Comparison of discoloration of ceramic containing 3D printable material and CAD/CAM blocks

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This study aimed to clarify aspects of the color and translucency of 3D printed dental material with CAD/CAM blocks. Three different ceramic-containing, resin-based CAD/CAM blocks and a 3D printable resin were evaluated after thermocycled and assessed for their degree of discoloration based on colorant types and storage times. Data were analyzed using repeated-measures analysis of variance followed by Tukey's *post-hoc* test. All materials in red wine had ΔE_{00} values higher than the clinically accepted threshold value. At 1 week and 1 month, the 3D material was statistically significantly more discolored than the other 3 materials ($p<0.05$). None of the materials exceeded the acceptable threshold value at any time point. The color changes increased over time in resin-based CAD/CAM blocks and 3D printable dental materials. After 1 week and 1 month, there was a statistically significant difference in the color change between the 3D printed material and the CAD/CAM blocks.

Keywords: 3D printing material, CAD/CAM block, Discoloration, Translucency parameter

INTRODUCTION

The application of three-dimensional (3D) printing technology has increased significantly over the past few years in many industries. For dental restorations or laboratory goods, 3D printing has increasingly become a frequent additional manufacturing method in the area of dentistry[1,2]. It may also be used in combination with other digital technologies including cone-beam computed tomography (CBCT), computer-aided design (CAD/CAM), and reductive manufacturing. Dental treatment is now more precise, quick, predictable, and affordable because of 3D printing, which is increasingly displacing older techniques. Currently, dental prostheses, study models, occlusal splints, and surgical guides are often fabricated using 3D printing[1-5]. The current tooth color scale and mechanical properties of 3D printed resins are inferior to those of zirconium, lithium disilicate, and ceramic based resin blocks[6]. Therefore, they are often used in temporary dental restorations. To be able to be used for permanent crowns, bridges, onlay and inlay, it has been planned that the addition of ceramic to the polymer resin printed material will render it more aesthetic, resistant, and biocompatible.

The optical properties and color stability of permanent restorations over time are critical points that must be taken into consideration with respect to the restoration remaining in the mouth for a long time.

The Munsell Color system defines colors in a 3D coordinate system based on color tone, color value, and color intensity. In addition to color, translucency is accepted as an important factor affecting the esthetics of dental restorations[7]. Translucency is the capacity to permit the visualization of a colorful material layer through a background[8]. The ability to maintain long-term esthetics is one of the most important criteria affecting the success of restorations in dental treatments.

Ceramics containing CAD/CAM resin blocks (also referred to as resin ceramic blocks and hybrid ceramic CAD/CAM composite blocks) have recently grown in popularity because they are thought to offer higher quality restorations than conventional composite resins. This is mostly because high-temperature and/or high-pressure polymerizations are utilized in standardized industrial production processes. The color and translucency of CAD/CAM blocks to which ceramic particles have been added in a resin matrix have been studied intensely[9,10]. Although 3D printed materials are similar in content to CAD/CAM blocks, differences such as microstructural geometry and the type and volume of polymer and filler can affect color stability in the long term.

Although 3D materials without ceramic fillers used in short-term temporary restorations have been subjected to color stability studies[11-14], the color stability of 3D materials with ceramic fillers used in long-term permanent restorations has not been reported. Therefore, the major objective of this study was to compare the color and translucency of 3D printable dental material with CAD/CAM blocks containing ceramic, used for permanent restorations. The color stability and translucency of the materials were evaluated after 24 h, 7 days, and 30 days.

The null hypothesis of this study was that there would be no distinction in color and transparency between CAD/CAM ceramic content resin blocks and 3D printed dental material and that these characteristics would not change over time.

MATERIALS AND METHODS

Production of samples

Three distinct ceramic-containing, resin-based CAD/

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CAM blocks and a 3D permanent resin were used in this *in-vitro* study. The supplies used are listed in (Table 1).

