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The Effect of Different Solutions on Optical Behavior of Polished and Glazed Zirconia-Reinforced Lithium Silicate Ceramics

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Abstract

Background: This study sought to assess the effect of glazing and polishing surface treatments on the optical behavior of zirconia-reinforced lithium silicate ceramics thermocycled in different solutions.

Methods: Computer-aided design/computer-aided manufacturing ceramics (VITA Suprinity) were cut into samples (n=104) measuring 1.5x14x10 mm according to the manufacturer's instructions. Also, the samples were then randomly divided into four groups for immersion in artificial saliva, tea, orange juice and cola. A spectrophotometer was used to assess the color change and changes in L* coordinate against a white and a black background. The translucency parameter and contrast ratio were also calculated. The ΔE and L* values were analyzed using two-way ANOVA test. Student's t-test was applied to analyze TP and CR.

Results: The interaction effect of the type of solution and type of surface treatment on color change against a white ($P=0.008$) and black ($P<0.001$) background was statistically significant. Immersion of ceramic samples in orange juice and cola caused significant changes in TP and CR in the polishing and glazing groups ($P < 0.05$).

Conclusion: Immersion in orange juice causes clinically perceivable color change in glazed ZLS ceramics. Immersion in cola decreases the translucency of both polished and glazed ZLS ceramics.

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Introduction

Great advances have been made in the field of ceramic materials for prosthetic dental restorations, and several techniques have been suggested to achieve a better match with natural teeth (1-3). Advances in Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technology have profoundly increased the fabrication of all-ceramic restorations (4). Fabrication of monolithic restorations (not requiring veneering with other ceramics) using the CAD/CAM technology has also increased in the recent years due to their optimal mechanical properties and favorable esthetics (5, 6). Monolithic restorations are made of zirconia, lithium disilicate ceramics, Zirconia-reinforced Lithium Silicate (ZLS) ceramics, feldspathic ceramics, and leucite-based ceramics or glass/ceramic polymers (5). Of the afore-mentioned materials, lithium disilicate and ZLS ceramics better meet the esthetic demands of patients (7). Lithium disilicate ceramics were first introduced as core build-up or substructure materials (8). ZLS ceramics were introduced as machined (Vita Suprinity PC; Vita Zahnfabrik) materials for the CAD/CAM technology, which have mechanical properties comparable to those of lithium disilicate glass ceramics. This technology is based on the addition of 10 mass percent zirconium oxide to lithium silicate glass (9). The main difference between ZLS and lithium disilicate ceramics is in their final crystallization phase (7). Both types of these ceramics are suitable for the fabrication of monolithic anatomical restorations for the anterior region due to their improved esthetics and translucency (5, 7, 8, 10-14). Only a limited number of studies have evaluated the surface texture and mechanical properties of lithium disilicate and ZLS ceramics after their crystallization, and the effect of surface finishing on their optical behavior has not been well studied either (7, 15). Optical properties, color stability and translucency are among the important parameters affecting the esthetic appearance of all-ceramic restorations during their clinical service (16). Moreover, the color change of restorations over time can affect their longevity and quality of service (17). Furthermore, the esthetic appearance of all-ceramic restorations is affected by their surface texture (18). The manufacturers of lithium disilicate and ZLS ceramics recommend their glazing and/or polishing protocols to improve esthetics. However, it is not well clear whether glazing and/or polishing of these ceramics affects their color stability or translucency. This study sought to assess the effect of different surface treatments namely glazing and polishing on the optical behavior of ZLS ceramics immersed and thermocycled in artificial saliva, tea, cola and orange juice. We propose a test of the null hypothesis that there would be no significant difference regarding the effects of different surface treatments on optical behavior of ZLS ceramics following their immersion in different solutions.

Materials and Methods

A type of ZLS ceramic (Vita Suprinity PC; Vita Zahnfabrik) fabricated by the CAD/CAM technology was subjected to two types of surface treatments namely glazing and polishing to assess the resultant color change against a white and a black background. The changes in value (L*), translucency and opacity after thermocycling were also evaluated

Table 1. Shows the characteristics of the ceramic used in this study.

