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RESEARCH AND EDUCATION

Discoloration and translucency changes of CAD-CAM materials after exposure to beverages

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ABSTRACT

Statement of problem. Color and translucency changes of recently introduced composite resin blocks after long-term exposure to various staining agents have not been fully investigated.

Purpose. The purpose of this in vitro study was to evaluate the color stainability and translucency changes of computer-aided design and computer-aided manufacturing (CAD-CAM) materials immersed in beverages with staining potential.

Material and methods. Three types of CAD-CAM blocks were used: 3M Lava Ultimate (LU), GC Cerasmart (CS), and VITA Enamic (VE). Forty-five rectangular specimens (1.5-mm thickness) of each product were prepared. The specimens were divided into 3 subgroups (n=15 in each) according to the immersion beverage. The specimens were then immersed in distilled water, red wine, and coffee for 30 days. Color parameters (ΔE_{00}), the translucency parameter, and the contrast ratio were determined after 24 hours and 1 month. The Kruskal-Wallis and Mann-Whitney U tests and the Wilcoxon, Freidman, and repeated measurement ANOVA tests were used for statistical analysis (α=.05).

Results. None of the materials showed clinically perceptible color changes except CS specimens immersed in coffee for 24 hours. The materials immersed in red wine and coffee for 1 month showed greater discoloration than those immersed in water (P<.05). The LU immersed in red wine showed the highest translucency changes, and VE was more resistant to translucency changes, as compared with the other materials tested. The contrast ratio values of the LU material were higher than those of the CS and VE materials in all the beverages.

Conclusions. The red wine and coffee caused significant changes in the color and translucency of these novel CAD-CAM materials after a long immersion period. (J Prosthet Dent 2019;122:325-31)

The development of computer-aided design and computer-aided manufacturing (CAD-CAM) technology has facilitated the production of esthetic restorations. Composite resin blocks are popular materials for producing tooth-colored CAD-CAM restorations.[1] As an alternative to ceramic blocks, the polymer-infiltrated ceramic-network (PICN) material, VITA Enamic (VE), and resin nanoceramic blocks, Lava Ultimate (LU), and GC CeraSmart (CS) have been developed. VE has a dual network structure that can combine the properties of ceramic and composite resin materials.[2] Della Bona et al[3] reported that the properties of PICN materials are between those of porcelain and highly filled composite resin. Resin nanoceramic blocks have been reported to have better or comparable fracture toughness and higher wear potential than commonly used composite resin materials.[2] Moreover, the mechanical properties of these materials were found to be close to those of enamel.[4]

The color stability of restorative materials is an important property.[5] Although the color stability of direct resin-based restorative materials under clinical conditions has been reported,[6-8] an evaluation of the color change of recently introduced resin nanoceramic or PICN CAD-CAM materials is lacking. Matching the translucency of enamel and dentin is important to the esthetic outcome.[9] Translucency is affected not only by the composition of the material but also by thickness, shade,

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Clinical Implications

CAD-CAM materials exposed to colored beverages for a long time discolor more than the clinically acceptable threshold level. In addition to color stainability, colorant dietary habits may reduce the translucency of these novel restorative materials.

production technique, and illuminants. The translucency parameter (TP) and contrast ratio (CR) are two widely used indices to determine translucency values and changes.[10] Studies considering the color stainability and translucency changes of contemporary CAD-CAM materials against commonly used colored beverages are limited, especially those focusing on their translucency properties. Thus, the purpose of this in vitro study was to determine the color stainability and translucency changes of recently developed CAD-CAM materials after immersion in water, red wine, and coffee for up to 30 days. The null hypotheses were that the type of CAD-CAM material would not affect the color stainability, translucency, and contrast ratio and that the type of beverages and immersion time would not affect the color stainability and optical properties of CAD-CAM materials.

MATERIAL AND METHODS

Three CAD-CAM blocks were tested: 3M Lava Ultimate (3M ESPE), GC Cerasmart (GC Europe), and VITA ENAMIC (VITA Zahnfabrik). The materials and their properties are shown in Table 1. Three blocks were used for each product. A slow-speed diamond saw (Isomet 1000; Buehler) was used under water cooling to cut each CAD-CAM block into 1.5-mm-thick specimens (n=5), and their thickness was checked with digital calipers. Forty-five rectangular specimens were prepared for each material. One wet ground surface of the slices was polished with 600-, 800-, and 1200-grit silicon carbide papers. The specimens were divided into 3 subgroups of 15 according to the immersion beverage and numbered from 1 to 15. By numbering the specimens, the measurement order was standardized, and all subsequent measurements were performed in compliance with this order.