A diamond saw (Accutom 10, Struers, Rdovre, Denmark) was used to prepare the CAD/CAM blocks. Under water cooling, 6×6×2 mm blocks were sliced from the top to the lower surface. Forty-eight samples (12 from each group, 10 for color analysis and 2 for SEM analysis) were produced. Following a 24-h soak in deionized water at 37°C, all the samples were abraded using 500, 1,200, and 2500 grid SiC abrasive sheets (Exakt 400 CS, Norderstedt, Germany) respectively.

The 6×6×2 mm^3 design from Thingiverse.com (a well-known website for open-source 3D design repositories) was saved in the standard mosaic language (STL) format to produce the permanent resin sample. It was moved to the PreForm software (Formlabs, Somerville, MA, USA) to manufacture many examples of this design.

In the PreForm program, the samples were positioned to avoid touching each other, and the support contact points were put in at a 0-degree angle. The samples were placed in two parallel rows facing the stainless-steel structure on one side of the 3D printer platform, as suggested in the PreForm, to achieve the quickest print time.

The samples were created using a permanent photopolymerized resin and a Stereolithography (SLA) 3D printer (Form 3, Formlabs) in accordance with the protocol. The 3D printer used in this study was powered by Low Force Stereolithography (LFS)™ using 405 nm UV light with a laser power of 250 mW. It took approximately 40 min to print, with a layer thickness of 50 µm. After manufacture, the specimen was immersed in Form Wash (Formlabs) for 3 min to remove any remaining resin, followed by a 3 min wash in isopropyl alcohol (IPA 99%). Subsequently, the specimens were allowed to dry for half an hour. Post-curing called for two phases.

While the scaffolds were still connected to the samples, they were first cured in a Form Cure curing chamber (Formlabs) at 60°C for 20 min and ultraviolet light (405 nm). After removing the scaffolds, a second UV cure, lasting 20 min, was performed with the sample in another position. All steps have been completed according to the manufacturer's recommendations. Afterward, each sample was polished with water and pumice.

All the samples were aged using 10,000 thermocycles at 55°C (+/−2°C) and 5°C (+/−2°C). The dwell time was 30 s and the transfer time was 10 s.

Color analysis

The color of the samples was assessed using a clinical spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bad Säckingen, Germany) using the CIEDE2000 coordinates. The instrument has been described in the literature as having a reliability and validity of >90%. All measurements were performed using an optical setup with 0–45 degree observation geometry under D65 standard light. A standard black backdrop (L^*=0.7, a^*=3.2, b^*=−2.9) and a standard white backdrop (L^*=90.1, a^*=−0.7, b^*=3.0) were utilized to evaluate the translucency in the measurements. Each sample measurement began with the calibration of the equipment.

Baseline color was measured and saved as T0. Afterward, the samples were submerged in distilled water, red wine (Buzba Közgözü-Boğazkere, 2019, Kayra, Turkey), and instant coffee (Nescafe Classic, Single Bags, Nescafe Classic, Bursa, Turkey). To prepare the coffee, 200 mL of heated water without any added sugar or milk was used to dissolve 2 g of coffee. Every day, the liquids were switched to clean ones. The samples were all kept for 30 days in an incubator at 37°C. The measurements were taken at 24 h (T1), 7 days (T2) and 30 days (T3). Prior to the measurement, the samples were dried with absorbent paper after being rinsed with clear water for 10 s. Three measurements were taken from the center of each disc.

Table 1 The CAD/CAM blocks and 3D printable dental material used in this study

Material	Company	Organic contain	Inorganic filler	%
Cerasmart	GC Europe, Leuven, Belgium	Bis-MEPP, UDMA, other dimetacrylate monomers	Barium glass (300 nm), silica (20 nm)	71 wt%
Lava Ultimate	3M ESPE, St. Paul, MN, USA	UDMA	Zirconia (4–11 nm), silica (20 nm), zirconia-silica cluster (0.6–10 µm)	79 wt%
Vita Enemic	VITA, Bad Säckingen, Germany	UDMA, TEGDMA	Glass-ceramic sintered network	86 wt%
*Permanent Crown Resin A2 Resin 1 kg (0.7 L)	Formlabs, Somerville, MA, USA	Ethoxylated bisphenol A dimethacrylate, methyl benzoylformate, Diphenyl (2,4,6-trimethyl benzoyl) phosphine oxide	Silanized glass fillers, (particle size 0.7 µm)	30–50% by mass

