RESEARCH ARTICLE

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Effect of Ultrasonic Cleaning on Flexural Strength of Different 3D-Printed Crown Resins

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Objective: This study aims to evaluate the effect of the ultrasonic cleaning method on the flexural strength of resin-based composites used in 3D printing production.

Materials and Methods: 55 samples were produced according to the appropriate procedures on 3D printers using three different 3D printer resins (CDS Custom Composite Resin, Saremco Crowntec, Senertek P Crown V3). Post-curing procedures were carried out in accordance with the manufacturer's recommendations. ANOVA test and post Hoc Tukey HSD tests were used to compare flexural strength among the different crown resins. Independent-t test was used to compare the flexural strength between the groups of ultrasonic and non-ultrasonic groups. Statistical significance was accepted as $p<0.05$.

Results: The flexural strength value of Saremco Crowntec composite resin was 93.58±5.43 MPa, while the flexural strength of CDS Custom composite resin was 74.69±6.90 MPa and the difference between them was found to be highly significant ($p<0.001$). The flexural strength value of Senertek P Crown V3 composite resin was 87.26±15.22 MPa and the difference with CDS Custom composite resin was found to be highly significant ($p= 0.002$). The flexural strength value of Senertec P Crown V3 resin in the non-ultrasonic cleaning procedure was 87.26±15.22 MPa. The flexural strength value of Senertec P Crown V3 resin in the ultrasonic cleaning procedure was found to be 73.56±4.61 MPa. According to the results of the independent samples t-test, only the comparison of ultrasonic and non-ultrasonic cleaning values of Senertek P Crown V3 composite resin was statistically significant ($p= 0.028$).

Conclussion: Ultrasonic cleaning method reduced the flexural strength value of Senertek P Crown V3 resin.

Key Words: *Ultrasonic cleaning, resin, flexural strength, 3D Printing*

Ultrasonik Temizliğin Farklı 3 Boyutlu Baskı Kron Reçinelerinin Bükülme Direnci Üzerine Etkisi

Amaç: Bu çalışma, ultrasonik temizleme yönteminin, 3 boyutlu baskı üretiminde kullanılan reçine esaslı kompozitlerin bükülme mukavemeti üzerindeki etkisini değerlendirmeyi amaçlamaktadır.

Gereç ve Yöntem: Üç farklı 3D yazıcı reçinesi (CDS Custom Composite Resin, Saremco Crowntec, Senertek P Crown V3) kullanılarak 3D yazıcılarda uygun prosedürlere göre 55 numune üretildi. Ultrasonik ve ultrasonik olmayan temizleme yöntemleri sonrasında üç farklı 3D yazıcı reçinesi ile üretilen numunelere üç nokta eğilme mukavemeti testi uygulandı. Veri dağılımı normalliği için Shapiro-Wilk normallik testi kullanıldı ve tek yönlü ANOVA testi ve farklı kron reçineleri arasındaki bükülme mukavemetini karşılaştırmak için Hoc Tukey HSD testleri kullanıldı. İstatistiksel anlamlılık $p<0.05$ olarak kabul edildi.

Bulgular: Saremco Crowntec kompozit reçinenin eğilme mukavemeti değeri 93.58±5.43 MPa, CDS Custom kompozit reçinenin eğilme mukavemeti ise 74.69±6.90 MPa olarak tespit edildi ve aralarındaki farkın oldukça anlamlı olduğu görüldü ($p<0.001$). Senertec P Crown V3 reçinesinin ultrasonik olmayan temizleme işleminde bükülme mukavemeti değeri 87.26±15.22 MPa olarak bulunmuştur. Senertec P Crown V3 reçinesinin ultrasonik temizleme işleminde bükülme mukavemeti değeri 73.56±4.61 MPa olarak bulunmuştur. Bağımsız örnekler t-testi sonuçlarına göre Senertek P Crown V3 kompozit reçinenin sadece ultrasonik ve ultrasonik olmayan temizleme değerlerinin karşılaştırılması istatistiksel olarak anlamlı bulunmuştur ($p=0.028$).

Sonuç: Ultrasonik temizleme yöntemi Senertek P Crown V3 reçinesinin eğilme dayanımı değerini azaltmıştır.