Baseline color measurements were performed, and specimens were immersed in distilled water, red wine (Doluca Öküzgözü, 2011; Doluca), and coffee (Nescafé Classic, Single Bags; Nestlé) to evaluate the optical properties of the CAD-CAM materials. For the coffee, the contents of a 2 g sachet were dissolved in 200 mL boiled water with no sugar or milk. All specimens were immersed in the beverages for 1 month before being measured. The measurements were taken at 24 hours and 1 month. The staining solutions were renewed daily. The specimens were rinsed with distilled water for 10 seconds and dried with mild air pressure for 5 seconds before being measured.

All color measurements were performed by using a clinical spectrophotometer (VITA Easyshade Compact; VITA Zahnfabrik) according to the CIEDE2000 color coordinates. The Easyshade was chosen for the analysis because it has more than 90% reliability and validity as previously reported.[11] Therefore, the repeatability of the experimental design was not evaluated in the present study. All measurements were performed under the D65 standard illumination, and the illumination and observation geometry for the reflectance measurements was a 45 and 0-degree optical configuration.[12] The measurements were done and recorded against a standard black background (L^*=2.3, a^*=0.5, b^*=2.1), and the following measurements were completed against a standard white background (L^*=94.6, a^*=0.2, b^*=-0.8). The instrument was calibrated before color measurement. All measurements were done in Tooth Single mode of Easyshade, which has an aperture size of 6 mm in diameter. To determine the color differences between groups, the ΔE_{00} values were calculated by using the following formula[13]:

$$\Delta\mathbf{E}_{00}=\sqrt{\left(\frac{\Delta\mathbf{L}}{K_L S_L}\right)^2+\left(\frac{\Delta\mathbf{C}}{K_C S_C}\right)^2+\left(\frac{\Delta\mathbf{H}}{K_H S_H}\right)^2+\mathbf{R}_T\left(\frac{\Delta\mathbf{C}}{K_C S_C}\right)\left(\frac{\Delta\mathbf{H}}{K_H S_H}\right)},$$

with the set of L^*, a^*, b^* values taken with respect to the white background. For this study, each K_L, K_C, and K_H was set to 1.0. The clinically 50:50% acceptable color change threshold level was determined as ΔE_{00}=2.25.[14]

To evaluate changes in translucency, translucency parameters (TP) and the contrast ratio (CR) were used. The TP was determined by calculating the differences in the L^*, a^*, b^* values recorded against the white (W) and black (B) backgrounds by using the following formula:

$$TP=\sqrt{(L_W-L_B)^2+(a_W-a_B)^2+(b_W-b_B)^2}.$$

CR values were calculated as previously described.[15] To calculate CR, the spectral reflectance Y values (luminance from Tristimulus Color Space-XYZ) were calculated first by using the L^* values. CR was then calculated using the Y values obtained. In the following formula, Y_n is equal to 100, and this formula was calculated separately for the values obtained on the white background (Y_W) and on the black background (Y_B).

$$Y=\left(\frac{L+16}{116}\right)^3\times Y_n CR=\frac{Y_W}{Y_B}$$

The ΔTP and ΔCR were calculated to determine the changes in translucency. The TP and CR values were recorded at 3 different times: baseline measurement (TP_0, CR_0), measurement at 24 hours (TP_1, CR_1), and

Table 1. CAD-CAM materials used

Product (Code)	Manufacturer	Shade	Type	Content: Organic Matrix and Fillers	Content: Amount (%w)	Batch Number
3M Lava Ultimate (LU)	3M ESPE	A2 - LT	Resin nanoceramic block	BisGMA, TEGDMA, UDMA, BisEMA	20	N515648
				SiO_2 (20 nm), ZrO_2 (4-11 nm), aggregated ZrO_2/SiO_2 microcluster	80	
GC CeraSmart (CS)	GC Europe	A2 - HT	Nanoceramic block	Bis-MEPP, UDMA, DMA	29	1408201
				Silica (20 nm), barium glass (300 nm)	71	
VITA ENAMIC (VE)	VITA Zahnfabrik	2M2 - HT	Polymer-infiltrated ceramic-network block	UDMA and TEGDMA	14	45810
				Fine-structure feldspar ceramic with aluminum oxide	86	

