

Original research article

Physicochemical evaluation of the recently developed 3D-printed resin fabricated with different printing orientations

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ABSTRACT

OBJECTIVE: This study aimed to examine the physicochemical characteristics, including water absorption, solubility, flexural strength, and flexural modulus of a newly developed 3D-printed resin material, considering variations in printing orientation.

MATERIALS AND METHODS: Two experimental groups were created using a 3D-printed denture base material (Power Resins Denture NF Resin, 3bfab, Türkiye) printed at 0-degree and 90-degree orientations. In total, 10 disc-shaped and 10 bar-shaped specimens were fabricated. Water sorption, solubility, flexural strength, and flexural modulus were assessed in alignment with ISO 20795-1:2013 standards. The differences between the groups were statistically analyzed through an Independent Samples T-Test, with significance set at $p < 0.05$.

RESULTS: When the printing orientation shifted from 0-degree to 90-degree, there was a significant increase ($p < 0.05$) in water sorption, flexural strength, and flexural modulus. However, solubility did not show a statistically significant variation ($p > 0.05$) between the two orientations.

CONCLUSION: While the specimens printed at a 90-degree orientation exhibited superior mechanical and physical properties, their water absorption levels indicate a need for further research to assess the material's long-term performance.

KEYWORDS: Acrylic resins; Printing; Three-dimensional

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[Abstract in Turkish is at the end of the manuscript]

INTRODUCTION

In recent years, advancements in technology have transformed the field of dentistry by introducing three-dimensional (3D) printing techniques. The benefits of this technology include the ability to produce intricately shaped objects, reduced costs, quick production times, and minimal material waste.¹⁻⁴ The evolution of 3D printing has also spurred the creation of materials, such as acrylic resin, specifically designed for this process. Consequently, examining the physical and mechanical properties of these materials, along with their efficacy in practical applications, has become crucial.

The presence of water can significantly influence the dimensional and mechanical traits of polymers, which tend to absorb small amounts of water in aqueous environments. Water infiltrates the polymer chains, acting as a plasticizer and causing a slight expansion of the solidified material. It was indicated that resins created via 3D printing showed greater water absorption and solubility,⁵ and reduced flexural strength compared to conventional heat polymerization.⁶ Nevertheless, their flexural strength neared the 65 MPa threshold established by ISO standards,⁷ while the water absorption and solubility of these resins fall below ISO recommendations.⁸

These limitations hinder the clinical applicability of 3D printing technology, particularly for denture base

production.⁹ Consequently, previous studies have explored multiple factors that influence the properties of 3D-printed resins, including the orientation of printing, post-polymerization duration, and layer thickness.^{5,6} This research aims to address these limitations and take advantages of 3D printing technology,^{10,11} along with the development of diverse resin compositions for dental applications.

The present study focuses on evaluating water absorption/solubility and flexural strength in newly developed 3D-printed resin materials fabricated with various printing orientations. The null hypothesis was that there would not be significant differences in water absorption/solubility and flexural strength/flexural modulus among the 3D-printed resins based on their printing orientations.

MATERIALS AND METHODS

Specimen Preparation

Disk-shaped specimens ($15 \pm 1 \text{ mm} \times 1 \pm 0.1 \text{ mm}$)⁸ (Fig. 1) and bar-shaped specimens ($65 \pm 1 \text{ mm} \times 10.0 \pm 0.2 \text{ mm} \times 3.3 \pm 0.2 \text{ mm}$)⁸ were fabricated from 3D-printed denture base material (Power Resins Denture NF Resin, 3bfab, Türkiye) using different printing orientations. Two resin test groups were established: 0-degree printing orientation (0-R) and 90-degree printing orientation (90-R). The properties of the resin utilized in this investigation are listed in Table 1. The designs were saved as standard tessellation language (STL) files and imported into the 3D printer system (DentaFab, 3bfab, Türkiye). After the printing process,

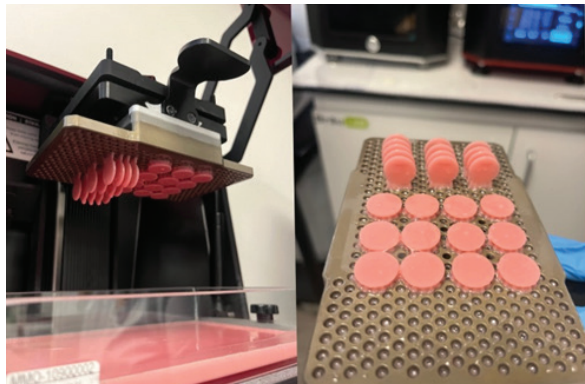


Figure 1. Disk-shaped specimens that were prepared for water sorption and solubility tests.

the support structures were detached. A post-curing treatment using Power Apply (3bfab, Türkiye) was conducted according to the manufacturer's guidelines.

