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Research / Araştırma Makalesi

Effects of Mouthwashes and Surface Treatments on the Color Stability and Surface Roughness of a Three-Dimensional Printed Interim Crown Material

Ağız Gargaraları ve Yüzey İşlemlerinin Üç Boyutlu Baskılı Geçici Kron Materyalinin Renk Stabilitesi ve Yüzey Pürüzlülüğü Üzerindeki Etkileri

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ABSTRACT

Background: To evaluate the color stability and surface roughness of a 3D-printed interim crown material subjected to different surface treatments while immersed in various mouthwashes.

Methods: The specimens (n=56) were manufactured with a digital light processing 3D printer. Half of the specimens were coated with one layer of Ultra Glaze varnish, and other half were polished with OptraGloss. After the initial color and surface roughness values were measured, specimens were immersed in different solutions [3 mouthwashes (Andorex, Tantum Verde and Listerine) and distilled water] for 24 hours. After solution exposures, color and surface roughness measurements were repeated, and color change (ΔE_{00}) was calculated using CIEDE2000 formula. Two-way ANOVA and Tukey's test were performed to analyze the color difference and surface roughness of the specimens ($p < .05$).

Results: Listerine caused lower discoloration compared with other mouthwashes in both polish (4.11±1.0) and glaze (3.71±0.98) groups ($p < .05$). ΔE_{00} was greater than the perceptibility (1.3) and acceptability thresholds (2.25) for both polish and glaze groups immersed in mouthwashes. Before solution immersion, the polish group (0.421±0.122) had greater surface roughness values than did glaze group (0.073±0.024) ($p < .001$). The surface roughness of the mouthwashes and distilled water were similar for both polish and glaze groups ($p > .05$). After solution immersion, all groups showed greater surface roughness, except for the polish group, which was immersed in Tantum Verde ($p < .05$).

Conclusion: Mouthwashes negatively impacted the surface roughness and color stability of 3D-printed resin. The use of glazes for 3D-printed interim crowns can be recommended for long-term use.

Keywords: Mouthwashes, Surface Properties, Temporary Dental Restoration, Tooth Discoloration

ÖZ

Amaç: Bu çalışmanın amacı, farklı yüzey işlemlerine tabi tutulmuş üç boyutlu (3B) baskılı geçici kron materyalinin çeşitli gargaralara batırıldığında renk stabilitesini ve yüzey pürüzlülüğünü değerlendirmektir.

Gereç ve Yöntemler: Örnekler (n=56) dijital ışık işlemeli 3B yazıcı ile üretildi. Örneklerin yarısına tek kat Ultra Glaze verniği uygulandı, diğer yarısına ise OptraGloss polisaj kiti ile polisaj uygulandı. Başlangıç renk ve yüzey pürüzlülük değerleri ölçüldükten sonra numuneler 24 saat boyunca farklı solüsyonlarda [3 gargara (Andorex, Tantum Verde ve Listerine) ve distile su] bekletildi. Solüsyona maruz bırakıldıktan sonra renk ve yüzey pürüzlülüğü ölçümleri tekrarlanarak örneklerin renk değişimi (ΔE_{00}), CIEDE2000 formülasyonu kullanılarak hesaplandı. Örneklerin renk değişimi ve yüzey pürüzlülüğünü analiz etmek için iki yönlü ANOVA ve post hoc Tukey testi yapıldı ($p < 0,05$).

Bulgular: Listerine, hem polisaj (4,11±1,0) hem de glaze (3,71±0,98) yüzey işlemlerinde diğer gargaralara göre anlamlı derecede daha düşük renk değişim değerlerine neden oldu ($p < 0,05$). ΔE_{00}, hem glaze hem de polisaj grupları için klinik olarak algılanabilirlik (1.3) ve kabul edilebilirlik eşiklerinden (2.25) daha yüksekti. Solüsyona batırılmadan önce polisaj grubu (0,421±0,122), glaze grubuna (0,073±0,024) göre anlamlı derecede daha yüksek yüzey pürüzlülüğü değerleri gösterdi ($p < 0,001$). Gargaralar ve distile su hem polisaj hem de glaze grupları için benzer yüzey pürüzlülüğüne sebep oldu ($p > .05$). Tantum Verde'ye batırılan polisaj grubu dışında tüm gruplar, solüsyona batırıldıktan sonra önemli ölçüde daha yüksek yüzey pürüzlülüğü gösterdi ($p < .05$).

