Original Article

Influence of Ceramic Translucency, Ceramic Thickness, and Resin Cement Shades on The Color of CAD-CAM Lithium Disilicate Veneers

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Abstract

This study aimed to evaluate the effect of ceramic translucency, ceramic thickness, and cement color on the final optical color of a CAD-CAM lithium disilicate ceramic. A total of 180 ceramic specimens were prepared into two thicknesses, 0.5 and 1.0 mm, from high translucency (HT), medium translucency (MT), and low translucency (LT) CAD-CAM lithium disilicate ceramics (IPS e.max CAD; Ivoclar Vivadent) in shade A1. Substrates were fabricated from resin composite in shade A3. Two shades of light-cure resin cement, neutral and light plus (Variolink Esthetic LC; Ivoclar Vivadent), were used for cementation, whereas glycerine was used for the control groups. CIE L*a*b* color coordinates for each combination were measured via a spectrophotometer (Ultrascan Pro, Hunter Lab). The data were calculated using the CIEDE2000 (ΔE_{00}) formula to find color differences and analyzed with three-way ANOVA and the Bonferroni post-hoc multiple comparison tests ($\alpha = 0.05$). Additionally, ΔE_{00} values were evaluated by comparing the perceptibility threshold (PT) and the acceptability threshold (AT) of 0.8 and 1.8, respectively. The results revealed that ceramic translucency, ceramic thickness, and cement color had statistically significant effects on the final colors of the ceramic veneers. Mean ΔE_{00} values fell within the acceptable range for most groups, except those using 0.5 mm HT ceramics with light plus cement, which was also the highest mean ΔE_{00} value (1.85 ± 0.14). The lowest mean ΔE_{00} value was obtained from a group using 1.0 mm LT ceramics with light plus cement (0.35 ± 0.15). In conclusion, ceramic translucency, ceramic thickness, and cement color influenced the final color of lithium disilicate veneers. In most of the study groups, a decrease in ceramic translucency and an increase in ceramic thickness lessened color differences. A white, more opaque shade cement provided better color modification and brightness enhancement than a highly translucent shade cement.

Keywords: Adhesive resin luting cement, Ceramic thickness, Ceramic translucency, Lithium disilicate, Veneer color

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Introduction

Restoring teeth with ceramic veneers has gained popularity as it not only provides esthetically pleasing results but also conserved natural tooth structure.[1,2] Matching thin restorations, such as veneers, to adjacent natural teeth has always been difficult, especially in the anterior zone. In most cases, patients would desire a brighter smile to improve their esthetics.[3,4] For natural teeth, the color mainly resulted from the amount of scattering and reflecting light within enamel and dentin layers.[5-7] However, for ceramic restorations, the color was primarily influenced by the thickness and translucency of the materials along with the underlying tooth structure and luting agent selection.[8-10]

Lithium disilicate ceramics have been well accepted in restorative dentistry due to their excellent esthetic properties, adequate mechanical strength (350-450 MPa), biocompatibility, and relative ease of application.[11,12] Advancements in computer-aided design and computer-aided manufacturing (CAD-CAM) systems allow machinable fabrication of lithium disilicates, which are available in selections of shade and translucency. Some previous studies may have documented that more opaque and thicker ceramics could provide better coverages over dark substrates;[13-15] however, information regarding resulting colors from thin veneers of different ceramic translucencies is still limited. In addition to ceramic materials, luting cement could modify or enhance the final color of the restorations.[14,16] Some previous studies, however, reported that cement color added minimal changes to the final results; however, opaque cement shades showed superior in masking ability.[13,14,17] Hence, using resin cements representing a highly translucent shade with minimal effects and an opaque shade with more lightening effects could be useful in this study. Therefore, the purpose of this study was to evaluate the influence of different ceramic translucencies, ceramic thicknesses, and shades of resin cement on the final color of veneer restorations with CAD-CAM lithium disilicate ceramic. The null hypothesis was that the final color of the veneers would not be affected by ceramic translucency, ceramic thickness, or shades of resin cement.

