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# Effects of different surface finishing procedures and staining solution applications on lightness, chroma and hue of zirconia-reinforced lithium silicate glass ceramics

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## Abstract

**Aim:** The aim of this study was to evaluate the differences in lightness (ΔL), chroma (ΔC), and hue (ΔH) of zirconia-reinforced glass ceramic (ZLS) samples of various thicknesses, which underwent different surface finishing procedures, after aging and staining solutions.

**Methodology:** Sixty samples of ZLS blocks were produced in two different thicknesses (12x14x1 mm, n=30; 12x14x1.5 mm, n=30), and different surface treatments were applied to them (mechanical polishing or glaze; n=15). After polishing and glazing, all samples were cleaned using an ultrasonic cleaner for 10 minutes. Color measurements were taken using a spectrophotometer before and after autoclave aging and immersion in staining solutions (tea, coffee, and coke), and color values were calculated using the CIEDE2000 formula. The Kolmogorov-Smirnov, Shapiro, three-way ANOVA, and Tukey HSD tests were used for statistical evaluation.

**Results:** The common effects of surface finishing treatment, staining solution, and thickness interaction on ΔL and ΔC values were found to be statistically significant ($p<0.05$), while the common effect on ΔH values was not found to be significant ($p>0.05$). The ΔL and ΔH values (5.06 ± 1.60 and 2.95 ± 0.61, respectively) were the highest in the groups with 1 mm thickness, mechanical polishing, and immersion in tea solution. The highest ΔC value (4.21 ± 0.35) was noted for the group with 1 mm thickness, mechanical polishing, and immersion in cola solution.

**Conclusion:** Differences in material thickness and the staining solution affected the lightness, hue, and chroma of the ZLS samples. The difference in the surface finishing procedure affected the hue and chroma but not the lightness.

**Keywords:** Color, surface finishing, aging, lithium silicate, glass ceramic, zirconia

## Introduction

All-ceramic materials have superior mechanical properties, such as biocompatibility, low thermal conductivity, inertness, and high wear resistance. Due to their optical properties, such as translucency and transparency, they provide an aesthetic appearance close to natural teeth (1, 2). In recent years, due to high aesthetic expectations and with the development of computer-aided design and computer-aided manufacturing (CAD-CAM) technology, various ceramic materials have emerged and gained popularity due to their high precision and satisfactory aesthetic results (3, 4). In particular, zirconia-reinforced lithium silicate glass ceramic (ZLS), which combines the desirable mechanical properties of zirconia with the optical properties of glass ceramics, is increasingly being used (5, 6). ZLS has a unique structure with a binary microstructure consisting of 10 wt% zirconium and lithium metasilicate and lithium disilicate crystals dissolved in a glassy matrix (7, 8). Currently, ZLS is available in fully crystallized (Celtra Duo and Dentsply Sirona) and semi-crystallized forms (Vita Suprinity and Vita Zahnfabrik) for dental uses. Although both of these forms have similar microstructures (9, 10), a study has shown that semi-crystallized ZLS has higher flexural strength compared to crystallized ZLS (11).

The surface roughness and color stability of prostheses are important factors in ensuring aesthetics. Rough surfaces cause plaque accumulation, resulting in staining of the restoration surface and thus reducing the clinical aesthetic success of the restoration in the long term (12).

Surface finishing and polishing procedures aim to create smooth and shiny surfaces with light-reflecting properties similar to natural teeth (13). Aesthetic CAD-CAM restorations can be prepared using different finishing and polishing processes. Although ceramic restorations are mostly glazed by firing, resin-ceramic CAD-CAM materials can be completed in a single session using the manual polishing technique (14). It has been reported that both glazing and mechanical polishing can be used as surface finishing procedures on zirconia-reinforced lithium silicate (ZLS) ceramics (15). It has also been stated that polishing reduces the surface roughness but does not affect the biaxial bending resistance of ZLS ceramics, although applying glaze after surface wear increases the resistance (16).

Various factors affect the color of the restoration. These include the chemical and physical composition of the material used, its thickness, the angle of incidence of light, and the surface coating of the material (17). The composition and thickness of the material affect the transmission of incident light. The greater the thickness, the less light passes through, which affects the translucency of the restoration. Since restorations made with minimum thickness are more transparent, they allow more light to pass through and provide an appearance close to natural teeth (18, 19).