Bis-MEPP: 2,2-bis[4-(methacryloxy polyethoxy)phenyl]propane, UDMA: urethane dimethacrylate, TEGDMA: triethyleneglycol dimethacrylate

*The manufacturer has kept the composition of the item a trade secret, thus it is unknown.

According to ISO/TR 28642 (2016), the color differences defined by the Commission Internationale de l'Éclairage (CIE) are denoted as delta E (ΔE). There are two formulas for the calculation of ΔE, namely ΔE^*ab and ΔE_{00}. The 1976 CIE L^* a^* b^* color coordinates are traditional systems used in the evaluation of color change. L^* represents the brightness of the objects, a^* green-red, and b^* blue-yellow coordinates. These coordinates are used to define clinical perception and acceptability by calculating the amount of color difference between two objects or two samples. where SL, SC, and SH are the functions used to calibrate the absence of visual homogeneity in the CIELab formula for lightness (L), chroma (C), and hue directions (H). The environmental correction parameters used were KL, KC, and KH. The L^*, a^*, and b^* values were measured on a white background and the KL, KC, and KH parametric values were adjusted to 1. The distinctions in lightness, chroma, and hue between the first and second measurement color coordinates are represented by the letters "ΔL," "ΔC," and "ΔH."

The ΔE_{00} values were calculated using

$$\Delta E_{00}=\sqrt{(\frac{\Delta L}{K_L S_L})^2+(\frac{\Delta C}{K_C S_C})^2+(\frac{\Delta H}{K_H S_H})^2+R_T(\frac{\Delta C}{K_C S_C})(\frac{\Delta H}{K_H S_H})}$$

By contrasting the colors of the specimens with a black and white backdrop and applying the following formula, the values for the translucency parameter (TP_{00}) were determined:

$$TP_{00}=\sqrt{(\frac{\Delta L'}{K_L S_L})^2+(\frac{\Delta C'}{K_C S_C})^2+(\frac{\Delta H'}{K_H S_H})^2+R_T(\frac{\Delta C'}{K_C S_C})(\frac{\Delta H'}{K_H S_H})}$$

A high translucency value indicates high translucency and low opacity. The difference of the TP values before and after coloring agent application (ΔTP) was calculated as:

ΔTP_{00}=TP(after staining)–TP(baseline)

SEM analysis

For surface morphological analysis, three types of CAD/CAM blocks and one types of 3D printed resin specimens were used. The specimens were then examined using scanning electron microscopy (Quanta 650 Field Emission SEM, FEI, Hillsboro, OR, USA) for qualitative (SEM images) analyses.

Statistical analysis

The sample size of each experiment was calculated using a freeware program (G*Power 3.1, Heinrich-Heine-Universität Düsseldorf, Germany) based on the results of a previously published study[13]. The required sample size of each experiment was calculated for a power of 0.80 at a significance level of 0.05 using the program SPSS v.23, all statistical analyses were performed with a 95% confidence level (IBM, Armonk, NY, USA). The data were examined for conformance to the normal distribution using the Shapiro-Wilk test ($p<0.05$). ΔE and ΔTP values were evaluated between various materials and storage times using repeated-measures analysis of variance and Tukey's *post hoc* tests.

