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Evaluation of the Color Stability of 3D-printed Provisional Materials Against Different Mouthwashes: An *in vitro* Study

Farklı Ağız Gargaralarına Karşı 3D Yazıcıyla Üretilen Geçici Materyallerin Renk Stabilitesinin Değerlendirilmesi: *İn vitro* Çalışma

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ABSTRACT Objective: This study aimed to evaluate the color stability of three-dimensional 3D-printed and conventional provisional restorative materials exposed to different mouthwashes. **Material and Methods:** Disc-shaped specimens (Ø6×2 mm) of 3D-printed [Temp PRINT™ (TP)]; [Powerresins Temp Resin (PTR)] and conventional [Acrytemp (ACR)] provisional materials were fabricated (n=120). Each material group was divided into 4 subgroups for immersion in different mouthwashes (n=10). Initial color measurements (t0) were performed using a dental spectrophotometer (Vita Easyshade). The specimens were immersed in 0.20% chlorhexidine [Curasept ADS 220 (CHX20)] 0.05% chlorhexidine [Curasept ADS 205 (CHX05)], alcohol-containing [Listerine Cool Mint (LIS)] mouthwashes, and artificial saliva (CON) solutions for 12 hours (t1) and 2.5 days (t2) to simulating 1-5 year clinical use, respectively. Color change (ΔE_{00}) was calculated between different immersion periods (ΔEt0-t1, ΔEt0-t2) using the L*a*b values. Data were analyzed with Robust three-way analysis of variance and Bonferroni multiple comparisons (α=0.05). **Results:** TP exhibited the highest ΔE_{00} among all materials. LIS caused the greatest discoloration in 3D-printed materials (p<0.001), while ACR showed the highest ΔE_{00} in CHX20 mouthwash (p=0.001). 5 year exposure (ΔEt0-t2) to CHX20 and LIS solutions caused significantly greater discoloration than 1 year exposure (ΔEt0-t1) (p=0.002). **Conclusion:** TP demonstrated the least color stability, while LIS caused the highest discoloration of 3D-printed materials. The 3D-printed provisional material PTR and daily use of CHX05 mouthwash are clinically recommendable for long-term periods.

Keywords: Color; mouthwashes; dental materials; printing; three-dimensional

ÖZET Amaç: Bu çalışmanın amacı, üç boyutlu [three-dimensional (3D)] yazıcıyla üretilmiş ve konvansiyonel geçici restoratif materyallerin farklı gargaralara karşı renk stabilitesini değerlendirmektir. **Gereç ve Yöntemler:** 3D yazıcıyla üretilmiş [Temp PRINT™ (TP)]; [Powerresins Temp Resin (PTR)] ve konvansiyonel [Acrytemp (ACR)] geçici materyalden disk şeklinde (Ø6×2 mm) numuneler üretildi (n=120). Her materyal, farklı solüsyonlara daldırılmak üzere 4 alt gruba ayrıldı (n=10). Başlangıç renk ölçümleri (t0), dental spektrofotometre (Vita Easyshade) ile değerlendirildi. Örnekler, 1-5 yıllık kullanımı simüle etmek amacıyla %0,20 klorheksidin Curasept ADS 220 (CHX20), %0,05 klorheksidin Curasept ADS 205 (CHX05), alkol içeren Listerine Cool Mint (LIS) gargaralar ve yapay tükürüğe (CON) 12 saat (t1) ve 2,5 gün (t2) süreyle daldırıldı. Renk değişimleri (ΔE_{00}) L*a*b değerleri kullanılarak hesaplandı. Veriler Robust üç-yönlü varyans analizi ve Bonferroni çoklu karşılaştırma testiyle analiz edildi (α=0,05). **Bulgular:** TP, diğer materyallere kıyasla en yüksek bir ΔE_{00} değeri gösterdi. LIS 3D yazıcıyla üretilmiş materyallerin en fazla renklenmesine sebep olan solüsyon grubu oldu (p<0,001). ACR, CHX20'de daha yüksek bir ΔE_{00} sergiledi (p=0,001). CHX20 ve LIS solüsyonlarına 5 yıllık maruziyet (ΔEt0-t2), 1 yıllık maruziyetten (ΔEt0-t1) daha fazla renklenmeye sebep oldu (p=0,002). **Sonuç:** TP en düşük renk stabilitesine sahipken, alkol içeren LIS 3D yazıcıyla üretilen materyallerde en yüksek renk değişimlerine yol açtı. 3D yazıcıyla üretilen PTR ile %0,05 klorheksidin içeren gargaraların (CHX05) uzun süreli günlük kullanımı önerilebilir.

