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# Printing Orientation and Layer Thickness of Nitrogen Post-Cured LCD 3D-Printed Dental Resins

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## Abstract

This study investigated the impact of two printing orientations (45° and 90°) and two-layer thicknesses (50 µm and 100 µm) on the compressive, tensile, and flexural strengths of a 3D-printed dental resin post-cured in a controlled nitrogen atmosphere. A total of 120 specimens were virtually designed according to ISO standards and then fabricated utilizing an LCD-based 3D printer (SOL, Ackuretta). The specimens were divided into four groups (n = 30/group). All specimens underwent post-curing in a nitrogen ($N_2$) atmosphere and were tested using a universal testing machine. Data analysis was performed using two-way ANOVA and Tukey's HSD test. Group 2 (45° orientation, 50 µm layer thickness) exhibited significantly higher compressive strength (138.2 ± 11.9 MPa) compared to all other groups ($p < 0.001$). Tensile strength showed no statistically significant differences among the tested groups ($p > 0.05$). Specimens printed at a 90° orientation demonstrated significantly higher flexural strength compared to the 45° groups ($p < 0.001$), with printing orientation exhibiting a greater influence than layer thickness. The compressive and flexural strengths of the tested resin are highly affected by the changes in printing parameters, whereas the tensile strength remained statistically unaffected among the groups. The ideal setting for restorations bearing compressive loads is a 45° orientation with a 50 µm layer thickness, whereas a 90° orientation is highly recommended for long-span restorations subject to flexural loads.

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## Introduction

Additive manufacturing technology (AM), also known as 3D-printing, has become one of the most rapidly developing technologies in dentistry. It provides many advantages such as high accuracy restorations and reasonable material loss [1-3]. Among the various types of 3D-printing technologies, the Liquid Crystal Display (LCD) technique is getting considerable attention, as it provides a distinctive combination of high printing quality and cost-effectiveness [4].

The recent improvements in dental hybrid composite resins for 3D-printing have expanded the practical applications of AM, extending from provisional crowns and bridges to final restorations. These materials provide many valuable clinical properties, including high aesthetics, adequate strength and wear resistance. The printing parameters for these materials dictate their mechanical properties, which in turn modulate their clinical performance. Additionally, they follow an anisotropic behavior meaning their mechanical properties depend on the printing parameters, which might affect their clinical performance [2].

Among these parameters, printing orientation and layer thickness primarily dictate the material performance [5]. Printing orientation dictates the layers arrangement and the interlayer bonding configuration [6,7]. While most previous studies investigated 0° and 90° printing angles, there is a growing progression to utilize the intermediate 45° angle to promote surface quality and applied loads distribution [8]. Layer thickness is considered a crucial parameter as it defines the degree of polymerization and the number of interlayer bonds. Although thinner layers provide superior polymerization depth and enhanced resolution, they are associated with higher interfaces numbers which increase the material failure points [9].

Additionally, the post-curing procedure is essential for optimizing the degree of polymerization of dental resins. The atmospheric oxygen present during this process promotes the formation of an under-cured, tacky surface, known as the oxygen-inhibited layer (OIL). This layer can compromise the mechanical performance of the printed restorations [10]. To overcome this challenge, a nitrogen gas ($N_2$) atmosphere is increasingly employed, which results in more homogeneously cured restorations [11,12].

While previous studies reported that the mechanical performance of 3D-printed resin was affected by printer type, printing parameters and post-curing conditions [13,14], there is limited evidence regarding the mechanical performance of specific dental resins, such as Shining 3D Ceramic CB resin, when printed by specific printers, such as the Ackuretta Sol, in various printing settings. Accordingly, this study aims to evaluate the effect of two printing orientations (45° and 90°) and two-layer thicknesses (50 µm and 100 µm) on the compressive, tensile and flexural strengths of a 3D-printed dental resin (Shining 3D Ceramic CB Resin) post-cured under a nitrogen atmosphere. The clinical relevance of the study findings is also discussed.

The null hypotheses tested were:

(1) Printing orientation has no significant effect on the compressive, tensile, or flexural strengths of the tested resin.

(2) Layer thickness has no significant effect on the compressive, tensile, or flexural strengths of the tested resin.

