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The effects of cement thickness and cement shade on the final color of lithium disilicate crowns

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PURPOSE. The aim of this study is to evaluate the effect of resin cement color, cement thickness, and thermocycling on the final color of monolithic lithium disilicate crowns. **MATERIALS AND METHODS.** A total of ninety prepared central incisors of typodont teeth were restored with lithium disilicate crowns which have different cement thicknesses (40 µm, 80 µm, and 120 µm) and cement shades (clear, yellow, and white). Color parameters of restorations were measured with a spectrophotometer in three different steps 1) before cementing 2) after cementing and 3) after thermocycling with 10000 cycles. Color differences (ΔE_{00}) were calculated with the CIEDE2000 formula and evaluated according to perceptibility (0.8) and acceptability (1.8) thresholds. The ΔE_{00} data were analyzed by using two-way ANOVA before and after thermocycling ($\alpha = .05$). **RESULTS.** There was no interaction between the cement shade and the cement thickness factors. After cementation, the mean ΔE_{00} was under the perceptibility threshold in the group of 40 µm cement thickness and clear cement while it was between the perceptibility and acceptability thresholds ($0.8 < \Delta E_{00} < 1.8$) for all other groups. After thermocycling, the ΔE_{00} values were between the perceptibility and acceptability thresholds for all experimental groups. Although there were no significant differences among the groups, thermocycling increased the color difference values. **CONCLUSION.** The cementation of restorations with clear, yellow, and white resin cements resulted in color differences with uncemented restorations except for the group cemented with clear cement in 40 µm cement thickness. All study groups revealed perceptible color change after thermocycling. [J Adv Prosthodont 2023;15:93-100]

KEYWORDS
Aging; Ceramics; CAD-CAM; Color

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INTRODUCTION

Material properties and manufacturing techniques of monolithic ceramics have been improved over the last few years. Especially with the improvements in microstructure and manufacturing process of glass ceramics, these materials get popularity with their highly esthetic and adequate mechanical properties which allow them to be used in a wide range of indications.[1,2] Lithium disilicate is one of the prominent materials in glass ceramics. This material either can be in a block form (partially or fully crystallized) and produced by milling in a CAD-CAM unit or can be in a pressable ingot form and produced by heat-pressing following the lost wax technique.[1,2] With the advances in CAD-CAM technology and time-consuming workflow, CAD-CAM-produced lithium disilicate restorations moved to the forefront.

The production process and microstructure of the material often change according to its manufacturer. The material "IPS e.max CAD (Ivoclar Vivadent)" is in a partially crystallized state and composed of 40% lithium metasilicate crystals which are 0.2 to 1 µm size and platelet-shaped and set in a glassy phase along with lithium disilicate nuclei.[1] The unique microstructure of the material provides easier milling and less bur wear.[1] After the milling process, the material is fully crystallized and heat treatment transforms it to lithium disilicate glass-ceramic with 70% fine-grain lithium disilicate crystals.[1,2] During the last heating step, the restoration undergoes 0.2% linear shrinkage; however, this shrinkage does not cause discrepancies and is often compensated by the CAD software.[2] The main shade of the CAD-CAM blocks is controlled by dispersing staining ions in the glassy matrix and different degrees of translucency arising from the size and distribution of the crystals.[2,3]

To measure the color difference, color systems and concepts of numerical color differences were developed by the Committee on Illumination (CIE).[4,5] The color differences can be calculated by using both CIELab and CIEDE2000 formulas. Using CIEDE2000 has been widely considered because it provided a better fit for evaluating the color difference, perceptibility, and acceptability thresholds.[5-7] The color stability of the restorations is critical for long-term success, especially for esthetical reasons.[8] Thus, acceptability and perceptibility thresholds are important for evaluating undesirable color differences. Although lithium disilicate ceramics have low color difference potential, they are subjected to many environmental factors in the oral cavity that can lead to the esthetic failure of these restorations.[8] Also, cement related factors have an influence on the final esthetic result and the color of the restoration.[2] Studies regarding CAD-CAM produced monolithic lithium disilicate restorations have investigated the surface characteristics, surface finishing, and aging procedures.[6,9-11] The effect of cement was also investigated;[12,13] however, studies which focused on the cement thickness were limited.

The purpose of the present study is to evaluate the effects of cement thickness and cement shade on the final color of lithium disilicate crowns before and after thermocycling. The research hypothesis was that the cement thickness and cement shade would be effective on the final color of lithium disilicate crowns.

MATERIALS AND METHODS

A total of ninety lithium disilicate crowns were prepared and divided to nine experimental groups according to cement thickness (40 µm, 80 µm, and 120 µm) and cement shade (clear, yellow, and white). IPS e.max CAD HT (high translucency) lithium disilicate blocks (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein) and self-adhesive resin cement (Maxcem Elite; Kerr, Bioggio, Switzerland) with three different shades (clear, yellow, and white) were used in the present study (Table 1).