Anahtar Kelimeler: Renk; gargaralar; dental materyaller; yazıcı; üç boyutlu

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Provisional restorations, like crowns and bridges, are frequently utilized in fixed partial denture treatments, meet functional and esthetic needs until the placement of definitive prosthesis.[1,2] The intraoral duration of provisional restorations typically averages a few weeks but can extend beyond 6 months or longer in extensive prosthetic treatments or patients with systemic diseases.[3] Therefore, materials used for provisional restoration should fulfil sufficient color stability.[1,2]

Color stability is a key esthetic consideration for restorative materials, as discoloration compromises the long-term appearance of restorations.[4] Assessing color differences (ΔE_{00}) is essential for determining clinically and socially perceptible and acceptable thresholds, reported as 0.8 and 1.8, respectively.[5] Among various evaluation methods, the CIEDE2000 formula is most widely accepted for measuring ΔE_{00}.[6] Since provisional materials serve as interim solutions before definitive prostheses, their ability to maintain color stability is crucial for patient satisfaction and treatment success.[7] Exposure to beverages and oral hygiene products, such as mouthwashes, can accelerate discoloration, making resistance to staining a critical property for provisional materials.[8]

Mouthwash use is an efficient method to manage plaque and support periodontal health.[9] Common ingredients include chlorhexidine gluconate, ethanol, essential oils, and detergents, with varying chemical compositions that can influence color stability of restorative materials.[10] Alcohol, often present in mouthwashes, possesses antiseptic properties, aids in dissolving antimicrobial agents like essential oils, and helps preserve the formulation.[11] However, it can also weaken the bonding between the resin matrix and inorganic components, increasing susceptibility to staining.[12] Chlorhexidine gluconate, widely used for its antibacterial efficacy, is frequently recommended by clinicians. However, it is also a major contributor to discoloration, making it a common focus in studies evaluating the impact of mouthwashes on color stability.[13]

Provisional restorations can be fabricated using conventional, subtractive, three-dimensional (3D) printing techniques. Resin-based bis-acryl composites, the most common conventional material, are known for their low cost, ease of adjustment, and repairability.[14] With advancements in digital dentistry, 3D printing has emerged as a faster, more precise, and cost-effective alternative over conventional methods, offering advantages in clinical applications.[15] However, despite its mechanical advantages, the long-term color stability of 3D-printed provisional materials remains a concern, especially in long-term applications where discoloration becomes more pronounced than bis-acryl resin.[16] Research comparing different provisional materials in terms of color change suggests that 3D-printed materials exhibit lower reliability than conventional ones.[16] Various factors, including printing technology, processing parameters, and post-curing methods, contribute to discoloration, which tends to worsen the color stability of 3D-printed materials over time, further compromising the longevity of these materials.[17] Further research is needed to evaluate the long-term color stability of variable 3D-printed provisional materials.