Sonuçlar: Gargaralar, 3B baskılı geçici kron rezininin yüzey pürüzlülüğünü ve renk stabilitesini olumsuz yönde etkilemiştir. Uzun süreli kullanılması planlanan 3B baskılı geçici kuronlar için glaze ile yüzey işlemi uygulanması tavsiye edilebilir.

Anahtar Kelimeler: Dişte Renk Değişikliği, Gargaralar, Geçici Diş Restorasyonu, Yüzey Özellikleri

Introduction

Interim dental prostheses, such as temporary crowns, play a crucial role in protecting the underlying tooth structure and preserving patient aesthetics during the production of permanent restorations. While these temporary materials are designed for limited use, their ability to maintain color stability and surface integrity is of paramount importance, especially when the restoration is situated in the aesthetic zone and must be worn for extended durations.[1] Numerous studies have reported significant color changes, rough surfaces and marginal discrepancies in interim restorations made from various materials.[1-5] Since the properties of the materials produced with the 3D printing technique, such as aesthetics, wear resistance and dimensional accuracy, continue to improve and there are still not enough clinical reports, these materials are mostly used in the construction of temporary restorations that are planned for long-term use, such as implants.[4,6,7] The composition and surface characteristics of 3D-printed interim materials may influence their susceptibility to discoloration and surface alterations, including the presence of glazed surfaces, when exposed to common oral beverages and surface treatments.

Mouthwashes are a common part of oral hygiene routines, and their impact on dental restorations has been the subject of numerous studies.[8-11] The effects of mouthwashes on dental restorations vary depending on their composition and the type of restoration material. Some mouthwashes can increase the surface roughness of dental restorations. For instance, acidic mouthwashes can erode the surface of composite resins and ceramics, making them rougher. This increased roughness can promote plaque accumulation and compromise the aesthetics and longevity of restorations.[12,13] Fluoride-containing mouthwashes can have a protective effect by reducing surface roughness due to their remineralization properties. However, the overall impact depends on the pH and composition of the mouthwash. Chlorhexidine (CHX) or alcohol-containing mouthwashes can cause discoloration of composite resins and ceramics.[14] CHX mouthwashes are particularly prone to causing brownish stains due to their staining properties.[13] Alcohol in mouthwashes can degrade the surface of composite resins and ceramics, leading to changes in their optical properties and resulting in color shifts.[8,15] This effect is more pronounced with prolonged exposure.[16] Therefore, the selection of mouthwash should be tailored to the type of dental restoration to

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maintain its integrity and aesthetics.

Surface finishing is a critical aspect of the fabrication of interim dental crowns because it can impact the overall quality and longevity of the restoration.[17] Surface roughness is closely related to the gloss and aesthetic appearance of the restoration, as a smooth surface is more reflective and visually appealing.[18] Rough and irregular surfaces can lead to increased plaque accumulation, gingival inflammation, and secondary caries, which can compromise the clinical durability of the restoration.[18] It was also observed that mechanical polishing and the use of polishing kits and pastes can effectively reduce the surface roughness of restorative materials.[19] The color stability of interim crown materials is also influenced by surface finishing, as discoloration can occur over time due to factors such as staining, degradation, and wear.[19] In vitro studies have shown that glazing improves resistance to discoloration.[2,20] Proper finishing and polishing or glazing techniques can help maintain the original color and aesthetics of the restoration, ensuring a more natural and long-lasting appearance.

There are limited studies that have tested the color stability and surface roughness of 3D-printed interim crown resins.[5,20] The purpose of this study was to evaluate the color stability and surface roughness of a 3D-printed interim crown resin material subjected to different surface treatments while immersed in various mouthwashes. The first null hypothesis was that the color stability of 3D-printed interim crown resin would not be affected by different surface treatments or immersion in mouthwashes. The second null hypothesis was that the surface roughness of 3D-printed interim crown resin would not be affected by different surface treatments or immersion in mouthwashes.