The Commission Internationale de l´Eclairage (CIE) L*a*b* is a system that defines the color space in 3 coordinates. This system expresses two color scales. In CIE L*a*b* and CIE L*C*h, L* refers to the lightness/darkness, a* refers to the coordinates of the object between red (positive value) and green (negative value), and b* refers to the coordinates of the object between yellow (positive value) and blue (negative value). In CIE L*C*h, L stands for brightness, C stands for saturation, and h stands for hue (20). Although color difference formulas using different parameters were developed in the past to evaluate color differences, today the CIEDE2000 formula has been developed by international color scientists to determine acceptability and perceptibility more appropriately and accurately (21).

In the literature, there is limited data as to the effects upon hue, chroma, and lightness of exposing fully crystallized ZLS ceramics with different thicknesses to hydrothermal aging and staining solutions after surface finishing procedures.

This study aimed to investigate the changes in lightness, chroma, and hue of ZLS ceramics with different thicknesses and different surface finishes after aging in an autoclave and being exposed to various solutions. The study's null hypothesis is that the lightness, chroma, and hue values of ZLS samples would be affected by different thicknesses, surface finishing procedures, and staining solutions.

## Materials and Methods

In this study, ZLS glass ceramic (Celtra Duo) (A2 color, High Translucent) CAD-CAM block material (Dentsply Sirona DeguDent GmbH, Hanau-Wolfgang, Germany) was used. According to G*Power software (Version 3.1.9.7, Heinrich Heine University, Dusseldorf, Germany), when the effect size was taken as f:1.380 and the standard deviation (SD) value was 0.45, the sample size for power was determined as: 0.90 and α:0.05, minimum n=4 for each group. Additionally, the sample size was supported by a previous article (8).

In this study, 60 samples were divided into two groups of different thicknesses (1 and 1.5 mm) (n = 30), and each of the two thickness groups was divided into two groups of different surface finishing procedures (glazing and mechanical polishing) (n = 15). A total of 60 samples (12×14×1 mm, n = 30; 12×14×1.5 mm, n = 30) were produced using a low-speed (150 rpm) precision cutting device (Micracut 201; Metkon. Bursa, Türkiye) with a water-cooled diamond disc. When preparing the samples according to their thickness groups, a tolerance value of ± 0.05 mm was accepted. All samples were polished underwater for 30 s with 400-, 600-, and 800-grit silicon carbide papers (Sankyo Rikagaku Co., Ltd., Saitama, Japan), respectively, to standardize and obtain smooth surfaces. Then, the thicknesses of the samples were measured with a digital caliper (Dental Digital Caliper, Prodent, NJ, USA), ultrasonically cleaned in deionized water for 10 min, and dried.

In the glazing group, the glazing material (Celtra Universal Overglaze, DeguDent GmbH, Hanau-Wolfgang, Germany) was applied in a single layer with a brush to the color measurement surfaces of the samples and fired at 820°C for 60 s (Multimat Touch&Press (Dentsply GmbH).

In the mechanical polishing group, a Startec polishing set was used (Startec, Edenta AG, Hauptstrasse, Switzerland) to polish the samples with purple rubber at 10,000 rpm and yellow rubber at 7000 rpm. The samples were then water cooled for 60 s.

The final thicknesses of the samples were remeasured using a digital caliper (12×14×1 mm; 12×14×1.5 mm). Inappropriate samples were reproduced. All samples were then ultrasonically cleaned for 10 min. Initial color measurements of the samples were made using a spectrophotometer (Vita Easy Shade Advance, Vita Zahnfabrik, Germany) and recorded (Fig. 1). Before each sample measurement, the spectrophotometer was calibrated according to the manufacturer's instructions. The CIEDE L, C, and H values of the samples were measured on black-and-white backgrounds at 10 nm intervals under xenon-filtered D65 illumination at 400–700 nm (wavelength range of visible light). The same researcher measured each sample three times and calculated the averages. Following the initial measurements, all samples were subjected to hydrothermal aging in an autoclave at 134°C and 0.2 MPa (Lisa autoclave, W&H, Austria) for 5 hours. After hydrothermal aging, each group was divided into three staining solution subgroups: tea (Lipton, Unilever, Turkey) (n = 5), coffee (Nescafe Classic, Türkiye) (n = 5), and cola (Coca-Cola, Türkiye) (n = 5).


