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Evaluating the Color Stability of 3D Printed Temporary and Permanent Composite Resins After Exposure to Common Beverages

3D Baskı Geçici ve Kalıcı Kompozit Reçinelerin Genel İçeceklere Maruz Kalma Sonrası Renk Stabilitesinin Değerlendirilmesi

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ABSTRACT

Objective: This study aimed to evaluate the color stability of 3D printed permanent and temporary composite-based restorative materials by assessing their stainability after immersion in tea, coffee, and water.

Methods: The composite resins used included Temp Ultra (TU) and Custom Composite Resin (CR) (for temporary restorations) and Crowntec (for permanent restorations). Specimens were 3D printed, post-polymerized, and polished. They were then immersed in tea, coffee, or water at 37°C for 7 days. Color changes were measured using the CIE Lab* system and analyzed using IBM SPSS 26, with ΔE00 values compared to clinical thresholds.

Results: After 7 days, the greatest color change (ΔE00) was observed in all coffee-immersed groups, with the TU + coffee group showing the highest ΔE00 value (2.38 ± 0.21), exceeding the clinically acceptable threshold of 2.25. The CR + water group exhibited the least color change (0.16 ± 0.05). Color changes in tea-immersed groups were statistically significant, with CR showing reduced color change (1.97 ± 0.15). Only the coffee-exposed groups exceeded the acceptable ΔE00 value.

Conclusion: The study found that the type of composite material significantly affects color stability, with Temp Ultra showing the most color change in coffee. The results suggest that while these materials demonstrate acceptable color stability.

Keywords: 3D Printing, Composite Resins, Color Stability, Staining, CAD/CAM Technology

ÖZ

Amaç: Bu çalışma, 3D baskılı kalıcı ve geçici kompozit bazlı restoratif materyallerin çay, kahve ve suya batırıldıktan sonra lekelenebilirliklerini değerlendirerek renk stabilitesini değerlendirmeyi amaçladı.

Yöntemler: Kullanılan kompozit reçineler arasında Temp Ultra ve Custom Composite Resin (geçici restorasyonlar için) ve Crowntec (kalıcı restorasyonlar için) yer aldı. Numuneler 3D olarak basıldı, polimerize edildi ve cilalandı. Daha sonra 7 gün boyunca 37°C'deki çay, kahve veya suya batırıldılar. Renk değişiklikleri CIE Lab* sistemi kullanılarak ölçülmüş ve IBM SPSS 26 ile klinik eşik değerlerine kıyasla ΔE00 değerleri ile analiz edilmiştir.

Bulgular: 7 gün sonra en büyük renk değişimi (ΔE00) kahveye batırılan tüm gruplarda gözlemlendi; TU + Kahve grubu en yüksek ΔE00 değerini (2,38 ± 0,21) göstererek klinik olarak kabul edilebilir eşik olan 2,25'i aştı. CR + Su grubu en az renk değişimini sergiledi (0,16 ± 0,05). Çaya batırılan gruplardaki renk değişiklikleri istatistiksel olarak anlamlıydı; CR, renk değişiminde azalma gösterdi (1,97 ± 0,15). Yalnızca kahveye maruz kalan gruplar kabul edilebilir ΔE00 değerini aştı.

Sonuç: Çalışma, kompozit malzeme türünün renk stabilitesini önemli ölçüde etkilediğini, Temp Ultra'nın kahvede en fazla renk değişimini gösterdiğini buldu. Sonuçlar, çalışmada kullanılan materyaller kabul edilebilir renk stabilitesi göstermişlerdir.

Anahtar Kelimeler: 3D Baskı, Kompozit Reçineler, Renk Stabilitesi, Renkleşme, CAD/CAM Teknolojisi

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INTRODUCTION

Restorative dentistry focuses on rebuilding natural tooth structures with an emphasis on both aesthetics and functionality. The growing demand for restorations that combine excellent aesthetics with higher durability has driven the development of new material solutions for indirect restorations, including veneers, inlays, onlays, and crowns.[1] The advancements in digital technology, particularly the integration of computer-aided design and computer-aided manufacturing (CAD/CAM) systems, have become commonplace in the production of dental restorations.[2]