RESULTS

The mean ΔE_{00} values and standard deviations of the CAD/CAM blocks and 3D printable material at different times and in different storage media are listed in Table 2. According to the color measurements at 24 h, all the tested materials showed a greater color change after

Table 2 Mean values and standard deviation for ΔE_{00} of 3D printable material and CAD/CAM blocks specimens after different periods and storage medias

ΔE_{00}	Cerasmart	Lava Ultimate	Vita Enamic	3D resin	Means of staining solutions
24 h					
Coffee	1.00 (0.19)	1.76 (0.74)	1.40 (0.37)	1.13 (0.41)	1.33 (0.54)^{A}
Red wine	2.42 (1.47)	2.12 (1.48)	2.94 (1.74)	4.11 (1.68)	2.90 (1.72)^{B}
Distilled water	0.73 (0.25)	0.76 (0.46)	0.44 (0.32)	0.73 (0.27)	0.67 (0.35)^{A}
Mean of materials	1.39 (1.13)^{a}	1.55 (1.13)^{a}	1.60 (1.46)^{a}	1.99 (1.82)^{a}	
1 week					
Coffee	1.26 (0.51)	2.39 (0.36)	1.79 (0.49)	2.09 (0.76)	1.89 (0.68)^{A}
Red wine	3.32 (1.27)	3.12 (1.48)	3.57 (1.66)	6.16 (2.02)	4.04 (2.00)^{B}
Distilled water	1.06 (0.78)	1.28 (1.65)	0.86 (0.66)	1.02 (0.60)	1.06 (0.99)^{C}
Mean of materials	1.88 (1.36)^{a}	2.27 (1.47)^{a}	2.08 (1.54)^{a}	3.09 (2.57)^{b}	
1 month					
Coffee	1.93 (0.76)	2.67 (0.61)	2.02 (0.39)	2.43 (0.75)	2.26 (0.69)^{A}
Red wine	4.30 (1.57)	3.99 (1.88)	4.60 (1.85)	7.14 (2.40)	5.01 (2.26)^{B}
Distile water	1.66 (0.86)	0.89 (0.33)	0.68 (0.41)	1.38 (0.55)	1.15 (0.68)^{C}
Mean of materials	2.63 (1.62)^{a}	2.51 (1.71)^{a}	2.44 (1.97)^{a}	3.65 (2.92)^{b}	

Different lowercase letters indicate a significant difference between materials, and different capital letters a significant difference between coloring solutions according to Tukey's test ($p<0.05$).

immersion in red wine compared to coffee and distilled water (p<0.001). All the materials in the red wine had a ΔE_{00} value higher than the clinically accepted threshold value (ΔE_{00}=1.8)[15]. No significant difference was observed in the color changes of the different materials at 24 h (p=0.113).

At the end of 7 days, in addition to the red wine solution, the Lava Ultimate and 3D resin had ΔE_{00} values higher than the clinically acceptable threshold (ΔE_{00}=1.8) in the coffee solution. At the end of one week, the 3D material was significantly more discolored than the other three materials (p<0.05). No statistically significant differences were observed among the other three materials (p=0.578).

At the end of 30 days, with the exception of distilled water, all the materials had ΔE_{00} values higher than the clinically acceptable threshold (ΔE_{00}=1.8) in all other solutions. The 3D printed material was significantly more discolored than the other three materials (p<0.001). No statistically significant differences were observed among the other three materials (p=0.931).

Statistically significant differences were found between the discoloration of the materials at all the time points. The greatest discoloration was in the red wine, followed by coffee, then distilled water (Table 2 and Fig. 1).

