



Evaluation of printing orientation and postcuring time influence at the flexural durability of 3D-Printed resin

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Abstract

Introduction: The notion of restorative dentistry has undergone significant development as a result of the usage of computer-aided design and computer-aided manufacturing (CAD-CAM) in the dental industry.

Methodology: Two 3D-printed acrylic resins and one heat-polymerized resin (HP) were used to design and create 480 rectangular samples, each measuring 64103.3 mm. Three sets of 3D-printed objects were created using different printing orientations (0, 45, and 90 degrees), and each group was then separated into four separate sets using different postcuring times (30, 60, 90, and 120 minutes). Prior flexural strength testing, all specimens underwent 10,000 cycles of thermal cycling. Scanning electron microscopes (SEM) were used to investigate fractured surfaces. Statistical evaluation was done using ANOVA and Tukey's post hoc tests ($p < 0.05$).

Results: The findings of this investigation demonstrated that 0-degree groups had the highest flexural strength values of 3D-printed resin. (Additionally, despite of the printing orientation, the values for flexural strength rose as postcuring time extended; the highest flexural strength was noted at 120 minutes postcuring time in all orientations. It was confirmed by SEM research that a ductile fracture had a coarser surfaces and irregular lamellae, and that these characteristics become noticeably more pronounced with longer postcuring times. In light of the findings.

Conclusion: It may be concluded that groups with a 0-degree orientation had more flexural strength than other groups. The flexural strength also increased with longer postcuring times.

Keywords: 3D-printed resin, postcuring periods, CAD- CAM system

Introduction

The notion of restorative dentistry has undergone significant development as a result of the usage of computer-aided design and computer-aided manufacturing (CAD-CAM) in the dental industry. When using a CAD-CAM system, there are two ways to make a dental prosthesis: subtractive manufacturing, or milling, which involves cutting a block-shaped piece of material, and additive manufacturing, or 3D printing, which involves layering photocurable resin or thermoplastic filaments³. In comparison to the subtractive process, the additive method has a number of important advantages, such as preventing material waste and not requiring bur replacement due to wear³. The variety of 3D printing designs, which enables the manufacturing of more complicated objects like hollow structures^[3]. However, a number of variables can affect the 3D printing process. According to reports in the literature, the quantity and angle of the illumination source, depth of polymerization, polymerization shrinkage, and the thickness of the printed layer all affect both mechanical and physical characteristics^{4, 5}. Understanding the various factors influencing the characteristics of the 3D printing result is crucial for this^{5, 6}.

The printing direction of the additive process is one of these factors. It is essential to the first stage since it affects the precision and mechanical attributes of the printed object^{7, 8}. It was claimed that printing configurations with various printing methods, such as stereolithography (SLA), selective laser sintering (SLS), and fused deposition modelling (FDM) via rapid prototyping (RP), had an impact on the

strength of 3D-printed resins^{7, 8}. Further, the shape and printing orientation, such as horizontal, oblique, and vertical (0, 45, 90), respectively, affect the amount of prototypes printed. For instance, more prototypes may be produced with vertical printing than horizontal printing^[9].

Postcuring duration is a further variable that has been researched in the past to improve the mechanical characteristics of printed prostheses. To ensure complete polymerization of unreacted monomers in every area, it entails subjecting the photopolymerized resin to an extra polymerization step in an ultraviolet (UV) oven after printing¹⁰. The length of the postcuring technique might change and vary depending on the various photopolymerized resin products made by various businesses. Additionally, it stands out from both the 3D printer and the postcuring device^[11, 12].

Only a few investigations have specifically examined the impact of postcuring time, despite earlier research on the impacts of printing orientation and postcuring time. Furthermore, no research have examined the combined impact of postcuring time and printing orientations. Consequently, the goal of the present investigation was to assess how different postcuring periods and printing orientations affected the flexural strength of resin used in 3D printing. According to the null hypothesis, postcuring time and printing orientation have no impact on the flexural strength of denture base resins that are 3D printed.