To the best of our knowledge, although previous studies have evaluated the color change of provisional materials exposed to different mouthwashes, no study has compared the color stability of different 3D-printed and conventional provisional materials after 1 year and 5 years of exposure to chlorhexidine and alcohol-containing mouthwashes.[18,19] Therefore, the present study aims to evaluate the long-term color stability of 3D-printed and conventional provisional restorative materials against simulated 1-5 years of mouthwash use. The null hypotheses were that (1) there would be no difference between the color stability of provisional restorative materials exposed to different mouthwashes and (2) different mouthwashes would have no effect on the color stability of provisional restorative materials in 1-5 year simulated periods.

MATERIAL AND METHODS

This study was conducted in accordance with the latest guidelines of the Declaration of Helsinki. Since the present study was an in vitro study in which humans and animals, including human/animal materials or data, were not used for experimental purposes, ethical approval and informed consent were not required.

The sample size calculation was performed using a G*Power statistical software program (v3.1.9.2, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) with an effect size of 0.05 based on data from a previous study by Kara et al.[20] A minimum of 5 specimens per group was achieved 95% power to detect significant differences at 0.05 significance level, to test the null hypotheses. Ultimately, ten samples (n=10) were included in each group.

Three provisional materials in the A2 shade, varying in chemical composition and manufacturing methods, were evaluated, as detailed in Table 1. Two commercially available 3D-printing provisional resins (TP; Temp PRINT™, GC Corporation, Leuven, Belgium and PTR; Powerresins TempResin, DentaFab, İstanbul, Türkiye) and a conventional bis-acryl resin material (ACR; Acrytemp, Zhermack SPA, Italy) as a control group were used. A total of 120 disc-shaped samples, 10 specimens for each group, were fabricated with a 6 mm diameter and 2 mm thickness. Conventional provisional material was applied by a single operator (SÖ) through a dispensing gun using disposable tips following the manufacturer's instructions and allowed to set. The material was precisely placed into a silicone mould (6x2 mm) and covered with a glass slide to ensure the uniformity and accuracy of the samples. Gentle pressure was applied to remove excess material, resulting in a flat surface. After chemical polymerization, the samples were carefully removed from the mould. For the fabrication of 3D-printed materials, a virtual disc shape design was performed using CAD software (Shapr 3D, Budapest, Hungary) and saved as a standard tessellation language (STL) file. TP resin samples were fabricated using a stereolithography 3D printer [Asiga Ultra (50), ASIGA, Sydney, Australia] with a layer thickness of 100 µm by using an STL data file. After the samples were printed, they were washed with 99% isopropanol alcohol for 3 minutes (Form Wash, Formlabs, Somerville, USA) and post-cured twice for 20 minutes at 60^0 (Form Cure, Formlabs, Somerville, USA) according to the manufacturer recommendations. PTR resin samples were fabricated using another digital light processing 3D printer (Sega Dental Printer; Dentafab, İstanbul, Türkiye) with the same layer thickness of 100 µm. After printing, the samples were washed with 96% ethanol for 3 minutes in the 1st chamber of the resin cleaner (Twin 3D Cleaner, Medifive, Seoul, Korea). Then, the samples were cleaned for 3 minutes in the 2nd chamber. After both stages, the samples were dried with a spray air gun. Care was taken not to exceed the total cleaning procedure time of 6 minutes. For post-curing, the samples were exposed to 2x2,500 times of light exposure in the postpolymerization device (Otoflash G171, NK-Optik GmHb, Baierbrunn, Germany). Then, all the specimens were cleaned in an ultrasonic bath for 15 minutes and air-dried for 30 seconds. After cleaning, the specimens were polished using composite polishing discs (Optidisc, Kerr, USA) with grit sizes of 80-, 40-, 20-, and 10- µm, respectively, under water cooling for 10 seconds each. Following this, a mixture of pumice powder and water was applied to the surface of each sample using a bristle brush for 1 minute. Polishing was finalized by applying a polishing paste (Diamond Polish Mint, Ultradent, UT, USA) with a cotton brush for 1 minute. All finishing and polishing procedures were performed by a single experienced operator (İTK) to ensure consistency and avoid bias. After pol-