CAD-CAM, computer-aided design and computer-aided manufacturing. BisGMA, bisphenol-A glycidylmethacrylate; TEGDMA, triethylen; UDMA, urethane dimethacrylate; BisEMA, ethoxylated bisphenol-a dimethacrylate; Bis-MEPP, 2,2-bis(4-methacryloxyethoxyphenyl) propane; DMA, dimethacrylate.

measurement at 1 month (TP_2, CR_2), and these values were used in these calculations:

$$\Delta TP_1=TP_1-TP_0 \text{ and } \Delta CR_1=CR_1-CR_0$$
$$\text{and } \Delta TP_2=TP_2-TP_0 \text{ and } \Delta CR_2=CR_2-CR_0.$$

Higher TP values indicate more translucent materials, negative ΔTP values show decreases in translucency, and positive ΔTP values show increases in translucency. CR values range between 0.0 and 1.0; the 0.0 values of CR indicate completely transparent material, whereas completely opaque materials have a CR value of 1.0. Therefore, positive ΔCR values indicate increase in opalescence.

The Kolmogorov−Smirnov test was performed to analyze the normality of the ΔE_{00}, ΔTP, and ΔCR values. As a result of the normality test, the Kruskal-Wallis and Mann-Whitney U tests were used. In addition, to determine the time-dependent changes of the ΔE_{00}, TP, and CR values between different times, the Wilcoxon, Friedman, and repeated measurement ANOVA tests were conducted. Statistical software (IBM SPSS Statistics, v20; IBM Corp) was used for the statistical analysis (α=.05), and the power analysis was performed by using a software package (G*Power 3.1; Universität Düsseldorf).

RESULTS

The mean ΔE_{00} values and standard deviations of the CAD-CAM materials in the storage solutions at different times are presented in Table 2. According to the color measurements at 24 hours, all tested materials had higher discoloration when immersed in coffee than in red wine or distilled water (*P*<.001). CS had ΔE_{00}=2.33, which was higher than the clinically acceptable threshold level (ΔE_{00}=2.25).[14] After 1 month, all specimens immersed in water had statistically lower discoloration than those immersed in red wine or coffee (*P*<.001). In addition, unlike red wine or coffee, immersion in distilled water did not cause the color change to be higher than the clinically acceptable threshold. The LU specimens had higher discoloration (ΔE_{00}=3.46) than the CS and VE specimens in red wine (*P*=.010), and the highest discoloration for VE (ΔE_{00}=3.62) and CS (ΔE_{00}=3.11) was calculated after coffee immersion. According to the results of the Wilcoxon test, at the 1-month immersion period, all tested materials had statistically higher ΔE_{00} values than the ΔE_{00} values of 24 hours of immersion, except for specimens immersed in distilled water (Fig. 1; *P*=.061, *P*<.001, and *P*<.001 for LU; *P*=.443, *P*<.001, and *P*<.001 for CS, and *P*=.057, *P*<.001; and *P*<.001 for VE specimens immersed in distilled water, red wine, and coffee, respectively).

Table 2. Mean ΔE_{00} values ±standard deviations of CAD-CAM blocks after 24 hours and 1 month of immersion in colorant beverages

ΔE_{00}	LU	CS	VE
24 h			
Water	1.1 ±0.6^{a,A}	0.9 ±0.3^{a,AB}	0.7 ±0.1^{a,B}
Red wine	1.6 ±0.3^{b,A}	1.1 ±0.5^{a,B}	1.6 ±0.4^{b,A}
Coffee	2.1 ±0.5^{c,A}	2.3 ±0.8^{b,A}	2.2 ±0.4^{c,A}
1 mo			
Water	1.3 ±0.8^{a,A}	0.9 ±0.4^{a,A}	0.5 ±0.3^{a,B}
Red wine	3.5 ±0.3^{c,A}	2.7 ±0.7^{b,B}	2.9 ±0.7^{b,B}
Coffee	3.2 ±0.5^{b,A}	3.1 ±1.1^{b,A}	3.6 ±1.2^{b,B}

CAD-CAM, computer-aided design and computer-aided manufacturing; CS, GC CeraSmart; LU, 3M Lava Ultimate; VE, VITA ENAMIC. In same column, subgroups identified by different superscript lowercase letters are statistically different; also in same row, subgroups identified by different superscript uppercase letters are statistically different according to Kruskal-Wallis test and Mann-Whitney U test (*P*<.05).