Materials and methods

In this study, the sample size was calculated using the G*Power V. 3.1.9.6 software. With a 95% confidence level (1-α), 95% test power (1-β), and an effect size of f = 0.62365, a total of 48 specimens should be included in the study, with a minimum of 6 samples in each group.[21] However, considering the potential specimen loss, the study included 7 specimens per group, for a total of 56 specimens.

Disk shaped specimens (n=56) were designed with a diameter of 10 mm and a height of 2 mm using design software (Autodesk, San Rafael, USA) and the design was saved in the appropriate file format (standard tessellation language (STL)). According to the STL file, 56 specimens were printed from A1 colored resin-containing temporary crown material (PowerResins Temp, 3BFAB Technology, Istanbul, Türkiye) using digital light processing technology (DLP) on a 3D printing device (Dentafab Sega 3D printer, Istanbul, Türkiye). A DLP 3D printer was used to print the with a 405- nm UV LED as the light source. Specimens were printed with a thickness of 50 µm and an exposure time of 3 s for each layer. The horizontal printing orientation was selected to optimize both precision and efficiency. The printed specimens were washed in a washing machine (Twin Tornado, Medifive, Seoul, Republic of Korea) with 90% isopropyl alcohol for 5 min according to the instructions of the manufacturer. The specimens were postcured for 20 min under the conditions recommended by the manufacturers using UV postcuring equipment (Twin Cure V; Medifive, Republic of Korea). The materials used in the study are listed in **Table 1**.

Table 1. 3D printing resin and mouthwashes used in the study

Product	Manufacturer	Product type	Composition
Temp Resin	3BFAB Technology, Istanbul, Türkiye	3D printable light polymerizing acrylic resin material	isopropylidenediphenol peg-2 dimethacrylate < 60%, 1,6-hexanediol dimethacrylate, 2-hydroxyethyl methacrylate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide, hydroxy propyl methacrylate, phenyl bis(2,4,6-trimethylbenzoyl)-phosphine oxide
Ultraglaze	Dokuz Kimya-Alias, Türkiye	Light cured protective coating	Methylmethacrylate monomer phosphine oxide
Andorex	Pharmactive, Tekirdağ, Türkiye	Topical antiseptic	0.12% clorhexidine digluconate, 0.15% benzydamine hydrochloride, sorbitol (70%), glycerol, polysorbate 20, ethanol, tartrazine, peppermint essense, patent blue, purified water, pH=5.5-7
Tantum Verde	Santa Farma, Kocaeli, Türkiye	Topical anti-inflammatory	0.15% w/v benzydamine hydrochloride, ethanol, glycerol, methyl parahydroxybenzoate, mint flavour, saccharin, sodium hydrogen carbonate, polysorbate 20, quinoline yellow, patent blue V, purified water, pH=5.1
Listerine Total Care	Johnson& Johnson, Pomezia, Italy	Topical antiseptic	Aqua, sorbitol, propylene glycol, sodium lauryl sulfate, poloxamer 407, benzoic acid, eucalyptol, methyl salicylate, thymol, sodium saccharin, sodium fluoride, sodium benzoate, menthol, aroma, benzyl alcohol, sucralose, zinc chloride, contains sodium fluoride (220 ppm F), pH=4.3

The surface of each specimen to be measured was abraded for 1 min under finger pressure with 600-800-1000-1200 grid silicon carbide sandpapers. Half of the specimens (n=28) were coated with one layer of Ultra Glaze (Dokuz Kimya-Alias, Türkiye) varnish and polymerized in a light polymerizing device (TRIAD 2000; Dentsply Sirona, York, PA) for 3 mins. The other half was polished with an OptraGloss (Ivoclar Vivadent, Schaan, Liechtenstein) polishing kit (dark and light blue cup-shaped rubber polisher) for totally 30 seconds at 15,000 rpm for each specimen. The specimens were kept in distilled water at 37°C for 24 hours and then dried with blotting paper. There were 8 experimental groups based on their surface treatment (polish and glaze) and immersion solution (distilled water, Andorex, Tantum Verde and Listerine). Seven specimens were allocated to each group.