Material	Composition	Manufacturer	Code	Shade/Translucency
Vita Suprinity PC	Zirconia reinforced Lithium silicate glass-ceramic (SiO_2, Li_2O, K_2O, P_2O_5, Al_2O_3, ZrO_2, CeO_2, pigments)	Vita Zahnfabrik Germany	VS	A2/HT

Preparation of samples

Pre-crystalized CAD/CAM ceramic blocks were cut into samples measuring 10x14 mm with 1.5±0.3 mm thickness using a cutting machine (Vari/cut VC-50; Leco Corp) with a diamond blade (series 15 LC diamond; Buehler Microstructural Analyses Division). The ZLS ceramic samples were cleaned in an ultrasonic bath containing distilled water for 15 minutes according to the manufacturer's instructions. They were then completely crystalized in a furnace (Programat EP5000; Ivoclar Vivadent AG) at 840°C for 8 minutes. The samples were polished with 600-grit silicon carbide abrasive papers under running water to reach 1.5±0.02 mm thickness. The samples were then randomly assigned to the polishing and glazing groups. Each sample received the assigned surface treatment only at one side. In the polishing group (n=13), the samples were polished with a low-speed hand piece according to a two-step protocol recommended by the manufacturer (Vita Suprinity Polishing Set Technical; VITA Zahnfabrik). In the first step, pre-polishing was carried out using the diamond-coated, pink instrument (tip, S5m) at a speed of 10, 000 rpm. In the second step, high-gloss polishing was subsequently carried out with the diamond-coated, grey instrument (tip, S5f) at a reduced speed of 6, 000rpm.

In the glazing group (n=13), a thin layer of glaze (Vita Akzent plus Glaze LT; Vita Zahnfabrik) was applied on the surface of samples and they were heated at 800°C for 60 seconds. The samples were then randomly divided into four groups for immersion in artificial saliva, tea, orange juice and cola (n=13, ceramic samples in each group).

Table 1. Characteristics of the solutions used in this study

Immersion solution	Manufacturer	Chemical Composition	PH	Immersion Temperature (22, 23)
Artificial saliva	Professional Dietetics, Italy	KCl (0.4 g L−1), NaCl (0.4 g L−1), CaCl2_2H2O (0.906 g L−1), NaH2PO4_2H2O (0.690 g L−1), Na2S_9H2O (0.005 g L−1), and urea (1 g L−1)	6.5	37 ℃
Orange juice	Coca-Cola	Orange juice, water, sugar, orange pulp, natural flavors, antioxidant ascorbic acid, and citric acid	3.5	5 ℃
Cola	Coca-Cola	Carbonated water, sugar, cola nut extract, yellow dye IV, acidulant INS 338, and natural flavors	2.4	5 ℃
Tea	Tetley	Tea leaves	4.9	55 ℃

Thermocycling

Samples in artificial saliva group were incubated at 37°C for 125 hours. Samples in tea, orange juice and cola groups were immersed in the respective solutions and subjected to 5000 thermal cycles in a thermocycler (MSCT-3; Convel) for aging. One container contained 37°C artificial saliva and another container contained the respective solution at 5 or 55°C (16, 19, and 20). In the interests of test standardization, each bath transfer time was 10 seconds, and the dwell time was 30 seconds (19, 21). For baseline assessments prior to thermocycling, the samples were immersed in distilled water and incubated at 37±1°C. Characteristics of the solutions are presented in table 2.

Assessment of color change and translucency

A spectrophotometer (Vita easy shade compact, Zahnfabrik, Germany) in tooth single mode was used to measure the color parameters of the samples against a standard white (CIE L*= 96.68, a* = -0.18, b* = -0.22) and a standard black (CIE L*= 1.15, a* = -0.11, b* = -0.50) background. The measurements were made using a D65 illuminant. Also, one drop of optical liquid (1.5 index of refraction fluid, Cargille lab, Cedar Grove, NJ, USA) was applied on the standard background to establish an optical communication between the sample and the background (24). Table 3 shows the characteristics of the spectrophotometer used in this study (25). The samples were placed in the positioning jig and subjected to spectrophotometry under standard conditions (26) (Figure 1).