Water Absorption and Solubility

Disk-shaped specimens were employed to assess water absorption and solubility. The evaluation methods were similar to those outlined in ISO 1567-1999 standards.⁸ The volume (v) of each specimen was determined by calculating the average values of its diameter and thickness. The diameter was measured at three points, and the mean value was recorded. The thickness was gauged at five locations, starting from the center and extending to the edges.

The specimens were conditioned in silica gel desiccators at $27 \pm 1^\circ\text{C}$ until achieving a stable mass, recorded as m_1 , using a precision balance (Mettler AE 163; Mettler, Greifensee, Switzerland). They were then submerged in water until their mass became constant, noted as m_2 . After that, specimens were conditioned again to achieve a steady mass in desiccators, with the final mass recorded as m_3 . Water absorption (W_{sp}) and solubility (W_{sl}) were computed with the following equations:

$$W_{sp} = [(m_2 - m_3) / v]$$

$$W_{sl} = [(m_1 - m_3) / v]$$

Flexural Strength

The specimens underwent a three-point bending test on a rig with a span of 50 mm while maintaining a constant crosshead speed of 5 mm/min, as per ISO 1567:1999⁸ (Fig. 2). Ten specimens from each group were examined via a Lloyd LRX testing machine (Lloyds Instruments, Fareham, Hampshire, UK) using

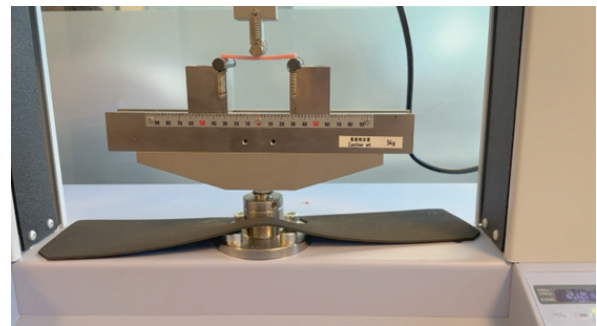


Figure 2. Bar-shaped specimens loaded on a universal testing machine.

Table 1. Material properties of Denture NF Resin TDS.

Material Properties	Value	Standard
Flexural Strength	>130 MPa	ASTM D790-02
Flexural Module	5000 MPa	ASTM D790-02
Shore Hardness	>93 D	ASTM D2240
Density	1.1 g/cm ³	ASTM D1475
Viscosity	2000 - 3000 mPa.s (Anton Paar L3 Spindle 23 °C)	DIN 53211-4
Color	Opaque Pink	

the Noxygen software program. The ultimate flexural strength (FS) was calculated with the equation: $FS = (3Fl) / (2bh^2)$ where F represents the applied load (N) at the peak of the load-deflection curve, l is the span length (50.0 mm), b is the specimen width, and h is the specimen thickness. The flexural modulus (E) was computed using: $E = (l^3F) / (4bh^3d)$, where d denotes the deflection corresponding to load F in the linear portion of the curve. The strain at ultimate flexural strength (ϵ) was determined by: $\epsilon = (6hsi) / (l^2)$, where si represents an individual deflection.

Statistical Analysis

Statistical analysis was performed using SPSS version 20 (IBM, New York, NY, USA). The normality of data distribution was assessed via the Shapiro-Wilk

test. Comparison of data was conducted using the Independent Samples T Test. A p-value of <0.05 was considered statistically significant.

RESULTS

The outcomes for water absorption and solubility in resin test groups with 0-degree printing orientation (0-R) and 90-degree printing orientation (90-R) are presented in Table 2. Similarly, the ultimate flexural strength and flexural modulus for the two resin test groups are shown in Table 2. Water absorption, flexural strength, and flexural modulus were observed to significantly increase ($p < 0.05$) when the printing orientation was altered from 0-degree to 90-degree. However, no significant difference ($p > 0.05$) in solubility was noted between the groups with different printing orientations.

Table 2. Evaluation of the properties of resin test groups with 0-degree printing orientation (0-R) and 90-degree printing orientation (90-R).

	0-R			90-R		
	Mean \pm SD	Min	Max	Mean \pm SD	Min	Max
Water sorption (mg/mm ³)	2059.16 \pm 174.80	1892.80	2321.01	2564.99 \pm 29.89	2534.81	2614.94
Water solubility (mg/mm ³)	2.09 \pm 2.72	-2.56	4.26	-0.35 \pm 3.85	-4.48	4.50
Flexural strength (MPa)	51.42 \pm 5.71	44.57	58.33	87.77 \pm 7.06	79.50	96.94
Flexural modulus (GPa)	0.97 \pm 0.14	0.82	1.16	2.07 \pm 0.24	1.82	2.42

DISCUSSION

A denture base resin material needs to exhibit mechanical characteristics capable of withstanding masticatory forces while exhibiting relatively low water absorption and solubility. This research examined the properties of an innovative 3D-printed resin material fabricated with different printing orientations. The results demonstrated that changing the printing orientation from 0-degree to 90-degree significantly increased tested properties (except solubility). Thus, the null hypothesis was partially rejected.

