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BASIC RESEARCH:

The Effect of Various Mouthwashes on the Surface Roughness and Discoloration of Provisional Fixed Materials

El efecto de varios enjuagues bucales sobre la rugosidad superficial y la decoloración de materiales provisionales fijos

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ABSTRACT: This study aims to evaluate the effects of mouthwashes on surface roughness and discoloration of provisional materials produced by different methods. Disk-shaped specimens were prepared from conventional [acrylic- and composite-based (PEMA and BCR)] and digital methods (CAD/CAM milling and 3DP). Specimens were divided into 4 subgroups (Kloroben, Meridol, Aloe vera, and artificial saliva as control). Color and surface roughness (Ra) values were measured by spectrophotometer and profilometer at baseline and after mouthwash application. Color changes (ΔE_{00} and ΔE_{ab}) were calculated using L, a, and b values. In artificial saliva, the 3DP group's ΔE_{00} values were higher than CAD/CAM milling. ΔE_{00} and ΔE_{ab} of the BCR group were higher than others after Meridol immersion. In Aloe vera, ΔE_{00} and ΔE_{ab} values of the BCR group were higher than CAD/CAM milling. Ra values of BCR increased after all solutions, and 3DP increased after Aloe vera immersion. CAD/CAM milling and PEMA subgroups, artificial saliva, and Kloroben subgroups of BCR material exhibited clinically acceptable values ($\Delta E_{00} \leq 2.25$). CAD/CAM milling specimens (except Kloroben) and PEMA artificial saliva group (ΔE_{ab}) also showed clinically acceptable values. Ra values of CAD/CAM milled (artificial saliva and Kloroben subgroups) and all 3DP subgroups were below the threshold (0.2 μm) for plaque accumulation.

KEYWORDS: 3D printing; CAD/CAM; Temporary; Color; Surface properties.

RESUMEN: Este estudio tiene como objetivo evaluar los efectos de los enjuagues bucales sobre la rugosidad superficial y la decoloración de materiales provisionales producidos por diferentes métodos. Se prepararon especímenes en forma de disco a partir de métodos convencionales [basados en acrílico y composite (PEMA y BCR)] y digitales (fresado CAD/CAM e impresión 3D). Los especímenes se dividieron en 4 subgrupos (Kloroben, Meridol, Aloe vera y saliva artificial como control). Los valores de color y rugosidad superficial (Ra) se midieron mediante espectrofotómetro y perfilómetro al inicio y después de la aplicación del enjuague bucal. Los cambios de color (ΔE_{00} y ΔE_{ab}) se calcularon utilizando los valores L, a y b. En la saliva artificial, los valores de ΔE_{00} del grupo de impresión 3D fueron mayores que los del fresado CAD/CAM. Los valores de ΔE_{00} y ΔE_{ab} del grupo BCR fueron mayores que los de los demás grupos después de la inmersión en Meridol. En Aloe vera, los valores de ΔE_{00} y ΔE_{ab} del grupo BCR fueron mayores que los del fresado CAD/CAM. Los valores de Ra del BCR aumentaron después de todas las soluciones, y los del grupo 3D aumentaron después de la inmersión en Aloe vera. Los subgrupos de fresado CAD/CAM y PEMA, la saliva artificial y los subgrupos de Kloroben del material BCR mostraron valores clínicamente aceptables ($\Delta E_{00} \leq 2.25$). Los especímenes fresados con CAD/CAM (excepto el subgrupo Kloroben) y el grupo PEMA con saliva artificial (ΔE_{ab}) también mostraron valores clínicamente aceptables. Los valores de Ra de los subgrupos de fresado CAD/CAM (saliva artificial y Kloroben) y de todos los subgrupos de impresión 3D estuvieron por debajo del umbral (0.2 μm) para la acumulación de placa.

PALABRAS CLAVE: Impresión 3D; CAD/CAM; Temporal; Color; Propiedades superficiales.

INTRODUCTION

The prosthetic restoration plays a vital role in maintaining dental and facial aesthetics for the patient. In this regard, provisional restorations serve as a pivotal step in the restoration process and are indispensable for ensuring the clinical efficacy of the fixed prosthesis (1). These provisional restorations are required to restore teeth's vitality, function, and aesthetics until the final restorations are cemented following dental preparation (2, 3). They should correlate anatomy and shade of natural teeth as well as be resistant to discoloration, especially in the aesthetic area (2).

Provisional restorations are used for short periods (approximately 7-10 days) while permanent restorations are being made in the laboratory (4, 5). They are also used for longer periods in cases where the occlusion is to be rehabilitated, their compatibility with the surrounding neuromuscular system needs to be assessed (6), during the period after implant surgery, when osteointegration is expected to take place and multidisciplinary situations (7). Consequently, preserving the intraoral long-term of a provisional restoration depends critically on both the fabrication method and the material choice (8).

There are a variety of commercially available products for the fabrication of provisional prostheses, both conventional and, more recently, digitally produced. The majority of conventional materials are composed of bis-acrylate composite resin or methacrylate resin (4). The processing of acrylic resins is simple and affordable, but it produces heat during polymerization, and because acrylic shrinks differently from enamel, there may be micro-leakages (9). Bis-acryl composite materials are preferred due to their improved properties such as ease of use, low exothermic reaction, good wear resistance, and minimal pulpal irritation compared to acrylic resins (5). On the other hand, color change and brittleness are significant drawbacks of conventional materials (8). Resin-based provisional restorations can now be developed and produced chairside thanks to advancements in digital dentistry technology (6). This technology involves using either additive or subtractive manufacturing processes through computer-aided design and manufacturing (CAD/CAM) (8).