Table 2. Characteristics of the spectrophotometer used in this study

Operation mode	Calibration	Light source	Measurement range (nm)	Measurement region	Spectral resolution (nm)
Spectrophotometer	Ceramic standard	LED	400–700	Spot measurement	25

Figure 1. Measurement of color parameters under standard conditions with the sample placed in the positioning jig

After thermocycling, the samples were cleaned by a toothbrush and toothpaste (Crest; Procter and Gamble) for 10 times and were then cleaned in an ultrasonic bath for 10 minutes prior to second-time measurements (27).

Color change (ΔE) was calculated using the CIE LAB system and the ΔE_{76} formula below. The L* value was also measured against the black and white backgrounds.

Formula 1: $\Delta E_{76} = ((L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2)^{1/2}$

Translucency was quantified by calculating the Contrast Ratio (CR) and Translucency Parameter (TP) using the formula below (28):

Formula 2: $TP = ((L_B^* - L_W^*)^2 + (a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2)^{1/2}$

Formula 3: $CR = Y_B / Y_W$

The L* values were also used to calculate the spectral reflectance, Y (luminance from Tristimulus Color Space/XYZ).

Formula 4: $Y = ((L + 16) / 116)^3 Y_n$

For simulated object colors, the specified white stimulus normally chosen is one that has the appearance of a perfect reflecting diffuser, normalized by a common factor so that Yn is equal to 100 (28).

Statistical analysis

Two-way ANOVA test was used to analyze ΔE and L* variables against the white and black backgrounds. The simple main effect analysis was applied to analyze the interactions. In case of the presence of a significant difference shown by two-way ANOVA, Tukey's test was applied for pairwise comparisons (a=0.05). Student's t-test was applied to analyze the translucency and opacity values (a=0.05).

Results

The results showed that the interaction effect of the type of solution and type of surface treatment on color change against a white background was statistically significant (P=0.008, Table 4). Also, the ΔE value against a white background in orange juice solution was greater than that in other solutions (Figure 2). In addition, the interaction effect of the type of solution and type of surface treatment on color change against a black background was statistically significant (P<0.001, Table 5). The ΔE value against a black background in orange juice solution was greater than that in other solutions (Figure 3). The interaction effect of the type of solution and type of surface treatment on ΔL* (L^*_1-L^*_2) against white (P<0.01, Table 6, Figure 4) and black (P<0.001, Table 7, Figure 5) backgrounds was statistically significant. Immersion of ZLS ceramic samples in orange juice caused significant changes in TP parameter in the polishing (P=0.017) and glazing (P<0.001) groups as well as CR parameter in the polishing (P=0.034) and glazing (P<0.001) groups. The TP parameter in the polished and glazed ZLS ceramic samples (P<0.001) and also the CR parameter in the polished and glazed ZLS ceramic samples (P<0.001) experienced significant statistical changes after thermocycling in cola solution. Immersion in the remaining two solutions (artificial saliva and tea) had no significant effect on TP and CR parameters (Figures 6 and 7).