Figure 1. Color measurements with spectrophotometer

To prepare the coffee solution, 2 g of coffee granules (Nescafe Classic, Turkey) were poured into 200 mL of boiled distilled water. The tea solution was prepared by pouring 3.2 g of tea (Lipton Earl Grey, Türkiye) into 300 mL of boiled distilled water. Each prepared solution was mixed for 5 min. The cola solution came from a 330 mL can of cola (Coca-Cola Company, Türkiye).

The samples were stored in 100 ml of solution in a dark environment for 7 days at 37°C. The solutions were renewed by mixing every 8 hours. The samples were rinsed with distilled water for 5 minutes and dried using paper towels. After the aging and staining processes, color measurements were made as in the first measurements. The CIEDE2000 lightness (ΔL), chroma (ΔC), and hue (ΔH) color differences were calculated according to the following equation (20):

$$\Delta L=\Delta L'/K_LS_L;\quad \Delta C=\Delta C'/K_CS_C;\quad \Delta H=\Delta H'/K_HS_H$$

Where KL, KC, and KH are parametric factors, and ΔL', ΔC', and ΔH' represent lightness, color, and hue differences, respectively. Parametric factors were set to 1. The weighting functions are indicated as SL, SC, and SH, and these adjust the total color difference for variation in the location of the color difference pair in L, a, and b coordinates.

## Statistical analysis

Analyses were performed by using SPSS software (IBM SPSS Statistics version 22.0, IBM Inc., Armonk, NY, USA).

Using the Kolmogorov-Smirnov and Shapiro-Wilk tests, it was determined that the parameters were suitable for normal distribution. The effect of surface finish, staining solution, and thickness interaction on ΔL, ΔC, and ΔH values was evaluated by a three-way ANOVA test, and the Tukey HSD test was used for post hoc analyses. Significance was evaluated at an alpha level of 0.05.

# Results

The joint effects of different surface finishing procedures, staining solutions, and thicknesses on ΔL values are shown in Table 1.

While there was no statistically significant difference in terms of ΔL values between surface finishing procedure groups ($p$=0.186; $p$>0.05), a statistically significant difference was found in terms of ΔL values between different staining solutions ($p$=0.001; $p$<0.05) and thicknesses ($p$=0.001; $p$<0.05).

ΔL values of 1 mm thick samples, which were mechanically polished and immersed in a coffee solution, were found to be statistically significantly higher than the 1.5 mm thick samples ($p$=0.021; $p$<0.05).

The ΔL values of 1.5 mm thick samples that were glazed and exposed to staining solutions (tea, coffee, cola) were found to be statistically significantly higher than the values of 1 mm thick samples ($p$<0.05).

It was determined that the ΔL values of the 1 mm thick samples kept in tea solution and mechanically polished were statistically significantly higher than the values of the samples applied with glaze ($p$=0.001; $p$<0.05). It was determined that the ΔL values of the samples with a thickness of 1.5 mm, immersed in coffee and cola solutions and glazed, were statistically significantly higher than the values of the mechanically polished samples ($p$=0.001; $p$<0.05). The highest ΔL change was detected in the samples that were mechanically polished at 1 mm thickness and kept in tea solution (5.06 ± 1.60), and the lowest value was found in the samples kept in cola solution (1.04 ± 0.76).

Table 1. Evaluation of the joint effect of different surface finishing procedures, staining solutions, and thicknesses on ΔL values

| ΔL | Type III Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Surface finishing procedure | 1.267 | 1 | 1.267 | 1.799 | 0.186 |
| Staining solution | 12.337 | 2 | 6.169 | 8.759 | 0.001* |
| Thickness | 10.35 | 1 | 10.35 | 14.696 | 0.001* |
| Surface finishing procedure/Staining solution | 25.954 | 2 | 12.977 | 18.426 | 0.001* |
| Surface finishing process/Thickness | 38.528 | 1 | 38.528 | 54.705 | 0.001* |
| Staining solution/Thickness | 10.824 | 2 | 5.412 | 7.684 | 0.001* |
| Surface finishing procedure/ Staining solution/Thickness | 4.746 | 2 | 2.373 | 3.369 | 0.043* |

Three-Way ANOVA test *$p<0.05$

The joint effect of surface treatment, staining solution, and thickness interaction on ΔL values was found to be statistically significant ($p=0.043$; $p<0.05$).