Provisional materials milled from pre-polymerized blocks have better physical properties such as strength and material density (9). They also exhibit better accuracy, marginal fit, and color stability compared to conventional restorations (2, 10). However, the high expense of the milling method due to the costly milling burs and significant material waste may prevent it from being widely used (9). Moreover, the creation of microcracks and the restricted replication of surface characteristics in various restorative designs may limit its use (2). The three-dimensional printing (3DP) method is gaining more popularity in the production of provisional materials as it reduces material waste and multiple restorations can be produced without increasing production time (11, 12). However, there have been concerns about the 3DP materials' mechanical and optical qualities (3, 6).

Long-term treatment-related discoloration of provisional crowns and bridges may cause patient dissatisfaction and increase replacement costs (3, 13). Color stability is a key aesthetic characteristic of dental prostheses (1, 10). These prosthesis stains may be caused by a variety of materials-related issues, including composition, surface roughness, fabrication technique, and inadequate polymerization (2). In addition, the restoration material's color may eventually change due to plaque buildup, chemical deterioration, colored beverage consumption, and mouthwash use (14).

The topography of provisional resin restorations affects the periodontal health of adjacent gingival tissue. Ensuring a smooth surface on provisional restorations helps prevent plaque and stains from adhering and causing gingival irritation (15). Surface roughness can induce alterations in material color, potentially impacting the aesthetic quality of restorations. The surface roughness of provisional crowns is influenced by factors such as material composition, fabrication technique, and the type of surface polishing employed (15).

Provisional restorations should possess satisfactory esthetic, biological, and mechanical attributes (16), particularly if they are intended for long-term usage due to various considerations (17). As these restorations are employed during the postoperative healing phase following surgical procedures like tooth extraction or implant placement, they are frequently subjected to the regular use of mouthwashes (6). These mouthwashes enhance oral health and avoid periodontal diseases (18). Normally, oral mouthwashes consist of ethanol, essential oils, detergents, and chlorhexidine gluconate (19). Chlorhexidine digluconate (CHX) causes negative effects including calculus formation and discoloration of restorative materials and enamel (14). Therefore, interim restorations are anticipated to be resistant to damage caused by the use of mouthwashes (6). Mouthwashes with varying ingredients that lessen the staining impact of chlorhexidine gluconate are being introduced to the market (19). Information about how meridol (19) or aloe vera mouthwash (20) restorations affect color change is scarce.

The color stability of provisional restorations made using conventional, 3DP, and milling processes has already been evaluated (2, 6, 15). Studies on the effects of food and drink on the color (3, 9) and surface roughness of newly designed provisional materials have been conducted extensively

(12, 15). There are few studies examining how mouthwashes affect the color change and surface roughness characteristics of provisional restorations made both conventionally and digitally (6), but none examine the impact of herbal mouthwash.

The ΔE_{ab} formula was employed in the majority of the investigations to estimate color differences (3-5, 8, 10, 13, 15, 16, 18, 20-25). However, Luo *et al*. (26) presented a more recent formula for computing color differences from L*a*b* values. The CIE (27) recommends using the ΔE_{00} formula instead of the ΔE_{ab} formula since the ΔE_{00} is more accurate for little color differences and has a stronger association with the visual perception of color differences, particularly on high chroma hues (28). This novel formula is being used in an increasing number of dental research related to provisional restorations (1, 2, 6, 9, 11, 12, 14, 17, 29). Although there is one study that evaluated both color change formulas (ΔE_{00} and ΔE_{ab}) in polyetheretherketone (PEEK) and polyoxymethylene (POM) denture base materials (28), there is no study that uses both formulas for color change in provisional fixed materials.

This study aims to evaluate the effects of soaking in various types of mouthwashes (Kloroben, Meridol, and Aloe vera) on surface roughness and discoloration of provisional materials produced by digital (CAD/CAM milling or 3DP) and conventional methods. The null hypothesis of this study was that provisional fixed materials produced by different methods would not affect the surface roughness and color change both on a material basis and the basis of various oral washing solutions. Also, there would be no correlation between color change and surface roughness.

MATERIALS AND METHODS

In this study, provisional materials produced by conventional (acrylic- and composite-based) and digital methods (CAD/CAM milling and 3DP), three types of mouthwash (Kloroben, Meridol, and Aloe vera), and artificial saliva were used (Table 1 and Table 2).

G*Power (version 3.1.9.4) software was used for sample size estimation, assuming a comparison between 16 groups. The analysis determined that a minimum sample size of 112 (7 per subgroup) was sufficient for an alpha level of 0.05, power of 80%, and effect size of 0.45. A2 shade was chosen for all test materials. A total of 128 disk-shaped samples (n=8), with a diameter of 2 mm and a thickness of 10 mm were prepared.

For the conventional method, a Teflon mold was used to create test specimens. After mixing acrylic-based provisional material [Dentalon Plus-poly (ethyl methacrylate) (PEMA)] with a glass spatula for 40 seconds at a ratio of 2 g per 1.2 mL to create a homogenous mixture, the mixture was poured into the Teflon block's holes. After the polymerization process was completed, they were removed from the mold. The composite-based provisional material (BCR) was filled into the Teflon mold with a special dispenser gun and glass sheets were placed on the top and bottom surfaces to prevent the formation of an oxygen inhibition layer.

For the digital method, test specimens of the same size were designed using a software program (Materialise 3-matic 15.0, Leuven, Belgium). Afterward, a Standard Tessellation Language (STL) file format export was performed. CAD/CAM milling specimens were prepared by milling from the block on a milling machine (CORiTEC 350i, imes-icore GmbH, Eiterfeld, Germany). 3DP specimens were printed with a printing device (FreeShape 120, Accuretta, Taipei, Taiwan) using the DLP technique with a layer thickness of 50 μm and an angle of 0º. Post-polymerization processes were carried out by the manufacturer's directives. All prepared test specimens were finished and polished by the same researcher with 180, 600, 800, and 1200-grit sandpaper to ensure standardization. Each specimen's thickness was confirmed to be 2.0 ±0.05 mm using digital calipers (Mahr, GmbH, Esslingen, Germany).

