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The Flexural Strength of 3D-Printed Temporary Fixed Prosthetic Materials with Different Orientation Angles

Farklı Oryantasyon Açılara Sahip 3B Baskılı Geçici Sabit Protez Malzemelerinin Bükülme Dayanımı

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ABSTRACT

Objective: The objective of this study is to investigate the flexural strength and modulus of elasticity values of temporary fixed prosthetic materials produced with different orientation angles (0°, 45°, 90°).
Methods: In this study, bar-shaped specimens (25 mm × 2 mm × 2 mm) with 0°-45°-90° orientation angles were prepared by 3D printing using a temporary restoration resin (Ackuretta Qura Crown Temporary Crown Photopolymer Resin), totaling thirty-nine specimens (n=13). The specimens underwent a twenty-four-hour storage period in distilled water at 37°C, after which their flexural strength and their modulus of elasticity values were measured and subsequently compared.
Results: The flexural strength and modulus of the elasticity values of the temporary fixed prostheses produced with different orientation angles (0°, 45°, 90°) exhibited no statistically significant difference (*P*>.05).
Conclusion: The different production angles did not affect the flexural and modulus of the elasticity values of the test specimens produced by the 3D printing. According to the ISO 10477 standards, the flexural strength values meet the criteria (fifty MPa value).
Keywords: temporary fixed prosthesis,flexural strength, elastic modulus, 3D printing

ÖZ
Amaç: Bu çalışmanın amacı, farklı oryantasyon açılarında (0°, 45°, 90°) üretilen geçici sabit protez materyallerinin bükülme dayanımı ve elastisite modülü değerlerini araştırmaktır.
Yöntemler: Bu çalışmada, geçici restorasyon rezini (Ackuretta Qura Crown Temporary Crown Photopolymer Resin) kullanılarak 3D baskı ile 0°-45°-90° oryantasyon açılarına sahip bar şeklinde örnekler (25 mm × 2 mm × 2 mm) hazırlanmıştır, toplam 39 örnek (n=13). Örnekler 37°C'de distile su içinde 24 saatlik bir saklama süresine tabi tutulmuş, ardından bükülme dayanımı ve elastisite modülü değerleri ölçülmüş ve daha sonra karşılaştırılmıştır.
Bulgular: Farklı oryantasyon açılarında (0°, 45°, 90°) üretilen geçici sabit protezlerin bükülme dayanımı ve elastisite modülü değerleri istatistiksel olarak anlamlı farklılık göstermedi (*P*>.05).
Sonuç: Farklı üretim açıları, 3D baskı ile üretilen test numunelerinin bükülme dayanımı ve elastisite modülü değerlerini etkilememiştir. ISO 10477 standartlarına göre bükülme dayanımı değerleri kriterleri karşılamaktadır (50 MPa değeri).
Anahtar Kelimeler: Geçici Sabit Protez, Bükülme Dayanımı, Elastisite Modülü, 3B baskı

INTRODUCTION

Temporary restorations are crucial in fixed prosthodontic treatment, as they not only replace the abutment and missing tooth but also preserve the pulpal and periodontal tissues, restore function and phonetics, as well as providing aesthetics.[1,2] These temporary restorations prevent the displacement of tooth abutments, offer a trial phase for evaluating the form and function of the permanent prosthesis, and help achieve a good emergence profile by shaping the soft tissue.[3] Temporary restorations should be designed to provide structural stability, marginal sensitivity, and stable tooth positioning. They are typically intended for short-term use before the placement of permanent restorations, but they can also be a long-term option in multidisciplinary cases before orthodontic, endodontic, and surgical treatment.[4,5] Digitally produced temporary restorations can offer a practical solution for long-term use.[2,6] Temporary restorations can be produced by conventional and digital methods.[7]

Materials commonly used in conventional fabrication methods include polymethylmethacrylate (PMMA) resins, bisacrylate, polyethylmethacrylate (PEMA) resins, polyvinylmethacrylate (PVMA), and urethane dimethacrylate (UDMA) resins.[8] PMMA and PEMA possess economical and formable properties. However, PMMA can generate high temperatures during polymerization, which should be carefully considered.