The translucency changes of all specimens immersed in beverages are presented in Table 3. No statistical differences were found in the beverages for the ΔTP_1 and ΔTP_2 values of any material for the tested specimens. After 1 month of immersion, red wine led to significant translucency changes in the LU and VE groups only (*P*=.013). In Figure 2, red wine for LU (*P*=.282, *P*<.001, and *P*=.085 in distilled water, red wine, and coffee, respectively) and CS (*P*=.420, *P*=.002, and *P*=.055 in distilled water, red wine, and coffee, respectively) as well as red wine and coffee for VE (*P*=.766, *P*<.001, and *P*<.001 in distilled water, red wine, and coffee, respectively) resulted in significant decreases in translucency according to the result of the Friedman test.

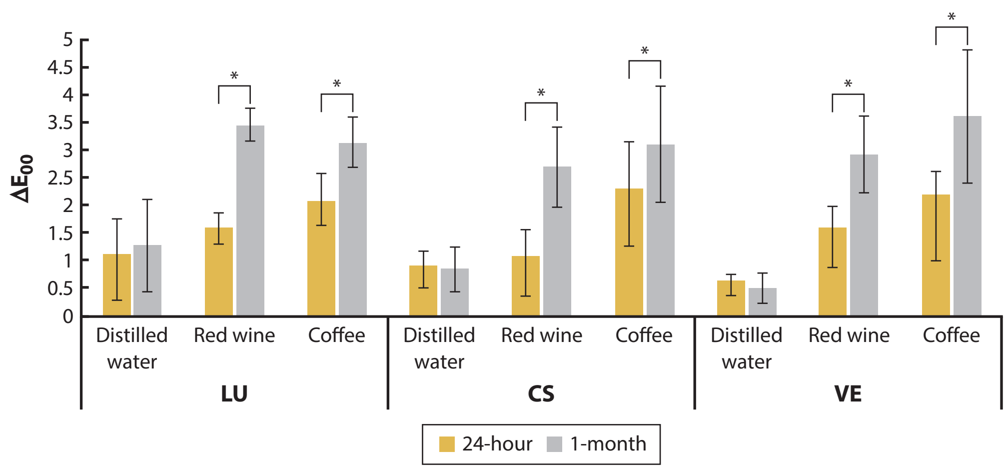

Figure 1. Time-dependent changes of ΔE_{00} values at 2 measurements. *Indicates statistically significant difference with time in same group according to Wilcoxon test (P<.05).

Table 3. Mean ΔT values and standard deviations of CAD-CAM blocks after 24 hours and 1 month of immersion in colorant beverages

ΔTP	LU	CS	VE
ΔTP1 (24 h)			
Water	-0.6 ±1.8	0.1 ±1.6	-0.5 ±0.9
Red wine	-0.3 ±0.4	-0.7 ±1.3	-0.1 ±0.6
Coffee	-0.2 ±1.8	-1.1 ±2.3	-0.1 ±0.7
ΔTP2 (1 mo)			
Water	-0.8 ±1.7	-0.1 ±2.2	-0.2 ±0.7
Red wine	-1.6 ±0.4^{A}	-1.4 ±1.4 ^{AB}	-0.8 ±0.7^{B}
Coffee	-0.7 ±1.8	-1.1 ±2.3	-0.7 ±0.7

CAD-CAM, computer-aided design and computer-aided manufacturing; CS, GC CeraSmart; LU, 3M Lava Ultimate; VE, VITA ENAMIC. Subgroups identified by different superscript uppercase letters are statistically different according to Kruskal-Wallis test and Mann-Whitney U test (P<.05).

When evaluating the ΔCR results, the 24-hour and 1-month immersion in colorant beverages statistically increased the opacity of only the VE specimens in comparison with the distilled water groups (Table 4). In red wine, the CR values of the LU specimens increased after the 24-hour (P=.034) and 1-month immersions and were statistically higher than those of the VE specimens (P=.008). In addition, LU had higher CR values than the CS and VE specimens because the LU specimens were low in translucency and the others were high in translucency. Essentially, when the time-dependent changes in the CR values were evaluated, as shown in Figure 3, red wine and coffee statistically increased the opacity of all tested materials during the 1-month immersion period. According to the results of the repeated measurements ANOVA, the F and P values were 0.363 and .699, 189.329 and <.001, 12.776 and <.001 for LU; 0.846 and .440, 3.898 and .032, 8.996 and <.001 for CS; and 0.631 and .501, 6.592 and .005, 15.367 and <.001 for VE in distilled water, red wine, and coffee, respectively.