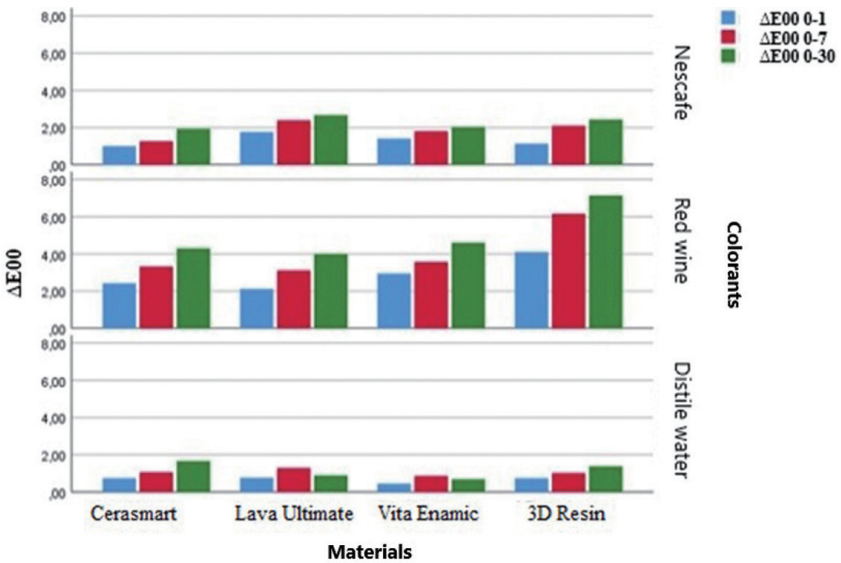


Fig. 1 Time-dependent changes of ΔE_{00} values at 3 measurements.

Table 3 Mean values and standard deviation for ΔTP_{00} of 3D printable material and CAD/CAM blocks specimens after different periods and storage medias

ΔTP_{00}	Cerasmart	Lava Ultimate	Vita Enamic	3D resin	Means of staining solutions
24 h					
Coffee	−0.28(0.56)	0.64(1.49)	0.00(0.84)	−0.99(1.06)	−0.15(0.6)^{A}
Red wine	−0.13(0.64)	−0.14(0.22)	0.55(1.02)	−0.02(0.99)	0.06(0.10)^{A}
Distilled water	0.06(0.54)	0.81(1.90)	0.75(1.19)	−0.37(0.62)	0.31(1.01)^{A}
Mean of materials	−0.11(0.58)^{ab}	0.43(1.41)^{b}	0.43(1.41)^{b}	−0.46(0.97)^{a}	
1 week					
Coffee	−0.16(0.60)	0.32(0.45)	0.65(1.41)	−1.23(1.18)	−0.10(0.82)^{A}
Red wine	−0.31(0.51)	−0.46(0.31)	0.30(1.39)	−1.07(0.90)	−0.38(0.77)^{A}
Distilled water	−0.05(0.58)	0.31(1.24)	0.08(1.00)	−0.27(1.68)	0.01(1.12)^{A}
Mean of materials	−0.17(0.56)^{ab}	0.58(0.84)^{b}	0.34(1.26)^{b}	−0.86(1.32)^{a}	
1 month					
Coffee	−0.08(0.69)	0.08(0.26)	−0.30(0.23)	−1.23(1.04)	−0.38(0.50)^{A}
Red wine	−0.35(0.49)	−0.52(0.48)	−0.25(0.82)	−1.35(0.59)	−0.61(0.48)^{A}
Distilled water	0.02(0.47)	0.26(0.34)	1.45(1.68)	0.14(1.33)	0.47(0.95)^{B}
Mean of materials	−0.14±0.56^{a}	−0.05±0.50^{a}	0.29±1.34^{a}	−0.81(1.21)^{b}	

Different lowercase letters indicate a significant difference between materials, and different capital letters a significant difference between coloring solutions according to Tukey's test (p<0.05).