Methodology

The research was conducted at Department of Prosthodontics, and Crown & Bridge at Baba Jaswant Singh Dental College and Hospital, Ludhiana between dec 2022 to June 2022. The analysis of variance was used to determine the sample size, with the power set at 80%, the degree of significance set at 0.05, and the averages and standard deviations obtained from other research with a design that was comparable.^{1,9} The present study required 480 specimens (180 each material, 90 per test, $n = 10$). Specimens made of acrylic resin were created in accordance with ISO 20795-1: 2013 specifications.¹³ rectangular samples measuring 64103.3 mm were created using two acrylic resins for 3D printing and one heat-polymerized (HP) acrylic resin as a control. Table 1 provides an overview of the materials, composition, printers, curing equipment, and printing settings.

For the conventional acrylic resin samples, the formerly documented traditional compression moulding process was utilised with HP acrylic resin (Major base²⁰, Major Prodotti Dentari SPA, Moncalieri, Italy)¹⁴. The samples were generated using an open-source CAD software programme (123D design, Autodesk, version 2.2.14, CA) for 3D printing acrylic resin. The specimens' virtual designs were exported as standard tessellation language (STL) files to the ASIGA MAXTM and Next Dent 3D printers before being manufactured in three dimensions using the resources and settings.

The resin vessel was homogenised using a roller/tilting mixer prior to the resin material being dispensed into the printing tank. The samples were then 3D-printed in accordance with the the manufacturer's guidelines at 50 microns/layer density and 0-, 45-, and 90-degree orientation (Fig 1). The extra unpolymerized material was removed from the printed specimens using isopropyl alcohol (99.9%) before postcuring time. To get the ultimate material qualities, specimens were separated into 4 groups based on the postcuring time (30, 60, 90, and 120 minutes). The samples were put into curing machines for Next Dent groups after being submerged in glycerol¹⁵.

Utilising low-speed rotational equipment, the lattice frameworks were cut free from the samples following the postcuring procedure. The samples were then ground using

a series of silicon carbide papers (800, 1500, and 2000 grit), and they were then washed with water¹⁶. With an accuracy of 0.01 mm, a computerised calliper was utilised to verify the samples' dimensions. The authorised samples were then kept in 37°C agitated water for 48 hours¹⁷. After that, according to a prior investigation, all specimens were subjected to 10,000 cycles of heat cycling using a thermocycler¹⁸.

As an the flexural strength test, samples were taken out of the thermal cycling machine and put right away on a specially made jig with two supports spaced 50 mm apart (Fig. 1). They were then fixed to a universal testing machine (Electropuls E3000, Instron, UK), where the load was applied at the specimen's centre and increased gradually at a crosshead velocity of 5 mm/min until fracture. The fracture load (N) and the following equation were used to determine the strength of flexion (MPa): $FS \text{ equals } 3Fl/2bh^2$. Utilising a scanning electron microscope (SEM) (TESCAN VEGA3 LM model, Tescan Orsay Holding, Kohoutovice, Czech Republic), the topographic characteristics of the broken specimens (both 3D-printed resins and HP resin) upon flexural tests were investigated. Utilising a secondary electrons (SE) detector and a 20 kV accelerating voltage, the SEM was conducted on gold-coated specimens (Quorum, Q150R ES, UK). Diverse magnifications were used to inspect the SEM micrographs of the HP resin and 3D-printed resin specimens in order to determine the failure mode based on the traits and features of the shattered surfaces. The corresponding micrograph from each group, ASIGA and Next Dent (0, 45, and 90 degrees), treated over various periods of time (30, 60, 90, and 120 minutes) was shown with a magnification of 500 and a field of view of 277 μm .

All statistical data analyses were performed using SPSS version 20.0. Due to insignificant results from the normality test (Shapiro Wilk test), parametric tests were used for analysis. One-way ANOVA was used to study the effect of one factor (either orientation or postcuring time) on tested properties. For the combined effect (orientation and postcuring time), two-way ANOVA was used. With significant findings, pairwise comparison was performed using post hoc Tukey HSD with significant level less than 0.05.