The specimens prepared according to the mouthwash to be used were randomly divided into subgroups, ensuring an equal distribution across each subgroup. Then, the surfaces that were not measured were numbered and marked with a bur. Initially, the samples were randomly allocated, and each specimen was assigned a unique number. Color differences and surface roughness values were measured both before and after immersion for each specimen. This process followed the principles of block randomization, which ensured a balanced distribution of specimens across the different materials and conditions, allowing for an unbiased and objective assessment of each material's performance.

They were ultrasonically cleaned in distilled water for 5 minutes. Then they were kept at 37°C for 24 hours. After drying with tissue paper, initial color measurements (T_0) were made. The specimens were soaked in 10 milliliters of mouthwash solutions for 14 days, undergoing two-minute treatments twice daily (with a 12-hour interval between each treatment)(30). Following each immersion process, the discs were rinsed with running water, dried, and subsequently kept in distilled water at 37°C until the next immersion. Control group specimens were submerged in 10 milliliters of freshly prepared artificial saliva.

Color measurements of the test specimens before immersion in the solution and after 14 days were performed using a digital spectrophotometer (VITA Easyshade® V; Vita Zahnfabrik, Germany). All color measurements were performed using a standard color assessment procedure on a black background, which is commonly employed in clinical dentistry to simulate the dark environment of the oral cavity. The measurements were conducted by a single operator. The 'shade of restoration' mode was set for the measurements. Before taking any measurements, the device was first calibrated using a white calibration plate by the manufacturer's instructions. The measurement tip was then positioned perpendicular to the specimen surface to be measured, leaving no space between it and the surface. When the color measurement of each subgroup was completed, the device was recalibrated.

Furthermore, all color measurements were conducted under standard D65 illumination, which simulates natural daylight conditions. The measurements were performed in a light-controlled box to eliminate interference from external light sources. This setup ensured consistent and controlled lighting conditions throughout the study, allowing for accurate and reliable color assessment.

For every specimen, color measurements were taken three times, and the average result was noted. While "a*" (green~magenta) and "b*" (blue~yellow) represent the chromatic axes, L* represents the lightness. The colorants were responsible for the variations in color tones, and the CIEDE2000 formula (ΔE_{00}) was utilized to assess the L*, a*, and b* values measured at each time. Equation (1) was used to calculate the standard ΔE_{ab} color value (31), while Equation (2) was used to calculate ΔE_{00} values (11, 26).

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)]^{1/2}$$

$$\Delta E_{00} = [(\frac{\Delta L'}{k_L S_L})^2 + (\frac{\Delta C'}{k_C S_C})^2 + (\frac{\Delta H'}{k_H S_H})^2 + R_T(\frac{\Delta C'}{k_C S_C})x(\frac{\Delta H'}{k_H S_H})]^{1/2}$$

Where the terms K_L, K_C, and K_H are regulated according to various viewing conditions and were set to 1, and the variables ΔL_0, ΔC_0, and ΔH_0 are differences in lightness, chroma, and hue; RT is a rotation function that represents the interaction between chroma and hue in the blue region; and S_L, S_C, and S_H are weighting functions.

The surface roughness values of the test specimens were measured before immersion in mouthwash (T_0-baseline) and after 14 days (T_1) using a profilometer (Perthometer M2, Mahr, Gottingen, Germany). Before each subgroup measurement, calibration was performed. Each specimen was subjected to three concurrent measurements, each covering a length of 5.6 millimeters, at a speed of 0.5 millimeters per second. These measurements were conducted horizontally, traversing three points along a vertical line: one centrally and two at the edges. The average surface roughness value (Ra) for each specimen was computed by averaging the results of the three measurements.

In the study, descriptive statistics for the data (number, percentage, mean, standard deviation, minimum, maximum, and median) were provided. The Shapiro-Wilk test and Levene's test were used to verify the assumption of normal distribution and homogeneity of variance, respectively. The dependent Sample t-test was used to compare two dependent groups with normal distribution. However, when there was no normal distribution for the two groups, the Wilcoxon Sign Rank test was used to compare. ANOVA was utilized to compare three or more independent groups with normal distribution, and the Kruskal-Wallis test was employed when there was no normal distribution. Post Hoc Bonferroni, Tamhane, and Adjusted Bonferroni tests were used to determine the group or groups that made the difference. Analyses were performed in the IBM SPSS 25 program.

Table 1. Provisional fixed prosthetic materials used in the study.

Product	Group code	Resin type	Fabrication method	Manufacturer	Lot no
Dentalon Plus	PEMA	Polyethyl methacrylate resin	Powder/liquid	Heraeus Kulzer, Hanau, Germany	K010047 (powde K010103 (liquid)
Protemp 4	BCR	Bis-acryl composite resin	2 pastes Auto-mix syringe	3M ESPE, Seefeld, Germany	8915977
Tempo CAD	CAD/CAM milling	Polymethyl methacrylate	Milling disk	Turkuaz Dental, Izmir, Turkey	21072
MACK4D Temp	3DP	Methacrylate based resin	3D-printing	MACK4D, GmbH, Neukiritzsch, Germany	23040882

(CAD/CAM: Computer-aided design/computer-aided manufacturing; 3DP: three-dimensional printing).

Table 2. Chemical composition of mouthwashes.

