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COMPARISON OF COLOR STABILITY AND SURFACE ROUGHNESS OF 3D PRINTED AND CONVENTIONALLY PRODUCED TEMPORARY MATERIALS

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ABSTRACT

Introduction: Temporary restorations produced with a 3D printer have become very popular recently. There are limited studies in the literature comparing 3D printing and traditionally produced temporary materials.

Objectives: The aim of this study is to examine the color and roughness changes of different temporary materials produced by a 3D printer and the traditional method after being kept in coffee, and also to evaluate the effect of the polishing process applied to the surfaces.

Material and methods: Two types of 3D printing resin and a conventional autopolymerized PMMA material were selected. Half of the samples in each group were polished with polishing paste ($n = 15$). The first color values and surface roughness were measured, then samples were kept in coffee. 48 hours later, the second color measurements of the samples were made with spectrophotometer and ΔE00 values were calculated. Surface roughness values were measured with a profilometer device. Data were analyzed with the two-way analysis of variance and Tukey test. The relationship between roughness and color change in the coloring process was evaluated by Spearman correlation analysis ($p < 0.05$).

Results: According to two-way ANOVA analysis the color change between the materials and the color change in the polishing state of the surface were found to be statistically significant. The ΔE values listed from the highest to the lowest were as follows: unpolished PMMA > polished PMMA > polished temporary 3D resin > unpolished temporary 3D resin > unpolished standard 3D resin group > polished standard 3D resin.

Conclusions: The conventionally produced PMMA group was the material that underwent the most color change. From the materials produced by 3D printing, the temporary resin is more colored than the standard resin. A significant relationship was found between color change and roughness change. Less color change was found on polished surfaces.

Key words: 3D printing, color stability, surface roughness, temporary dental restorations.

J Stoma 2023; 76, 3: 161-166
DOI: https://doi.org/10.5114/jos.2023.131316

INTRODUCTION

Temporary restorations meet functional and aesthetic needs after tooth preparation until the permanent prosthesis is completed [1]. Although the duration of temporary restorations in the mouth is a few weeks on average, this period may be longer in complex cases and in the presence of systemic diseases [2]. Aesthetics and color stability are of great importance, especially in temporary restorations used in the anterior region. Temporary

JOURNAL OF STOMATOLOGY
CZASOPISMO STOMATOLOGICZNE
OFFICIAL JOURNAL OF THE POLISH DENTAL ASSOCIATION | ORGAN POLSKIEGO TOWARZYSTWA STOMATOLOGICZNEGO

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Received: 6.12.2022 • **Accepted:** 20.03.2023 • **Published:** 20.09.2023

restorations that change color with long-term use cause patient dissatisfaction and additional expense to remake them [3]. Therefore, color stability is an important criterion when choosing a temporary restoration material. The polishing process is also effective in the color stability of restorations. The surface smoothness of the temporary material to be selected is as clinically important as the color stability. Beverages such as coffee, tea, cola and wine adversely affect the color and shine of dental materials. The literature shows that coffee causes the most coloration [4, 5]. The fact that the surfaces are polished also reduces bacterial uptake on restorations and affects color stability. Color systems using coordinates have been developed to express colors in 3D space. The CIELab color system and CIEDE2000, which is a modified version and evaluates color perception and acceptability better, are the most widely used systems for this purpose. The color change can be measured objectively by calculating the distance between the initial color and the final color in 3-dimensional space, based on the coordinates.

Temporary restorations can be prepared directly in the mouth or indirectly on a model outside the mouth. The indirect technique is preferred over the direct technique in terms of clarity. Also, additive manufacturing technology has been used in temporary restorations in recent years. The basic principle is to design directly in the computer, create a three-dimensional model, and combine light curable materials from these data, layer upon layer with a 3D resin printer [6]. Compared to the traditional method, this new method has simpler, more accurate procedures and better sensitivity. In addition, dentists and dental technicians can observe the design of the prosthesis digitally and the design data can be stored as a digital file. Studies have reported that digitally produced temporary crowns were more successful with a shorter production time and at a lower cost [7, 8], but the long-term size and color stability, biocompatibility and mechanical properties are unknown due to a lack of clinical studies.