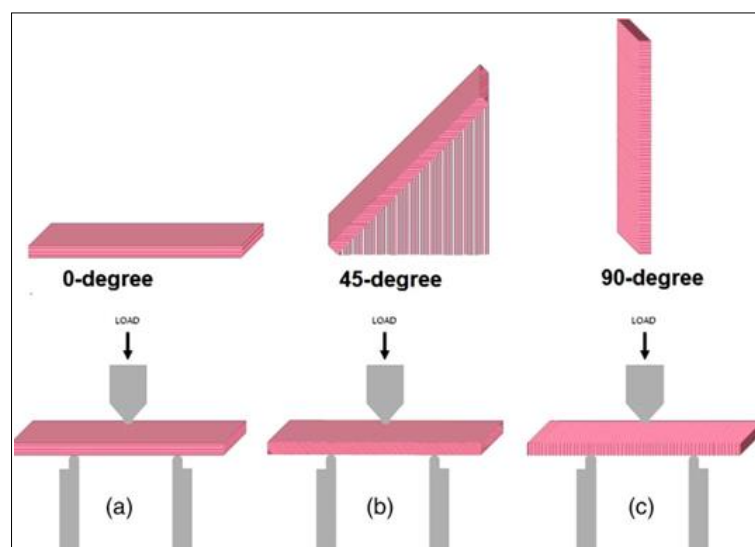


Fig 1: Illustration of the different printing orientations and load directions in relation to printing layers during flexural strength testing. (a) 0-degree (horizontal), (b) 45-degree (Oblique), (c) 90-degree (vertical).

Results

The effects of printing orientations and postcuring time on the flexural strength of each material were significant for all groups in a one-way ANOVA analysis ($p < 0.001$). Table 1 provides a summary of the post hoc test findings, including the mean values, standard deviation, and significance of flexural strength between groups. As the postcuring period extended from 30 to 120 mins for ASIGA at a 0° orientation, the flexural strength risen, with significant variations among 30 and 90 minutes ($p = 0.01$) and 30 and 120 minutes ($p < 0.001$). At 120 minutes, the flexural strength value reached its maximum (82.15 ± 2.08 MPa). The flexural strength at 45 degrees increased over time, peaking at 120 minutes with a substantial flexural strength ($p < 0.001$) and reported value (76.90 ± 1.97 MPa). At 90 degrees, there were no discernible variations amongst the groups after 30, 60, or 90 minutes ($p > 0.05$), but after 120 minutes, there was a discernible improvement in flexural strength across the board ($p < 0.001$).

Having significant variations among 30 and 90 minutes ($p = 0.001$) and 30 and 120 mins ($p < 0.001$), Next Dent's flexural strength rose as the duration increased from 30 to 120 minutes at a 0-degree orientation; 120 mins revealed the

highest flexural strength result (76.90 ± 1.97 MPa). At 45-degree, significant differences were found between all groups ($p < 0.001$) except for 30 minutes versus 60 minutes groups ($p = 0.919$). At 90-degree, the 120-minute group exhibited a significant increase in flexural strength in comparison to 30, 60, and 90 minutes ($p < 0.001$), while there were no significant differences between the other groups ($p > 0.05$).

Significant variations were recorded with different orientations per respective times, as indicated in Table 1 for orientations impact per material, compared to traditional substances, with the exception of 0 degrees with all-time ($p < 0.001$) for ASIGA and 0 degrees/120 minutes for Next Dent ($p > 0.05$). According to the findings, specimens printed using both ASIGA and Next Dent substances at a 0-degree orientation exhibited the maximum flexural strength when compared to 45 and 90 degree groups ($p < 0.001$ and $p < 0.05$, respectively). Regardless of orientation, the flexural strength increased as the postcuring period rose ($p < 0.001$). Additionally, when contrasted to the other categories, the analysis revealed statistical significance for the 120 minute postcuring period ($p < 0.001$) and revealed the maximum flexural strength.