Mouthwashes	Chemical composition	Manufacturer	pH
Kloroben	Chlorhexidine gluconate, benzidamine hydrochlorid.	Drogsan Drugs Corp, Ankara, Turkey	5.35
Meridol	Aqua, Xylitol, PVP, PEG-40 Hydrogenated Castor Oil, Olaflur, Aroma, Stannous Fluoride, Sodium Saccharin, CI 42051.	Colgate-Palmolive, Warszawa, Poland	3.56
Aloe Vera	Aqua, Glycerin, Polysorbate 80, Aloe Barbadensis, Leaf Juice, Menthol, Stevioside, Zingiber officinale root (Ginger) oil, Thymus vulgaris (Thyme) oil, Salvia officinalis (Sage) oil, Mentha piperit (Peppermint) oil, Potassium sorbate, Sodium benzoate, Citric acid, CI 19140, CI 42090	Norm Herbal Products Paz. San. Tic. Ltd. Şti., İstanbul, Turkey	5.15
Artificial saliva	0.4 g/L NaCl, 0.4 g/L KCl, 0,0067 g/L $CaCl_2$, 0,0889 g/L $NaH_2PO_4(H_2O)$, 0.005 g/L Na_2S, 1 g/L CH_4N_2O	-	7.03

RESULTS

Color differences (ΔE_{00} and ΔE_{ab}) values for the test materials are presented in Table 3. As a result of the analyses performed for the test materials, statistically significant differences were found when the ΔE_{00} and ΔE_{ab} values of the BCR material were compared in terms of the immersion solutions ($p<0.05$). The color difference (ΔE_{00}) of the Meridol group (5.31±1.84) was significantly higher than that of the artificial saliva (1.98±1.31) and Kloroben groups (2.24±0.77) when the BCR test material was evaluated in terms of the immersion solutions (Tamhane test, p=0.007 and p=0.010, respectively). The color change (ΔE_{ab}) of the BCR material showed a statistically significant difference between the Meridol (10.6±3.52) and artificial saliva (4.84±3.58) groups (Bonferroni test, p=0.020).

On the other hand, there were no statistically significant differences between intragroup ΔE_{00} and ΔE_{ab} values for PEMA, CAD/CAM milling, and 3DP groups according to immersion solutions ($p>0.05$).

ΔE_{00} values in artificial saliva according to the materials, while there was no difference between the ΔE_{ab} values. In artificial saliva, the ΔE_{00} values of the 3DP group were higher than those of the CAD/CAM milling group (Bonferroni test, p=0.002). There was no statistically significant difference between the ΔE_{00} and ΔE_{ab} values of the materials immersed in the Kloroben solution ($p>0.05$). In the Meridol solution, the BCR group had statistically higher ΔE_{00} and ΔE_{ab} values than the other three test materials (PEMA, CAD/CAM milling and 3DP groups) ($p<0.001$, $p<0.001$, and p=0.005). In the aloe vera solution, ΔE_{00} values were significantly higher in the 3DP and BCR groups than in the CAD/CAM milling group (p=0.026 and p=0.002), while ΔE_{ab} values were significantly higher in the BCR group than in the CAD/CAM milling group (Bonferroni test, p=0.007).

The surface roughness values of the test specimens before and after immersion in the solution are presented in Table 4. Statistically significant differences were determined between the Ra values (baseline) before solutions immersion according to the test material groups ($p<0.05$). According to Bonferroni tests, the Ra values (baseline) of PEMA and BCR groups were higher than those of CAD/CAM milling and 3DP groups ($p<0.001$, $p<0.001$, p=0.003, $p<0.001$). Additionally, the BCR group's Ra values are higher than PEMA p=0.001).

The surface roughness values of the test specimens after immersion in the solution show a significant difference only for CAD/CAM milling material ($p<0.05$). Ra values after immersion in Aloe vera mouthwash were found to be higher compared to artificial saliva and Kloroben groups (Bonferroni test, p=0.011 and p=0.021). The significant difference between the amount of roughness change of the test specimens was found only in 3DP material ($p<0.05$). Ra change values for Aloe vera and Kloroben mouthwashes were higher than the Meridol group (Bonferroni test, p=0.021 and p=0.013). In addition, the surface roughness values of the BCR material after immersion in all solutions are higher than the baseline Ra values. The Ra values of the 3DP material after Aloe vera immersion were found to be higher than the baseline Ra ($p<0.05$).

After artificial saliva immersion, the Ra values of the BCR group are higher than those of the PEMA, CAD/CAM milling, and 3DP group

(Tamhane test, p=0.014, p=0.004, p=0.007). Also, the PEMA and 3DP groups' Ra values are higher than that of the CAD/CAM milling group (Tamhane test, p=0.008 and p=0.002). When Ra values after immersion in Kloroben mouthwash are compared between materials; the BCR group was higher than those of CAD/CAM milling and the 3DP group (Bonferroni test; p<0.001, p=0.004). Additionally, the PEMA group' Ra is higher than that of the CAD/CAM milling group (Bonferroni test; P=0.006). After soaking in Meridol mouthwash, Ra values of the BCR group were higher than PEMA, CAD/CAM milling, and 3DP group (Bonferroni test; p=0.005, p=0.002 and p=0.002). After immersion in Aloe vera mouthwash, the Ra values of the BCR group were higher than CAD/CAM milling and the 3DP group (Bonferroni test; p<0.001 and p=0.005).

The correlation between roughness and color change (ΔE_{00} and ΔE_{ab}) values is presented in Table 4. In PEMA and CAD/CAM milling groups, statistically significant, positive, and very high correlations were found between ΔE_{00} and ΔE_{ab} measurements in all solutions (p<0.05). In addition, statistically significant, positive, and very high correlations were found between Ra values before and after immersion in Meridol and Aleo vera solutions in these two test groups (p<0.05).

In the BCR group, there were statistically significant, positive, and high to very high correlations between ΔE_{00} and ΔE_{ab} values in artificial saliva, Kloroben, and Aleo vera solutions (p<0.05; 0.996, 0.994 and 0.894 respectively). Additionally, statistically significant, positive, and very high correlations were found between Ra values before and after immersion in Meridol and Aleo vera solutions (p<0.05; 0.952 and 0.955 respectively).