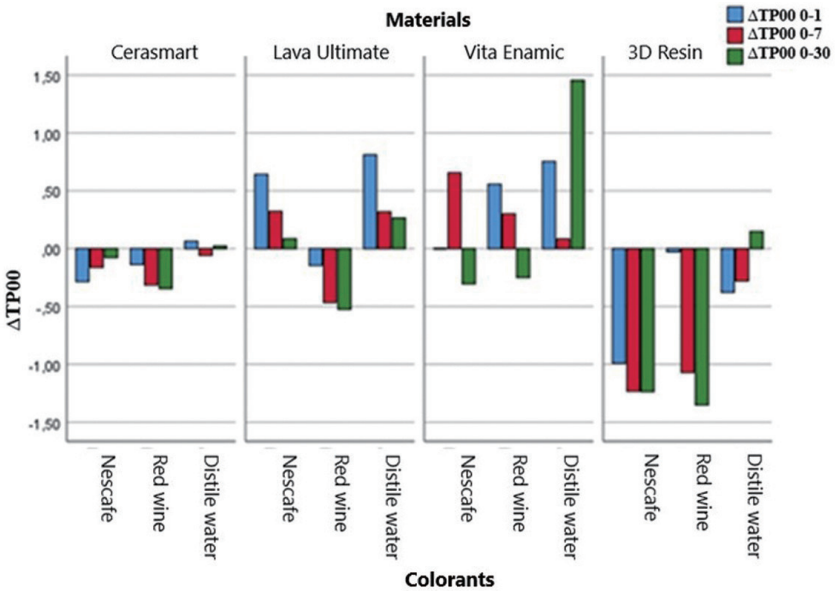


Fig. 2 Time-dependent changes of ΔTP_{00} values at 3 measurements.

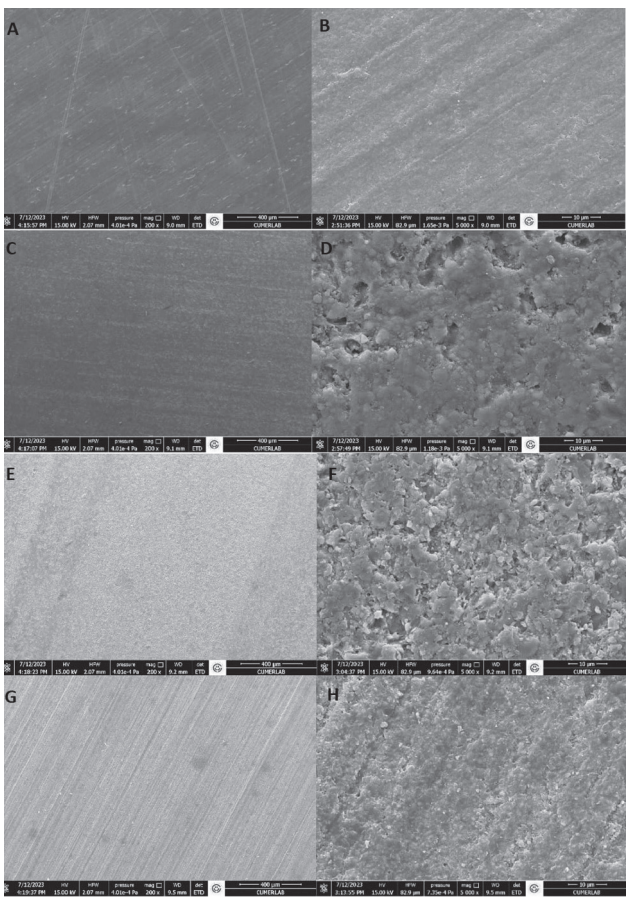


Fig. 3 Qualitative scanning electron images of the surface topography of four restorative material specimens at (A, C, E, G) 200×, and (B, D, F, H) 5,000× magnifications. A-B: Cerasmart CAD/CAM Block, C-D: Lava Ultimate, E-F: Vita Enemic, G-H: Permanent Crown Resin made with 3D printer.

The acceptable translucency threshold value of ΔTP_{00} is 2.62 units[16]. The mean ΔTP_{00} values and standard deviations of the CAD/CAM blocks and 3D printable material at different times and in different storage media are listed in Table 3. None of the materials exceeded this threshold value at any time point

At 24 h and 7 days, the ΔTP_{00} values of the 3D resin were significantly different from those of the Lava Ultimate and Vita Blocks (Fig 2, $p<0.005$).

After 30 days, the ΔTP_{00} values of the 3D resin were significantly different from those of the other three materials ($p<0.01$, Fig 2).

At 24 h and 1 week, no difference was found between the staining solutions, and at 30 days, distilled water differed from red wine and coffee (Table 3).