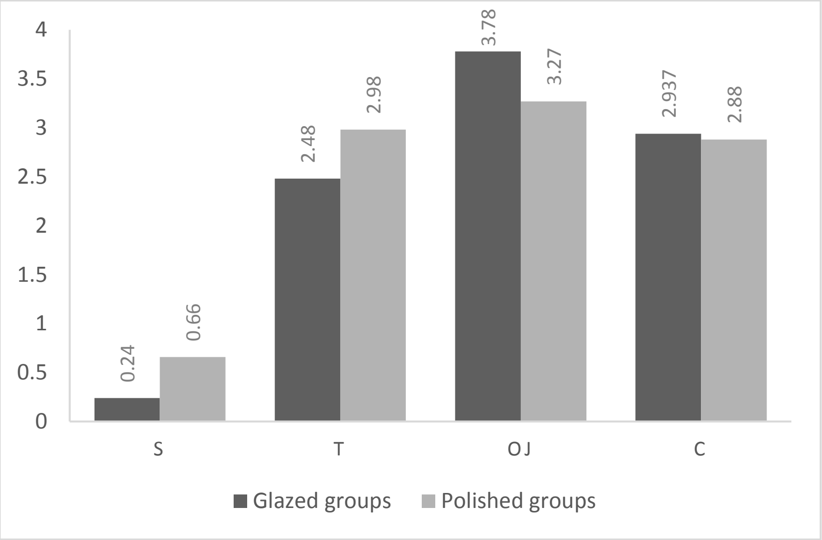

Figure 2. Interaction effect of the type of solution and type of surface treatment on color change of ZLS ceramic against a white background after thermocycling in different solutions (P=0.008). S: Artificial saliva; T: Tea; OJ: Orange juice; C: Cola

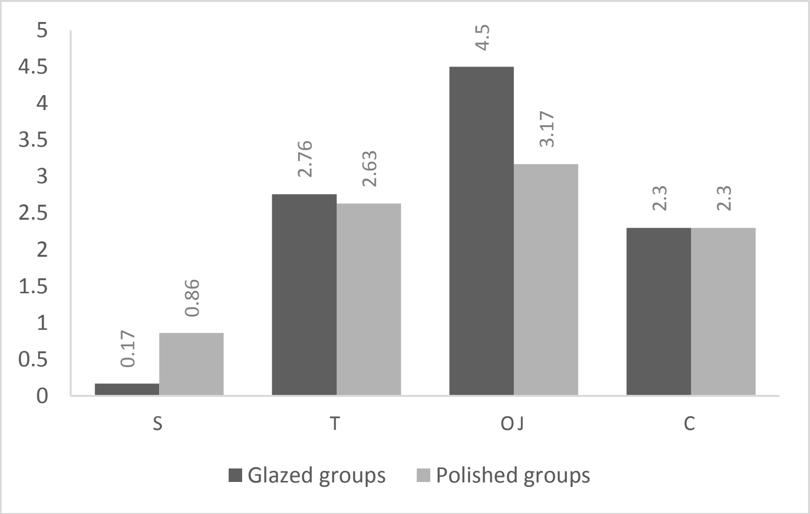

Figure 3. Interaction effect of the type of solution and type of surface treatment on color change of ZLS ceramic against a black background after thermocycling in different solutions (P<0.000). S: Artificial saliva; T: Tea; OJ: Orange juice; C: Cola

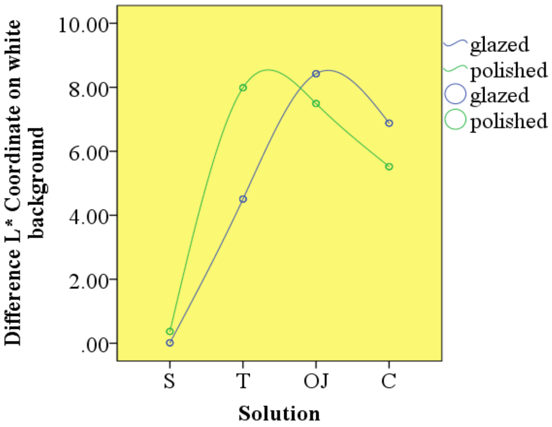

Figure 4. Interaction effect of the type of solution and type of surface treatment on L* coordinate of ZLS ceramic against a white background after thermocycling in different solutions (P=0.011). S: Artificial saliva; T: Tea; OJ: Orange juice; C: Cola

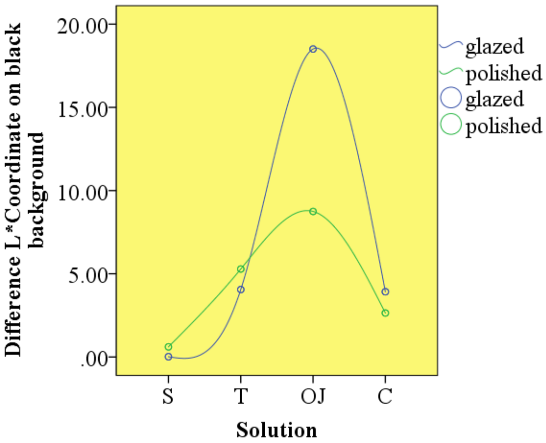

Figure 5. Interaction effect of the type of solution and type of surface treatment on L* coordinate of ZLS ceramic against a black background after thermocycling in different solutions (P<0.000). S: Artificial saliva; T: Tea; OJ: Orange juice; C: Cola