A prepared right central incisor typodont tooth (ANA-4 Z; frasaco GmbH, Tettnang, Germany) was inserted into a maxillary silicone mold (ANA-4 G; frasaco GmbH, Tettnag, Germany) and poured in gypsum to obtain study model (Fig. 1A). The model with the prepared typodont tooth was scanned (D1000; 3Shape, Copenhagen, Denmark) and a virtual model was created. A monolithic ceramic crown was designed (Fig. 1B) and three different cement thicknesses (40 µm, 80 µm, and 120 µm) were determined on the virtual model. The labial thickness of the crown was set as 1.5 mm. All restorations in the experimen-

Table 1. Materials used in the study

Material	Brand and manufacturer	Content	
Lithium disilicate CAD-CAM block	IPS e.max CAD HT; Ivoclar Vivadent AG, Schaan, Liechtenstein		Wt%
		SiO_2	57-80
		Li_2O	11-19
		K_2O	0-13
		P_2O_5	0-11
		ZrO_2	0-8
		ZnO	0-8
		Al_2O_3	0-5
		MgO	0-5
		Colouring oxides	0-8
Self-adhesive resin cement (clear, yellow, white)	Maxcem Elite; Kerr, Bioggio, Switzerland	Resin matrix: bis-phenol-A-diglycidylmethacrylate-glycero-phosphoric acid dimetacrylate Filler: 67 wt%, 3.6 µm particle size barium aluminoborosilicate glass	
Hydrofluoric acid	IPS Ceramic Etching Gel; Ivoclar Vivadent AG, Schaan, Liechtenstein	< 5% hydrofluoric acid	
Silane coupling agent	Calibra Silane Coupling Agent; Dentsply Sirona, Bensheim, Germany	methacryloxypropyl trimethoxysilane (MPTMS), ethanol, acetone	

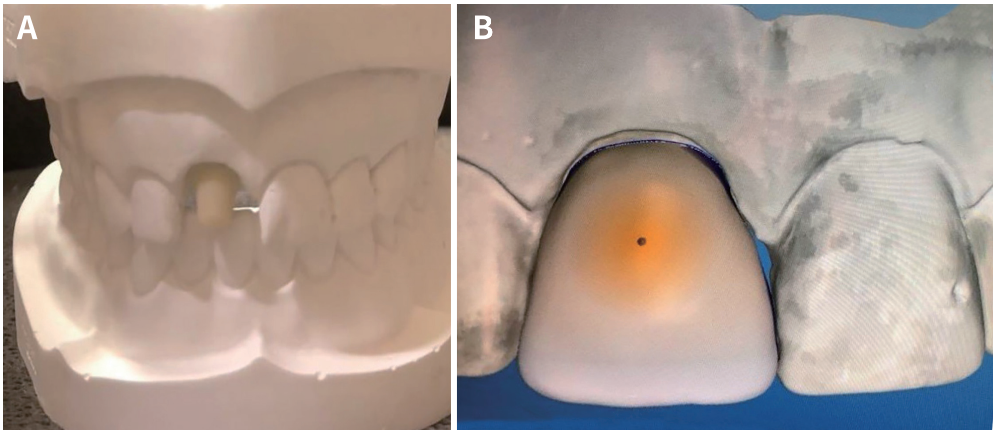

Fig. 1. (A) Prepared tooth on the study model, (B) Digital design of the restoration.

tal groups were milled by using CAD-CAM device (CAD/CAM milling machine CORiTEC® 250i Loader PRO; imes-icore GmbH, Eiterfeld, Germany) in the same design from high translucent lithium disilicate glass-ceramic (IPS e.max CAD HT; Ivoclar Vivadent, Schaan, Liechtenstein). The milled crowns were crystallized and glazed according to the manufacturer's recommendations. Lithium disilicate crowns were steam cleaned and etched with 5% hydrofluoric acid for 20 seconds. Then, specimens were ultrasonically cleaned for 10 minutes and air dried. After cleaning the intaglio surfaces of the crowns, silane was applied for 60 seconds. Contamination was avoided during cementation. Resin cement was mixed according to the instructions of the manufacturer and crowns were cemented to the phantom teeth. Excess cement was removed and resin cement was polymerized by using an LED light device (Radii Plus LED curing light, SDI, Bayswater Victoria, Australia) for 20 seconds from each side. Then, specimens were subjected to 10000 thermal cycles in a thermocycling device (MTE 101; MOD Dental, Esetron Smart Robotechnologies, Ankara, Türkiye). Thermocycling was performed in 5°C - 55°C water for 30 seconds dwell time in each bath.