CAD/CAM systems offer numerous benefits such as freeform design, customized manufacturing, reduced chair time, enhanced infection control by eliminating certain laboratory processes, and exceptional accuracy. Digital technology is increasingly used in various dental fields, including surgical, restorative, endodontic, prosthetic, and orthodontic dentistry. Technological advancements have led to the development of new materials for CAD/CAM restorations, including glass ceramics, zirconia, and composites, which provide a range of mechanical and optical properties.[3]

Previously, CAD/CAM technology was primarily associated with subtractive manufacturing or milling. However, restorations can now also be produced using additive manufacturing or three-dimensional (3D) printing technology. Both CAD/CAM techniques are based on the principle that restorations are digitally designed using a CAD software program with patient data, saved as standard tessellation language (STL) files. In the milling technique, these files are transferred to a computer-controlled machine that produces the restorations from blocks using milling tools. Conversely, the 3D printing method builds restorations layer by layer from the transferred STL file data. Various 3D printing technologies are employed in dental restoration production, with stereolithography (SLA) and direct light processing (DLP) being particularly popular.[4] An SLA 3D printer uses an ultraviolet laser light source to polymerize photosensitive resin layer by layer. Although similar to SLA, DLP technology uses digital micro-mirrors beneath the resin tank, polymerizing all layers in a single exposure, thus making DLP faster than SLA.[5] However, Masked Stereolithography Apparatus (MSLA) 3D printers are also available today. Unlike SLA, which reflects UV light from a single point, MSLA can illuminate the entire surface simultaneously. This capability allows MSLA printers to print multiple models at once, regardless of the layer surface area, without increasing the print time.[6]

3D printing technology offers cost-effectiveness, minimal resin material waste, and the ability to produce more complex structures compared to milling.[7] Recent developments in 3D printing technologies and materials have introduced new printable permanent composite resins for indirect restorations. Color stability is crucial for patient satisfaction and the aesthetic appearance of composite resins in the dynamic oral environment. However, composite materials face challenges such as water absorption, inadequate polymerization, absorption of food or beverages, poor oral hygiene, and thermal processes in the oral environment.[8]

Current studies often compare the color stability of composite-based restorative materials produced by subtractive manufacturing techniques.[9,10] Although 3D printing technology and materials are increasingly used for permanent composite restorations, these materials are relatively new, necessitating further laboratory and clinical data. Studies examining the color stability of 3D printed permanent materials are limited. Thus, this study aims to compare the color stability of 3D printed permanent and temporary composite resin after immersion in tea, coffee and water. The null hypothesis is that the stainability of the 3D printed composite resin restorative materials tested will remain unaffected by the type of material after being stored in either tea, coffee or water.

METHODS

Specimen Preparation

The printable composite resins used in our study are detailed in Table 1. Temp Ultra (Arma Dental, Kocaeli, Turkey) and Custom Composite Resin (CRSCAM Teknoloji AŞ., Antalya, Turkey) are utilized for temporary restorations, whereas Crowntec (SAREMCO Dental AG, Rebstein, Switzerland) is suitable for use as a permanent composite restoration. The 3D models for cylindrical specimens (10 mm × 2 mm) were designed using Fusion 360 CAD software (Autodesk, San Rafael, CA, USA). These digital designs were exported as STL files for specimen production. Thirty specimens were produced for each 3D printed material. The SC specimens were printed using an MSLA-based 3D printer (Sonic Mini 8K, Phrozen Tech Co, Hsinchu, Taiwan) with a layer thickness of 50 µm and a build orientation of 90 degrees. Following the printing process, the specimens were cleaned with a cloth soaked in 96% alcohol and then underwent post-polymerization using a wash and cure machine (Anycubic Wash & Cure Plus, Anycubic, Shenzhen, China) according to the manufacturer's recommendations. After cooling, the support structures were removed from the specimens using low-speed rotary instruments. All specimens were then stored in distilled water at 37°C for 24 hours. Post-polymerization, the specimens were polished with aluminum oxide-coated discs (Sof-Lex XT, 3M, St. Paul, MN, USA). Standardization was ensured by measuring the thickness of the specimens with a digital caliper (Ultra-Cal V, Fowler Corp., Newton, MA, USA).

Table 1. Materials used in this study.