In mechanically polished samples with a thickness of 1 mm, a statistically significant difference was detected between the ΔL values obtained after the application of different staining solutions ($p=0.001$; $p<0.05$), and it was observed that the ΔL values of the tea solution were significantly higher than those of the coffee ($p=0.041$) and cola solutions ($p=0.001$) ($p<0.05$). No statistically significant difference was found between the staining solutions in mechanically polished samples with a thickness of 1.5 mm ($p=0.058$; $p>0.05$) (Table 2 and Fig. 2).

While there was no statistically significant difference in terms of ΔL values between the staining solutions in the samples with 1-mm-thick glaze applied ($p=0.064$; $p>0.05$), it was determined that the difference between the 1.5-mm-thick-glazed samples was significant ($p=0.001$; $p<0.05$), and the value of the cola solution was significantly higher than those of the coffee ($p=0.001$) and tea solutions ($p=0.027$) ($p<0.05$).

Table 2. Comparison of ΔL values of different surface finishing procedures, staining solutions, and thicknesses

| ΔL | Thickness | | Coffee Mean ± SD | Tea Mean ± SD | Cola Mean ± SD | *p* |
|---|---|---|---|---|---|---|
| Mechanical polishing | 1 mm | | 3.12 ± 0.70 | 5.06 ± 1.60 | 1.04 ± 0.76 | 0.001* |
| | 1.5 mm | | 1.72 ± 0.84 | 3.26 ± 1.35 | 1.92 ± 0.62 | 0.058 |
| | p | | 0.021* | 0.092 | 0.080 | |
| Glazing | 1 mm | | 2.44 ± 0.75 | 1.20 ± 0.23 | 1.64 ± 1.04 | 0.064 |
| | 1.5 mm | | 3.70 ± 0.39 | 4.18 ± 0.15 | 4.70 ± 0.21 | 0.001* |
| | | p | 0.010* | 0.001* | 0.002* | |
| Mechanical polishing/Glazing | 1 mm | p | 0.176 | 0.001* | 0.328 | |
| | 1.5 mm | p | 0.001* | 0.170 | 0.001* | |

Three-Way ANOVA test *$p<0.05$

The joint effects of different surface finishing procedures, staining solutions, and thicknesses on ΔC values are shown in Table 3.

A statistically significant difference was detected in terms of ΔC values between groups with different surface finishing procedures, staining solutions, and different thicknesses ($p<0.05$), and the joint effect of these three parameters on ΔC values was also found to be statistically significant ($p=0.001$; $p<0.05$). A detailed analysis of the results is shown in Table 4 and Figure 3.

A statistically significant difference was detected in the ΔC values of the mechanically polished samples produced with a thickness of 1 mm ($p=0.001$; $p<0.05$), and the ΔC values of the samples immersed in cola solution were found to be significantly higher than the coffee ($p=0.001$) and tea solutions ($p=0.012$) ($p<0.05$).

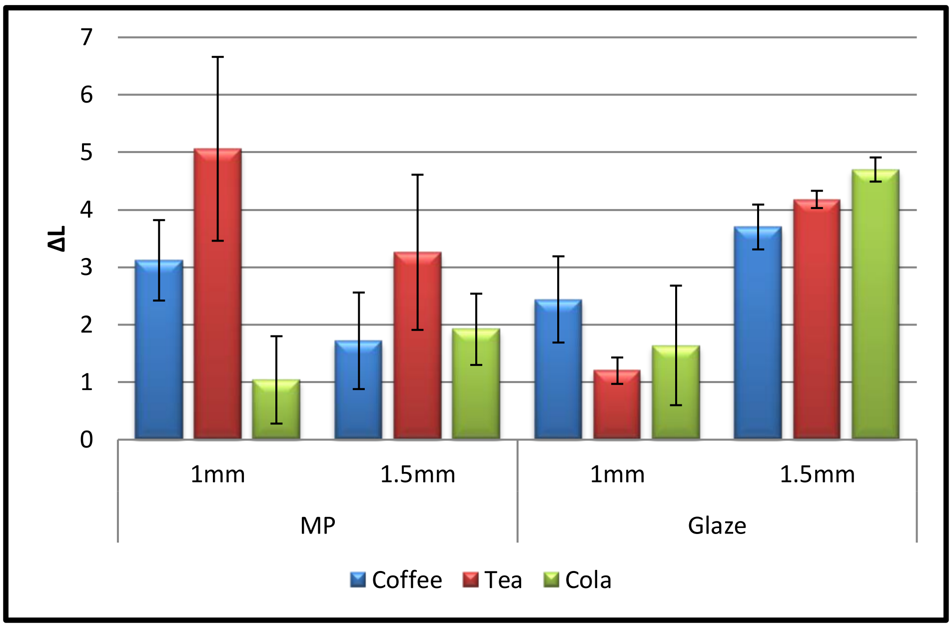


Figure 2. ΔL values for different surface finishing processes, staining solutions, and thicknesses

