. This discrepancy may be explained by advances in resin formulations and printing technology, which have enhanced the mechanical performance of 3D-printed materials in more recent investigations.

Conversely, our findings are in agreement with those of Suralik et al [23] and Perea-Lowery et al [24] observed higher flexural strength in 3D-printed specimens compared to milled counterparts, although they emphasized that outcomes may vary depending on resin type, build orientation, printer system, and manufacturer-recommended parameters. This aligns with the current study, highlighting the role of optimized manufacturing conditions.

Partial agreement was also found with Al-Qahtani et al[5] reported that a 3D-printed resin (Free Print Temp) demonstrated flexural strength comparable to a CAD/CAM material (Ceramill Temp) and superior to a self-cured acrylic. While our study recorded a more distinct superiority of 3D-printed materials over CAD/CAM, the general trend remains consistent. Similarly, Pantea et al[25] found that several 3D-printed resins outperformed conventional materials in flexural and compressive strength, although results varied according to resin composition and post-curing protocol factors also observed in the present study.

Our results are further supported by Park et al [26] demonstrated that resin composition, print parameters, and curing conditions significantly influence the mechanical performance of 3D-printed restorations. In line with this, our findings partially agree with those of Wechkunanukul et al [27] reported that CAD/CAM provisionals exhibited higher flexural strength than conventional materials due to the superior properties of pre-polymerized PMMA blocks. While this was confirmed in the current study, where high-speed CAD/CAM milling outperformed conventional and low-speed milling, 3D printing still yielded the highest flexural strength overall.