The initial color coordinates of the specimens were measured using a digital spectrophotometer (Vita Easyshade Advance 4.0, Vita Zahnfabrik, Bad Säckingen, Germany) with a white background (L=21.2, a=4.4, b=6.2) and under D65 standard illumination conditions. Before each measurement, the spectrophotometer was calibrated according to the manufacturer's instructions. The measurements were repeated three times on each specimen surface, and the average L, a, and b values were recorded.

The initial surface roughness (Ra) was measured using a contact profilometer (TR-200, Time Group, USA) with 0.01 µm accuracy and a speed of 0.25 mm/s. For each specimen, roughness measurements were performed at 3 points 2.5 mm from each other. The surface roughness values were then displayed in micrometers after these measurements were averaged.

The specimens were subjected to three different mouthwashes and distilled water solution once the baseline measurements were finished. The 3D-printed interim crown resin specimens were kept in 20 mL volumes of three different mouthwashes and antiseptic agents (Andorex, Tantum Verde and Listerine) and distilled water (control) for 24 hours at room temperature. A previous study reported that exposure to dental materials in mouthwashes for 12 hours was equivalent to mouthwash usage for 1 year (2 times a day for 1 minute).[8] It is recommended to use mouthwashes and antiseptics twice a day for 2 minutes each, in accordance with the manufacturer's instructions. Considering this situation, in this study, the specimens were kept in the solutions for 24 hours to achieve an effect equivalent to 1 year of exposure to the solutions.[22] The solutions were changed every 4 hours to ensure that they maintained their effectiveness. After solution exposure, the samples were washed with pressurized water for 3 minutes to remove the solution. Then, the color and surface roughness measurements of the specimens were repeated.

In the evaluation of the color change due to exposure to mouthrinse, ΔE_{00}, which represents the distance of two colors to the 3-dimensional space, was used. The following formulation was used for the calculation of ΔE_{00}:

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

In this formula, S_L, S_C, and S_H are used to adjust for visual nonuniformity in the CIELab formula along the axes of lightness (L), chroma (C), and hue (H). The parameter RT is set to 0 ($\Delta C = 0$) for colors within the same density range. The environmental correction parameters K_L, K_C, and K_H are applied, with L*, a*, and b* values measured against a white background and K_L, K_C, and K_H values set to 1. A ΔE_{00} greater than 1.30 is clinically perceptible, and a value up to 2.25 is considered clinically acceptable.[23,24]

The data were analyzed using Jamovi (V2.3.28, The Jamovi Project, Australia) software. Levene's test was used to evaluate homoscedasticity, and the Shapiro–Wilk test was used to assess data normality (p=0.480 for color difference and p=0.064 for surface roughness data). Two-way analysis of variance (ANOVA) was used to analyze the effects of surface treatment methods and different mouthwashes on the color difference and surface roughness of the 3D-printed interim crown resin specimens. Tukey's test was performed for post hoc analysis ($p < .05$). Independent t tests were applied to compare the initial surface roughness of the specimens and to evaluate the effect of surface treatment methods. The surface roughness values before and after solution immersion were compared via the Wilcoxon test. The analysis results are reported as the mean ± standard deviation and median (minimum-maximum). A significance level of $p < 0.05$ was used.

Results

Color difference

There were significant effects of solution and surface treatment * solution interaction on ΔE_{00} at the $\alpha = .05$ level. (**Table 2**). The descriptive statistics (mean ± standard deviation) of the ΔE_{00} are shown in **Table 3**. Regardless of the surface treatment, distilled water (0.89±0.54) had the lowest difference in color, while Tantum Verde (11.7±2.36) had the greatest difference in ΔE_{00}.

Table 2. Two-way ANOVA of color differences

	Sum of Squares	df	Mean Square	F	p
Overall model	956.00	7	136.57	68.40	< .001#
surface treatment	14366	1	14366	25600	0.107
solution	899.48	3	299.83	150.16	< .001#
surface treatment * solution	51.13	3	45399	19937	< .001#
Residuals	95.84	48	2.00		

 # p< .05

Table 3. Mean values ± standard deviations of ΔE_{00} after solution immersion

Solutions	Surface treatment	
	Polish	Glaze
Distilled water	0.83±0.60 Aa	0.94±0.52 Aa
Andorex	8.78±1.45 Ab	5.08±0.75 Bb
Tantum Verde	11.0±1.04 Ab	12.5±3.11 Ac
Listerine	4.11±1.0 Ac	3.71±0.98 Ad

Note: Surface treatment groups marked with the same uppercase letters show no significant difference (p > 0.05). Solution groups marked with the same lowercase letters show no significant difference (p > 0.05).