(3) There is no interaction effect between printing orientation and layer thickness on the tested mechanical properties.

## Materials and Methods

### Study Design and Specimens Preparation

The specimens for each test were virtually designed using Exocad dental CAD software (Exocad GmbH, Darmstadt, Germany). Subsequently, the specimens were printed using a tooth-colored dental resin (Shining 3D Ceramic CB Resin, Shade CB12; lot number: 20250218-19, Shining 3D, Hangzhou, China). The total number of the printed specimens was 120, which were divided into three groups according to their geometry (following ISO standards of each mechanical test):

Compressive Strength: Cylindrical specimens measuring 5 mm in diameter and 10 mm in height (ISO 604) [15].

Tensile Strength: Dog-bone shaped specimens. Dimensions were: length=75 mm, width= 5 mm, and thickness= 2 mm (ISO 527-2) [16].

Flexural Strength: Rectangular bar specimens measuring 25 mm in length, 2 mm in width, and 2 mm in thickness, designed in accordance with ISO 4049 [17].

All specimens were printed using an LCD-based 3D printer (SOL, Ackuretta Technologies Pvt. Ltd., Taipei, Taiwan). The printing parameters were standardized, with the only variables being the selected layer thickness (50 µm or 100 µm) and printing orientations (45° or 90°) relative to the build platform.

After printing, samples were distributed into four groups (n=30 /group, with n=10 /each mechanical test) depending on layer thickness and printing orientation:

Group 1: 45° printing orientation + 100 µm layer thickness

Group 2: 45° printing orientation + 50 µm layer thickness

Group 3: 90° printing orientation + 100 µm layer thickness

Group 4: 90° printing orientation + 50 µm layer thickness

### Post-Processing and Storage Protocol

An automatic cleaning device (CLEANI, Ackuretta) was utilized to eliminate any residue from the printing process that might affect the mechanical properties of the tested specimens. This step was performed in 99% isopropyl alcohol (IPA) for two 3-minute washing cycles. The subsequent step included air-drying and post-curing of the specimens using a UV light-curing unit (Curie Plus, Ackuretta) [18]. This essential step promotes complete polymerization and enhances the mechanical performance of the printed material [19]. The post-curing procedures were executed in an inert nitrogen ($N_2$) environment generated by an integrated nitrogen gas generator (N-finity, Ackuretta), following the manufacturer's instructions [11,20]. To simulate the oral environment, the specimens were then stored in distilled water at 37°C for approximately 24 hours prior to mechanical testing, according to the ISO 4049 testing protocol for dental materials [21].

### Mechanical Testing and Statistical Analysis

A Universal Testing Machine (Tinius Olsen, Horsham, PA, USA) was utilized to perform the mechanical tests. The analysis of data was done using a statistical software (IBM SPSS Statistics for Windows, Version 25.0; IBM Corp., Armonk, NY, USA). A two-way analysis of variance (ANOVA) was performed at a significance level of 0.05 to determine the effects of printing orientation, layer thickness, and their interaction.

## Results

The initial step in the data analysis was obtaining descriptive statistics, including means and standard deviations (SD). Data normality was confirmed using the Shapiro-Wilk test and the homogeneity of variances using Levene's test. Levene's test showed homogeneity of variances for compressive, tensile, and flexural strengths ($p$ = 0.17, 0.57, and 0.26, respectively). Subsequently, a two-way analysis of variance (ANOVA) was performed to evaluate the effects of printing orientation, layer thickness, and their interaction on the tested mechanical properties. When significant differences were identified, Tukey's HSD post hoc test was applied for pairwise comparisons. The descriptive statistics of all experimental groups are presented in Table 1.

### Compressive Strength

The mean compressive strength values for the tested groups were 107.0 ± 11.4 MPa for Group 1, 138.2 ± 11.9 MPa for Group 2, 99.7 ± 6.4 MPa for Group 3, and 106.7 ± 11.1 MPa for Group 4. Effect size analysis (Partial Eta Squared) revealed moderate-to-high

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contributions to compressive strength from both printing orientation ($\eta^2$ = 0.486) and layer thickness ($\eta^2$ = 0.479), along with a moderate interaction effect between the two variables ($\eta^2$ = 0.271). Tukey's HSD multiple comparisons showed that Group 2 (45°, 50 µm) exhibited a significantly higher compressive strength than all other groups ($p$ < 0.001). Conversely, there were no statistically significant differences among Groups 1, 3, and 4 regarding compressive strength. The compressive strength results are presented in Figure 1.