DISCUSSION

The first null hypothesis was rejected as the results revealed that material type had a significant effect on color and translucency changes. The discoloration of composite resin restorations has been mainly correlated with the organic portion of materials.[16] Recently introduced CAD-CAM resin-based or PICN materials have reduced the organic phase. Arocha et al[17] evaluated 2 CAD-CAM composite resin materials and 2 laboratory indirect composite resins for color stainability against colored beverages. After 4 weeks of immersion, they reported that LU was one of the most discolored materials tested. Acar et al[2] evaluated the color change of 3 CAD-CAM restorative materials after thermocycling in coffee and compared the discoloration values of the materials with the perceptibility threshold (ΔE_{00}=1.28) and clinical acceptability threshold (ΔE_{00}=2.25) levels. At the end of 5000 thermocycles, VE had a higher discoloration than the perceptible level, and LU had a higher discoloration than the clinically acceptable threshold level, consistent with the present study. Although the results were similar to those of the present study, the authors only compared the discoloration values of materials with the perceptibility and acceptability threshold levels. Also, the authors did not evaluate the translucency of CAD-CAM materials. In a recent study, Alhabri et al[18] evaluated the staining susceptibility of CAD-CAM materials after long-term exposure to various staining agents. In their study, 6 different CAD-CAM materials, including VE and LU, were immersed in 4 different beverages and artificial saliva for up to 120 days. After the immersion period, the color changes were calculated using the CIELab coordinates and determined with the ΔE_{ab} values. The authors reported that red wine and coffee caused the highest discoloration on VE and LU compared with distilled water and artificial saliva, consistent with the

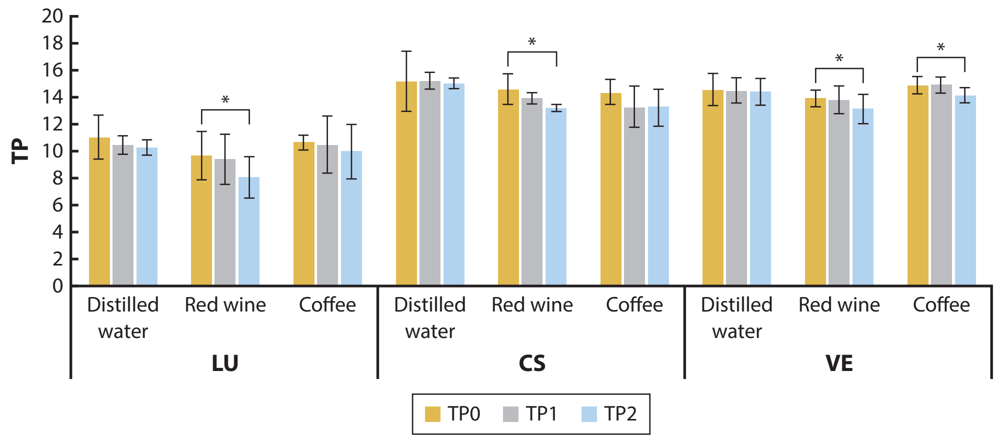

Figure 2. Time-dependent changes of TP (translucency parameters) values at 3 measurements. *Indicates statistically significant difference with time in same group according to Friedman test (*P*<.05). CS, GC CeraSmart; LU, 3M Lava Ultimate; VE, VITA ENAMIC.