When comparing the ΔE_{00} among the solution groups, all the mouthwashes showed significantly greater ΔE_{00} than distilled water for both the polishing and glazing surface treatments ($p < 0.001$ for all comparisons). Listerine caused a significantly lower color change than other mouthwashes for both the polish and glaze surface treatments ($p < 0.05$). The Tantum Verde group showed significantly greater ΔE_{00} than the other groups that received glaze surface treatment ($p < .001$). However, the ΔE_{00} of the Tantum Verde group was similar to that of the Andorex group when the specimens were polished (p=0.150).

When comparing the ΔE_{00} between the polish and glaze surface treatments, the polish group showed a significantly greater ΔE_{00} than did the glaze group immersed in Andorex ($p < .001$).

ΔE_{00} was tested against the 1.3 perceptibility threshold and 2.25 acceptability threshold (**Fig. 1**). ΔE_{00} was greater than the perceptibility and acceptability thresholds for both the polish and glaze groups (Andorex, Tantum Verde and Listerine). ΔE_{00} showed a color change that was lower than the perceptibility and acceptability thresholds for the control group (distilled water) for both surface treatment groups.

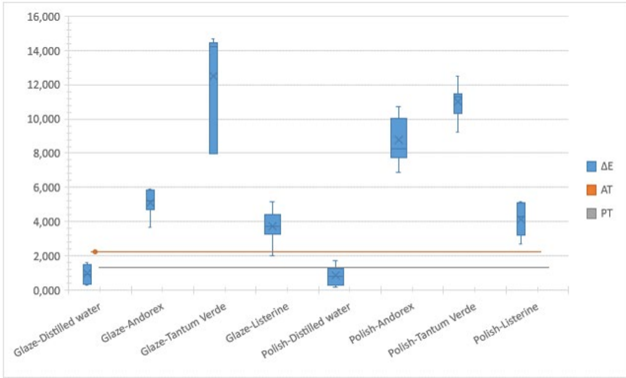

Figure 1. Significance of the effect of color changes on the acceptability threshold (AT) and perceptibility threshold (PT) on ΔE_{00} after solution immersion. AT is defined as 2.25, and PT is defined as 1.3.

Surface roughness

Before solution immersion, the polish group (0.421±0.122) had significantly greater Ra values than did the glaze group (0.073±0.024) ($p < .001$) (**Fig. 2**).

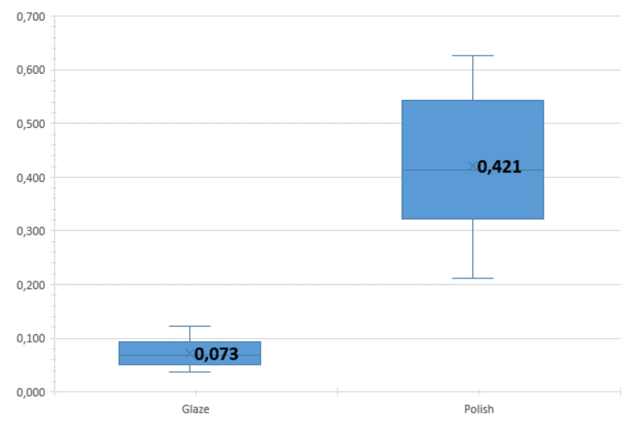

Figure 2. Surface roughness of the surface treatment groups before solution immersion

After solution immersion, the surface treatment and solution had significant effects on the surface roughness at the $\alpha = .05$ level (**Table 4**). The descriptive statistics (mean ± standard deviation) of the ΔE are shown in **Table 5**. Regardless of the solution, the polished surfaces (0.619±0.193) had a significantly greater surface roughness than did the glazed surfaces (0.212±0.145) ($p < .001$). Regardless of the surface treatment, the specimens immersed in Listerine (0.505±0.208) had a significantly greater surface roughness than those immersed in Tantum Verde (0.314±0.240) (p=0.011).