Table 1: Mean, SD, and significance of flexural strength (MPa) between tested groups

| Materials | Orientation | Postcuring time | | | | HP | p |
|-----------|-------------|---------------------------------|---------------------------------|---------------------------------|------------------------------------|--------------------------|--------|
| | | 30 min | 60 min | 90 min | 120 min | | |
| HP | | 79.46 ± 2.6 | 79.46 ± 2.6 ^a | 79.46 ± 2.6 ^a | 79.46 ± 2.6 ^a | | |
| ASIGA | 0 | 73.38 ± 2.18 ^B | 77.24 ± 2.96 ^{a, B, C} | 78.35 ± 5.09 ^{a, A, C} | 82.15 ± 2.08 ^{a, A} | 79.46 ± 2.6 ^A | 0.000* |
| | 45 | 69.55 ± 2.46 ^{a, B} | 70.44 ± 3.85 ^{b, B} | 73.16 ± 3.64 ^{b, B, C} | 76.76 ± 2.85 ^{a, b, A, C} | 79.46 ± 2.6 ^A | 0.000* |
| | 90 | 67.15 ± 3.23 ^{a, B} | 69.40 ± 2.67 ^{b, B} | 69.97 ± 3.50 ^{b, B} | 75.52 ± 3.42 ^{b, A} | 79.46 ± 2.6 ^A | 0.000* |
| | P | 0.00* | 0.00* | 0.00* | 0.00* | | |
| NextDent | 0 | 79.46 ± 2.6 | 79.46 ± 2.6 | 79.46 ± 2.6 | 79.46 ± 2.6 ^a | 79.46 ± 2.6 ^A | 0.000* |
| | 45 | 67.07 ± 3.40 ^a | 70.80 ± 1.70 ^B | 72.38 ± 3.63 ^{a, B} | 76.90 ± 1.97 ^{a, A} | 79.46 ± 2.6 | 0.000* |
| | 90 | 65.55 ± 1.73 ^{a, b, A} | 66.28 ± 2.63 ^{a, A} | 69.69 ± 2.99 ^{a, b} | 74.53 ± 2.65 ^a | 79.46 ± 2.6 | 0.000* |
| | P | 63.26 ± 2.94 ^b | 66.54 ± 2.06 ^{a, A} | 67.76 ± 2.00 ^{b, A} | 71.03 ± 1.68 | 79.46 ± 2.6 | 0.000* |
| | | 0.017* | 0.00* | 0.06* | 0.00* | | |

*Statistically significant at 0.05 level of significance.

Lowercase letters indicate insignificant difference between the pairs within the same column, while capital letters

indicate insignificant difference between the pairs within the same row.

Table 2: Two-way ANOVA for combined effect of time and orientation on flexural strength per material

| Materials | Source | Type III sum of squares | df | Mean square | F | Sig. |
|-----------|---------------------|-------------------------|-----|-------------|--------|-------|
| ASIGA | Time | 1050.074 | 3 | 350.025 | 33.785 | 0.000 |
| | Orientations | 1131.961 | 2 | 565.980 | 54.629 | 0.000 |
| | Time * orientations | 35.215 | 6 | 5.869 | 0.566 | .756 |
| | Error | 1212.174 | 117 | 10.360 | | |
| | Total | 716499.267 | 130 | | | |
| | Corrected total | 3747.280 | 129 | | | |
| Next Dent | Time | 1260.571 | 3 | 420.190 | 64.881 | 0.000 |
| | Orientations | 436.112 | 2 | 218.056 | 33.670 | 0.000 |
| | Time * orientations | 48.388 | 6 | 8.065 | 1.245 | 0.288 |
| | Error | 757.732 | 117 | 6.476 | | |
| | Total | 642265.293 | 130 | | | |
| | Corrected total | 3452.405 | 129 | | | |

Discussion

One of the crucial characteristics that can impact the mechanical behaviour of denture base resin is the flexural strength values. According to published research, a number of factors, including build orientation, postcuring techniques and processes, CAD-CAM software, layer density and number, shrinkage between layers, and build orientation, affect the mechanical properties of 3D-printed resins 19–22.