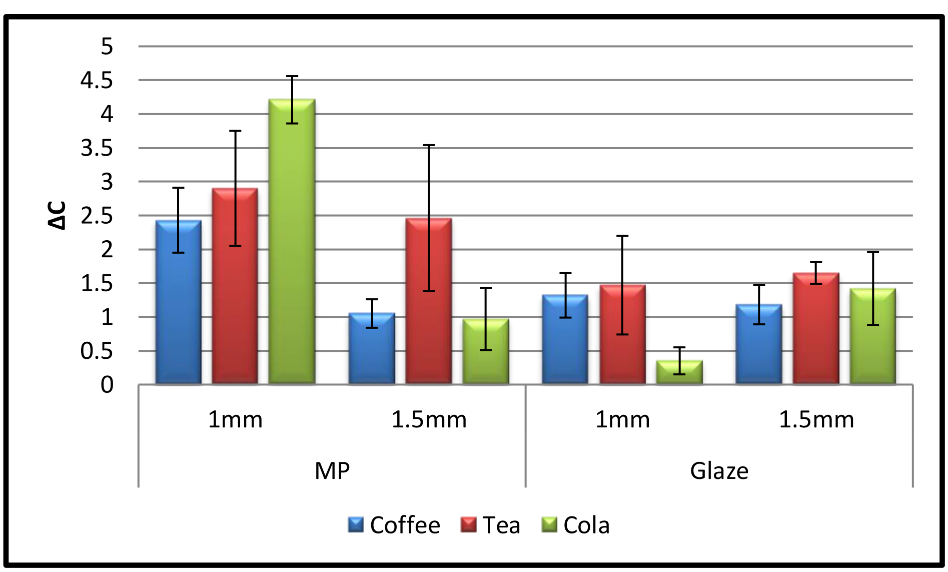


Figure 3. ΔC values for different surface finishing processes, staining solutions and thicknesses

Table 3. Evaluation of the joint effect of different surface finishing procedures, staining solutions, and thicknesses on ΔC values

| ΔC | Type III Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Surface finishing procedure | 18.321 | 1 | 18.321 | 61.3 | 0.001* |
| Staining solution | 3.987 | 2 | 1.993 | 6.67 | 0.003* |
| Thickness | 6.45 | 1 | 6.45 | 21.582 | 0.001* |
| Surface finishing procedure/Staining solution | 3.698 | 2 | 1.849 | 6.186 | 0.004* |
| Surface finishing procedure/Thickness | 15.798 | 1 | 15.798 | 52.857 | 0.001* |
| Staining solution/Thickness | 2.342 | 2 | 1.171 | 3.917 | 0.027* |
| Surface finishing procedure/Staining | 9.691 | 2 | 4.845 | 16.212 | 0.001* |

Three-Way ANOVA test *$p$<0.05

Table 4. Comparison of ΔC values of different surface finishing procedures, staining solutions, and thicknesses

| ΔC | Thickness | | Coffee Mean ± SD | Tea Mean ± SD | Cola Mean ± SD | p |
|---|---|---|---|---|---|---|
| Mechanical polishing | 1 mm | | 2.43 ± 0.48 | 2.90 ± 0.85 | 4.21 ± 0.35 | 0.001* |
| | 1.5 mm | | 1.05 ± 0.21 | 2.46 ± 1.08 | 0.97 ± 0.46 | 0.008* |
| | p | | 0.001* | 0.492 | 0.001* | |
| Glazing | 1 mm | | 1.32 ± 0.33 | 1.47 ± 0.73 | 0.35 ± 0.20 | 0.006* |
| | 1.5 mm | | 1.18 ± 0.29 | 1.65 ± 0.16 | 1.42 ± 0.54 | 0.168 |
| | | p | 0.502 | 0.615 | 0.009* | |
| Mechanical polishing/Glazing | 1 mm | p | 0.003* | 0.022* | 0.001* | |
| | 1.5 mm | p | 0.458 | 0.171 | 0.204 | |

Three-Way ANOVA test *$p$<0.05

In the 1.5 mm thick group, a statistically significant difference was detected in terms of ΔC values between the staining solutions of the mechanically polished samples ($p$=0.008; $p$<0.05), and the ΔC values of the tea solution were determined to be significantly higher than the values of coffee ($p$=0.018) and cola solutions ($p$=0.013) ($p$<0.05).