In the 3D group, statistically significant, positive, and very high correlations were observed between ΔE_{00} and ΔE_{ab} measurements in Kloroben and Aloe vera solutions (p<0.05; 0.985 and 0.905 respectively). In addition, statistically significant, positive, and highly significant correlations were found between Ra values before and after immersion in artificial saliva, Kloroben and Meridol solutions (p<0.05; 0.790, 0.777 and 0.888 respectively). In the Aloe vera solution, a statistically significant, negative, and high-level correlation was obtained between ΔE_{ab} and Ra values after immersion (p<0.05 ; -0.716) (Table 5).

Table 3. Comparison of ΔE_{00} and ΔE_{ab} values for materials and solutions.

		Artificial saliva	Kloroben	Meridol	Aleo Vera		
		Mean±SD(Median)	Mean±SD(Median)	Mean±SD(Median)	Mean±SD(Median)	F/X²	P
ΔE_{00}	PEMA	1.54±0.82(1.37) ^{AB}	2.02±1.1(1.85)	1.86±1.15(1.85)^{A}	2.04±1.3(1.81)^{AB}	0.354	0.787
	BCR	1.98±1.31(1.77) ^{bAB}	2.24±0.77(2.28)^{b}	5.31±1.84(5.17)^{aB}	4.77±2.67(5.91)^{abB}	8.014	0.002*
	CAD/CAM	1.02±0.74(0.79) ^{A}	1.61±0.99(1.4)	1.29±0.54(1.31)^{A}	0.79±0.48(0.83)^{A}	5.846†	0.119
	3DP	3.51±1.35(3.76)^{B}	4.28±3.17(2.84)	2.82±1.41(2.45)^{A}	3.62±3.51(2.29)^{B}	1.021†	0.796
	F/X2	13.196†	1.843	14.469	14.691†		
	P	0.004*	0.183	<0.001*	0.002*		
ΔE_{ab}	PEMA	3.63±1.92(3.29)	4.96±2.68(4.77)	4.42±2.78(4.23)^{A}	5.15±3.65(4.34)^{AB}	0.463	0.710
	BCR	4.84±3.58(4.35)^{b}	5.65±2.09(5.89)^{ab}	10.6±3.52(10.73)^{aB}	8.84±4.67(10.29)^{abB}	4.559	0.010*
	CAD/CAM	2.69±1.95(1.97)	4.22±2.82(3.58)	3.39±1.55(3.47)^{A}	2.02±1.28(2.07)^{A}	5.369†	0.147
	3DP	4.87±1.42(4.65)	5.4±3.7(3.38)	4.29±1.77(4.46)^{A}	5.98±5.16(4.39)^{AB}	0.299†	0.960
	F/X2	5.111†	1.430†	8.669	10.785†		
	P	0.164	0.699	0.001*	0.013*		

*p<0,05, †: Kruskal Wallis test, lower case letters indicate the difference between solutions; upper case letters indicate the difference between materials.

Table 4. Comparison of roughness values of test specimens according to solutions.

		Mean±SD(Median)	Mean±SD(Median)	Mean±SD(Median)	Mean±SD(Median)	Total	F/X^2/P
Before	PEMA	0.24±0.07(0.24)	0.3±0.11(0.32)	0.26±0.1(0.25)	0.27±0.12(0.26)	0.27±0.10(0.25)^{A}	80.258
	BCR	0.66±0.26(0.61)	0.62±0.54(0.4)	1.08±1.05(0.46)	1.29±0.98(1.14)	0.91±0.79(0.55)^{c}	<0.001*
	CAD/CAM	0.11±0.02(0.11)	0.12±0.03(0.12)	0.18±0.05(0.19)	0.21±0.05(0.23)	0.16±0.06(0.14)^{B}	
	3DP	0.17±0.03(0.17)	0.18±0.05(0.16)	0.17±0.02(0.17)	0.17±0.02(0.17)	0.17±0.03(0.17)^{B}	
		Artificial saliva	Kloroben	Meridol	Aleo Vera	F/X2	P
After	PEMA	0.29±0.06(0.3)^{c}	0.30±0.05(0.29)^{AB}	0.28±0.09(0.26)^{A}	0.27±0.09(0.25)^{AB}	0.179	0.9910
	BCR	1.19±0.6(0.94)^{B}	1.15±0.9(0.82)^{B}	1.47±1.25(1.07)^{B}	1.69±1.12(1.43)^{A}	1.366†	0.713
	CAD/CAM	0.12±0.02(0.11)^{aA}	0.11±0.02(0.11)^{ac}	0.21±0.08(0.21) ^{abA}	0.22±0.05(0.24) ^{bB}	14.756 †	0.002*
	3DP	0.17±0.03(0.16)^{c}	0.19±0.04(0.18)^{Ac}	0.17±0.02(0.17)^{A}	0.19±0.03(0.2)^{B}	1.009	0.403
	F/X^2	26.259	28.116†	7.871	20.825†		
	P	<0.001*	<0.001*	<0.001*	<0.001*		
Amount of change	PEMA	0.07±0.06(0.06)^{AB}	0.09±0.06(0.07)^{AB}	0.05±0.04(0.05)^{AB}	0.04±0.03(0.03)^{A}	1.577	0.217
	BCR	0.61±0.49(0.38)^{A}	0.53±0.41(0.41)^{A}	0.39±0.38(0.31)^{A}	0.43±0.28(0.39)^{B}	0.535	0.662
	CAD/CAM	0.02±0.01(0.01)^{B}	0.03±0.02(0.02)^{B}	0.05±0.03(0.05)^{AB}	0.02±0.02(0.02)^{A}	7.542†	0.056
	3DP	0.01±0.01(0.01)^{abB}	0.026±0.02(0.03)^{bB}	0.01±0.01(0)^{aB}	0.03±0.03(0.02) ^{bA}	8.521†	0.036*
	F/X^2	22.194†	21.186†	19.746†	18.652†		
	P	<0.001*	<0.001*	<0.001*	<0.001*		
PEMA	F/X^2	-2.273	0.066	-1.303	0.072		
	P	0.057	0.949	0.234	0.945		
BCR	F/X^2	-2.559	-2.521**	-2.524**	-3.262		
	P	0.038*	0.012*	0.012*	0.014*		
BCR	F/X^2	-2.559	-2.521**	-2.524**	-3.262		
	P	0.038*	0.012*	0.012*	0.014*		
CAD/CAM	F/X^2	-0.707	0.614	-1.204	-0.755**		
	P	0.502	0.559	0.268	0.450		
3DP	F/X^2	0.000	-0.768**	-1.930	-2.714		
	P	1.000	0.443	0.095	0.030*		

* P<0.05, †: Kruskal Wallis testi, **: Wilcoxon signed-rank test, lower case letters indicate the difference between solutions; upper case letters indicate the difference between materials.