Anahtar Kelimeler*: Ultrasonik temizleme, reçine, eğilme dayanımı, 3 boyutlu yazıcı*

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Introduction

Currently, digital technology affects all aspects of orthodontic treatment, not just the collection and storage of medical records (1). Computer-aided design (CAD) and computer-aided manufacturing (CAM) systems and 3D printing technology are frequently preferred in the field of clinical orthodontics, especially in recent years, and are included in the workflow of orthodontic laboratories (2, 3). With the widespread use of these technologies, various orthodontic needs, such as indirect bonding trays, custom-made brackets, and bent wires, are digitally planned and robotically produced in a virtual environment (1, 4).

While computer-aided CAD/CAM technologies work as a subtractive system in production, 3D printers work as an additive system (3). 3D printing or additive manufacturing is the process of making three-dimensional solid objects from a digital file (5). Some of the materials used in 3D printers are plastic, cobalt, nickel, steel, aluminum, and titanium (5). Literature reports that mechanical and physical properties depend on the printed layer thickness, polymerization depth and shrinkage, amount and angle of light source, and properties of the composite resins used (6, 7). Therefore, it is extremely important to understand the different parameters.

The cleaning procedure aims to remove the unpolymerized resin, and different cleaning methods have been reported to have an impact on the properties such as biocompatibility, mechanical properties, and wear of the produced structure (8, 9). Ultrasonic cleaning is a cleaning procedure that has been used widely for years. It has been shown in the literature that ultrasonic power creates a stronger mechanical effect by concentrating on a small area, enabling rapid cleaning (10-13).

3D resin manufacturers state that when production is finished, a quick and lightless wash can also be performed with isopropyl alcohol or ethyl alcohol to remove the final resin residues (14). However, the widespread use of 3D printing technology may raise concerns that organic solvents (alcohol) may not sufficiently remove plastic residues from the environment. Nanoparticle formation is explained by the solubility of the resin in organic solvents (alcohol) and its hydrophobic nature (15). Users are often concerned about toxicity related to the alcohol/plastic resin mixture. As a result, resins may need alternative cleaning methods other than organic solvents such as ultrasonic cleaning (16).

Durability is a criterion for determining the success of dental restoration. Durability is defined as the highest stress value achieved during breakage of a material (17). Factors affecting the durability of 3D printed resin can be classified as pre-processing, printing, and post-processing factors. Post-processing factors include post-curing parameters (time, temperature, and curing unit), post-rinse time, and finishing and polishing method (18). The materials' durability is evaluated with the help of different laboratory tests as it affects clinical performance (19). Flexural strength is basically a strength test performed by applying a static load to a bar supported at both ends or a thin disk supported from the bottom by a smaller circle, right at the center (20). The three-point flexural strength test is defined according to ISO 1567 standards for acrylic resins. As the flexural strength increases, the sensitivity of the material to fracture decreases and its durability increases (21, 22).

The aim of this study is to evaluate the effect of the ultrasonic cleaning method on the flexural strength of resin-based composites used in 3D printing.

Materials and Methods

The samples were produced according to the appropriate procedures on two different 3D printers using three different 3D printer resins (CDS Custom Composite Resin, Saremco Crowntec, Senertek P Crown V3). Power analysis (G*Power version 3.1.9.7, Universität Düsseldorf, Germany) was calculated using effect size 0.50. According to this, it was seen that a statistical difference could be obtained at 82% power at $p<0.05$ significance level in at least 55 samples in total.

The specimens prepared for flexural strength tests were designed in 2×2×25 mm dimensions according to ISO 4049 standards using the online design program https://www.tinkercad.com. The designs were exported in stereolithography file format and produced using a 3D printer. In line with the manufacturer's recommendations, all samples produced on 3D printers were produced with a layer thickness of 50 m perpendicular to the tray. The specimens Senertek P-crown V3 and CDS Custom Composite Resin were produced on Anycubic Photon Mono X (LCD-based SLA printer, 405 nm light source, 0.05 mm 3840×2400, China). The specimens produced using Saremco Crowntec dental resin were prepared on the NexDent 5100 (NextDent® LCD1 3D Printer, Netherlands) in a closed system in accordance with the manufacturer's recommendations. Post-curing procedures were carried out in accordance with the manufacturer's recommendations. Senertek P Crown V3, CDS Custom Composite Resin dental resins and Saremco Crowntec resins were washed in ethanol with 35 watts ultrasonic for 3 minutes and cured under 36 watts UV light for 20 minutes.