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PEMA has the advantages of low shrinkage and biocompatibility, but it is mechanically weak. Bis-acryl materials have been developed to reduce the disadvantage of conventional acrylic materials and to minimize any potential heat damage to the pulp due to their low exothermic reaction.[9-11]

The digital manufacturing processes, such as the subtractive and additive methods, offer superior quality and precision compared to conventional fabrication. Furthermore, these digital methods enable the production of temporary prostheses with better mechanical and physical properties by reducing any errors associated with manual manufacturing.[4,12,13] In subtractive manufacturing, the restoration is designed from a ready-made block or disk and fabricated using a milling device. The accuracy of milling depends on the characteristics of the milling tools used, the mechanical properties of the block, and the hardness of the material. However, a number of the disadvantages of subtractive manufacturing are material wastage, the cost of the milling device, the repair and maintenance costs, and the limitations in the production of complex geometries.[14-16]

Additive manufacturing or three-dimensional (3D) printing, is a method that produces the designed structure layer by layer.[15] There is a limited selection of polymer materials available for intraoral use in temporary restorations produced by this method. These materials may have similar classifications to conventional temporary materials in terms of their chemical structure, but definitive information on this issue is lacking due to the incomplete information provided by the manufacturers.[17] Production with 3D printing eliminates the problems encountered in subtractive manufacturing, such as the wear problem of the milling tools and the shape limitation of the diameter of the milling tools. Additive manufacturing allows the production of designs with more complex geometries and causes less waste of raw materials.[4,18] Furthermore, human intervention in the manufacturing process is kept to a minimum, which allows human-based errors to be minimized.[19] Currently, there are many additive manufacturing methods in dentistry such as stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM), digital light projection (DLP), liquid crystal display (LCD) and PolyJet.[20] Among these methods, DLP is seen to be more preferred over other methods in terms of parameters such as the production time, material waste, accuracy, and cost.[21] The products produced by 3D printing can be affected by such factors as layer thickness, laser intensity, print angle, and post-processing procedures. Proper management of these factors is important for the production quality and accuracy of the designed object. [17,22,23]

The mechanical properties such as the flexural strength and modulus of elasticity of the materials from which temporary restorations are produced are important when the patient has parafunctional habits such as bruxism when long-term use of temporary materials is required, and when long-span prosthetic restorations are planned. [22]

This study aims to investigate the flexural strength and modulus of the elasticity values of temporary fixed prosthetic materials produced with different orientation angles (0°, 45°, 90°). The null hypothesis of the study is that different manufacturing angles will not affect these properties.

METHOD

The flowchart of this study is illustrated in Figure 1. These specimens and their supports were designed in a software program (Blender, Blender Foundation, Amsterdam, the Netherlands) and converted to STL format. The specimens were designed as rectangular bars (n=13) sized 25 mm × 2 mm × 2 mm with orientation angles of 0°, 45°, and 90° for a three-point bending test to calculate the flexural strength according to the International Organization for Standardization (ISO) 10477 standard.[24] These were manufactured with the 3D Printing Machine (Runyes Dental 3D Printer, Zhejiang, China) using the DLP technique following the manufacturer's instructions. The production layer thickness of the specimens was set to 70 µm. The resin (Ackuretta Qura Crown Temporary Crown Photopolymer Resin, Taiwan) intended for temporary crown and bridge restorations was utilized in the 3D printing device. Following the printing process, the samples were cleaned with isopropyl alcohol for five minutes in an ultrasonic device. The final curing stage was then carried out for three minutes in an ultraviolet device (UV Box, Ackuretta, Taiwan). The cured bar specimens were separated from their supports and sanded with water sanders of grain sizes 600, 800, and 1000 to remove surface roughness at the support joints and ensure surface homogeneity between the specimens. The specimens were stored in distilled water at 37°C for twenty-four hours. Subsequently, their thickness, height, and length were measured using digital calipers and recorded. A universal testing machine (Lloyd LRX Material Testing, Hampshire, UK) was used for the flexural strength measurement. The distance between the supports was set to 20 mm and the cross-head speed was set to 1mm/min. Based on the data obtained, we calculated the flexural strength and modulus of elasticity using the following equation.

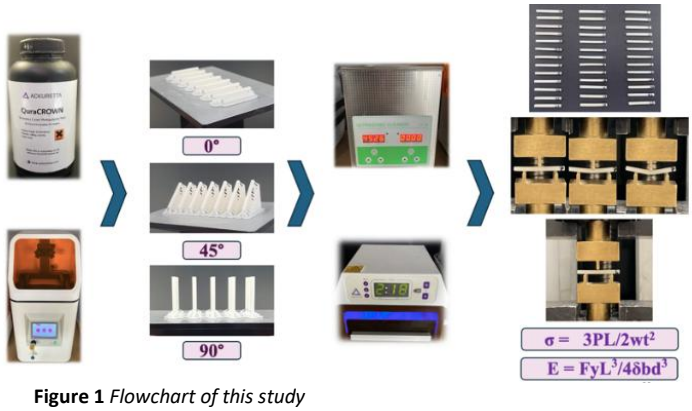

Figure 1 *Flowchart of this study*

$$\sigma = 3PL/2wt^2$$

σ: Maximum flexural stress (MPa)
L: Distance between supports (mm)
w: Width of the specimen (mm)
P: Force (N)
t: Thickness of the specimen (mm)

$$E = FyL^3/4\delta bd^3$$

L = Distance between supports (mm)
Fy = Yield force
b = Width of the specimen (mm)
d = Height of the specimen (mm)
δ = The deflection of the tested specimen