A statistically significant difference was found in terms of ΔC values between the coloring solutions of the glazed samples produced with a thickness of 1 mm ($p$=0.006; $p$<0.05), whereas no significant difference could be detected in the 1.5 thick group ($p$=0.168; $p$>0.05).

The difference in ΔC values between samples of different thicknesses, applied to mechanical polishing and immersed in coffee and cola solutions, was found to be statistically significant ($p$=0.001; $p$<0.05). In the glaze group, a statistically significant difference was detected between samples of different thicknesses immersed in cola solution ($p$=0.009; $p$<0.05), but no significant difference was found in the coffee ($p$=0.502; $p$>0.05) and tea solution groups ($p$=0.615; $p$>0,05).

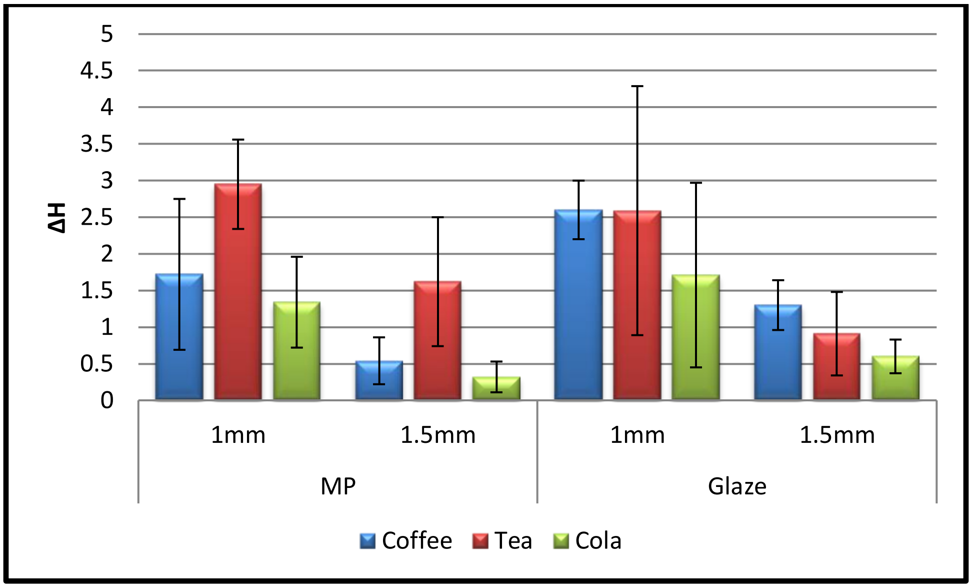


**Figure 4.** ΔH values for different surface finishing processes, staining solutions, and thicknesses

The ΔC values of the 1 mm thick mechanically polished samples kept in coffee ($p$=0.003; $p$<0.05), tea ($p$=0.022; $p$<0.05), and cola solutions ($p$=0.001; $p$<0.05) were found to be statistically significantly higher than the glazed samples. In terms of ΔC values; it was determined that the highest value was in the 1 mm thick samples that were mechanically polished and immersed in cola solution after hydrothermal aging (4.21 ± 0.35), and the lowest value was in the 1.5 mm thick samples that were mechanically polished and immersed in coke solution (0.97 ± 0.46).

It was determined that there were statistically significant differences in terms of ΔH values between groups with different surface finishing procedures, staining solutions, and different thicknesses ($p$=0.033, $p$=0.001, $p$=0.001; $p$<0.05), and the joint effect of these three parameters on ΔH values was not found to be statistically significant ($p$=0.960; $p$>0.05) (Table 5). Detailed analyses of different surface finishing procedures, staining solutions, and thicknesses in terms of ΔH values are shown in Table 6 and Figure 4.