Table 4. Two-way ANOVA of surface roughness

	Sum of Squares	df	Mean Square	F	p
Overall model	2.736	7	0.3908	16.26	< .001#
surface treatment	2.316	1	2.3162	96.37	< .001#
solution	0.300	3	0.0999	4.16	0.011#
surface treatment * solution	0.120	3	0.0399	1.66	0.188
Residuals	1.154	48	0.0240		

# p< .05

Table 5. Mean values ± standard deviations of Ra after solution immersion

Solutions	Surface treatment	
	Polish	Glaze
Distilled water	0.678±0.205 Aa	0.243±0.073 Ba
Andorex	0.649±0.233 Aa	0.115±0.032 Ba
Tantum Verde	0.503±0.196 Aa	0.125±0.051 Ba
Listerine	0.644±0.105 Aa	0.365±0.193 Ba

Note: Surface treatment groups marked with the same uppercase letters show no significant difference (p > 0.05). Solution groups marked with the same lowercase letters show no significant difference (p > 0.05).

When comparing Ra among the solution groups, mouthwashes and distilled water had similar surface roughnesses for both the polishing and glazing groups (p> .05). When comparing Ra between the polish and glaze surface treatments, the polish group had a significantly greater Ra than did the glaze group for all the solutions (p< .05).

Regardless of the surface treatments, the surface roughness of the specimens increased significantly after immersion in the solutions (before Ra: 0.247±0.196, after Ra: 0.415±0.266) (p< .001). According to pairwise comparisons, only the polish group showed similar surface roughness values before [0.498 (0.327-0.597)] and after [0.447 (0.211-0.773)] immersion in Tantum verde. The other groups exhibited significantly greater surface roughness after solution immersion (p< .05) (**Fig. 3**).

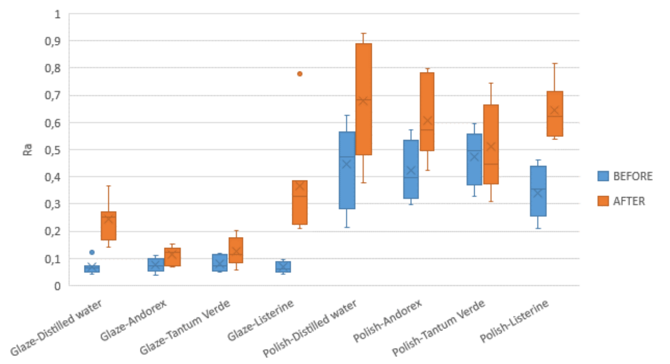

Figure 3. Pairwise comparison of Ra for the groups before and after solution immersion

Discussion

The surface properties of 3D-printed interim materials, such as color stability and surface roughness, are essential for their clinical performance and aesthetic appearance.[19] Clinicians must carefully consider the optical properties and long-term color stability of provisional restorations, as patient aesthetic concerns and demands increase when these restorations are required for extended periods.[25] Polishing and finishing treatments are crucial steps to optimize the surface characteristics of 3D-printed interim materials. These treatments can minimize the wear effect on the opposing teeth by reducing the abrasiveness of the restoration and ensuring proper hygiene by preventing bacteria from adhering to the restoration surface.[19] While chairside polishing can be an effective method for improving the surface characteristics of 3D-printed interim materials, clinicians must exercise great caution when employing these techniques, as excessive or inappropriate polishing can have a detrimental impact on the color stability and long-term success of the restoration.[19,25] Based on the data, the color change values differed after immersion in the mouthwashes. For this reason, the first null hypothesis that the color stability of 3D-printed interim crown resin would not be affected by different surface treatments and immersion in mouthwashes was partially rejected. Based on the data, the surface roughness values differed according to the surface treatment methods and immersion in mouthwashes. For this reason, the second null hypothesis that the surface roughness of 3D-printed interim crown resin would not be affected by different surface treatments and immersion in mouthwashes was rejected.