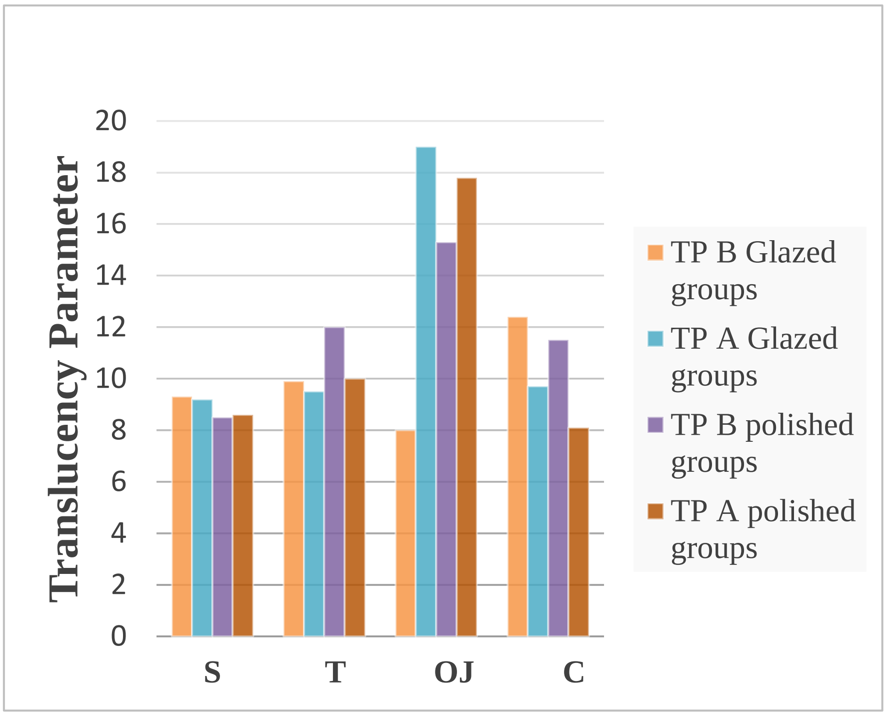

Figure 6. Mean TP values before and after immersion in different solutions. S: Artificial saliva; T: Tea; OJ: Orange juice; C: Cola; B: Before immersion, A: After immersion