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Similarly, Yao et al [28] showed that CAD/CAM interim materials achieved higher flexural strength and superior marginal fit compared to conventionally fabricated restorations after thermal aging. Regarding the influence of building orientation, several studies [29-34] emphasized that 3D-printed materials are anisotropic, with mechanical properties varying according to layer orientation. However, no statistically significant differences were found among the build angles tested in the present study, which may suggest that the specific resin formulation and post-processing protocols applied here mitigated the expected anisotropic effects.
The present study demonstrated that conventional provisional materials exhibited the highest surface microhardness, followed by CAD/CAM specimens, while 3D-printed resins displayed the lowest values. Among the 3D-printed subgroups, the 15° build angle had the highest hardness, followed by 0°and 45°. This can be explained by the reason that a 15° inclination allows better interlayer fusion, less void formation, and a more compact structure, which leads to higher hardness. Furthermore, the 0° group demonstrated significantly higher hardness than the 45° group. The reason is that at 0°, the printed layers are parallel to the applied load, which reduces weak spots, while at 45°, the load is applied more perpendicularly to the layer boundaries, causing easier interlayer separation and lower hardness. As a result, the 45° group consistently showed the lowest microhardness because of its weak interlayer adhesion and increased porosity.
These findings partially disagree with de Castro et al [29] reported no significant influence of build orientation on microhardness, likely due to differences in resin type, curing protocol, or layer thickness. Nonetheless, de Castro et al [29] noted that the build angle significantly affected other mechanical properties such as flexural strength and dimensional accuracy, consistent with the present study's observations on strength.
Milling speed significantly impacts various properties of polymers and polymer composites, primarily affecting particle size distribution, surface morphology, and mechanical characteristics like hardness and wear resistance. For the CAD/CAM groups, the Low-Speed milling group had higher hardness than the High-Speed group (Table 2), although the difference was not statistically significant. The reason could be that slower milling generates less frictional heat, which prevents thermal softening of the pre-polymerized PMMA blocks [35]. Additionally, lower cutting stress may preserve the compact microstructure, leading to slightly higher hardness compared to faster milling [35].
When comparing all fabrication methods, the conventional group achieved the highest hardness due to complete polymer cross-linking and density, while CAD/CAM blocks, despite industrial pre-polymerization under pressure and heat, experienced some machining-induced defects, and 3D-printed materials suffered from incomplete polymerization and interlayer defects.
Comparison with the literature shows that these results disagree with Jain et al [14] and Digholkar et al [22] reported superior hardness of CAD/CAM materials over conventional and 3D-printed specimens. Conversely, our findings agree with Burduroğlu & Keyf [3] and two studies [36,37] demonstrated that conventional acrylics possess higher surface hardness than other provisional materials. Partial agreement exists with Wechkunanukul et al [27] as CAD/CAM performed better than 3D printing but remained inferior to conventional specimens.
Overall, the present study confirms that 3D-printed materials currently exhibit lower surface hardness compared to conventional and CAD/CAM techniques, consistent with previous findings. Additionally, printing orientation significantly influences microhardness under specific conditions, although intrinsic material properties and curing dynamics remain dominant factors.
In the present study, surface roughness varied significantly among different fabrication techniques and build orientations. Among 3D-printed groups, the 15° build angle exhibited the highest surface roughness, followed by 45°, while 0° showed the lowest, because printing at 0° allows more regular layer deposition and smoother polymerization, producing a more uniform surface. This is likely due to improved layer deposition and polymerization alignment at 0°, whereas steeper angles increase the stair-step effect and surface protrusions. Overall, a statistically significant difference in surface roughness was observed among the 3D-printed groups, indicating that build angle strongly influences surface quality
These findings agree with two studies [38,39] reported that horizontal printing (0°) produces smoother surfaces, while steeper or vertical orientations increase roughness.
For CAD/CAM groups, high-speed milling produced significantly rougher surfaces than low-speed milling, likely due to attributed to higher milling speeds, which induce vibrations or minor surface defects. Increasing milling speed can lead to smaller particle sizes, altered surface morphology, and improved wear resistance, though excessively high speeds might cause delamination and increased processing temperatures. An increase in milling speed can lead to lower friction coefficients and reduced wear volume up to a certain point. For interim resins, maintaining a balance between efficiency and surface finish is crucial, as excessive speed can compromise aesthetics and potentially require more post-milling polishing. Whereas slower milling produces a smoother, more controlled surface.
Conventional groups displayed the smoothest surfaces, similar to CAD/CAM low-speed milling and 3D-printed 0° orientation, due to dense polymer structure and uniform material processing.
Comparison with the literature shows that these results agree with Al-Qahtani et al [5] reported superior surface smoothness of CAD/CAM compared to 3D-printed materials and partially agree with Wechkunanukul et al [27] observed the highest roughness for 3D printing, followed by conventional and CAD/CAM, with minimal difference between conventional and CAD/CAM. Our results agree with the findings of Sonmez et al [40] support the present study, as they reported that CAD/CAM-milled restorations exhibit clinically acceptable surface quality without additional polishing, aligning with our observation that both low- and high-speed CAD/CAM groups produced surface roughness within acceptable clinical limits. Similarly, Taşın et al [21] partially agree with our results, showing that 3D-printed hybrid resins had lower surface roughness than conventional and CAD/CAM PMMA resins, while also confirming that surface roughness in 3D-printed materials is significantly affected by resin composition and printing orientation.
Overall, the findings confirm that both fabrication technique and 3D printing orientation strongly influence surface roughness, while CAD/CAM and conventional methods generally produce smoother surfaces than 3D-printed specimens, especially at steeper build angles**.**
Color stability (measured as DeltaE) indicates how much a material's color changes over time or due to environmental factors [41]. Lower Delta E values represent better color stability. The present study employed coffee as a staining medium to evaluate the color stability of provisional restorative materials. Coffee was chosen because it is one of the most widely consumed beverages worldwide and is consistently reported as a strong extrinsic staining agent in dental research.