Group	Material Name	Purpose of usage	Manufactorer
CR	Crowntec	Permanent	SAREMCO Dental AG, Rebstein, Switzerland
TU	Temp Ultra	Temporary	Arma Dental, Kocaeli, Turkey
CCR	Custom Composit Resin	Temporary	CRSCAM Teknoloji AŞ., Antalya, Turkey

Color Measurement

In this study, color values were assessed using the Commission International de l'Eclairage (CIE) Lab* system with a spectrophotometer (VitaEasyshade V, Vita Zahnfabrik, Bad Säckingen, Germany) on a neutral gray background (L*=64.1; a*=0.3; b*=−3.4), with measurements taken under D65 standard lighting conditions after calibrating the spectrophotometer according to the manufacturer's recommendations.

Initial color measurements (L0, a0, b0) of the specimens were taken after storing them in distilled water at 37°C for 24 hours. The specimens were then divided into three groups according to the type of resin (n=30). Thirty randomly selected specimens were immersed in tea (Lipton Yellow Label Tea, Unilever, Istanbul, Turkey), 30 in coffee (Nescafe Classic, Nestle, Vevey, Switzerland), and 30 in water, all stored in an incubator at 37°C for 7 days. The solutions were prepared and refreshed daily. Color measurements were then taken at the end of the 1st and 7th days as previously described. The color change levels in the specimens were calculated using the following CIEDE2000 formulation: [11]

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{\frac{1}{2}}$$

Statistical Analysis

Statistical analysis was conducted using IBM SPSS 26 (IBM Corp., Armonk, NY, USA). Normality of data was evaluated by using the Shapiro-Wilk test. Post-hoc Tukey test was used to make multiple comparisons. ΔE00 values were compared with one-way ANOVA. (*P*.<05)

In this study, the parametric factors for the ΔE00 were set to 1. The threshold for clinical perceptibility was established at ΔE00 ≤ 1.30, while the threshold for clinical acceptability was set at ΔE00 ≤ 2.25. [12]

RESULTS

According to the data presented in Table 2, after 7 days, the greatest ΔE was recorded in all groups immersed in coffee. Color changes were noted across all groups exposed to tea and coffee, with the most significant color change observed in the TU + Coffee group (2.38 ± 0.21). Conversely, the least color change was observed in the CR + Water group (0.16 ± 0.05). The color change in the groups exposed to tea was statistically significant, with the CR group (*P*.<05) demonstrating a reduced color change (1.97 ± 0.15). Color change exceeded the acceptable value only in the coffee-exposed groups.

Table 2. Mean ΔE00 values ± standard deviations of printable resins after 7 days of immersion in solutions.

ΔE	Temp Ultra	Custom Composite Resin	Crowntec
Tea	2,22 ± 0,18^{aA}	2,13± 0,25^{aC}	1,97 ± 0,15^{bE}
Coffee	2,38 ± 0,21^{cA}	2,36 ± 0,44^{cC}	2,28 ± 0,23^{cE}
Water	0,26 ± 0,07^{dB}	0,35 ± 0,04^{dD}	0,16 ± 0,05^{dF}

*Lowercase letters indicate differences in the column, uppercase letters indicate differences in the row

DISCUSSION

The current study evaluated the stainability of permanent and temporary composite-based restorative materials that were produced additively by testing their color stability after being submerged in water, tea, and coffee. The results showed that the kind of material had a substantial impact on the color stability of the studied restorations, confirming the rejection of null hypothesis.

The popularity of 3D printed tooth-colored restorations among clinicians has recently increased. Given their advantages, 3D printed materials could potentially replace CAD/CAM milled materials and serve as alternatives to feldspathic ceramics, which, despite their aesthetic appeal, are prone to fragility.[13] The current study aimed to address the lack of literature on critical properties, such as color stability, that are essential for the longevity of these materials.

The study's results demonstrated that the Temp Ultra with coffee group exhibited the highest mean ΔE00 values, surpassing the clinically acceptable threshold of 2.25. In contrast, other tested solution groups maintained ΔE00 values below the acceptable threshold.