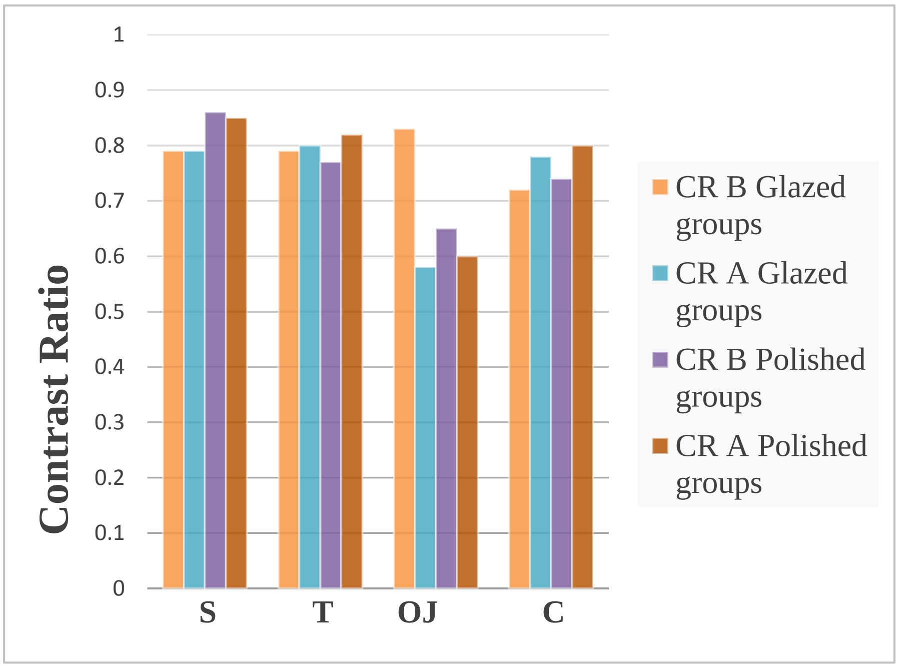

Figure 7. Mean CR values before and after immersion in different solutions. S: Artificial saliva; T: Tea; OJ: Orange juice; C: Cola; B: Before immersion, A: After immersion

Table 3. Results of two-way ANOVA test regarding ΔE of ZLS ceramic against a white background after thermocycling in different solutions

Variation Factor	df	Sum of Squares	Mean of Squares	F	ρ
Solution	3	2036.676	678.892	64.004	<0.001
Method	1	1.126	1.126	0.106	0.745
Solution*method	3	133.619	44.540	4.199	0.008
Total	102	8436.90			

Table 4. Results of two-way ANOVA test regarding ΔE of ZLS ceramic against a black background after thermocycling in different solutions

Variation Factor	*df*	Sum of Squares	Mean of Squares	F	*ρ*
Solution	3	2921.892	973.964	143.475	< 0.001
Method	1	171.073	171.073	25.201	< 0.001
Solution*method	3	523.384	174.461	25.700	< 0.001
Total	102	9512.290			

Table 5. Results of two-way ANOVA test regarding ΔL* of ZLS ceramic against a white background after thermocycling in different solutions

Variation Factor	*df*	Sum of Squares	Mean of Squares	F	*P*
Solution	3	899.967	299.989	38.682	< 0.001
Method	1	3.720	3.720	0.480	0.490
Solution*method	3	90.390	30.130	3.885	0.011
Total	102	4460.280			

Table 6. Results of two-way ANOVA test regarding ΔL* of ZLS ceramic against a black background after thermocycling in different solutions

Variation Factor	*df*	Sum of Squares	Mean of Squares	F	*P*
Solution	3	2545.515	848.505	73.265	< 0.001
Method	1	132.795	132.795	11.466	0.001
Solution*method	3	503.156	167.719	14.482	< 0.001
Total	102	7410.960			

Discussion

Changes were noted in ΔE and translucency following immersion in different solutions. The greatest ΔE and ΔL* were recorded following the immersion of glazed ceramic samples in orange juice, while the immersion of samples in cola increased their opacity and the immersion in orange juice increased the translucency of samples.