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In the present study, the 3D-printed 45° group showed the greatest discoloration, while 0° and 15° demonstrated better stability. The superior performance of lower angles can be attributed to the fact that when layers are oriented horizontally (closer to 0°), they overlap more uniformly, reducing interlayer gaps and minimizing pigment penetration or light scattering that cause discoloration. In contrast, higher build angles increase the exposure of interlayer junctions, which may act as weak zones for staining. This agreement supports the concept that layer orientation during additive manufacturing substantially influences the optical properties of printed resins.
These results agree with Temizci and Kölüş [42] reported that higher printing angles increase discoloration, and with Espinar et al [43] confirmed the effect of build orientation on both color and translucency.
For the CAD/CAM groups, the Low-Speed subgroup exhibited better color stability than the High-Speed subgroup. Overall, CAD/CAM groups demonstrated greater stability compared to conventional and 3D-printed materials. This improvement can be attributed to the fact that low-speed milling produces a smoother surface, with fewer micro-defects and reduced surface porosity, which minimizes the penetration and retention of pigments or staining agents. In comparison, the reduced color stability of 3D-printed provisional resins has been linked to several factors. CAD/CAM-milled PMMA resins are produced through industrial processes, characterized by a high degree of polymerization and extensive crosslinking, which result in a denser structure. In contrast, 3D-printed PMMA resins exhibit lower polymerization rates, leading to compromised surface integrity and diminished color stability [44,45].
These findings agree with these four studies [3,37,46,47] confirmed that CAD/CAM resins exhibit higher resistance to discoloration than either conventional or 3D-printed alternatives.
The relatively poor performance of 3D-printed resins in this study agrees with two studies [44,45] attributed low stability to incomplete polymerization and porosity. Similarly, Sarac et al [48] and Taşın et al [21] explained this by the hydrophilic nature of light-cured resins, which facilitates pigment absorption. Furthermore, the systematic review by Shin et al [49] supports our conclusions, emphasizing that 3D-printed provisional resins generally display higher ΔE values than CAD/CAM or conventional ones. Collectively, these agreements highlight that the superior surface finish, higher density, and reduced porosity of CAD/CAM resins explain their improved color stability compared to both conventional and 3D-printed materials.

Conclusion

Within the limitations of this in-vitro study, it can be concluded that the fabrication technique significantly affects the performance of provisional restorations. 3D-printed specimens showed the highest flexural strength but the lowest microhardness, surface smoothness, and color stability, particularly at higher build angles. Conventional resin demonstrated superior hardness and moderate results in other properties, while CAD/CAM material exhibited the most favorable balance, with smooth surfaces, excellent color stability. Overall, CAD/CAM milling remains the most consistent approach, whereas improvements in 3D printing technology are still required to optimize surface quality, hardness, and color resistance.

Clinical Significance

The method used to create provisional restorations plays a key role in determining their mechanical and esthetic qualities, which in turn impact their performance in the mouth, how long they last, and how satisfied patients are with them. 3D printing, particularly at a 15° build angle, produces restorations with high flexural strength, making it a good option for areas that bear a lot of chewing force or for situations where a strong temporary is needed. However, 3D printed restorations tend to have lower microhardness, rougher surfaces, and less color stability. These drawbacks can result in quicker material wear, more plaque buildup, and a decline in appearance over time. Conventional self-curing resins provide higher surface hardness and smoother finishes, which help with wear resistance and patient comfort. However, they may not offer the same level of strength as restorations made with digital methods. CAD/CAM milled materials, especially when milled at slower speeds, maintain very stable color, making them a strong choice for temporary restorations in the front (esthetic) areas of the mouth. The downside is their relatively lower flexural strength, which can be a disadvantage in areas under higher biting pressure.

Author Contributions

Conceptualization: Qasim HH and Abdulla MA; methodology: Qasim HH and Abdulla MA; software: Qasim HH and Abdulla MA; formal analysis: Qasim HH and Abdulla MA; investigation: Qasim HH and Abdulla MA; data curation: Qasim HH and Abdulla MA; writing—original draft preparation: Qasim HH; writing—review and editing: Qasim HH and Abdulla MA; supervision: Abdulla MA; funding acquisition: Qasim HH and Abdulla MA; administration: Qasim HH and Abdulla MA. All authors have read and agreed to the published version of the manuscript.