(Test group codes presented as PEMA: Polyethyl methacrylate resin; BCR: Bis-acryl composite resin; CAD/CAM milling: Computer-aided design/computer-aided manufacturing; 3DP: three-dimensional printing)

Table 5. Relationships between roughness, ΔE_{00} and ΔE_{ab} values by material, solution and time.

			Artificial Saliva			**Kloroben**			**Meridol**			**Aleo Vera**		
			ΔE_{ab}	Baseline, Ra	14 days, Ra	ΔE_{ab}	Baseline, Ra	14 days, Ra	ΔE_{ab}	Baseline, Ra	14 days, Ra	ΔE_{ab}	Baseline, Ra	14 days, Ra
PEMA	ΔE_{00}	r	0.995	0.416	-0.084	0.994	-0.333	0.302	0.999	-0.527	-0.329	0.990	-0.517	-0.577
		P	<0.001*	0.305	0.844	<0.001*	0.421	0.468	<0.001*	0.179	0.426	<0.001*	0.189	0.134
	ΔE_{ab}	r		0.355	-0.082		-0.286	0.359		-0.517	-0.326		-0.443	-0.522
		P		0.388	0.847		0.492	0.383		0.190	0.431		0.272	0.184
	Baseline, Ra	r			0.468			0.343			0.810			0.912
		P			0.243			0.405			0.015*			<0.001*
BCR	ΔE_{00}	r	0.996	-0.211	-0.616	0.994	0.000**	0.048**	0.701	0.262**	0.132	0.894	-0.266	-0.373
		P	<0.001*	0.616	0.104	<0.001*	1.000	0.911	0.053	0.531	0.756	0.003*	0.524	0.363
	ΔE_{ab}	r		-0.156	-0.637		-0.108**	0.000**		0.286**	0.567		-0.170	-0.347
		P		0.713	0.089		0.799	1.000		0.493	0.142		0.688	0.400
	Baseline, Ra	r			0.276			0.671**			0.952**			0.955
		P			0.508			0.069			<0.001*			<0.001*
CAD/CAM	ΔE_{00}	r	0.976**	0.184**	-0.383**	0.998	0.036	-0.383	0.995	0.169	0.029	0.994	0.243	0.108**
		P	<0.001*	0.662	0.349	<0.001*	0.933	0.349	<0.001*	0.689	0.946	<0.001*	0.562	0.798
	ΔE_{ab}	r		0.184**	-0.420**		0.082	-0.391		0.112	0.017		0.271	0.108**
		P		0.662	0.300		0.847	0.339		0.792	0.969		0.516	0.798
	Baseline, Ra	r			0.287**			0.241			0.786			0.788**
		P			0.491			0.565			0.021*			0.020*
3D	ΔE_{00}	r	0.539	-0.215	-0.209	0.985	-0.108**	0.037	0.433	0.243	0.539	0.905**	-0.464**	-0.482**
		P	0.168	0.609	0.620	<0.001*	0.798	0.931	0.284	0.562	0.168	0.002*	0.247	0.227
	ΔE_{ab}	r		0.501	0.597		-0.096**	-0.048**		-0.061	-0.015		-0.644	-0.716
		P		0.206	0.118		0.820	0.910		0.887	0.972		0.085	0.046*
	Baseline, Ra	r			0.790			0.777			0.888			0.543
		P			0.020*			0.023*			0.003*			0.165

*P<.05 ve **: Spearman correlation
(Test group codes presented as PEMA: Polyethyl methacrylate resin; BCR: Bis-acryl composite resin; CAD/CAM milling: Computer-aided design/computer-aided manufacturing; 3DP: three-dimensional printing)

DISCUSSION

This study evaluated the color change and surface roughness parameters of test materials produced by digital (CAD/CAM milling and 3DP) and traditional methods after immersion in different mouthwashes. The null hypotheses were partially rejected based on the statistical analysis of the results.

Internal and external factors influence the color change of the material. Pigment penetration through tiny cracks or gaps between the filler and the matrix can lead to inherent discoloration. External staining may happen when polar pigments and colorants in the media adhere to the surface of provisional materials (4).

Sham *et al*. (32) reported that bis-acrylic resins caused more discoloration after coffee immersion than poly(methyl methacrylate) (PMMA) and PEMA. Another study found that following a thermal cycle (5-55 °C-5000 cycles), the color stability of PMMA materials that had been autopolymerized and CAD/CAM milled outperformed bis-acryl provisional resin and heat-polymerized PMMA (16). After the application of different mouthwashes (chlorhex, tantum verde, kloroben, and listerine), PMMA-based temporary materials were reported to show better color stability than bisacryl-based ones (33). In the present study, the BCR material showed the highest color change (ΔE_{00} and ΔE_{ab}) after soaking in Meridol mouthwash. In addition, BCR material showed more color change (ΔE_{00} and ΔE_{ab}) after Aleo vera mouthwash application than CAD/CAM milling. This can be attributed to the homogeneous content of the acryl-based material. Since bis-acryl composite resins contain both inorganic filler particles and an organic polymer matrix, they are recognized for their heterogeneous character. Nevertheless, the material's surface may not be able to be smoothed if filler particles are present (23). The variations in the study results could be attributed to the periods of immersion and the types of immersion media used (beverage, mouthwash, and aging media).