**Tensile Strength**

The mean tensile strength values for the tested groups were as follows: Group 1 = 47.8 ± 5.6 MPa, Group 2 = 50.3 ± 7.0 MPa, Group 3 = 52.7 ± 6.3 MPa, and Group 4 = 52.3 ± 5.7 MPa. There was no statistically significant differences among the tested groups regarding tensile performance ($p$ > 0.05). Furthermore, the minimal effect sizes for printing angle ($\eta^2$ = 0.078), layer thickness ($\eta^2$ = 0.007), and their interaction ($\eta^2$ = 0.016) confirmed that these parameters had no significant effect on the tensile strength of the tested resin.

**Flexural Strength**

Regarding flexural strength, the obtained results showed the following mean values: Group 1 = 102.0 ± 7.6 MPa, Group 2 = 139.6 ± 10.0 MPa, Group 3 = 153.8 ± 9.8 MPa, and Group 4 = 159.0 ± 7.2 MPa. Effect size analysis revealed that the partial eta-squared value for the printing angle was remarkably high ($\eta^2$ = 0.819), implying its major influence on flexural strength. Additionally, the effect size for layer thickness was substantial ($\eta^2$ = 0.620), while their interaction demonstrated a moderate effect ($\eta^2$ = 0.483).

Tukey's HSD multiple comparisons revealed that Group 1 had the weakest flexural strength in comparison to the other groups ($p$ < 0.001). Additionally, Group 2 showed a significantly lower bending strength when compared to Group 3 ($p$ = 0.005) and Group 4 ($p$ < 0.001). The flexural strengths of Groups 3 and 4 were comparable, as there was no statistically significant difference between them ($p$= 0.562).These results are illustrated in Figure 2.

## Discussion

This study aimed to assess the effect of printing orientation and layer thickness on the mechanical behavior of a 3D-printed dental resin post-cured in nitrogen atmosphere. The results showed that the tested parameters significantly affected the compressive and flexural strengths. Conversely, the tensile strength was not significantly affected among the four groups.

Group 2 demonstrated superior compressive strength in comparison to the other groups. This might be related to the combination of improved light penetration and more favorable structural load distribution within the printed structure. Printing the resin in a thin layer (50 µm) may improve light penetration across the printed layer, which would promote the Degree of Conversion (DC %), resulting in a denser polymer network [9]. When the resin material is printed at 45°, the acquired polymer networks might enhance the interlayer stress resistance along the obliquely printed resin [22].

The mean values for the tensile strength across the groups ranged between 47.8 and 52.7 MPa, with no statistically significant difference. This might be related to the use of a post-curing nitrogen environment as recommended by the printer's manufacturer. Nitrogen gas eliminates the oxygen inhibition layer, which might promote maximum polymerization of the surface. A high degree of polymerization reduces surface microcracks, resulting in a lower rate of interlayer separation (delamination) [23].

Both groups printed at 90° orientation (Groups 3 and 4) showed significantly superior flexural strength mean values when compared to the other groups. Aljehani et al. [6], who observed that changes in the printing orientation modify the mechanical behavior, reported similar findings. These findings may be attributed to their anisotropic behavior. At a 90° orientation, the stress generated by flexural loads needs to propagate through the dense intralayer matrix. In contrast, at 45°, the flexural stress propagates through the weak interlayer interfaces. This might cause premature layer separation [22,24].

No statistically significant difference was observed between Groups 3 and 4, suggesting that printing orientation exerted a greater influence on flexural strength than layer thickness under the tested conditions. However, within the 45° orientation groups, the 50 µm layer thickness demonstrated significantly higher flexural strength than the 100 µm thickness. This finding may be related to the enhanced light penetration and improved interlayer polymerization associated with thinner printed layers, which could contribute to improved structural integrity [9,25].