Color

The CIELAB system was used in this study since it quantifies color change (ΔE) by measuring the three-dimensional color coordinates. The L* parameter represents lightness (scale of 0 to 100; 0 indicates darkness and 100 indicates lightness). The a* coordinate represents redness (positive values)-greenness (negative values) and the b* coordinate represents yellowness (positive values)-blueness (negative values). This system is highly accurate for the detection of even the slightest color change and has been widely used in previous studies. Therefore, it was selected for use in our study as well (28-31). A white and a black background were also used for the assessment of optical properties because a black background further absorbs the light and better simulates the clinical condition for the anterior teeth, while a white background is used to simulate the clinical condition for the posterior teeth (30). As shown in Tables 4 and 5, the interaction effect of the type of solution and surface treatment on ΔE against a white and a black background was significant ($P=0.008$ and $P<0.001$). The simple main effect analysis showed a significant difference between the two surface treatments following immersion of samples in orange juice ($P=0.006$) and tea ($P=0.036$) against a white background and orange juice ($P<0.001$) against a black background. Although orange juice and tea had significant differences with other solutions in this respect, as shown in Figures 2 and 3, only immersion in orange juice caused a color change beyond the clinically acceptable threshold ($\Delta E<3.3$) (32). The obtained ΔE values were 3.78 and 4.5 against the white and black backgrounds, respectively, which are detectable by the naked eye of a layperson. This finding was in agreement with the study conducted by Dos Santos et al., who reported the greatest color change following immersion of samples in orange juice. According to Hipolito et al, the PH of solutions in which ceramics are immersed affects the magnitude of color change. Although the PH of cola was lower than that among other tested solutions, the color change of ceramics immersed in cola was clinically acceptable. This finding may probably be due to low amounts of yellow pigments in cola (33, 34). In fact, destruction of the superficial ceramic layer occurs following exposure to low PH, leading to dissolution of silica and loss of alkaline ions (35). Thus, the ceramic becomes susceptible to penetration of stains and pigments and subsequent discoloration (34). This type of discoloration of ceramic is extrinsic and occurs as the result of destruction of superficial ceramic layer. Moreover, cola drink contains carbonic and phosphoric acids while orange juice contains citric acid; this can also explain the difference in color change as the result of immersion of ceramics in these two solutions (33). Changes in L* coordinate (ΔL*) shown in Figures 4 and 5 also indicate that the greatest change (reduction) in L* coordinate occurred in glazed ceramics immersed in orange juice.

Translucency

Translucency of a ceramic depends on the passage of light through it, which can change following alterations in the external surface texture or the body mass of ceramic. Translucency can be quantified by calculating the TP, which is defined as color change of a sample with uniform thickness when placed against a white and a black background and is directly correlated with visual assessments (36). The TP value is 100 (CR=0) for a completely transparent material, which indicates CIE LAB color difference between the standard white and black backgrounds. The TP value for an opaque material is equal to 0 (CR=1), which indicates similar color against a white and a black background (28, 37). The translucency of ceramic samples decreased following their immersion in tea and cola solutions in our study; however, this reduction was only significant for glazed and polished samples immersed in cola solution. Also, comparing the glazing and polishing groups revealed that the mean change in TP in the polished group was slightly greater than that in the glazed group. Changes in translucency of ceramic samples immersed in orange juice and artificial saliva were in contrast to those in the other two solutions. The translucency of ceramic samples increased after thermocycling in artificial saliva and orange juice; however, these changes were only significant in orange juice solution for both types of glazed and polished samples. Although this increase was statistically significant in both glazing and polishing groups, it was much greater in the glazed group. The increase in translucency of the samples immersed in artificial saliva and orange juice and its reduction following immersion in tea and cola was in agreement with the findings of Dos Santos et al, who studied lithium disilicate ceramics (IPS Press VEST; Ivoclar Vivadent, AG) thermocycled in five different solutions namely artificial saliva, cola, orange juice, red wine and coffee. They noticed that coffee caused the highest opacity, while orange juice increased translucency after thermocycling (20). The mean change in optical parameters in their study was greater than our study. This may be attributed to the type of ceramic tested. The ZLS ceramic used in our study has a fine, homogenous surface with rod-like crystals with approximate size of 0.5 µm, while lithium disilicate ceramics have needle-like crystals with approximate size of 1.5 µm (38, 39). Similarly, the findings of the study conducted by Tan et al. were in accordance with our study. In their study they used 10 different tooth-colored restorative materials instead of ZLS ceramic and immersed the samples in artificial saliva, vodka, orange juice, tea, cola and coffee. They found that artificial saliva, vodka and orange juice acted differently from other solutions in terms of TP (40). In fact, the inverse changes of translucency in artificial saliva and orange juice compared to the other two solutions may be attributed to different types of color pigments in these solutions with different refractive indexes. These color pigments absorb and scatter the light and increase the opacity of the material. Also, darker solutions such as tea and cola have more pigments than lighter solutions such as artificial saliva and orange juice, which can consequently lead to inverse changes in translucency.

Conclusion

Considering the results of this study, the following conclusions may be drawn: 1) Immersion in orange juice can cause clinically perceivable color change in glazed ZLS ceramics. 2) Immersion in cola decreases the translucency of polished and glazed ZLS ceramics.

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