At SEM ×200 magnification, the grinding marks formed by SiC paper were observed moderately in the cerasmart group, slightly in the Lava ultimate group, clearly in the 3D group, but not in the Vita enamic group. At ×5,000, Cerasmart contained very small and uniformly distributed particles and presented a smoother appearance than the others. Lava ultimate and Vita enamic group contained relatively large and small and uniformly distributed particles. 3D materials exhibited small particles in the resin matrix and grinding marks were observed in these groups (Fig 3).

DISCUSSION

Tooth-colored restorations produced by 3D printing are increasingly used in dental clinics. In restorations with natural tooth color, color and translucency stability are important for providing and maintaining esthetics. The color and translucency of three distinct CAD/CAM blocks comprising resin and a 3D printed dental material, which are utilized for prosthesis restorations, were assessed

and compared in this study. The results showed that the color and translucency stability of the 3D printable material changed more over time compared with the CAD/CAM blocks. Therefore, the null hypothesis that there would be no difference between the 3D printable material and the CAD/CAM blocks with respect to color and translucency was rejected.

Although a number of studies have assessed the color of 3D printed materials used for temporary restorations[11-14], the color of 3D printed materials used for permanent restorations has not been measured. The findings of this study may offer important guidance for the practical application of 3D printing dental materials for long-term restorations.

When the CIEDE2000 developed in 2001 is compared with the CIELAB formula, advanced reliability factors in some areas to which the color extends are presented. When evaluating levels of perception and acceptability, the CIEDE 2000 color-difference calculation formula has been reported to provide better compatibility than the CIELAB formula[17].

As the CIEDE 2000 color difference calculation formula is more up-to-date and can better calculate small differences in dental materials, it was used in the current study. In a 2010 study by Ghinea *et al.*, the perception threshold value was determined as ΔE_{00}=1.28, and the acceptability threshold value was ΔE_{00}=2.24[18]. In another study in 2011 by Perez *et al.*[19], the acceptability threshold value was ΔE_{00}=1.87. As a result of a 2015 study by Paravina *et al.*, these threshold values were updated to the perception threshold value of ΔE_{00}=0.8, and acceptability threshold value of ΔE_{00}=1.8[15]. As this was the most recent study, these threshold values were used in the current study.

As reliable thresholds for translucency, Salas *et al.* determined the perception threshold value as 0.62 units, and the acceptability threshold value as 2.62 units[16].

Barutçugil *et al.*, in their study with the blocks used in the current study, observed after 1 month of immersion in coffee and red wine a discoloration higher than the clinically acceptable threshold level[9]. These findings were similar to those of the present study. Although no statistically significant difference was determined between the materials after 24 h immersion in the solutions, the ΔE_{00} values for both the CAD/CAM blocks and the 3D printable material exceeded the threshold after 24 h immersion in red wine. Red wine created statistically more discoloration than the other two solutions. After one week and one month, the ΔE values of all the materials greatly exceeded the threshold, except in the distilled water solution. The 3D printable material was statistically more discolored than the other three CAD/CAM materials. The absolute values of the translucency differences (ΔTP_{00}) were relatively smaller than the color differences (ΔE_{00}) at all the measured time points. The TP_{00} values were above the threshold values at different time points and in the different staining solutions.

Due to the porous structure in the nature of all the composites containing resin, staining and color change can occur over time (aging). Gale and Darvell[20] also suggested that 10,000 cycles would roughly equal 1 year of *in vivo* functioning, with 20 to 50 cycles being similar to one day. In order to evaluate the outcomes, we chose to continue thermal cycling for 10,000 cycles. This color change has been reported to vary according to the properties of the resin[21]. These color changes in composite resins can be attributed to chemical deterioration, oxidation of carbon double bonds that have not entered into reaction, dehydration, water absorption, leakage, or surface roughness[22].

All the resin-based materials used in the study exceeded the threshold value because all of them absorbed water. The majority of the resin matrix is composed of methacrylate monomer derivatives, and water can attack their ester linkages and cause hydrolysis. As a result of hydrolysis, monomers and deteriorated side products that have not entered the reaction form discoloration through exposure[23]. Aging was applied to the samples in the current study to accelerate the hydrolysis process. Berli *et al.* reported that water absorption was higher in 3D printed resin-based composites than in pressed and milled resin-based composites[24]. Therefore, there may be greater discoloration in 3D printed materials.