In vitro studies have demonstrated that surface finishing treatments, such as the use of disks, polishing kits, and polishing pastes, can significantly impact the color stability and surface roughness of various restorative materials.[19,26] In previous studies, glazing or surface-sealing materials were shown to reduce surface roughness.[17,27] In the present study, it was also found that glazed specimens had smoother surfaces than polished specimens before and after solution immersion. The composition of glaze materials affects their viscosity, flow rate, and penetration ability. This influence likely helps them fill microfissures and microdefects in interim prostheses, improving surface smoothness and optical properties.[27] The color stability increases because glazed surface layers protect polymers from colored pigments, whereas unglazed polymers have exposed surfaces.[2]

Yao et al.[17] reported that a nanofilled, light-polymerizing glaze material (Optiglaze; GC America Inc.) significantly increased the color stability of CAD-CAM and 3D-printed interim restorations after thermal aging. It was found that the light-polymerizing coating agent offered stronger protection against discoloration than did the polishing treatment. However, in this study, surface treatments had no effect on color stability except for immersion in Andorex. When specimens were immersed in Andorex, the glaze group demonstrated significantly less discoloration than the polish group. These results indicate that the tested glaze material (Ultra Glaze) provided significant protection against discoloration caused by chlorhexidine mouthwashes. The protective effect of surface treatment on interim restorations against discoloration from chromogenic immersion liquids is likely multifactorial and may require further extensive study. It was concluded that the chromogenic agent is the primary factor influencing the color stability of interim restorations, followed by the type of material and surface treatment.[2]

Recent studies have reported that 3D-printed resins exhibit greater discoloration and lower color stability than CAD/CAM resin blocks.[3,28] There are various reasons for the low color stability of 3D-printed resins. Since 3D printing is based on the additive manufacturing method, there are layers in the surface microstructure.[29] In the DLP method, since the 3D printing principle uses a micro mirror, a slightly more characteristic pattern appears on the surface, which may contribute to the decrease in color stability.[3] In the present study, 3D-printed resin samples produced with DLP technology showed discoloration above the clinically acceptable limit when immersed in mouthwash. The 3D printer used in the study operates with DLP technology at a wavelength of 405 nm, and the interim resin material used meets the criteria specified by the manufacturer. The phosphinoxides contained in the material have been marketed as alternative photoinitiators to camphoroquinone, which causes yellowing in resins. However, phosphinoxides exhibit a lower cure depth.[30,31] This may have caused the 3D-printed resin material to have a lower conversion degree and a greater amount of uncured residual monomer. Additionally, the 3D-printed resin used did not contain fillers. This can explain the large color change when the material is used for long-term temporary restoration.[4]

The specimens showed significantly greater surface roughness after solution immersion, except for a polished group immersed in Tantum Verde. As daily exposure to mouthwashes occurs, the adherence of plaque and the tendency to stain may be magnified with restorations having greater surface roughness.[32] In the present study, the color change was also greater than the perceptibility and acceptability thresholds for the mouthwash groups. When 3D-printed resins are used for long-term temporary restoration, gingival inflammation and deterioration of the aesthetic appearance may occur.

Before solution immersion, the measurements yielded an average surface roughness between 0.07 and 0.42 for the glaze and polishing groups, and this finding was found to be clinically acceptable.[33] After immersion in the solutions, the average surface roughness was found to be clinically acceptable for the glaze group (0.21) and clinically unacceptable for the polish group (0.62).

Two varieties of mouthwashes are available on the market: alcohol-free and alcohol-based, with alcohol mainly serving as the solvent.[8] In general, mouthwashes and antiseptic solutions contain antimicrobial agents, refreshing flavors, herbal extracts for scent, and solvents such as alcohol, sorbitol, or water. These active ingredients and flavoring agents often include coloring pigments. The regular use of mouthwashes has both benefits and drawbacks. On the positive side, their anti-inflammatory, antimicrobial, and analgesic properties help improve and maintain periodontal health. However, some components in mouthwash can also soften the organic resin matrix and lead to discoloration.[34,35]