TABLE 1: Materials used in the study

Material	Classification	Composition*	Manufacturer
GC temp print	3D printed	Urethane dimethacrylate dimethacrylate component** quartz (SiO_2) photoinitiator synergist UV-light absorber.	GC corporation, Leuven, Belgium and PTR
Powerresins C-temp resin	3D Printed	Acryl-containing additives and methacryl. (MMA free)	PowerResins Temp Resin™, İstanbul, Türkiye
Acrytemp	Conventional	Bisacrylic composite resin	Zhermack SPA, Italy

* Composition details are based on data supplied by the manufacturers.

**The exact chemical identity is a trade secret according to the manufacturer.

ishing, the specimen thickness was verified as 2.0±0.05 mm with digital calipers (Digimatic, Mitutoyo Corporation, Japan). Subsequently, all samples were immersed in distilled water and stored for 24 hours.

Forty specimens of each group were divided into 4 subgroups (n=10), which will be treated with 3 different types of mouthwashes and artificial saliva to observe the color change in various solutions after polishing. The solutions used in this study are shown in Table 2. The specimens of each material were individually immersed in light-proof vials, which were sealed to prevent the evaporation of the solutions. Each vial contained 20 mL of 0.20% chlorhexidine-containing (CHX20; Curasept ADS 220, Curaden AG, Kriens, Switzerland), 0.05% chlorhexidine-containing (CHX05; Curasept ADS 205, Curaden AG, Kriens, Switzerland), alcohol-containing (LIS; Listerine Cool Mint, Leuven, Belgium) mouthwashes and artificial saliva (CON; Testonic Laboratories, Colin, İstanbul, Türkiye) as a control group. Two minutes of daily usage of mouthwash for 1-year corresponds to 12 hours of *in vitro* exposure.[10,21] Measurements of the samples were repeated at time intervals simulating initial (t0), 12 hours (t1), and 2.5 days (t2) of exposure. The t0-t1 and t0-t2 correspond to 1-5 year mouthwash usage of 2 minutes daily. Before each exposure, the samples were rinsed with distilled water for 5 seconds and dried using absorbent paper (Rotilabo, Carl Roth GmbH, Germany). The initial (t0) color parameters (L^*, a^*, b^*, C, H) of all samples were recorded against a standard white background using a clinical spectrophotometer (Vita Easyshade V, Vita Zahnfabrik, Germany). The head of the spectrophotometer was centered on each specimen during the measurements. Each measurement was performed three times by a single operator (İTK), and the measurement averages were recorded. The calibration of the spectrophotometer was performed before each ten measurements. All measurements were repeated in 2 time periods (t1/t2) after immersion in solutions. The ΔE_{00} between the immersion intervals (ΔEt0-t1, ΔEt0-t2) was calculated according to CIEDE2000 using the formula as follows:

$\Delta E_{00}=[[(\Delta L'/ (k_L S_L)]^2+[\Delta C'/(k_c S_c)]^2+R_T [(\Delta C'/(k_c S_c) (\Delta H'/(K_H S_H)]^2]^{1/2}$, where L', C', and H' refer to the differences in lightness, chroma, and hue, respectively, and R_T and S indicate the rotation and weighting functions, respectively. The parametric factors, which serve as correction terms for the experimental conditions, k_L, k_C, and k_H, were set to 1.[22] The thresholds for perceptibility and acceptability of 0.8-1.8 were used to evaluate ΔE_{00}, respectively.[5]

Data analysis was performed using Jamovi statistical software (V2.3.28.0, Sydney, Australia). The normality of the data distribution was assessed using the Shapiro-Wilk Test. A three-way analysis of variance (ANOVA) was conducted to evaluate the effects of material, solution, and time on mean ΔE_{00} values