Ethical Approval

The present study obtained ethics approval from the Research Ethics Committee, College of Dentistry, University of Mosul, Iraq, and was authorized accordingly.

Availability of Data and Materials

The data will be available on reasonable request from the corresponding author.

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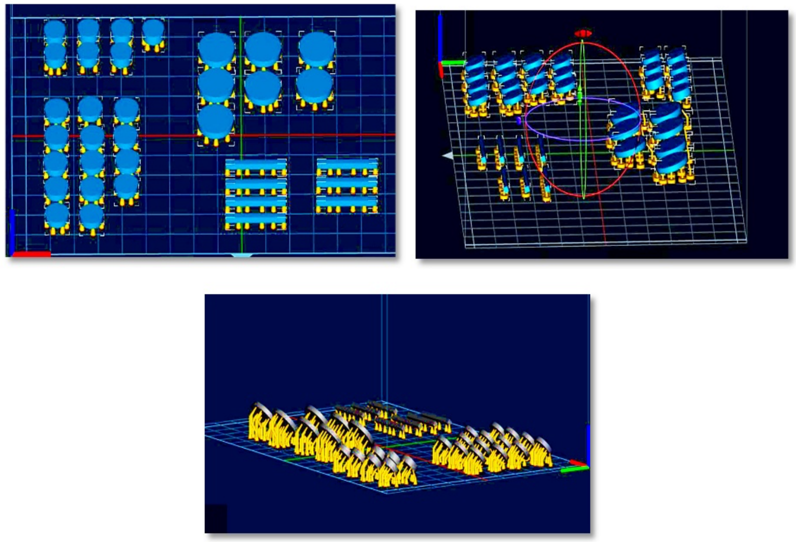

Figure 1. Sample design with HalotBox Creality Slicer software to be prepared for 3D printing the resin in different orientations (0º, 15º, and 45º).