Table 4. Mean ΔCR values and standard deviations of CAD-CAM blocks after 24 hours and 1 month of immersion in colorant beverages

ΔCR	LU	CS	VE
ΔCR1 (24 h)			
Water	0.006 ±0.048	0.016 ±0.058	-0.019 ±0.009[a]
Red wine	0.009 ±0.007[A]	0.014 ±0.036[A]	0.001 ±0.016[b,B]
Coffee	0.023 ±0.037[AB]	0.036 ±0.048[A]	0.008 ±0.017[b,B]
ΔCR2 (1 mo)			
Water	0.008 ±0.044	0.013 ±0.067	-0.010 ±0.012[a]
Red wine	0.033 ±0.007[A]	0.021 ±0.034[B]	0.013 ±0.019[b,B]
Coffee	0.037 ±0.026	0.037 ±0.046	0.026 ±0.022[b]

CAD-CAM, computer-aided design and computer-aided manufacturing; CR, contrast ratio; CS, GC CeraSmart; LU, 3M Lava Ultimate; VE, VITA ENAMIC. In same column, subgroups identified by different superscript lowercase letters are statistically different; also in same row, subgroups identified by different superscript uppercase letters are statistically different according to Kruskal-Wallis test and Mann-Whitney U test (*P*<.05).

present study. Although the result of this previous study was valuable in terms of color change, it did not evaluate the translucency change.

In a recent study, the color stainability and translucency changes of LU and VE immersed in different colorant beverages for 7 days were evaluated.[19] The authors reported that both CAD-CAM materials had higher discoloration than the clinically acceptable threshold level, especially when immersed in red wine and coffee.[19] Unlike this study, the present study used the ΔE_{00} values and conducted a 1-month immersion to evaluate the color differences.

To examine color differences in dentistry, both ΔE_{ab} and ΔE_{00} can be used,[1,20] although ΔE_{00} has been recommended[1] as the CIEDE2000 formula could be a more suitable and reliable way of evaluating color differences.[2] In addition, Perez et al[21] found that this formula corrected some specific points of the nonuniformities of the CIELab color space, such as the modification of the a* coordinate of the CIELab sphere, which affects color with low chroma and the interaction between chroma and hue differences in the blue region. Accordingly, for the present study, the CIEDE2000 formula and ΔE_{00} were chosen instead of ΔE_{ab}.

A clinical spectrophotometer designed for the shade determination of natural teeth and restorations was used in the present study. This device has a tip diameter of 6 mm, and measurements of the specimens for in vitro studies were made in “Tooth Single” mode. Kim-Pusateri et al[11] compared the reliability and accuracy of 4 dental shade matching instruments in a standardized environment and concluded that the Vita Easyshade had both reliability and accuracy values greater than 90%. Ertaş et al[22] observed that a 24-hour immersion in colorant beverages corresponded to approximately 1 month of clinical aging. In their study, all specimens were immersed in beverages up to 30 days, which simulated approximately 2.5 years of clinical evaluation. In terms of the translucency changes in LU and VE, Quek et al[19] found that red wine and coffee significantly reduced the translucency of both restorative materials after 7 days. However, no differences in the translucency of LU and VE were reported. Conversely, in the present study, red wine and coffee reduced the translucency of all tested materials after 1-month immersion and statistically significant changes were observed between the LU and VE specimens. Note that 2 translucency parameters were tested and that time-dependent changes in the ΔT and CR values were analyzed in the present study. The earlier study used only the ΔT values to evaluate the translucency.[19]

As reported in previous studies, the translucency and opacity of restorative materials can be evaluated using different methods, such as the transmittance of light, CR, and TP.[9,23] The TP is defined as the color difference of the material between a white and a black background based on the thickness of the material,[23] and CR is the wavelength-dependent parameter based on calculations of luminescence and reflectance.[15] Stawarczyk et al[24] evaluated the color changes and translucency of 5

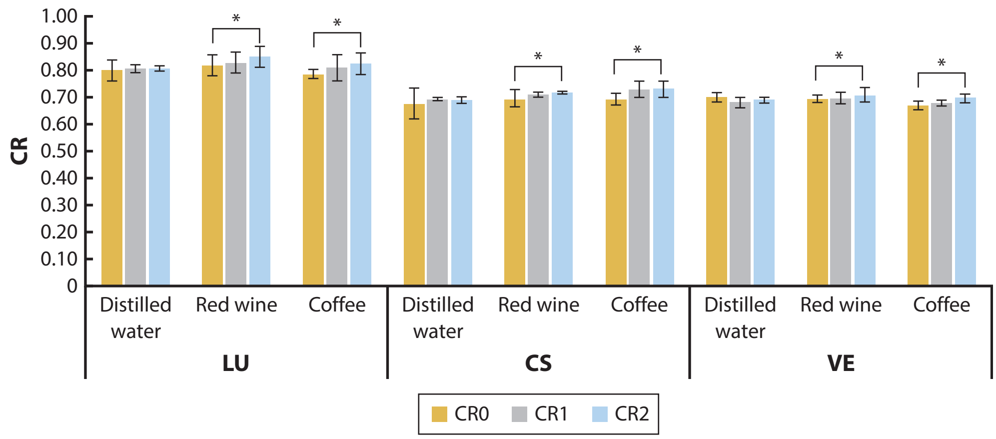

Figure 3. Time-dependent changes of CR (contrast ratio) values at 3 measurements. *Indicates statistically significant difference with time in same group according to repeated measurements ANOVA ($P<.05$). CS, GC CeraSmart; LU, 3M Lava Ultimate; VE, VITA ENAMIC.