Flexural Strength Test: For flexural strength evaluation, standardized 2x2x25 mm rectangular specimens were produced from each 3D printed resin. The specimens were placed in a customized apparatus with two supports spaced 20 mm apart for three-point testing and fixed on a universal testing machine (Shimadzu, Instron, UK) where the force was loaded (Figure 1). Forces were applied at a rate of 0.5 mm/min at the center of the specimen. It was calculated flexural strength value in megapascals (MPa) according to the following formula (23):

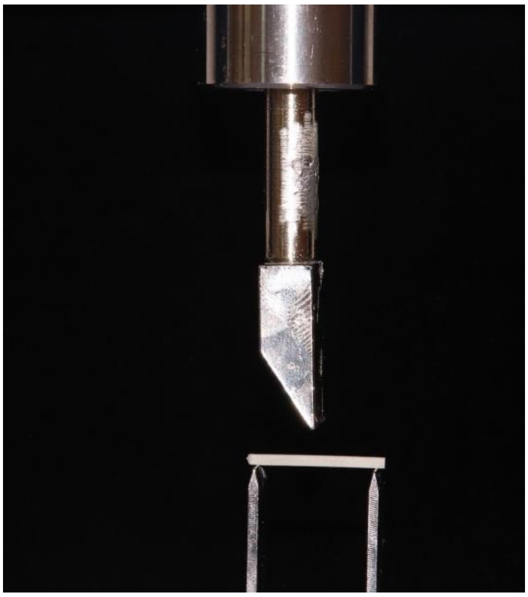

Figure 1: Three-point flexural test

$\sigma f\ (MPa) = \frac{3F*L}{2b*h^2}$ $\sigma f\ (MPa) = \frac{3F*L}{2b*h^2}$ [F: Breaking Force, L: length (mm), b: width (mm), h: thickness (mm)]

Statistical Analysis: Statistical analysis was performed on the data obtained from the flexural strength test evaluation. SPSS for Windows version 26.0 (SPSS Inc, Chicago, IL, USA) was used for statistical analysis. The Shapiro–Wilk normality test was used for data distribution normality. Parametric tests were used. One-way ANOVA test and post Hoc Tukey HSD tests were used to compare flexural strength between the different crown resins. Independent-t test was used to compare the flexural strength between the groups of ultrasonic and non-ultrasonic groups. Statistical significance was accepted as p <0.05.

Results

The mean flexural strength (MPa) and standard deviation values of three different ultrasonically cleaned 3D printing resins are given in Table 1. According to the results of one-way ANOVA test, there was a significant difference between the groups (*p*<0.05). The flexural strength value of Saremco Crowntec composite resin was 93.58±5.43 MPa, while the flexural strength of CDS Custom composite resin was 74.69±6.90 MPa and the difference between them was found to be highly significant (*p*<0.001). The flexural strength value of Senertek P Crown V3 composite resin was 73.56±4.61 MPa and the difference with Saremco Crowntec composite resin was found to be highly significant (*p*<0.001).

The MPa and standard deviation values of non-ultrasonically cleaned 3D printing resins are given in Table 2. According to the results of one-way ANOVA test, of variance, there was a significant difference between the groups (*p*<0.05). According to this table, the flexural strength value of Saremco Crowntec composite resin was 94.01±7.07 MPa, while the flexural strength of CDS Custom composite resin was 74.79±4.32 MPa and the difference between them showed a high level of significance (*p*= 0.002). The flexural strength value of Senertek P Crown V3 composite resin was 87.26±15.22 MPa and the difference with CDS Custom composite resin was found to be highly significant (*p*= 0.002).

Table 3 compares the MPa values of the three different 3D printed resins. According to the results of the independent samples t-test, only the comparison of ultrasonic and non-ultrasonic cleaning values of Senertek P Crown V3 composite resin was statistically significant (*p*= 0.028). The flexural strength value of Senertec P Crown V3 resin in the non-ultrasonic cleaning procedure was 87.26±15.22 MPa. The flexural strength value of Senertec P Crown V3 resin in the ultrasonic cleaning procedure was found to be 73.56±4.61 MPa.

Table 1. Comparison of mean values of the flexural strength (MPa) of different to ultrasonic cleaning 3D Print resins.