OBJECTIVES

The aim of this study was to examine the color and roughness changes of different temporary materials produced by a 3D printer and the traditional method after being kept in coffee, and also to evaluate the effect of the polishing process applied to the surfaces. The main hypothesis of this study is that the color change of the materials after being kept in coffee would be affected by the material type. Our second hypothesis is that the change in surface roughness after the materials had been kept in coffee would be affected by the material type. The third hypothesis we tested is that polishing of the materials would affect the color stability.

MATERIAL AND METHODS

A total of 90 samples were prepared for three different materials. The materials used in the study and their properties are shown in Table 1.

PREPARATION OF SAMPLES

For the conventional autopolymerized temporary material, 30 samples were prepared using a 10 mm diameter and 5 mm high disc-shaped Teflon mold. For 3D printing resin, discs with a thickness of 5 mm and a diameter of 10 mm were designed on a computer in the 3D design program (3D Builder, Microsoft) and saved in STL format. The 3D print was sent to a dental printer (Photon Mono X, Layer thickness: 50 µm, Ancubic) and 30 standard and temporary 3D resin samples were obtained. Residual resins were cleaned in a Wash & Cure Plus (Anycubic) device using isopropyl alcohol and kept under UV light for 10 minutes in the same device to fully polymerize.

POLISHING PROCESS

Half of the samples in each group were polished for 90 seconds by the same physician using aluminum oxide particle containing polishing paste (Universal Polishing Paste, Ivoclar Vivadent, Schaan, Liechtenstein). All samples were kept in distilled water for 24 hours.

COLOR MEASUREMENT

Values of L, a, b for initial color measurement were performed with the help of a spectrophotometer (CM-3600A, Konica Minolta, Japan) (Figure 1). Then, the samples were kept in coffee (2 g) prepared by adding 200 ml of boiled water (Nescafe Classic, Nestle Suisse S.A., Vevey, Switzerland) for 48 hours. It was previously stated that the 48-hour waiting period used in the study corresponds to a 2-month usage period [9].

TABLE 1. Details of the materials

Material	Production method	Material type	Manufacturer
Imident	Conventional autopolymerization	PMMA (polymethylmethacrylate)	Imicryl, Konya, Turkey
Alias C & B Temp	3D printing	Temporary 3D resin	Dokuz Kimya, Aydın, Turkey
Alias Sharp & Rigid	3D printing	Standard 3D resin	Dokuz Kimya, Aydın, Turkey

Color change values after 48 hours were calculated with the CIEDE 2000 formula. In the study, the parametric factors of kL, kC, and kH were set to 1, similar to previous studies [10, 11].

$$\Delta E_{00} = \sqrt{(\Delta L'/k_L S_L)^2 + (\Delta C'/k_C S_C)^2 + (\Delta H'/k_H S_H)^2 + R_T(\Delta C'/k_C S_C)(\Delta H'/k_H S_H)}$$

SURFACE ROUGHNESS MEASUREMENT

The roughness measurements of the samples were made at the beginning and after waiting in the coffee for 48 hours.

Surface roughness values were measured with a profilometer device (SJ-210, Mitutoyo, Japan) (Figure 2). The measuring length of the device was 5.5 mm and the measuring speed was set at 0.5 mm/s. The average Ra (µm) value was calculated by making three measurements from different parts of each sample.

STATISTICAL ANALYSIS

The effect of roughness and materials on color change was evaluated by two-way analysis of variance and the Tukey test. The relationship between roughness change and color change in the coloring process was evaluated by Spearman correlation analysis. A p-value < 0.05 was accepted for statistical significance.

RESULTS

According to two-way ANOVA analysis (Table 2) the color change between the materials and the color change in the polishing state of the surface were found to be statistically significant ($p < 0.05$).

The average color change (ΔE) value was 1.025 on polished surfaces, although in the absence of polishing it was 1.209. Color change is less on polished surfaces (Table 3).