## Conclusion

Within the limitations of this in vitro study, the mechanical performance of the tested 3D-printed resin was significantly influenced by printing orientation and layer thickness. The combination of a 45° orientation and a 50 µm layer thickness provided superior compressive performance when compared to the other groups. Tensile strength was not significantly affected by the investigated printing parameters.

Regarding the flexural strength, the primary effective factor among the groups was printing orientation, where the 90°-printed groups yielded better results. In circumstances where the printing angle is not optimal (45°), a lower layer thickness (50 µm) produced polymers with higher resistance to flexural loads when compared to the 100 µm group.

**Limitations**

This study evaluated only one commercially available resin material and one LCD printing system under controlled laboratory conditions. Furthermore, only short-term mechanical properties were investigated. Therefore, caution should be exercised when extrapolating these findings directly to clinical situations.

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Table 1. Descriptive statistics (mean ± SD) for the tested parameters across the experimental groups.

| Group | Print Angle | Layer Thickness | Compressive Strength (MPa) | Tensile Strength (MPa) | Flexural Strength (MPa) |
|---|---|---|---|---|---|
| Group 1 | 45° | 100 µm | 107 ± 11.4 | 47.8 ± 5.6 | 102 ± 7.6 |
| Group 2 | 45° | 50 µm | 138.2 ± 11.9 | 50.3 ± 7.0 | 139.6 ± 10 |
| Group 3 | 90° | 100 µm | 99.7 ± 6.4 | 52.7 ± 6.3 | 153.8 ± 9.8 |
| Group 4 | 90° | 50 µm | 106.7 ± 11.1 | 52.3 ± 5.7 | 159 ± 7.2 |