Statistical analysis

The statistical analysis of the data was conducted using the SPSS Statistica 22 (IBM SPSS Corp., Armonk, NY, USA) program. To assess the normal distribution of the data, both the Kolmogorov-Smirnov test and the Shapiro-Wilk test were utilized. The one-way ANOVA test was employed for the flexural strength values, as they adhered to a normal distribution, while the Kruskal-Wallis test was utilized for the modulus of elasticity values, which did not conform to normal distribution. The Levene's test was conducted to assess the homogeneity of the variances. The data are presented as mean, standard deviation, median, and interquartile range (IQR). The confidence interval was set to 95% and $P<.05$ was considered statistically significant.

RESULTS

The flexural strength and modulus of the elasticity values for the test specimens are presented in Table 1 and Table 2, respectively. The flexural strength and modulus of the elasticity values of the temporary fixed prostheses produced with different orientation angles (0°, 45°, 90°) exhibited no statistically significant difference (*P*>.05).

For all the pairwise comparisons of different manufacturing angles, namely 0° and 45°, 45° and 90°, and 0° and 90°, there was no statistically significant difference in the flexural strength values (*P*=.065, *P*=.199, and *P*=.837, respectively).

The lowest flexural strength was found at 33.49 MPa for the 45° print angle, while the highest value was 82.32 MPa for the 0° print angle. The modulus of the elasticity values were 1.65 (0.63) GPa at a 0° angle, 1.66 (0.43) GPa at a 45° angle, and 1.96 (0.55) GPa at a 90° angle.

Table 1. The flexural strength values of the test specimens at different orientation angles

	The printing layer orientation	Mean ± SD	The 95% Confidence Interval for the Mean			
			Lower Bound	Upper Bound	Min	Max
Flexural Strength (MPa)	0°	66.08 ± 9.10[a]	60.57	71.58	55.43	82.32
	45°	56.76 ± 13.59[a]	48.55	64.98	33.49	75.51
	90°	63.80 ± 6.71[a]	59.73	67.86	52.38	72.76
	Total	62,21 ± 10,72	58.74	65.69	33.49	82.32

Similar lowercase letters, as determined by the Tukey's test, suggest no statistical difference.

Table 2. The modulus of the elasticity values of the test specimens at different orientation angles

	Printing layer orientation	Median (IQR)	The 95% Confidence Interval for the Mean			
			Lower Bound	Upper Bound	Min	Max
The modulus of elasticity (GPa)	0°	1.65 (0.63)	1.52	2.24	1.03	3.22
	45°	1.66 (0.43)	1.47	2.07	1.29	3.26
	90°	1.96 (0.55)	1.58	2.02	1.13	2.19

The same capital letters indicate that there was no statistically significant difference between the groups by the Kruskal Wallis Test

DISCUSSION

In this study, the flexural strength, and the modulus of the elasticity values of the temporary fixed prosthetic materials produced by 3D printing using different manufacturing angles were investigated. The null hypothesis of the study was accepted. Temporary restorations must be able to withstand chewing forces without deforming the mouth during function. Therefore, the mechanical properties of the temporary restoration materials are critical. [8,23]

The elastic modulus is a measure of a material's rigidity within its elastic range, while flexural strength is the maximum strength of a beam in the direction of a force applied to the center of the beam without causing it to break. The relationship between the modulus of the elasticity of a material and its rigidity is directly proportional. Additionally, the flexural strength of a material is directly proportional to its resistance to fracture. [25-27] The three-point bending test is a method frequently used in studies to calculate the flexural strength and modulus of elasticity, despite the existence of various test methods that differ according to their axes.[28] Based on the test results following the ISO 10477 standards, the flexural strength values must be a minimum of 50 MPa for temporary restorations to be accepted for use in the mouth.

The mechanical properties of 3D-printed objects are influenced by various parameters, including the content and filler ratio of the resin material used, the print orientation angle, the number and thickness of the print layers, the temperature and time applied after polymerization, the ageing processes that simulate the oral environment, and the post-print cleaning procedures. [17,23,29] However, there is no consensus on the effect of print orientation on flexural strength. Different orientation angles can affect the strength of the material in various ways. In general, evaluations have shown that horizontal orientation angles exhibit higher flexural strengths than vertical orientation angles. This is thought to be because in vertical production, the layer extents become parallel to the applied force, which can reduce the flexural strength of the material due to poor adhesion between the successive layers. [29-31] Therefore, our objective is to examine the relationship between the flexural strength and the modulus of the elasticity values between our specimens obtained at different printing angles.