Ethanol can dissolve water-absorbing resin materials. As a result, mouthwashes containing ethanol may soften restorative materials.[9] For instance, Tantum Verde, which contains a high ethanol content (95 vol%), caused the most significant color change in this study. This solution, with 95 vol% ethanol, also includes methyl parabens, saccharin, quinoline yellow, and patent blue, which impart a greenish hue. The combination of yellow and blue pigments results in a green color that remains on the material as a surface-absorbed organic residue.[10]

CHX-containing mouthwash was used because it is considered the gold standard due to its proven potent antimicrobial activity. However, its ability to discolor and soften resin-containing restorations has been reported to have side effects. It was reported that CHX gluconate led to yellow–brown stains on the surface of restorative materials, as the CHX gluconate molecule could release parachloranilin with metal sulfide formation.[36] In the present study, Andorex and Tantum Verde caused the most significant color changes in the polish groups.

Listerine, which has a low pH, and alcohol can cause the dissolution of many cations by anions in solution, polymer matrix collapse, and erosion, resulting in discoloration.[15] In this study, Listerine caused a lower color change, except for the control specimens immersed in distilled water. This result may have been caused by the fact that Listerine solution is less dense and has less coloring pigment than other mouthwashes. It was found that nanofilled resin composites immersed in Listerine exhibited lower ΔE_{00} values than those immersed in the nonalcohol CHX, which supports the findings of the current study.[11] In contrast, Soygun et al.[10] reported that mouthwashes with higher alcohol content caused greater color changes in bioceramic materials. The variations between these studies could be due to differences in the types of materials (resin composite, ceramic, or temporary resin) exposed to the mouthwashes, the duration of exposure, and the surface texture following various surface treatments.

Although the mouthwashes used were acidic, there was no significant difference between the surface roughness of the 3D-printed resin and that of the resin immersed in distilled water. This acidic pH was not considered a significant factor affecting the surface roughness of the resin restorative materials.[37] Therefore, surface treatment could be considered a more effective factor affecting the surface roughness of 3D-printed resins than the chemical composition and pH of the mouthwashes. The chemical composition and pH of the mouthwash significantly affected the change in color of the 3D-printed resin above the clinically acceptable limit. It can be concluded that 3D-printed interim resin materials should not be the primary choice for patients who require long-term mouthwash use.

The present in vitro study has several limitations, such as the continuous normal washing effect of the saliva, which may reduce the staining effect. Additionally, the salivary pellicle and the consumption of different foods and beverages might influence the susceptibility to color change. In addition, one type of 3D printing resin was used in this study. Further studies are needed to compare the conventional production method, CAD-CAM and 3D printing with other technologies for permanent resins. Another limitation of this study was the use of a single type of photopolymerized glazing solution and a polishing kit, as different types of glazes and polishing kits may yield different results. Since the changes in the color and surface roughness of the tested 3D-printed interim resin were evaluated after one year of clinical use, the results cannot be generalized to short-term use. In future studies, the short- and long-term optical and mechanical properties of temporary materials with different production techniques and contents can be compared.

Conclusion

Within the limitations of the study, it can be stated that mouthwashes negatively impacted the surface roughness and color stability of the tested 3D-printed interim crown resin. The effect depended on the type of mouthwash and surface treatment for surface roughness and the type of mouthwash for color stability. The 3D-printed resin specimens showed discoloration above the clinically acceptable limit after immersion in the tested mouthwashes. Mouthwashes containing ethanol and benzydamine hydrochloride showed greater discoloration; thus, it is better to limit their prescription. Glazed specimens had smoother surfaces than polished specimens before and after solution immersion. Surface treatment with glaze can be recommended for 3D-printed interim crowns that are planned for long-term use.

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It is declared that during the preparation process of this study, scientific and ethical principles were followed and all the studies benefited are stated in the bibliography.

Benzerlik Taraması / Similarity scan

Yapıldı – ithenticate

Etik Bildirim / Ethical statement

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Yazarlar çıkar çatışması bildirmemiştir. | The authors have no conflict of interest to declare.

Yazar Katkıları / Author Contributions

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Veri Toplanması | Data Acquisition: GDG (%50), SÜA (%50)
Veri Analizi | Data Analysis: GDG (%100)
Makalenin Yazımı | Writing up: GDG (%70), SÜA (%30)
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