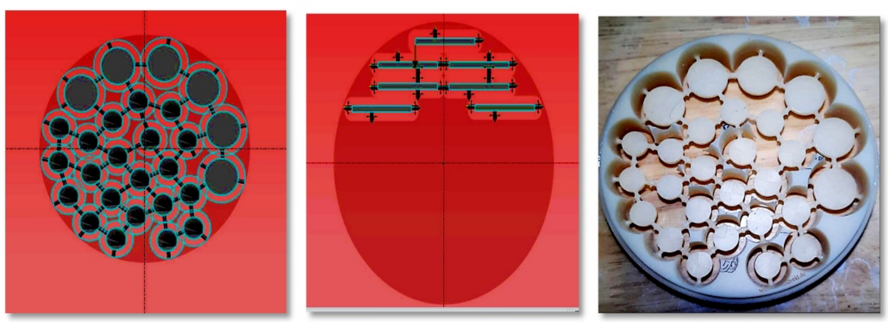

Figure 2. Sample design with GO2dental Cam software to be prepared for milling

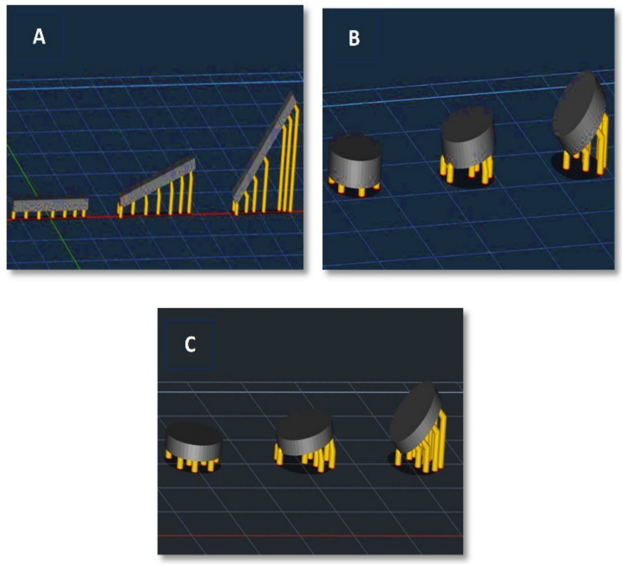

Figure 3. Samples for 3D-printed restoration resin were digitally designed (A, B, and C) at different build orientations (0°, 15°, and 45°) with the corresponding printing. support structures.

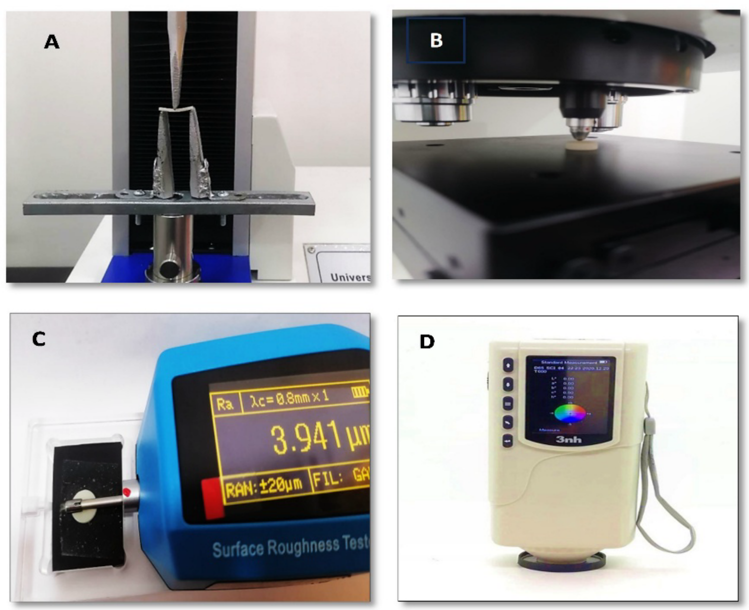

Figure 4. (A): Testing the specimens of flexural strength. **(B):** Vickers microhardness specimens. **(C):** Surface roughness specimens. **(D):** Portable colorimeter device for measuring color changes.