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Color parameters were measured in three different steps 1) before cementing the specimens, 2) after cementing the specimens, and 3) after thermal cycling. Color differences were calculated (ΔE_{00}-1 and ΔE_{00}-2). The specimens were cleaned ultrasonically in distilled water for 10 minutes before the measurements. The specimens' colors were measured according to the CIELab color scale under a standard illuminant D65 and on a neutral gray background using a dental spectrophotometer (Spectrophotometer CM-2600d; Konica Minolta, Tokyo, Japan). The spectrophotometer was calibrated by using a white tile before each measurement. All measurements were performed by the same investigator in the same conditions. Color differences were calculated by using the CIEDE2000 formula after thermal cycling. Color differences of the lithium disilicate ceramics were evaluated according to perceptibility (0.80) and acceptability (1.8) thresholds (ISO/TR 28642:2016).[7,14,15]

The normality of the color difference data was evaluated using the Shapiro-Wilk test, and the variances' homogeneity was tested with the Levene test. The assumptions of the ANOVA were tested and the ΔE_{00} data were analyzed by using two-way ANOVA (cement shade and thickness were the independent variables) before (ΔE_{00}-1) and after (ΔE_{00}-2) thermal cycling. Results were considered significant for $\alpha = .05$.

RESULTS

The mean color difference values and their standard deviations are shown in Table 2 and Table 3. There was no interaction between the cement shade and the cement thickness factors for both mean color difference values (P = .596) after cementation and after thermocycling (P = .939). When the color difference values were examined in the experimental groups after cementation, the mean value was under the perceptibility threshold (0.8) in the 40 µm cement thickness group which was cemented with clear shade. While, for all other groups, the color difference values were between the perceptibility and acceptability thresholds ($0.8 < \Delta E_{00} < 1.8$). When the color difference values were examined in the experimental groups after thermocycling, the color difference values were between the perceptibility and acceptability thresholds ($0.8 < \Delta E_{00} < 1.8$) for all experimental groups. Although there were no significant differenc-

Table 2. Mean color difference values (±SD) after cementation (ΔE_{00}-1)

Mean (±SD) n = 10	Cement Thickness		
Cement Shade	40 µm	80 µm	120 µm
Clear	0.60 (± 0.27)	0.82 (± 0.39)	0.82 (± 0.39)
Yellow	1.02 (± 0.35)	0.98 (± 0.24)	0.98 (± 0.24)
White	0.86 (± 0.30)	0.94 (± 0.35)	0.94 (± 0.35)
P value (color × thickness)		.596	

SD: Standard deviation

Table 3. Mean color difference values (±SD) after thermocycling (ΔE_{00}-2)

Mean (±SD) n = 10	Cement Thickness		
Cement Shade	40 µm	80 µm	120 µm
Clear	1.09 (± 0.68)	1.08 (± 0.27)	1.24 (± 0.51)
Yellow	1.13 (± 0.57)	1.44 (± 0.98)	1.35 (± 0.47)
White	1.30 (± 0.63)	1.26 (± 0.55)	1.15 (± 0.32)
P value (color × thickness)		.939	

SD: Standard deviation

es among the experimental groups, it was observed that thermocycling increased the color difference values.

DISCUSSION

The present study aimed to investigate the effects of cement thickness and cement shade on the final color of lithium disilicate crowns. The research hypothesis was that the cement thickness and cement shade would be effective on the final color of lithium disilicate crowns. The results have shown that the cement thickness and cement shade did not significantly affect the final color of lithium disilicate crowns. Thus, the research hypothesis was rejected. However, increasing the cement thicknesses resulted in higher color difference values above the perceptibility threshold and thermocycling increased these color difference values.

In the present study, high translucent partially crystallized lithium disilicate ceramic blocks were used to fabricate anterior monolithic crowns. The material's microstructure provides mechanical strength and high translucency, improving the restorations' esthetics. The esthetical properties of the high translucent lithium disilicate ceramics may be affected by several factors. Cement thickness and cement color, which are the crucial factors for the final color of lithium disilicate restorations can be controlled by the clinicians. Studies have stated that the color of the substructure and cement have a minimal influence on the final restoration color of glassy matrix ceramics when the ceramic thickness is 2 mm or more, while these factors alter restoration color if the thickness of the ceramic is 1 mm.[16-18] In the present study, the ceramic thickness was chosen as 1.5 mm in buccal surface according to the manufacturer's recommendations for a satisfying translucency of an anterior restoration.