The highest ΔE value was found to be 1,835 in the unpolished PMMA group, followed by 1,199 in the polished PMMA group. The lowest ΔE value was observed as 0.725 in the polished standard 3D resin group and 0.765 in the unpolished standard 3D resin group (Table 4).

The roughness change results of the materials after being kept in coffee are shown (Table 5).

The color change between materials was statistically significant in multiple comparisons (Table 6).

According to Spearman correlation analysis, there was a statistically significant relationship between color change and roughness change ($p < 0.05$).

DISCUSSION

This study compares the color stability and surface roughness of conventional and 3D printed temporary materials. All hypotheses of the study were accepted.

FIGURE 1. Color measurement with spectrophotometer

FIGURE 2. Surface roughness measurement with profilometer

TABLE 2. Tests of between-subjects effects

	Sum of squares	*df*	Mean square	*F*	Sig.
Material	8.981	2	4.490	35.154	0.000
Polishing	0.760	1	0.760	5.949	0.017
Material * polishing	2.410	2	1.205	9.434	0.000

TABLE 3. Color change values according to polishing condition

Polishing	Mean	Standard error	95% Confidence interval	
			Lower bound	Upper bound
Unpolished	1.209	0.053	1.103	1.315
Polished	1.025	0.053	0.919	1.131

TABLE 4. Descriptives

Material/Polishing	*n*	Mean	Standard deviation	Standard error	95% Confidence interval		Min.	Max.
					Lower bound	Upper bound		
Temporary 3D resin								
Unpolished	15	1.0273	0.33369	0.08616	0.8425	1.2121	0.45	1.69
Polished	15	1.1527	0.30170	0.07790	0.9856	1.3197	0.72	1.70
Standard 3D resin								
Unpolished	15	0.7647	0.39102	0.10096	0.5481	0.9812	0.25	1.47
Polished	15	0.7247	0.28765	0.07427	0.5654	0.8840	0.16	1.37
PMMA								
Unpolished	15	1.8353	0.49106	0.12679	1.5634	2.1073	0.97	3.09
Polished	15	1.1987	0.29539	0.07627	1.0351	1.3622	0.69	1.73

TABLE 5. Roughness changes of materials

	n	Mean	Standard deviation	Standard error	95% Confidence interval		Min.	Max.
					Lower limit	Upper		
PMMA	15	–0.5167	0.53324	0.13768	–0.8120	–0.2214	–1.57	0.12
PMMA + Polish	15	–0.2562	0.38686	0.09989	–0.4704	–0.0420	–1.23	0.44
Standard 3D resin	15	0.0063	0.46169	0.11921	–0.2493	0.2620	–0.80	0.62
Standard 3D resin + polish	15	–0.1798	0.39545	0.10211	–0.3988	0.0392	–0.84	0.37
Temporary 3D resin	15	0.0852	0.23978	0.06191	–0.0476	0.2180	–0.59	0.39
Temporary 3D resin + polish	15	–0.0412	0.17452	0.04506	–0.1378	0.0554	–0.31	0.27
Total	90	–0.1504	0.42472	0.04477	–0.2394	–0.0614	–1.57	0.62

TABLE 6. Multiple comparisons

(I) Material/(J) Material	Mean difference (I-J)	Standard error	Sig.	95% Confidence interval	
				Lower bound	Upper bound
Temporary 3D resin					
Standard 3D resin	0.3453*	0.09228	0.001	0.1252	0.5655
PMMA	–0.4270*	0.09228	0.000	–0.6472	–0.2068
Standard 3D resin					
Temporary 3D resin	–0.3453*	0.09228	0.001	–0.5655	–0.1252
PMMA	–0.7723*	0.09228	0.000	–0.9925	–0.5522
PMMA					
Temporary 3D resin	0.4270*	0.09228	0.000	0.2068	0.6472
Standard 3D resin	0.7723*	0.09228	0.000	0.5522	0.9925

**The mean difference is significant at the 0.05 level.*

The color and roughness changes of the materials after they were kept in coffee were affected by the material type. Polishing the materials affected the color stability.