different CAD-CAM composite resin materials (3 were commercially available, 2 were experimental), a PICN material, and 2 ceramic-based materials against different colorant beverages during a 14-day immersion. They reported that the translucency of the materials was affected by the internal structure and composition of the material. However, the authors did not calculate the translucency change; they measured only the translucency value once after the immersion period. The present study revealed the translucency changes in the contemporary CAD-CAM materials against simulated clinical conditions representing about 2.5 years.

Regarding the effects of staining solution types on the optical properties of the tested materials in the present study, the second null hypothesis was rejected because the commonly used colorant beverages, specifically red wine followed by coffee, caused higher discoloration and translucency changes than distilled water. In most previous studies, the discoloration of resin-based materials from coffee was based on the coffee content, which has yellow colorants with different polarities.[6] For red wine, the high concentration of pigment molecules, low pH, and alcohol content were thought to explain the discoloration of resin-based materials.[7,25] Some studies found that discoloration from red wine was caused by the alcohol and low pH softening the polymer matrix after the pigments had penetrated deeply into the resin matrix.[6,8] The results of the present study confirmed that coffee and red wine damage the optical properties, such as color and translucency, of resin-based and PICN restorative materials. Nevertheless, corroboration of these conclusions is required through long-term clinical and in vitro studies.

The limitations of the present study include that staining on both sides of the material was allowed, which is different from clinical staining conditions. Only 1 side of the specimens was polished, and to standardize the specimens' surface, a standard polishing method that differed from the manufacturer's directions was applied to the tested CAD-CAM materials. Different surface polishing protocols may yield different results.

CONCLUSIONS

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

1. After 1 month of immersion in coffee and red wine, a discoloration higher than the clinically acceptable threshold level (ΔE_{00}=2.25) was observed.
2. The color changes were statistically higher than when the specimens were immersed in distilled water for all tested CAD-CAM materials.
3. The opacity of all tested materials immersed in red wine and coffee increased statistically after 1 month of immersion.

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Noteworthy Abstracts of the Current Literature

New multi-layered zirconias: Composition, microstructure and translucency

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Objectives. To fully realize the range of indication and clinical advantages of the new multi-layered zirconias, a comprehensive understanding of their chemical composition, microstructure, low temperature degradation (LTD) resistance, and translucency properties is paramount.

Methods. A zirconia system (Katana, Kuraray Noritake), including 3 distinct grades of multi-layered zirconias, was selected for study: Ultra Translucent Multi-layered zirconia (UTML), Super Translucent Multi-layered zirconia (STML), and Multi-layered zirconia (ML). For different materials and their individual layers, the chemical composition, zirconia phase fractions, and microstructure were determined by X-ray fluorescence (XRF), X-ray diffraction (XRD), and field emission scanning electron microscopy (FE-SEM). Also, their resistance to LTD and translucency properties were characterized.

Results. Our findings revealed no major differences amongst layers, but the 3 materials were very distinct-UTML: 5Y-PSZ (5 mol% yttria-partially-stabilized zirconia) with ∼75 wt% cubic content and a 4.05 (±0.85) μm average grain size, STML: 4Y-PSZ with ∼65 wt% cubic content and a 2.81 (±0.17) μm average grain size, and ML: 3Y-PSZ with <50 wt% cubic content and a 0.63 (±0.03) μm average grain size. After water aging at 120 °C for 12 h, greater monoclinic content was found in ML. UTML and STML did not show detectable monoclinic phase. The translucency was similar among layers, and also between UTML and STML, which were superior to ML.

Significance. For each multi-layered zirconia grades, the layers are only differed in pigment types and contents, which yield remarkably natural shade gradients. Also, despite the significant compositional difference between STML and UTML, both materials showed similar translucencies.

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