**Table 5.** Evaluation of the joint effect of different surface finishing procedures, staining solutions, and thicknesses on ΔH values

| ΔH | Type III Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Surface finishing procedure | 0.628 | 1 | 0.628 | 0.955 | 0.033* |
| Staining solution | 10.555 | 2 | 5.277 | 8.019 | 0.001* |
| Thickness | 24.186 | 1 | 24.186 | 36.753 | 0.001* |
| Surface finishing procedure/Staining solution | 4.708 | 2 | 2.354 | 3.577 | 0.036* |
| Surface finishing procedure/Thickness | 0.132 | 1 | 0.132 | 0.200 | 0.57 |
| Staining solution/Thickness | 0.491 | 2 | 0.245 | 0.373 | 0.691 |
| Surface finishing procedure/ Staining solution/Thickness | 0.053 | 2 | 0.027 | 0.040 | 0.960 |

Three-Way ANOVA test *$p$<0.05

Table 6. Comparison of ΔH values of different surface finishing procedures, staining solutions and thicknesses

| | | | Coffee | Tea | Cola | |
|---|---|---|---|---|---|---|
| ΔH | Thickness | | Mean ± SD | Mean ± SD | Mean ± SD | p |
| Mechanical polishing | 1 mm | | 1.72 ± 1.03 | 2.95 ± 0.61 | 1.34 ± 0.62 | 0.017* |
| | 1.5 mm | | 0.54 ± 0.32 | 1.62 ± 0.88 | 0.32 ± 0.21 | 0.007* |
| | p | | 0.040* | 0.025* | 0.008* | |
| Glazing | 1 mm | | 2.60 ± 0.40 | 2.59 ±1.70 | 1.71 ± 1.26 | 0.451 |
| | 1.5 mm | | 1.30 ± 0.34 | 0.91 ± 0.57 | 0.60 ± 0.23 | 0.056 |
| | | p | 0.001* | 0.092 | 0.122 | |
| Mechanical polishing/Glazing | 1 mm | p | 0.110 | 0.677 | 0.581 | |
| | 1.5 mm | p | 0.007* | 0.170 | 0.077 | |

Three-Way ANOVA test *$p$<0.05

In mechanically polished samples with 1 mm and 1.5 mm thickness, a statistically significant difference was detected between the ΔH values obtained after the application of different staining solutions ($p$=0.017, $p$=0.007; $p$<0.05), and it was observed that the tea solution ΔH values were significantly higher in both thicknesses ($p$=0.025; $p$<0.05). The ΔH values of the 1 mm thick samples, which were glazed and immersed in coffee solution, were found to be statistically significantly higher than the ΔH values of the 1.5 mm thick samples ($p$=0.001; $p$<0.05). The ΔH values of the glazing procedure were found to be statistically significantly higher than the ΔH values of the mechanical polishing procedure from the samples kept in a 1.5 mm thick coffee solution ($p$=0.007; $p$<0.05). In terms of ΔH values; it was determined that the highest value was in the samples that were mechanically polished with a thickness of 1 mm and immersed in tea solution (2.95 ± 0.61), and the lowest value was in the samples that were mechanically polished with a thickness of 1.5 mm and immersed in cola solution (0.32 ± 0.21).

## Discussion

When the study findings were evaluated, different material thicknesses and staining solutions affected the lightness, hue, and chroma of the ZLS material. While the difference in surface finishing procedure affected the hue and chroma, it did not affect the lightness. Therefore, the null hypothesis of the study was partially rejected.

Material thickness may cause color changes in full ceramic materials. It has been reported that the color changes observed after thermal cycle application with coffee in 0.7 mm and 1 mm thick ZLS materials are within clinically acceptable limits, while the color change of the 0.5 mm thick ZLS material is above this limit (21). Additionally, another study reported that increasing the thickness of the material reduced coloration (22). This study found statistically significant differences between ΔL, ΔC, and ΔH values of mechanically polished 1 mm thick samples after applying different staining solutions ($p$<0.05). Statistically significant differences were found between the ΔC values of the glazed 1 mm thick samples after applying different staining solutions, but no difference was found between the ΔL and ΔH values ($p$<0.05). While there was a significant difference between the ΔL values of the glazed 1.5 mm thick samples after the application of different staining solutions ($p$<0.05), the differences between the ΔC and ΔH values were not found to be significant (p>0.05).

It has been reported that mechanical polishing and glazing procedures can be used in the surface finishing of ZLS restorations (23) and that neither application has a significant effect on the color change of the ZLS material (15, 24). In a study conducted on the effectiveness of different techniques in ensuring the surface gloss of ZLS and lithium disilicate (LS2), it was shown that 60 seconds of manual polishing and glaze application produced successful results. However, it was stated that ZLS samples have higher polishability than LS2 samples (25). In this study, while the effect of different surface finishing treatments on ΔL values was not found to be statistically significant (p>0.05), its effect on ΔC and ΔH values was found to be significant ($p$<0.05).