TABLE 2: Solutions used in the study

Mouth rinses	Description	Composition	pH	Manufacturer	Code
Listerine cool mint	Alcohol-containing	(PR-009972) Aqua, propylene glycol, sorbitol, poloxamer 407, sodium lauryl sulfate, eucalyptol, benzoic acid, sodium benzoate, methyl salicylate, thymol, sodium saccharin, sodium fluoride, menthol, sucralose, aroma, CL 42053	4.6	Listerine, Leuven, Belgium	LIS
Curasept ADS 220	Alcohol-free	Aqua, xylitol, propylene glycol, PEG-40 hydrogenated castor oil, ascorbic acid, chlorhexidine digluconate, aroma, poloxamer 407, sodium metabisulfite, sodium citrate, sodium dna, vp/va copolymer, sodium benzoate, C.I. 42090.	6.2	Curaden AG, Kriens, Switzerland	CHX20
Curasept ADS 205	Alcohol-free	Aqua, xylitol, propylene glycol, PEG-40 hydrogenated castor oil, sodium citrate, ascorbic acid, chlorhexidine digluconate, aroma, sodium flüoride, poloxamer 407, sodium metabisülfite, hydrolized rna/dna, leuconostoc/radish ferment filtrate, sodium benzoate, C.I. 42090	6.2	Curaden AG, Kriens, Switzerland	CHX05
Artificial saliva	Control group	Carboxymethyl cellulose, sorbitol, sodium chloride, sodium fluoride, magnesium 6.09 chloride, calcium chloride, sodium phosphate, nipacin, distilled water	6.09	Testonic Laboratories, Colin, İstanbul, Türkiye	CON

and their interactions. Due to violations of normality and homogeneity of variances, a Robust three-way ANOVA was applied for statistical reliability. Multiple comparisons were performed using the Bonferroni test. For non-normally distributed variables, analyses were conducted using the Walrus package, suitable for non-parametric tests. Results were presented as mean±standard deviation (SD), with a significance level set at p<0.05.

RESULTS

The ΔE_{00} values of provisional material groups were compared according to the main effects of materials, solutions, time and the interaction between them, as shown in Table 3. The mean±SD of ΔE_{00} values for each group according to solution and time parameters are shown in Table 4.

TP exhibited a higher ΔE_{00} value than other materials, with the highest discoloration observed in LIS mouthwash (p<0.001 and p=0.001, respectively). PTR showed the highest ΔE_{00} in LIS and the lowest in CHX05, while ACR exhibited higher ΔE_{00} in CHX20 and CHX05 mouthwashes compared to LIS and CON (p=0.001). The greater discoloration was observed at the ΔEt0-t2 time period compared to ΔEt0-t1 in CHX20 and LIS, whereas the opposite was seen in CHX05 and CON solution (p=0.002) (Table 4) (Figure 1).

Based on the perceptibility threshold of 0.8 and the acceptability threshold of 1.8, TP exhibited perceptible and clinically unacceptable color changes across all solution groups. PTR showed a mean ΔE_{00} value that was both perceptible and acceptable in the ΔEt0-t1 interval, while in ΔEt0-t2, the ΔE_{00} value was considered clinically unacceptable. ACR demonstrated perceptible but unacceptable color changes at both time intervals; however, these values were very close to the 1.8 threshold (Table 4).

TABLE 3: Comparison of color change (ΔE00) values according to material, solution and time.

	Test statistics	p value*
Material	1,337.051	**<0.001**
Solution	33.954	**<0.001**
Time	4.995	**0.029**
Material*solution	64.370	**0.001**
Material*time	0.902	0.643
Solution*time	18.797	**0.002**
Material*solution*time	4.166	0.684

*Robust three-way analysis of variance was used, and the pruned mean was chosen as the comparison method (the pruning rate was set to 5%).