Grzebieluch et al.[32] conducted a study and found that the print orientation angle affected the flexural strength of 3D fabricated temporary restorations and that the flexural strength and the modulus of elasticity of the specimens with a 45° print angle were higher than those with a 90° print angle. In their study, they used specimens with a print layer thickness of fifty microns and produced these specimens using an LCD-type printing device. Derban et al.[33] found that the flexural strengths of the specimens produced using resins with two different ingredients with 0°, 45°, and 90° printing orientation angles differed according to the printing angle. They report that the specimens produced with the Detax material exhibited maximum flexural strength at 90°, while the specimens produced with the Nexdent material exhibited similar flexural strength at 0°and 90°, and higher than flexural strength at 45°. In their study, they used specimens with a print layer thickness of fifty microns and produced these specimens using an SLA-type printer. They set the cross-head speed to 2 mm/minute in the three-point bending test. Unkovskiy et al.[31] studied 3D printed bar-shaped resin specimens with 0°, 45°, and 90° print orientation angles and found that the specimens with a 90° print angle had the highest flexural strength but the specimens with a 0° print angle had the highest elastic modulus. In their study, they produced specimens using an SLA printing device, determined the print layer thickness of the specimens as fifty microns and adjusted the cross-head speed value to 0.25 mm/minute in the three-point bending test. The results of these studies are different from our study. This difference may be due to the type of printing device used, the thickness of the printing layer, and the cross-head speed. The printing device used in our study was DLP, the thickness of the printing layer was seventy microns, and the cross-head speed was set to 1 mm/min.

There is an opposite relationship between the print layer thickness and flexural strength. As the printing layer thickness of a manufactured object increases, the flexural strength decreases. The reason for this is that thin layers tend to undergo a more homogeneous and easier polymerization compared to thick layers.[34] In addition, the number of layers used varies depending on the printing orientation of a manufactured object. Vertical printing orientations enable the production of the material using more layers compared to horizontal orientations. However, the amount of shrinkage in the final product increases with an increase in the number of layers.[33,35]

The ageing processes and soaking the produced materials in water or saliva have been reported as having an inverse effect on flexural strength. The longer the cleaning time, the more the solvent molecules penetrate the resin matrix, which causes deformation of the chemical configuration, reducing the flexural strength of the material. [29,35,36]

A study by de Castro et al.[37] evaluated the flexural strength and modulus of elasticity of the specimens produced by 3D printing with 0°, 45°, and 90° orientation angles using four different resins by subjecting them to an ageing process based on water storage for twenty-four hours and one year. They found that Cosmos SLA resin with a 90° printing angle showed higher flexural strength than other printing angles after one year of water storage. In their study, Väyrynen et al.[38] compared the flexural strength of bar-shaped resin specimens produced by 3D printing with 0°, 45°, and 90° printing orientation angles in dry and fourteen-day water storage. Although there was no statistical difference, they found that the flexural strength was highest in the specimens with a 45° printing angle and the modulus of elasticity was maximum in the specimens with a 90° printing angle. This difference with the result of our study may be due to the different ageing processes applied to the specimens. All the specimens in our study were soaked in 37° distilled water for twenty-four hours before the three-point bending test.[37]

The flexural strength values of the test specimens in our study ranged from 55.43 to 82.32 MPa at 0°, from 33.49 to 75.51 MPa at 45°, and from 52.38 to 72.76 MPa at 90°, while the elasticity values were from 1.03 to 3.22 GPa at 0°, from 1.29 to 3.26 GPa at 45°, and from 1.13 to 2.19 GPa at 90°. In the other studies compared, the 0° flexural strength values ranged from 73.4 MPa to 127.54 MPa, at 45° from 78.3 MPa to 143.39 MPa, and at 90° from 77.1 MPa to 135.69 MPa. The modulus of elasticity values ranged from 1.65 GPa to 3.28 GPa at 0°, from 1.46 GPa to 4.69 GPa at 45°, and from 1.45 GPa to 4.37 GPa at 90°.[31-33,37,38] The modulus of elasticity and flexural strength values of temporary materials may vary according to different chemical contents and configurations. It is believed that the differences in the results obtained in the studies may be due to this, as to other parameters that vary.

The limitations of this study include the utilization of a single commercial product, the selection of a sole value for the print layer thickness, and the absence of intraoral ageing simulations. Further research is warranted to explore the mechanical characteristics of temporary restorations considering various orientation angles.

CONCLUSION

Within the constraints of this study, the following conclusions can be drawn. The variation in production angles did not impact the flexural strength and the modulus of the elasticity values of the 3D printed materials. Furthermore, following ISO 10477 standards, the flexural strength values of the test specimens met the specified criteria (with a value of fifty MPa).

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