On the clinical level, varied oral temperatures are applied to denture base resins, so all specimens underwent 10,000 thermal cycles to simulate wearing dentures for a year 18, 23. Additionally, this ageing causes the components of the resin to leach and speeds up the water sorption and solubility procedure, as well as swelling and matrix degradation, all of which have an impact on the characteristics of the printed resins 24. The present

investigation aims to assess the impact of two of these variables after thermal cycling: printing orientation and postcuring time. The outcomes of the present investigation indicated that postcuring time did have an effect on the flexural strength of both the ASIGA and Next Dent groups, but that the combined effect of printing orientation and postcuring time on the 3D-printed resin failed to reach statistical significance. As a result, the null hypothesis was only partially declined.

Generally, the flexural strength of 3D-printed resins at baseline and according to manufacturer recommendations was the lowest when compared to the heat polymerized group. Similar findings were reported in previous studies [18, 20, 25]. The printing nature and curing conditions the second is weak interlayer bonding between successive printed layers [18, 20].

The strength of 3D-printed resins and printing direction were found to be correlated in earlier investigations 10, 23, 26. In the current investigation, the 0-degree (horizontal) orientation groups displayed the highest flexural strength values in both 3D-printed resins in comparison to 45- and 90-degree orientation groups. This can be due to the layering construct of the printing axis switching from parallel to perpendicular to the loading direction, which can produce stronger adherence across the same layers in comparison to 45-degree (oblique) and 90-degree (vertical) orientation (Fig. 1) [18, 19, 27]. This can be confirmed by SEM findings (more homogenous layers in 0-degree groups). As in the previous study by Shim [1], 0-degree showed the

highest flexural strength compared to 45- and 90-degree [1, 18]. This also agrees with a previous study by Keßler *et al* [23], who recommended the alignment of the printed layers to be perpendicular to the load direction which resulted in high strength compared to vertical when printing layers were parallel to load direction.

Because of the partial polymerization, the samples were in a weak condition known as the "green-state" as they were being printed [9, 10, 28]. As a result, it was recommended to use the postcuring method to boost conversions and reduce monomer leftovers [29]. A sufficient postcuring period for 3D-printed specimens to consistently polymerize, which enhances the mechanical characteristics [11]. The manufacturer states that 3D-printed resin needs to go through a postcuring procedure using a UV lightbox, with a suggested period of 15 to 30 minutes. Nevertheless, to improve the flexural strength of the 3D-printed resin, 1-2 hours of postpolymerization time was advised [11, 28]. According to the kind of printed material and the postcuring device, the postcuring time could differ [6, 30]. Regardless of the orientation in both 3D-printed resins, the values of the flexural strength rose as postcuring time increased. This may be connected to the enhanced postcuring time-induced polymerization of unreacted monomers [20]. The results of the current investigation concur with earlier studies that found that flexural strength rose as postcuring time risen, further contributing to the attainment of homogeneous polymerization across both superficial and deep layers within the 3D-printed resins [10, 11, 20, 29].