The BCR material contains Bisphenol A-Glycidyl Methacrylate (Bis-GMA), Urethane Dimethacrylate (UDMA), Triethylene Glycol Dimethacrylate (TEGDMA), and Ethoxylated Bisphenol A Dimethacrylate (Bis-EMA). Bis-GMA's monomer structure contains polar OH- groups that contribute to a greater degree of water absorption and influence discoloration (23). Additionally, because they are more polar than PMMA resins, most bis-acryl resins have a greater affinity for polar fluids like water (16). This information may explain the lower color stability of the BCR material in the present study.

The test specimens produced by CAD/CAM milling showed the lowest color change values. This may be due to polymerization under ideal production conditions. This finding is similar to Değer *et al*. (14). In conclusion, if a long-term temporary restoration is to be used in the aesthetic area, the material choice generated by CAD/CAM milling may be ideal.

Myagmar *et al*. (6) reported that 3D printing resin showed more discoloration when rinsed with distilled water and other mouthwashes compared to resins produced by CAD/CAM milling and conventional methods. Shin *et al*. (9) reported that additively manufactured resins showed higher color stainability than subtractively manufactured resins. Similarly to the aforementioned studies, the present study found that 3D-printed test specimens had greater ΔE_{00} values for rinsed with artificial saliva and Aleo vera solution than those of CAD/CAM milled. This can be attributed to the low polymerization rate of 3D printing resins compared to CAD/CAM milled, which may be the reason for their low color stability. Also, other causes may be water absorption and, the presence of oxygen-inhibiting layers (4).

Mouthwash, one of the extrinsic factors that can cause discoloration of teeth, restorations, and even the oral mucosa (19), has been studied by researchers (6, 18, 19). Kloroben mouthwash contains chlorhexidine and is effective in controlling microbial dental plaque (18). However, one of the most important side effects is discoloration of oral mucous membranes, teeth, and restorations (34). In this study, soaking all test materials (except for the BCR material) in artificial saliva and different mouthwashes did not significantly affect the color change.

Although fluoride is added to mouthwashes to promote remineralization, it also substantially alters the color of resin composite materials (19). Meridol mouthwash might have caused more discoloration (ΔE_{00}) in the composite-based BCR material compared to Kloroben and artificial saliva due to its Stannous Fluoride content. Fluoride particles adversely affect both the resin matrix of the material and the monomer content in the resin matrix. The use of agents with this content may increase color change (35).

Ertürk-Avunduk *et al.*(19) found that Meridol mouthwash led to visible discoloration only in bulk-fill composite resin, whereas other resin-based composites such as nanohybrid and compomer did not show noticeable changes. Similarly, our research revealed that Meridol mouthwash significantly discolored BCR material. This could be attributed to the presence of the TEGDMA monomer. Additionally, the pH level of the mouthwashes tested offers another potential factor contributing to the degradation of the composite matrix. The acidic nature of the active ingredients in mouthwashes may impact color, surface hardness, and wear (19).

Mahboub *et al.* (20) reported similar color changes of artificial acrylic teeth after immersion in Aloe vera gel and chlorhexidine solution for 36 hours. Similarly, in the present study, the test materials did not show color change after immersion in Aloe vera and Kloroben mouthwash. The ΔE_{ab} values in the present study were higher than those of Mahboub *et al.* (20) This may be due to the different content of the test materials and the form of aloe vera used.

All subgroups of the specimens produced by CAD/CAM milling (artificial saliva and Kloroben subgroups) and 3D printing before and after solution immersion have surface roughness values below the threshold value for 0.2 μm plaque accumulation. CAD/CAM test materials soaked in Meridol and Aloe vera mouthwash were slightly above 0.2 μm. On the other hand, all subgroups of BCR and PEMA were above the threshold value before and after the solution. However, it is lower than the clinically unacceptable value of 10 μm (6, 12).

In the present study, the baseline Ra values of conventionally produced temporary materials were higher than digitally produced ones. This finding is similar to the previous study (36). The air bubbles added by hand-mixing liquid and powder when filling an external mold can be the cause of the conventional group's (Dentalon plus-PEMA) high surface roughness. Baseline Ra values were higher for BCR material than acrylic-based, which is similar to Ozdogan *et al.* (37) and Şen *et al.* (38). This can be attributed to the heterogeneous structure of bis-acrylic resin.

The color of the restoration is greatly influenced by the smoothness of the surface texture; smooth surfaces reflect more light and do not hold stains as well as rough surfaces do. Surface roughness characteristics have an impact on material discoloration as well (39). After soaking in mouthwashes, the surface roughness of the BCR material increased in amounts ranging from 0.39 μm to 0.53 μm. This can be attributed to more discoloration of the BCR material.

In a study examining the effect of two different herbal (Persica and Matrica) and chlorhexidine mouthwashes on the surface roughness of self-cure acrylic resins, it was reported that all mouthwashes increased the surface roughness by more than 0.2 µm. In addition, the increase in surface roughness for herbal mouthwashes was reported to be higher than chlorhexidine (40). Similarly, in the present study, after immersion in Aleo vera mouthwash, the surface roughness of the 3DP material increased. The increase in surface roughness can primarily be attributed to the low pH of the mouthwash and the hygroscopic properties of the resin-based materials (40). On the other hand, Zica *et al*. (41), in their study examining the effect of mouthwashes with and without alcohol on the surface roughness of conventional composite and bulk-fill composite resins, found that the surface roughness of the tested composite resins did not increase. They reported the tested mouthwashes may have caused minor changes on the surface of the composite resin (FiltekTM Bulk-Fill) since a large part of its composition consists of low-solubility monomers (41). Similarly, the mouthwashes used in this study on CAD/CAM milling and PEMA test materials did not significantly affect surface roughness. This can be attributed to the high degree of conversion of these tested materials and the resulting decrease in their solubility. On the other hand, the increase in the surface roughness of the BCR material after immersion in mouthwashes may be attributed to the solubility of the monomers of this material or its chemical content.