Aguiar *et al.*[25] reported that there was greater water absorption at the filler-matrix interface because of the low filler content, and as a result of the absorbed water separating the filler and matrix or causing hydrolytic deterioration of the filler, greater discoloration was observed. The discoloration of composite resin materials is related to the hydrophilic/hydrophobic structure, which directly determines the degree of water absorption. The reason for the greater discoloration of the 3D printed material could be the lower ratio of the filler.

Another factor to consider is the amount of residual monomer formed due to the low polymerization rate. Previous research has reported that the polymerization rate of 3D-printed materials is lower after the curing procedure[26]. CAD/CAM blocks are polymerized industrially under conditions of high temperature (>100°C) and high pressure (>150 Mpa)[27]. Therefore, the amount of residual monomers is very low. The residual monomer is effective in stabilizing the color. One of the possible reasons for the lower discoloration of the blocks in this study was the completion of polymerization.

The size, type and ratio of the filler particles is an important factor affecting the surface roughness of resins and is therefore related to dental discoloration. Cerasmart's nano particles, Lava Ultimate's zirconia particles and Vita Enamic's glass ceramic network may have an advantage in terms of color stability over 3D material.

Shin *et al.*[14] reported that in the SEM images of their study, traces of milling passes remained on the surfaces of CAD/CAM blocks that they did not subject to any finishing and polishing, whereas the Formlabs resin sample printed by the SLA-type 3D printer showed a relatively smooth surface. In the current study, all sample surfaces were mechanically polished with SiC abrasive papers to ensure standardization. Grinding

marks created by SiC paper were more pronounced in the 3D group than in the other groups. This may be due to the small amount and type of filler in the 3D material.

In this study, less color change was observed in the composites immersed in distilled water, and a greater color change was observed in the samples immersed in red wine. Falkensammer *et al.*[28] also reported that the most discoloration was formed by red wine. Other than the acidic properties of red wine, one of the significant reasons affecting the degree of discoloration of composites immersed in the solution has been reported to be the change in the pigments contained in wine over time. It has been reported that low pH and alcohol can disrupt the surface integrity of composite restorations and could be a cause of discoloration[29]. Alcohol is known to impair the surface of composite materials. Therefore, a rougher and more disrupted surface provides a surface suitable for the absorption of pigments and this causes more discoloration[30,31].

According to Guler *et al.*[32], drinking a cup of coffee takes an average of 15 min, and it has been reported that coffee drinkers consume 3.2 cups of coffee per day. Thus, immersion of the samples in coffee for 24 h was equivalent to one month of coffee consumption. The color measurements taken after leaving the samples in the solution for one month in the current study were equivalent to 2.5 years of coffee drinking[14].

This study had some limitations. First, although the 3D-printed materials used in the study contained ingredients that were relatively similar to those of traditional resin-based composite materials, the precise composition and quantities of the matrix and filler were unknown because the manufacturer retained this information. If more information about the components of 3D printable materials was published, further analysis would be possible. Only distilled water was used in the aging process in this study. Further research on the consequences of aging in various solutions may be planned because it is known that changes in pH or the presence of enzymes speed up the degeneration of monomers[31]. A final limitation was that different polishing methods were applied to the surfaces of the tested samples according to the manufacturers' instructions, and different surface polishing protocols may produce different results.

CONCLUSION

Despite the limitations of the study, the results obtained demonstrated that color changes increased over time in resin-based CAD/CAM blocks containing ceramic and 3D printable dental materials. All materials showed a color change exceeding the threshold value when left in red wine solution for 24 h. After 1 week and 1 month, there was a statistically significant difference in the color change between the 3D printed material and the CAD/CAM blocks. The opacity of the 3D material immersed in red wine and coffee was statistically higher than CAD/CAM blocks after one month of immersion.

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CONFLICTS OF INTEREST

Not applicable

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