Water molecules infiltrate the gaps between polymeric chains, promoting a separation that results in expansion.¹² The absorbed water molecules may also function as plasticizers, enhancing the mobility of the polymethyl methacrylate (PMMA) chains. The physicochemical and mechanical properties can be influenced by the presence of absorbed water.¹³

The water absorption for the 90-R specimens was notably higher than that of the 0-R group. Previous study indicates that material water absorption increases substantially when shifting the printing orientation from 0-degree to 90-degree, corroborating the findings.⁵ The layer-by-layer rapid construction process may lead to insufficient bonding strength among layers due to differing orientations. Over time, increased water absorption can diminish the mechanical integrity of the material.¹³ This suggests that further investigations into

the impact of water absorption on the flexural properties of these materials are warranted.

The solubility measurements obtained for the 90-R and 0-R materials were similar and fell below the thresholds established for water absorption in international guidelines for denture-base polymers.⁸ The ISO 20795-1 guideline indicates that a three-point bending test is the standard for assessing the mechanical properties and clinical viability of polymer-based materials.¹⁴ Therefore, this test was utilized to evaluate the flexural strength of the materials, in which it is specified that acrylic resins should achieve a minimum flexural strength of 65 MPa.

In summary, the basic criteria outlined in the international standards for the properties under investigation are fulfilled by the 90-R specimens. Notably, the 90-R group exhibited superior flexural strength and modulus compared to the 0-R group. This aligns with prior research indicating that specimens oriented parallel to the loading direction demonstrate inferior mechanical properties.¹⁵

Discrepancies between the findings and the specifications provided by the manufacturer may be attributed to various pre- and post-processing adjustments, including the object's placement on the manufacturing platform, structural configurations, and the cleaning processes of the final product.¹⁵ The rapid layered construction can result in inadequate curing

density in each successive layer, which may hinder the effectiveness of extensive chain cross-linking. Implementing a final curing phase can transform partially cured monomers into fully formed polymers, enhancing the polymerization degree. Prolonging the final curing period correlates with an increase in double bond conversion. Thus, extending the final curing duration may further enhance the mechanical properties of 3D-printed denture base materials, as the flexural strength tends to improve with increased curing time.¹⁶

3D printing facilitates the creation of intricate designs that might be essential in clinical settings. It is crucial to acknowledge that 3D printers are complicated systems with numerous influencing variables, and utilizing these systems in dental base material production remains a relatively new endeavor. Therefore, further research is pivotal in understanding how different manufacturing parameters affect the outcomes.

CONCLUSION

Within the limitations of this *in vitro* study, printing orientation affected the water sorption, flexural strength, and flexural modulus of the newly developed 3D-printed resin material. However, printing orientation did not influence solubility values for the evaluated 3D-printed resin material.

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Farklı baskı yönelimlerinde hazırlanan yakın zamanda geliştirilen 3D-baskılı rezinin fizikokimyasal değerlendirmesi

ÖZET

AMAÇ: Bu çalışmada, yeni geliştirilen bir 3B baskılı reçine malzemesinin su emme, çözünürlük, bükülme mukavemeti ve bükülme modülü dahil olmak üzere fizikokimyasal özelliklerinin baskı yönelimindeki değişiklikler dikkate alarak incelenmesi amaçlandı.

GEREÇ VE YÖNTEM: 0° ve 90° yönlerde basılmış 3B baskılı protez kaide malzemesi (Power Resins Denture NF Resin, 3bfab, Türkiye) kullanılarak iki deney grubu oluşturuldu. Toplamda 10 adet disk şeklinde ve 10 adet çubuk şeklinde numune üretildi. Su emme, çözünürlük, eğilme mukavemeti ve eğilme modülü değerlendirmeleri ISO 20795-1:2013 standartlarına uygun olarak gerçekleştirildi. Gruplar arasındaki farklar bağımsız örneklem T-Testi ile istatistiksel olarak analiz edildi ve anlamlılık düzeyi p<0.05 olarak belirlendi.

BULGULAR: Baskı yönü 0°'den 90°'ye kaydırıldığında, su emme, bükülme mukavemeti ve bükülme modülünde önemli bir artış tespit edildi (p<0.05). Ancak çözünürlük, iki yönelim arasında istatistiksel olarak anlamlı bir değişiklik göstermedi (p>0.05).

SONUÇ: 90 derecelik bir yönelimle basılan numuneler üstün mekanik ve fiziksel özellikler sergilerken, su emme seviyeleri, malzemenin uzun vadeli performansını değerlendirmek için daha fazla araştırmaya ihtiyaç olduğunu göstermektedir.

ANAHTAR KELİMELER: Akrilik Rezineri; Basım; Üç Boyutlu