	Flexural Strength		*p**
	Mean	**Standard Deviation**	
CDS Custom Composite Resin	74.69^{A}	6.90	
Saremco Crowntec	93.58^{B}	5.43	**<0.001**
Senertek P Crown V3	73.56^{A}	4.61	

*Results of one-way ANOVA test, groups with different uppercase letter are significantly different (Tukey HSD test, *p*<0.05)

Table 2. Comparison of mean values of the flexural strength (MPa) of different to non-ultrasonic cleaning 3D Print resins

	Flexural Strength		*p**
	Mean	**Standard Deviation**	
CDS Custom Composite Resin	74.79^{A}	4.32	
Saremco Crowntec	94.01^{B}	7.07	**0.002**
Senertek P Crown V3	87.26^{B}	15.22	

*Results of one-way ANOVA test, groups with different uppercase letter are significantly different (Tukey HSD test, *p*<0.05)

Table 3. Comparison of the flexural strength (MPa) of different 3D Printed crowns

Resin	Cleaning Procedure	Flexural Strength		*p**
		Mean	Standard Deviation	
CDS Custom Composite Resin	Non-ultrasonic	74.79	4.32	0.966
	Ultrasonic	74.69	6.90	
Saremco Crowntec	Non-ultrasonic	94.01	7.07	0.887
	Ultrasonic	93.58	5.43	
Senertek P Crown-V3	Non-ultrasonic	87.26	15.22	**0.028**
	Ultrasonic	73.56	4.61	

*Results of independent t-test

Discussion

In the field of orthodontics, digital technologies are extensively used in all processes of diagnosis, planning and orthodontic treatment (3). Technologies such as CAD/CAM and 3D printing are examples of this digital workflow (24). While the subtractive method used in CAD/CAM technologies is produced by milling from a resin block, the additive method used in 3D printing technology produces the product by adding the resin layer by layer (25). There are studies in the literature reporting that the mechanical performance of 3D printer resins is affected by various parameters, such as structure orientation, post-curing procedures and methods, thickness and number of layers, and shrinkage between layers (26-28). This study aimed to test the durability after ultrasonic cleaning of resins with different composite content.

Lambart et al. (29) reported that 3D printed objects should be cleaned. Literature have reported that the mechanical properties change depending on the method (ultrasonic, centrifugal) or solution (isopropanol, ethanol, etc.) used in the cleaning procedure (9, 29-32).

In the study of Leila Perea-Lowery et al. (29) on prosthetic base resins, it was shown that the flexural strength value is one of the important properties that can affect the mechanical behavior of the resin. The flexural strength test is a mechanical test that aims to test the strength of a material under static bending loading of brittle materials placed between various ends, which can also be applied to materials used in dentistry (33). This test, which has many application methods, is often applied uniaxially or biaxially (34). Although there are studies reporting biaxial bending tests in the literature and the forces in the oral cavity are multidirectional (22, 35), the three-point bending test, which is one of the uniaxial bending tests frequently preferred by many researchers, was used in our study (33).

Flexural strength of resins used in 3D printers is a necessary physical property for the longevity and durability of the dental restoration produced. According to the statistical results of our study, Saremco Crowntec resin has the highest flexural strength under ultrasonic and non-ultrasonic cleaning compared to other resins (Table 3). In this study, the flexural strength of 3D printed dental resin by Alshamrani et al. (41) was attempted to be strengthened by adding glass, silica, and zirconium nanoparticles and flexural strength values were found between 80.02 and 113.80 MPa, which are lower than the mean values obtained with Saremco Crowntec resin without any additives in this study. This showed that Saremco Crowntec resin had a higher flexural strength than its counterparts. While the mean flexural strength value of Saremco Crowntec resin was reported to be 127–137 Mpa in other studies in the literature, it was found to be lower in our study. While the mean flexural strength value of Senertek P Crown 2 was between 48–56 Mpa, it was found to be higher in our study (42-44).

According to the results of the statistical analysis, there was a significant difference between ultrasonic and non-ultrasonic cleaning in only Senertek P Crown V3 resin. This result may be due to the low number of cross and double bonds in the resin polymer.

Herein, the three-point flexural test, which is a uniaxial bending strength test, was used. In the literature, it is stated that biaxial flexural strength tests are more effective in evaluating the flexural strength of materials used in dental restorations due to the multidirectional forces acting on the material in the mouth. Additionally, this study is important as a guide for future research because there is no other report of CDS Custom resin in the literature. The findings of our study will be guiding as it proves that the choice of resin compositions and post-curing cleaning procedure directly affects the mechanical properties of the restoration, such as bending strength, when making restorations with 3D printers. The number of researchers working on additive manufacturing technology is increasing day by day due to its potential use in dentistry. More research studies are needed on the manufacturing process, including printing conditions and their effects on the mechanical properties of 3D printing material.

As a result, ultrasonic cleaning method reduced the flexural strength value of Senertek P Crown V3 resin.

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