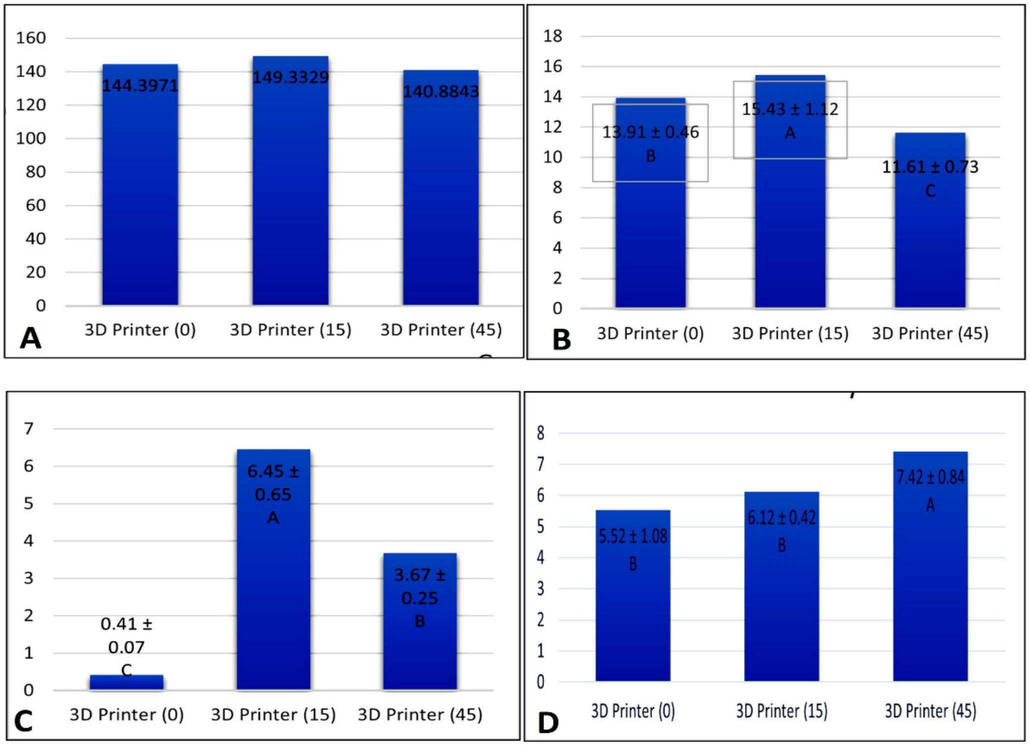

Figure 5. Duncan multiple range test, mean, standard deviation for Flexural strength A), Microhardness B), Surface roughness C), Color stability D) tests of 3D printing in different orientations (0°, 15°, and 45°) groups. Bars with similar letters indicate non-significant differences ($P > 0.05$), while bars with different letters indicate significant differences ($P \leq 0.05$).

Table 1. Materials used in the study.

Materials	Manufacturer	Source	Batch No.
3D printed material	FREEPRINT® temp	Germany	04059
CAD-CAM material	Dental Direct poly X ML	Germany	BIO 5193
Conventional provisional material	IMICRYL® (Imident powder)	Turkey	TS8230

Table 2. Mean, Standard Deviation of the Flexural Strength, Microhardness, Surface Roughness, and color stability (ΔE) for the Tested Materials.

	Flexural Strength (MPa)	Vickers Microhard-ness	Surface Roughness (Ra)	Color Stability ΔE	N
3D Printed (0°)	144.40± 6.79 A	13.91 ± 0.46 E	0.41 ± 0.07 µm E	5.52 ± 1.08 B	7
3D Printed (15°)	149.33±12.39A	15.43 ± 1.12 D	6.45 ± 0.65 µm A	6.12 ± 0.42 B	7
3D Printed (45°)	140.88 ±7.05 B	11.61 ± 0.73 F	3.67 ± 0.25 µm B	7.42 ± 0.84 A	7
CAD-CAM Low(8-15m)	95.83 ±1.29 D	19.33 ± 1.70 B	0.95 ± 0.21 µm D	1.18 ± 0.15 D	7
CAD-CAM High(5-8m)	108.34 ±1.45C	18.10 ± 0.99 C	1.27 ± 0.01 µm C	1.73 ± 0.42 D	7
Conventional	104.36 ±7.00C	23.70 ± 0.7 A	0.66 ± 0.07 µm E	3.50 ± 0.51C	7

N=number of samples. Different letters are statistically significantly different according to Duncan's test.

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Table 3. Independent Samples t-test of flexural strength, microhardness, surface roughness, and color stability between CAD/CAM groups.

Tests	Groups	N	Mean ±SD	t-value	Sig.
Flexural strength	CAD-CAM Low (8-15)	7	95.83 ± 1.29	-17.044	.000*
	CAD-CAM High (5-8)	7	108.34 ± 1.45		
Microhardness	CAD-CAM Low (8-15)	7	19.33 ± 1.70	1.651	.125
	CAD-CAM High (5-8)	7	18.10 ± 0.99		
Surface roughness	CAD-CAM Low (8-15)	7	0.95 ± 0.21	-4.176	.001*
	CAD-CAM High (5-8)	7	1.27 ± 0.01		
Color stability	CAD-CAM Low (8-15)	7	1.18 ± 0.15	3.196	.008*
	CAD-CAM High (5-8)	7	1.73 ± 0.42		

*Significant differences, SD= Standard Deviation