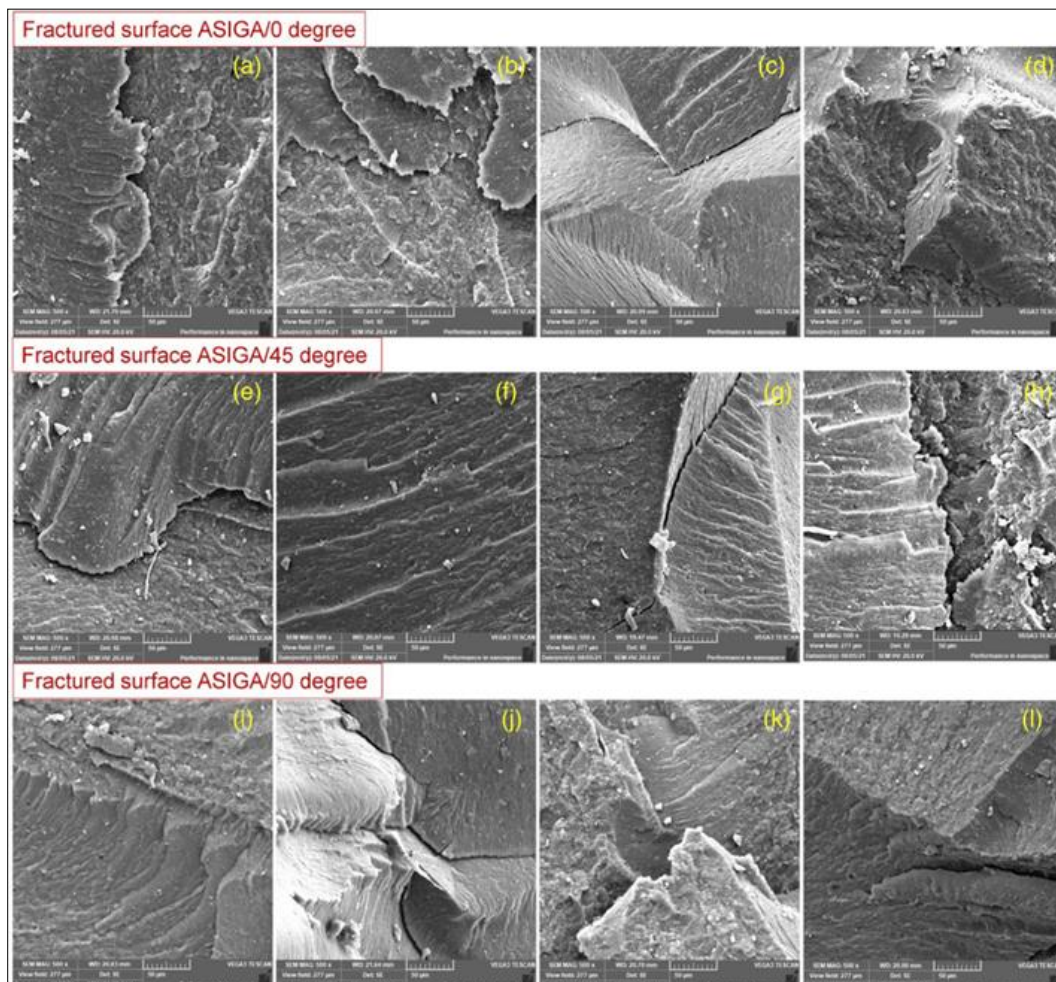


Fig 2: Representative SEM images (500x magnifications) of fractured surface ASIGA at 0, 45, and 90 degrees. (a, e, i) 30 minutes, (b, f, j) 60 minutes, (c, g, k) 90 minutes, and (d, h, l) 120 minutes.

According to Kim *et al.*, the postcuring period up to 60 or 90 minutes greatly boosts the flexural strength of the 3D-printed resins.¹¹ Parallel to this, Aati *et al.* explored how postcuring time (5-20 minutes) affected the flexural characteristics and degree of transformation in 3D-printed resins, and they found that as postcuring time grew, so did the flexural strength and degree of conversion^[29]. In accordance with the findings of the current investigation, previous research on the impact of postcuring time (varying from 15 to 120 minutes) on the strength of printed provisional prostheses¹¹ and printed denture teeth²⁸ indicates that 120 minutes demonstrated the maximum flexural strength.

However, the results of this study indicated that the flexural strength values of all ASIGA groups and all Next Dent groups were higher than the ISO requirements (65 MPa)^{12,13} except for the mean value of Next Dent (90-degree/30 min group).

Conclusion

Flexural strength was impacted by postcuring time and printing orientations. According to the findings, the groups with a 0-degree orientation exhibited more flexural strength than all other categories. The flexural strength additionally raised with longer postcuring times.

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