It has been stated that the color changes seen in the restorations are related to the nutritional habits of the patients and the beverages they consume (26). Consumption of tea, coffee, and cola is quite common. In most studies evaluating color changes, it is seen that they focus on the color changes observed after the restoration materials are kept in coffee, tea, and cola solutions (24, 27, 28). In the study, the effects of ZLS material with different thicknesses and surface treatments on the lightness, chroma, and hue after hydrothermal aging and immersion in tea, coffee, and cola solutions were examined.

Hydrothermal aging for the accelerated aging test is a method used for the color changes of dental materials. One-hour autoclave aging corresponds to 3-4 years of routine clinical use (29). In the study, all samples were exposed to hydrothermal aging in a steam autoclave at 134°C, 0.2 MPa for 5 hours (corresponds to 15-20 years of clinical use).

Although there are studies in the literature showing that coffee causes more color change than tea (30, 31), there are also studies showing that tea causes more color change than coffee (32). In a study, it was reported that both polishing and glazing applications caused clinically acceptable color changes in ZLS in samples where thermal cycling with coffee was applied (33). In this study, when the ΔL values of the 1 mm thick mechanically polished samples and the glazed groups were compared, a significant difference was found in the tea solution group, and the samples with 1.5 mm thickness, significant differences were found in the coffee and coke solution groups ($p<0.05$). When the ΔC values were compared, significant differences were found in the groups with a thickness of 1 mm ($p<0.05$), but no significant difference was found in the sample groups with a thickness of 1.5 mm ($p>0.05$). When the ΔH values were compared, no significant differences were found in the groups with a thickness of 1 mm ($p>0.05$), and only significance was found in the group immersed in the coffee solution with a thickness of 1.5 mm ($p<0.05$).

The L value in the CIEDE 2000 formula is proportional to the value in the Munsell color system. The L value indicates the lightness-darkness or black-white character of the color. Increasing the L value is interpreted as increasing the brightness of the object. As the L value decreases, it is expressed as less bright, and as it increases, it is expressed as more bright. The C parameter in the CIEDE2000 formula shows the chroma value, that is, the density, of the object. An increase in the C value indicates an increase in color intensity. The H values in the formula show the hue value, that is, the color tone, of the object. A decrease or increase in the H value indicates that the color tone has changed (34). The utilization of visual color threshold values is integral in assessing clinical and investigative outcomes in dentistry, particularly concerning the perceptual and/or acceptable discernment of color differences. Typically, a color variance encompasses variations in lightness, chroma, and hue concurrently. Therefore, these three parameters are combined, and potential interactions necessitate thorough examination (34-36). In the literature, 50% CIEDE2000 acceptability threshold values for ΔL, ΔC, and ΔH color differences are expressed as ΔL = 2.92, ΔC = 2.52, and ΔH = 1.90 (37). In terms of ΔL values, samples with a thickness of 1 mm that were mechanically polished and immersed in coffee and tea solutions were found to be above the acceptable limit. In terms of ΔC values, samples with a thickness of 1 mm mechanically polished and immersed in cola and tea solution were found to be above the acceptable limit. In terms of ΔH values, 1 mm thick samples that were mechanically polished and immersed in tea solution and 1 mm thick samples that were glazed and kept in coffee and tea solution showed values above the acceptable limit.

This study has some limitations. The most important of these is that the study was conducted in vitro. Other limitations include the use of single color (A2) and only highly translucent ZLS blocks. In future studies, there is a need to carry out studies using different CAD-CAM materials and blocks with different colors and translucency, considering these limitations.

## Conclusion

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

1. While the difference in surface finishing procedure does not affect the lightness of the ZLS material, material thickness, and staining solutions affect the lightness.
2. Differences in material thickness, surface finishing procedure, and staining solutions affect the chroma and hue of the ZLS material.
3. The joint effect of these three parameters affects lightness, chroma, and hue.
4. The highest lightness and hue change was observed in samples produced with 1 mm thickness, mechanically polished, and immersed in tea solution, while the highest chroma change was seen in samples with 1 mm thickness, mechanically polished, and immersed in cola solution.

## Disclosures

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Conception – C.K.; Design – C.K.; Supervision – C.K; Materials – C.K.; Data Collection and/or Processing – C.K.; Analysis and/or Interpretation – C.K.; Literature Review – C.K.; Writer –C.K.; Critical Review – C.K.

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