Teeth and dental restorations are exposed to colored foods and beverages in the mouth. Especially in the long-term use of restorations, color stability is of great importance in the aesthetic region. Many factors affect the degree of color change. The cause of the discoloration may be due to external factors or the material. These are fluid absorption, incomplete polymerization, surface roughness, dietary habits, and poor oral hygiene [2, 4, 12-15].

Regardless of their chemical structure, all dental polymers show some degree of fluid absorption [5, 12, 16]. For this reason, resins exposed to colored environments such as tea and coffee in the mouth show a color change [2, 14, 16-20]. Causes related to external factors include plaque deposition, surface staining, discoloration of the surface or subsurface layers, polishing of the restoration surface, superficial material degradation, and slight penetration of coloring agents into the resin [17, 21]. If the coloration depends on the material, it depends on the initiator systems in the resins, the polymerization time and form [17, 22, 23]. Since it causes a chemical change in the matrix of the material, it is effective in all layers of the material [17].

Sham *et al.* [4] colored five different temporary materials with distilled water and coffee for 20 days. Haselton *et al.* [16] colored 12 different temporary materials with artificial saliva and coffee solution for 1, 2, and 4 weeks. Yannikakis *et al.* [5] colored 6 different temporary restoration materials in water, tea and coffee for 1, 7 and 30 days. All researchers found that the most coloration was in coffee. Coffee causes coloration both by adhering to the surface and by the absorption of its pigments into the organic matrix. For this reason, in our study, the samples were kept in coffee solution for 48 hours to measure their color stability. With reference to the study of Güler *et al.* [9], all materials were kept for 48 hours, which was stated to correspond to 2 months of clinical use.

The CIEDE2000 color system is more suitable for human visual perception than the CIELab system. The detection threshold for color change was determined as $\Delta E00 = 0.8$ and the acceptability threshold as $\Delta E00 = 1.8$ [24]. In our study, only the unpolished PMMA group exceeded the acceptable threshold and $\Delta E00 = 1.835$ was found. Color change remained below the detectable threshold in all standard 3D resin groups.

The rough surface of temporary restorations is directly related to biofilm deposition. These materials should be polished prior to use in the mouth to obtain a surface with less bacterial build-up. Rough surfaces mechanically absorb more stains than smooth surfaces [25, 26]. The results of our study also support this. The color change was found to be higher in the unpolished group. Although some studies in the literature show that surface roughness has a direct effect on coloration [26-29], some studies have not found a significant relationship between surface roughness and coloration [25, 30, 31]. In our study, a significant positive relationship was found between surface roughness and color stability.

Rao *et al.* [32] polished three different heat-polymerized acrylic resins with various techniques and found that the universal polishing paste gave the best results. Similarly, Sofou *et al.* [33] reported that the application of universal pastes showed lower roughness values in heat-polymerized acrylics. In our study, the polishing process was done with universal polishing paste.

If we compare 3D-printed restorations with conventional restorations, 3D-printed restorations are more advantageous. They provide high quality restoration with fast and easy fabrication [34]. Peng *et al.* [7] reported that digitally produced temporary crowns were more successful than those produced by conventional methods. In our study, the color and roughness changes of the temporary materials produced by 3D printing were found to be smaller than those for the PMMA material produced in the conventional way.

This study has several limitations. Intraoral restorations have concave and convex irregular surfaces, while the sample surfaces used in this study are flat. In addition, restorations are exposed to many different solutions in the mouth, saliva containing various proteins and enzymes, thermal changes, poor hygiene caused by the patient, and smoking. Abrasive aging processes such as thermal cycling or chewing simulation were not applied in this study. Although the cost of the devices used with the 3D printing method limits its use, the additive method is a good alternative in prosthetic dentistry. However, more research is needed on the color stability roughness of 3D printing materials.

CONCLUSIONS

There were significant differences in color stability of temporary materials made with different techniques simulating two months of use. The conventionally produced PMMA group was the material that underwent the most color change. From the materials produced by 3D printing, the temporary resin is more colored than the standard resin. A significant relationship was found between color change and roughness change. Less color change was found on polished surfaces.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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