TABLE 4: Multiple comparison results of color change (ΔE_{00}) values according to material, solution and time

		Materials			
Time periods	Solutions	TP	PTR	ACR	X̄±SD
ΔEt0-t1	CHX20	7.26±0.318	1.58±0.196	2.07±0.339	3.55±0.555
	LIS	8.02±0.302	2.88±0.127	1.34±0.216	4.02±0.602
	CHX05	7.73±0.409	1.23±0.12	2.38±0.274	3.72±0.606
	CON	8.12±0.35	1.49±0.118	2.03±0.466	3.80±0.646
	X̄±SD	7.82±0.169	1.77±0.131	1.90±0.152	3.73±0.295
ΔEt0-t2	CHX20	7.21±0.294	2.14±0.132	2.24±0.706	3.81±0.549
	LIS	10.29±10.001	3.93±0.301	2.56±0.393	5.46±0.782
	CHX05	7.66±0.431	1.12±0.052	1.69±0.488	3.41±0.645
	CON	8.06±0.384	1.36±0.224	1.82±0.623	3.68±0.675
	X̄±SD	8.16±0.335	2.05±0.199	1.93±0.267	3.94±0.303
X̄±SD	CHX20	7.20±0,211[A]	1.89±0.136[D]	2.03±0.382[DG]	3.65±0.384
	LIS	9.02±0.585[ABC]	3.36±0.207[E]	1.90±0.268[DG]	4.58±0.491
	CHX05	7.77±0.289[B]	1.18±0.065[F]	2±0.287[H]	3.53±0.438
	CON	8.18±0.24[C]	1.41±0.108[G]	1.70±0.318[I]	3.70±0.462
	X̄±SD	7.88±0.129[a]	1.88±0.111[b]	1.88±0.134[b]	

Superscript letters indicate significant differences (p<0.05). Uppercase letters compare materials within or across solutions; lowercase letters compare overall material means.
TP: Temp PRINT™; PTR: Powerresins temp resin; ACR: Acrytemp; SD: Standard deviation; CHX20: Curasept ADS 220; LIS: Listerine cool mint; CHX05: Curasept ADS 205; CON: Artificial saliva

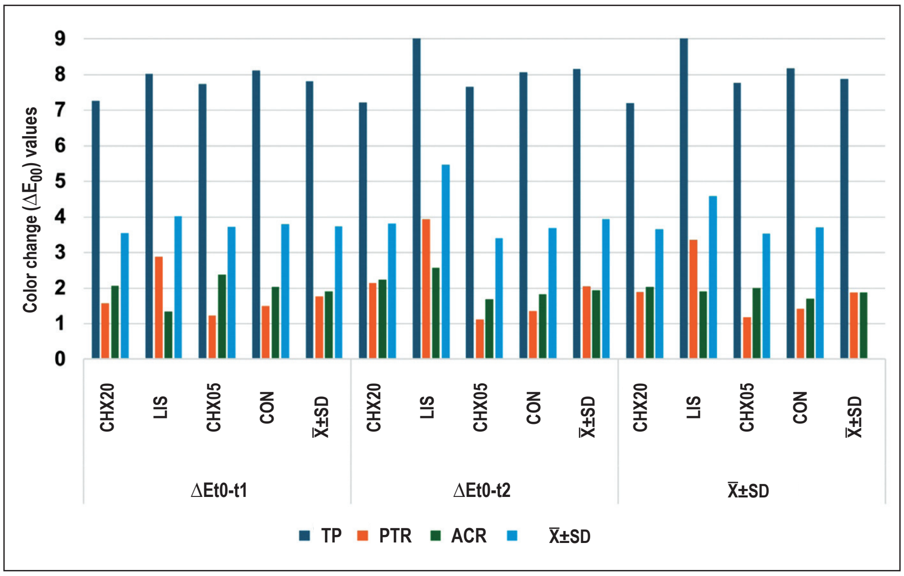

FIGURE 1: The column chart of color change (ΔE_{00}) values of materials according to solution exposures and time periods