According to Aguiar et al.,[14] the low filler content caused increased water absorption at the filler-matrix interface, and more discolouration was seen as a result of the absorbed water separating the filler and matrix or causing hydrolytic breakdown of the filler. The hydrophilic/hydrophobic nature of composite resin materials influences discolouration and directly impacts the level of water absorption. The reduced filler ratio may be the cause of the temporary 3D printed material's increased discolouration.

The color stability of resin-based composites is influenced by the hydrophobic or hydrophilic characteristics of the resin matrix, which affects water absorption. For instance, the Bis-EMA matrix monomer in CR has lower hydrophilicity compared to TEGDMA. Contrary to the current study's findings, Çakmak et al.[15] found that Saremco Crowntec exhibited similar color stability to milled composite and was more stable than other 3D printed resins after 10,000 coffee thermocyclings. Similarly, some studies reported higher color change values for another 3D printed composite resin compared to milled composite material after immersion in coffee.[13,16,17] A prior study on the color stability of 3D printed interim resin materials indicated that the production technology impacts color stability, with permanent resins generally showing better stability than temporary ones.

The quantity of residual monomer created as a result of the slow polymerization rate is another aspect to take into account. Prior studies have indicated that following the curing process, the polymerization rate of materials produced through 3D printing decreases.[18]

Differences in the production technology of 3D printed materials may have influenced the color stability observed in this study. Additionally, unreacted residual monomers, which are addressed through post-polymerization, may also contribute to color changes.[19] Among the materials tested, CR showed the lowest mean ΔE00 values after immersion in tea and coffee. However, the temporary resin groups demonstrated statistically significant color changes, possibly due to their microstructural properties and water absorption capacity. But as Berli et al.[20] also demonstrated, one of the investigated 3D printed resin materials had less water absorption than the PMMA resin in their study. Although water absorption cannot completely explain low color stability, the scientists pointed out that different materials can exhibit different properties even when utilizing the same 3D printing procedure.

Coffee and tea solutions are commonly used for staining due to their high colorant absorption potential. A one-week immersion period was selected based on previous research indicating significant color changes within the first week, to evaluate the long-term color stability of composite materials.[21] A cup of coffee takes 15 minutes on average to make, and coffee drinkers have 3.2 cups on a daily average, according to Guler et al.[22] As a result, the samples' 24-hour immersion in coffee is equal to a month's worth of coffee consumption. Moreover, Shin et al.[17] have pointed out that the color measurements acquired in this investigation following a month-long immersion of the samples in the solution are equivalent to 2.5 years of coffee intake.

This in vitro study has limitations, including the lack of simulation of clinical factors such as occlusal forces, saliva interactions, and mouth rinsing or brushing. Additionally, the flat surfaces of the specimens and absence of anatomical features did not fully replicate clinical conditions. Further investigation into other optical properties, such as translucency, and the use of different staining media may be warranted. Moreover, the VITA Easyshade V spectrophotometer, primarily a clinical device, may not be ideal for laboratory evaluations. Future research should focus on enhancing the color stability of 3D printed permanent composite resins produced using various techniques to ensure their suitability for long-term use in indirect restorations.

Etik Komite Onayı: Bu çalışmada deney gruplarında uygulanan çözümler herhangi bir hayvan veya insandan elde edilen hiçbir materyale uygulanmamıştır. Diş hekimliğinde kullanılan restorasyon malzemelerinin çay, kahve ve suya batırılması sonucu oluşabilecek renk değişikliklerinin değerlendirildiği bu çalışmada etik kurul onayı gerekmemektedir.
Hasta Onamı: Çalışmada hasta onamı gerekmemektedir.
Hakem Değerlendirmesi: Dış bağımsız.
Yazar Katkıları: Fikir - M.D.; Tasarım - Doktora; Denetleme - Doktora; Kaynaklar - MD; Malzemeler - M.D.; Veri Toplanması ve/veya İşleme - Doktora; Analiz ve/veya Yorum - Doktora; Literatür Taraması - M.D.; Makaleyi Yazan - M.D.; Eleştirel İnceleme - Doktora; Diğer – M.D..
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Ethics Committee Approval: In this study, the solutions applied in the experimental groups were not applied to any material obtained from any animal or human. Ethics committee approval is not required in this study, which evaluates the color changes that may occur as a result of immersion of restoration materials used in dentistry in tea, coffee and water.

Informed Consent: Patient consent is not required for this study.

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