The final color of the ceramic restorations is not only influenced by the microstructure or thickness of the ceramic, but also by other factors, such as the luting cement shade.[16,18-20] In this study, three cement colors were evaluated and no significant differences were found for ΔE_{00} values of specimen groups cemented with different shades of a brand of resin cement. Even though the statistical difference was not observed, the translucent cement revealed the lowest ΔE_{00} values for each cement thickness group. Especially 40 µm group showed a ΔE_{00} of 0.6, which is lower than the perceptibility threshold. Luting the restorations without the need of masking the abutment tooth with translucent resin cement with a thin cement layer can be suggested. Many studies reported that color differences were detected when a restorative material was cemented between different shades of a resin cement of one manufacturer as well as between the same shades of different manufacturers.[21-27] Therefore, they stated that resin cement shade is crucial for an esthetic outcome of ceramic restorations as well as ceramic type and color. The different findings of this study from the literature evaluating the effect of resin cement color on the final ceramic color may arise from the parameters of study designs. It is known that the translucency of glassy matrix ceramics is affected by material thickness as well as structural properties.[16,17] Previous studies used e.max CAD specimens to investigate the effect of resin cement color on restoration's final color, using ceramic thickness changing between 0.9 and 1.2 mm.[21,23,25,26] The ceramic thickness of 1.5 mm may lead to significant differences between different cement colors. On the other hand, crown-shaped specimens of this study and differences between commercially available cements may affect the results.

Another effective variable in manipulating the color of ceramic restorations is the thickness of the resin cement. However, there is little research on the influence of cement thickness on the final color and color stability of esthetic restorations.[18,28] Vichi *et al*.[18] evaluated the effects of cement thickness on the color of lithium disilicate glass ceramic. They reported that cement thickness (0.1 or 0.2 µm) had little effect on the final colors of restorations in agreement with the present study. On the other hand, a study by Niu *et al*.[28] evaluated the masking ability of different resin cements and CAD-CAM lithium disilicate ceramics on a metallic substructure. They reported that white opaque cements are more effective in masking the metal alloy and increasing the cement thickness above 100 µm did not improve the shade match. Considering these findings, a clinical suggestion can be made to avoid increasing the cement thick-

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ness, which may lead to microleakage or polymerization-related problems.[19]

To assess the color stability of the dental restorations under simulated clinical conditions, artificial aging variations including ultraviolet light, temperature, or humidity have been used. Thermocycling is commonly used *in vitro* aging method that simulates thermal variations in the oral cavity in a humid environment.[11] However, no standardized protocol has been established for the number of cycles for the aging of dental restorative materials. The initiator study on the thermal cycling of dental materials was referred to for selecting the number of cycles in the present study.[29] Color stability of lithium disilicate ceramics after thermocycling has been previously investigated.[8,11] These studies showed that thermocycling generates color changes in lithium disilicate ceramics. However, color changes were below human perceptibility or acceptability thresholds.[8,11,30] Palla *et al*.[11] also reported that CAD-CAM produced lithium disilicate (IPS e-max CAD) was more color stable than IPS e-max CERAM, and IPS e-max Press after thermocycling. Thermocyling was also performed with an accompanying staining solution, such as coffee, tea, coke, red wine, and lithium disilicate and zirconia reinforced lithium silicate ceramics showed acceptable color changes.[6,31-33] However, previous studies have some differences in methods (color measurement device, color difference formula, thermal cycles, and immersion beverages) from this study; therefore, making a direct comparison with color difference values is not possible.

The color change of ceramic restorations is also related to in the resin cement.[13,16,17] In the current study, standard ceramic specimens differ in resin cement thickness and color aged using thermocycling. The color evaluation revealed that yellow cement showed the highest color change after aging at 80 and 120 µm thickness although a statistical difference was not found. It has been reported that aging can affect cement color by shifting to yellow due to water absorption by components such as triethyleneglycol dimethacrylate and 2,2-bis (4-[2-hydroxy-3-methacryloyloxy] phenyl) propane. Color may also be influenced in time from uncured camphorquinone depending on the polymerization rate as previously mentioned.[23] Regarding the highest color difference of yellow cement after cementation, a clinical recommendation on the careful use of yellow resin cement can be made.

This study has some limitations. The aging procedure of 10000 thermal cycles, which simulates approximately 1 year of function in the oral cavity, represents a limited lifespan for prosthetic restoration. Tests simulating longer time of function would be beneficial. Thermal cycling was conducted in water in the present study. Further research should investigate the color stability of cemented ceramic restorations using other contributing factors such as coloring beverages, sunlight, saliva, and smoking. High translucent ceramic materials have a higher risk in terms of color difference. It is important to predict the color change at the time of cementation of a ceramic prosthesis and after aging in the oral environment. In future studies, the color change of different resin cements and different translucent ceramics should be evaluated. The color change in the cement layer is also an important factor to be separately evaluated.

CONCLUSION

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

The cementation of restorations with clear, yellow, and white resin cements resulted in color differences except for the group cemented with clear cement in 40 µm cement thickness. All study groups revealed perceptible color change after thermal cycling.

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