CHX20: Curasept ADS 220; LIS: Listerine cool mint; CHX05: Curasept ADS 205; CON: Artificial saliva; SD: Standard deviation; TP: Temp PRINT™; PTR: Powerresins temp resin; ACR: Acrytemp

DISCUSSION

The color stability of provisional materials is essential for both patients and clinicians, particularly in esthetically demanding cases or long-term prosthetic treatments where these materials may remain in the mouth for extended periods.[1] In this study, specimens were immersed in solutions for 12 hours and 2.5 days to simulate 1-5 years of mouthwash use, respectively. The results indicated that TP exhibited a greater color change than PTR and ACR. Thus, the first null hypothesis was rejected. All solutions caused more discoloration of TP compared to PTR and ACR. Additionally, prolonged LIS and CHX20 exposure of 5 years resulted in greater discoloration of provisional materials than 1 year. Consequently, the second null hypothesis was rejected as well.

Mouthwash exposure was simulated on various provisional restorative materials over different time periods. Provisional restorations are commonly used in prosthetic rehabilitation and different stages of dental implant treatments, typically for less than 6 months.[23] However, this period may extend beyond 6 months or longer due to treatment complexity, though no clear upper limit.[3,9] Değer et al. simulated a six-month mouthwash usage period to evaluate its effect on the color stability of provisional materials.[23] Similarly, Myagmar et al. applied a methodology comparable to the present study, simulating short-term usage for 1, 3, and 6 months and long-term exposure for 2, 6, and 14 years.[19] In the present study, long-term simulations of 1-5 years were conducted to assess the effects of mouthwash beyond the expected short-term period. As anticipated, greater discoloration was observed over extended exposure times, with significantly higher color change after 5 years (ΔEt0-t2=3.94±0.303) compared to 1 year (ΔEt0-t1=3.73±0.295).

The color stability of resin materials is affected by factors such as microstructure, polymerization type and degree, residual monomer content, and liquid absorption.[24] Given the distinct properties of different resins, clinicians should consider the relationship between the resin type and color stability to choose the most suitable material, ensuring esthetic and long-lasting restorations.[25] Scotti et al. reported that 3D-printed resins exhibited superior mechanical and surface properties to bis-acrylic resin; however, their color stability was lower, which may limit their use as long-term provisional restorations, particularly in esthetic regions.[16] Similarly, Song et al. found that 3D-printed provisional restorations discolored more rapidly than bisacryl (Luxatemp automix plus; DMG, Germany) resins after 8 weeks of exposure to staining beverages.[26] Consistent with these findings, the TP group in this study exhibited clinically unacceptable color differences (ΔE_{00}>1.8) compared to ACR. Additionally, TP showed greater discoloration than PTR, another 3D-printed material. PTR and ACR exhibited perceptible but unacceptable color changes (ΔE_{00}>0.8 and ΔE00>1.8, respectively). The heterogeneous structure of bisacryl resins may have facilitated staining agent penetration, contributing to the perceptible color change.[18] Tahayeri et al. reported that, despite post-curing, 3D-printed provisional materials exhibited lower polymerization compared to conventional resins, which may explain the inferior color stability.[27] The significant discoloration between TP (ΔE_{00}=7.88±0.129) and PTR (ΔE_{00}=1.88±0.111) observed in this study may be attributed to variations in polymerization process, 3D printing techniques, and post-curing protocols. TP underwent 2 20-minute post-curing cycles, while PTR was post-cured twice for 2,500 cycles totaling 1-2 minutes as per the manufacturer's instructions. The longer post-curing duration may have affected polymerization, leading to reduced color stability. Additionally, extended exposure to solutions likely exacerbated discoloration, as supported by Song et al. who reported that the discoloration of provisional materials increased with storage time.[26]