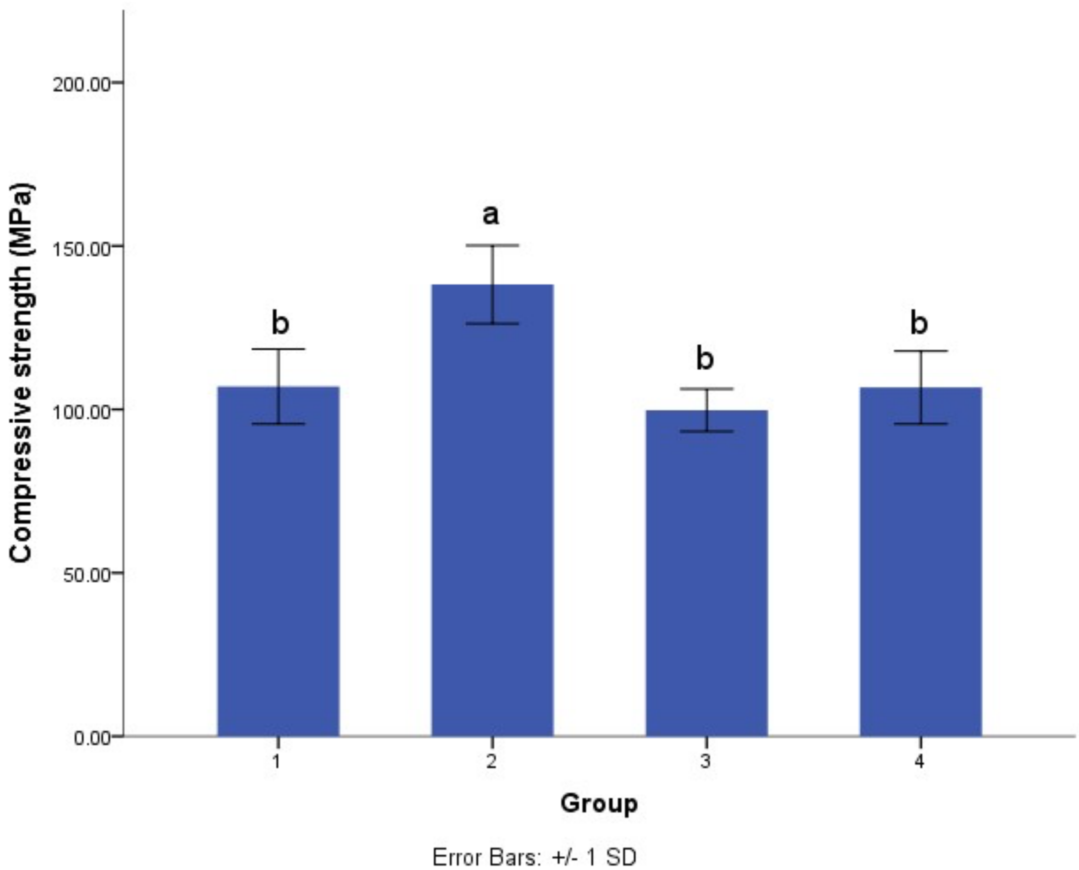


Figure 1. Mean compressive strength values (MPa) across the tested groups. Different letters (a, b) indicate statistical significance according to Tukey's HSD test ($p < 0.05$). Error bars represent ± 1 standard deviation.

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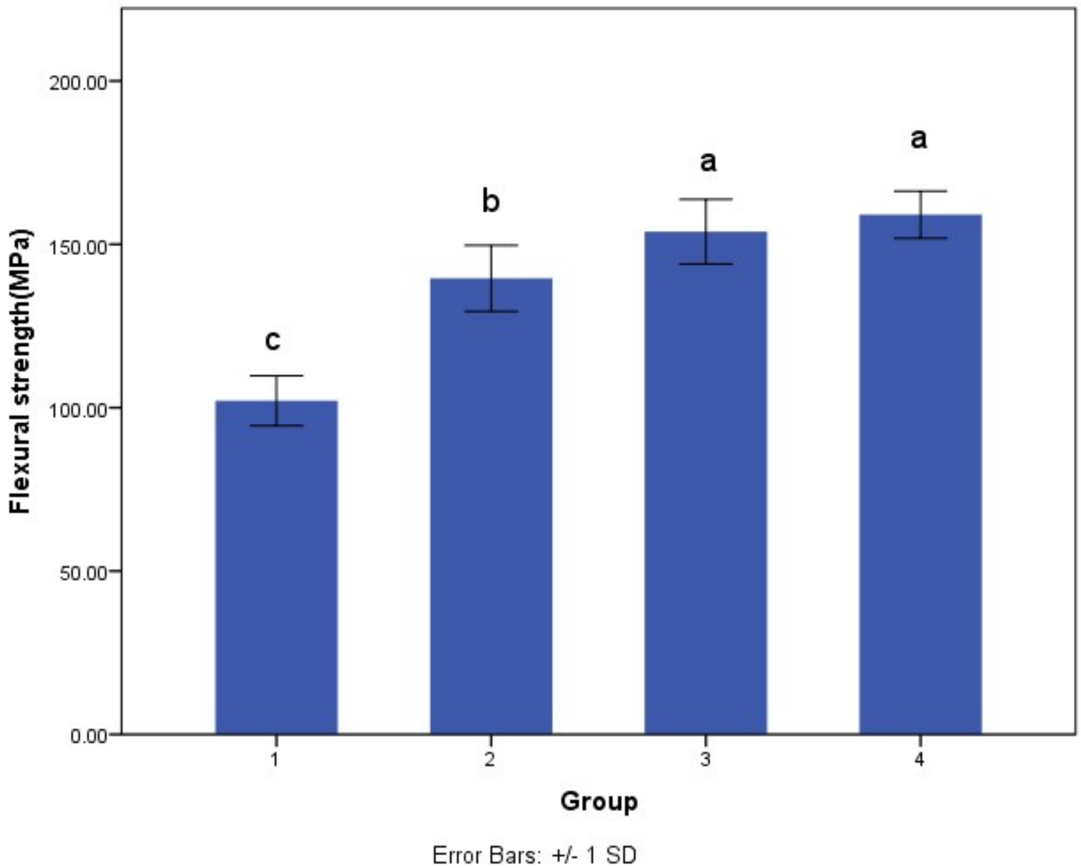


Figure 2. Mean flexural strength values (MPa) among the tested groups. Different letters (a, b, c) indicate a statistical significance according to Tukey's HSD test ($p < 0.05$). Error bars represent ± 1 standard deviation.