In earlier research, mouthwash was applied to all specimens for a continuous duration of 12 hours (42, 43). In this investigation, an immersion strategy that was more therapeutically suitable was chosen to replicate the patients' ongoing mouthwash hygiene regimen (30, 44).

Color changes can be evaluated through both visual and instrumental methods. Instrumental techniques remove the subjective interpretation that comes with visual color comparisons (45). Spectrophotometry was used in this study because it is a more accurate method for determining color changes. This technique overcomes disadvantages such as ambient light, material properties, and subjective differences in the visual perception of color (18). The CIELAB color difference formula has long been regarded as the standard method for assessing color differences in dentistry. However during the past ten years, interest in the CIEDE2000 formula has increased because it has been shown to more closely match visual experience. Based on adjustments for the impacts of hue-chroma interaction and brightness, chroma, and hue dependency on perceived color difference, it improves the computation of total color difference for color difference evaluation (11). The ΔE_{00} formula incorporates a corrected value for the CIEa* coordinate, which is why it may show differences compared to other formulas, particularly when the proportion of a* within chroma (a*/C*ab) varies significantly (28). According to the findings of this study, similar color differences were generally observed between these two color systems, although some minor differences were also noted. While the ΔE_{00} value of the BCR material showed a significant difference when immersed in Meridol solution compared to kloroben, no significant difference was detected in ΔE_{ab}. Similarly, in the test materials immersed in artificial saliva and Aloe vera solutions, the ΔE_{00} value of the 3DP material was higher than that of the CAD/CAM milling material, while this difference was not detected in ΔE_{ab}.

Studies have been conducted to assess the perceptibility and acceptability of color differences using the ΔE_{00} formula. In these studies, a clinically perceptible threshold value of ≤1.30 was identified, whereas the clinically acceptable value was found to be ≤2.25 units (2, 9, 12). In the present study, ΔE_{00} values of CAD/CAM milling material (except Kloroben mouthwash) were below the clinically perceptible threshold value ($\Delta E_{00} \leq 1.30$). Additionally, all subgroups of CAD/CAM and PEMA material, artificial saliva and Kloroben mouthwash subgroups of BCR material exhibited clinically acceptable values ($\Delta E_{00} \leq 2.25$). On the other hand, all subgroups of 3DP material and Meridol and Aleo vera subgroups of BCR material were found to be above the clinically acceptable value.

Eldiwany *et al*. (46) indicated that color differences (ΔE_{ab}) are visually noticeable when the value reaches 3.3 or higher. Goldstein *et al*. (47) noted that a ΔE_{ab} value of 3.7 or more surpasses the clinical tolerance threshold. Mugri *et al*. (48) reported values of ΔE_{ab} greater than 3.3 are deemed clinically noticeable: Clinically acceptable ΔE_{ab} values are those in the range of 3.3 to 5.0, while clinically unacceptable values are those over 5. Based on the result from this study, ΔE_{ab} value was found to be above the clinical tolerance limit value in PEMA (except artificial saliva subgroup), BCR and 3DP in all subgroups and CAD/CAM milling groups kept in Kloroben mouthwash. This indicates that these test groups had inferior color stability.

In this study, in which two different formulas were used to determine the color difference, the correlation in ΔE values (ΔE_{ab} and ΔE_{00}) is consistent with the findings of Polychronakis *et al*. (28). In a study examining the effect of different temporary materials (2 PMMA and 1 bis-acrylic composite resin) on the color stability and surface roughness of staining solutions, a strong correlation was observed between these two parameters in coffee, while a medium-weak correlation was observed in cola (49). In this study, a strong negative correlation was found between ΔE_{ab} and Ra values after immersion in Aloe vera solution.

The limitations of this study include several factors that may influence the generalizability of the results. Firstly, the effect of mouthwashes on the color and roughness of temporary materials could vary depending on factors such as food preferences, beverage consumption, and the presence of saliva, which were not controlled for in this study.

Additionally, in clinical situations, only the cameo surface of the restoration is typically affected by the use of mouthwash, whereas this study evaluated the effect of mouthwash on both sides of the specimen. This difference may limit the direct clinical relevance of the findings. Moreover, the effect of mouthwash contact on both sides of the specimen, as well as the application of surface coating materials, was not investigated.

Finally, while this study focused on specific materials and solutions, additional materials, such as conventional PMMA, hybrid composite blocks, and different 3D printing resins, were not tested. These materials could provide valuable insights into color stability and other properties under mouthwash exposure and could be considered for future research.

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn:

All subgroups of CAD/CAM milling and PEMA material, artificial saliva and Kloroben mouthwash subgroups of BCR material exhibited clinically acceptable values ($\Delta E_{00} \leq 2.25$). The CAD/CAM milling specimens (except for the Kloroben group) and the PEMA artificial saliva-soaked group (ΔE_{ab}) also show clinically acceptable values. The surface roughness values of CAD/CAM milled (artificial saliva and Kloroben subgroups) and all subgroups of 3DP test materials below the threshold value for plaque accumulation before and after mouthwash immersion.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization: Z.S.
Methodology, Software, Validation: Z.S. and N.E.O.
Formal analysis, Investigation, Resources, Data curation: Z.S. and N.E.O.
Writing-original draft preparation: Z.S.
Writing-review and editing, Visualization: Z.S. and N.E.O.
Supervision: Z.S.

DATA AVAILABILITY

All the data required to support the study's conclusions on mouthwashes' effects on the surface roughness and discoloration of temporary materials made using conventional and digital techniques are included in this paper and the supplementary information files.

DISCLOSURE STATEMENT

There are no conflicting interests to disclose, according to the authors.

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