Mouthwash use can cause discoloration of restorations.[28] Given that provisional restorations are frequently used in complex cases for long-term treatment, they are often expected to maintain color stability against mouthwash exposure. Studies have reported that Listerine causes the greatest discoloration of resin-based materials.[9,29] Likely due to its high alcohol content and low pH.[13] Sevimay et al. found that conventional provisional materials exhibited greater color changes in alcohol-containing Listerine (Leuven, Belgium) compared to chlorhexidine-containing mouthwashes.[29] LIS caused the highest color change of 3D-printed materials, possibly due to its low pH (4.6) and alcohol-induced matrix softening. Differences in material composition may also contribute, as TP, with higher dimethacrylate content, may allow greater infiltration of staining molecules. Additionally, chlorhexidine-containing mouthwashes are known to cause staining.[30] In this study, CHX20 and CHX05 resulted in greater discoloration of ACR than LIS. Addy et al. reported that a 0.06% chlorhexidine-containing mouthwash causes less staining than 0.2% chlorhexidine while maintaining antiplaque effects.[31] Similarly, ACR and PTR exhibited less discoloration with CHX05 exposure than CHX20, suggesting that CHX05 may be more suitable for long-term use. The comparable color changes observed with CHX05 and CON solutions on materials further support this finding.

The CIEDE2000 color system, developed by the International Commission on Illumination, is considered more accurate for human visual perception and assessing the discoloration of dental materials better than CIELab system.[29] Therefore, in the present study, color differences were measured using the CIEDE2000 formula for precise evaluations. The perceptibility threshold for ΔE_{00} was determined as 0.8, and the acceptability threshold was 1.8.[5] The results indicated that TP exhibited both perceptible and unacceptable ΔE_{00} values, whereas PTR and ACR remained within the perceptible but acceptable range.

Various background colors, including gray, white, black, and blue, have been used in color measurements in the literature, with gray being the most commonly preferred option.[19,28,32,33] While gray is often considered a neutral background, a previous study has suggested that a white background better represents the color of the tooth.[33] In this study, a white background was chosen based on the clinical scenario, as provisional restorations are typically cemented onto prepared teeth. This approach aimed to provide a standardized reference point, ensuring consistency and repeatability in measurements. However, different background colors may yield varying color change results, and future studies could explore measurements using alternative background colors.

This *in vitro* study has several limitations. The sample surfaces were flat, unlike clinical situations where anatomical grooves and pits on provisional restoration can affect the discoloration. Additionally, restorations in the oral environment are exposed to factors such as brushing, saliva flow, dietary habits, smoking, and poor oral hygiene, all of which contribute to color changes. All these factors contribute to the color changes in materials. Therefore, further *in vitro* studies are needed to test the effects of the oral environment on the color stability of provisional materials, along with *in vivo* studies to validate these findings under clinical conditions.

CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions were drawn:

- The 3D-printed provisional material TP exhibited the highest discoloration, while PTR demonstrated greater color stability, comparable to ACR.
- Alcohol-containing LIS caused the greatest discoloration in 3D-printed materials, whereas CHX20 had the highest impact on the conventional provisional material, ACR.
- Longer LIS and CHX20 exposure of 5 years resulted in more significant color changes of provisional materials than 1 year, negatively affecting color stability
- CHX05 and CON resulted in similar and relatively acceptable color changes across all materials.

Based on these findings, the 3D-printed provisional material PTR and the daily use of CHX05 mouthwash is clinically recommendable over long-term clinical applications.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

***Idea/Concept:** İzim Türker Kader, Safa Özer; **Design:** İzim Türker Kader, Safa Özer; **Control/Supervision:** İzim Türker Kader; **Data Collection and/or Processing:** İzim Türker Kader, Safa Özer; **Analysis and/or Interpretation:** İzim Türker Kader, Safa Özer; **Literature Review:** İzim Türker Kader; **Writing the Article:** İzim Türker Kader; **Critical Review:** İzim Türker Kader; **References and Fundings:** İzim Türker Kader, Safa Özer; **Materials:** İzim Türker Kader, Safa Özer.*

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