Material and Methods

A total of 180 ceramic specimens were fabricated from high translucency (HT), medium translucency (MT), and low translucency (LT) CAD-CAM lithium disilicate blocks in size C14 and shade A1 (IPS e.max CAD; Ivoclar Vivadent, Liechtenstein). Two different thicknesses, 0.5 and 1.0 mm, of ceramic specimens were prepared using a slow-speed diamond saw (Isomet Low-Speed Saw; Buehler, USA) and standardized into a square shape (10 x 10 mm) using high-speed diamond burs with water-coolant. Both the outer and intaglio surfaces were polished with 600- and 800-grit silicon carbide paper on a polishing machine (Minitech 233; PRESI, France) at a rate of 100 rpm for 30 seconds under running water to create a uniform roughness, which simulated preparation of ceramic surfaces with fine diamonds burs. The outer surfaces were further ground with 1,200-grit silicon carbide paper in the same manner. A digital micrometer (Mitutoyo, Japan) was used to confirm thicknesses of specimens to be 0.5 ± 0.05 mm and 1.0 ± 0.05 mm. Later, the specimens underwent crystallization according to the manufacturer's instruction in a ceramic furnace (Programat P700; Ivoclar Vivadent, Liechtenstein). A homogeneous gel-like consistency of a glaze mixture (IPS Ivocolor Glaze Power and IPS Ivocolor Mixing Liquids allround; Ivoclar Vivadent, Liechtenstein) was applied onto the outer surfaces of the specimens using a ceramic brush, followed by a glaze firing procedure in a furnace (Programat P700; Ivoclar Vivadent, Liechtenstein). Substrates were prepared using a resin composite in shade A3 (Premise; Kerr, USA). Dimensions of 10 x 10 x 2 mm of the substrates were fabricated using a mold with glass slab covers to create flattened surfaces; light-curing (Demi Plus; Kerr, USA) was applied from the top and bottom surfaces for 40 seconds on each side. The light output was calibrated for every ten specimens using a radiometer (LED Radiometer; Demetron/Kerr, USA). Intaglio surfaces of composite specimens were ground with 600-grit silicon carbide paper at 100 rpm for 30 seconds to simulate the roughness of dentin with bur-cut surfaces.[18,19]

For cementation procedures, lithium disilicate specimens were etched with a 4.5% HF (IPS ceramic etching gel; Ivoclar Vivadent, Liechtenstein) on their intaglio surfaces for 20 seconds, rinsed under running water for 60 seconds, ultrasonically cleaned with 98% alcohol for three minutes, and then dried with a gentle air stream. Ceramic primer (Monobond Plus; Ivoclar Vivadent, Liechtenstein) was applied and allowed to react for 60 seconds before being dispersed and dried with warm air for 60 seconds. Later, 37.5% phosphoric acid etching gel (Optibond FL Etchant; Kerr, USA) was applied, left to react for 15 seconds, and rinsed thoroughly with water for 15 seconds. OptiBond FL primer (Kerr, USA) was applied onto the etched substrates for 15 seconds with a light scrubbing motion followed by a gentle airstream for five seconds until there was no visible movement of liquid. Subsequently, the substrates were applied with OptiBond FL adhesive resin (Kerr, USA) by brushing motion for 15 seconds and then light-cured for 20 seconds. A light cure resin luting cement (Variolink Esthetic LC; Ivoclar Vivadent, Liechtenstein) was applied onto the bonded surfaces of the prepared resin composite substrates. Two shades of neutral and light plus resin cement were used, while glycerine was used for the control groups. A layer of 0.06-mm-thick polypropylene tape (Scotch Tape; 3M, USA) was used to control the film thickness. A constant load of 1 kg via a loading device (Durometer, ASTM D2240 Type A; PTC Instrument, USA) was applied on the top surface of the specimens for a uniform loading force as shown in Figures 1A and 1B. While the load was being applied, light-polymerization (Demi Plus; Kerr, USA) was performed with 1,100 mW/cm^2 intensity for 20 seconds per lateral surface of the specimens. After removing the load, the specimens were additionally light-polymerized from the top for 40 seconds (120 seconds of light-polymerization in total) (Fig. 1).

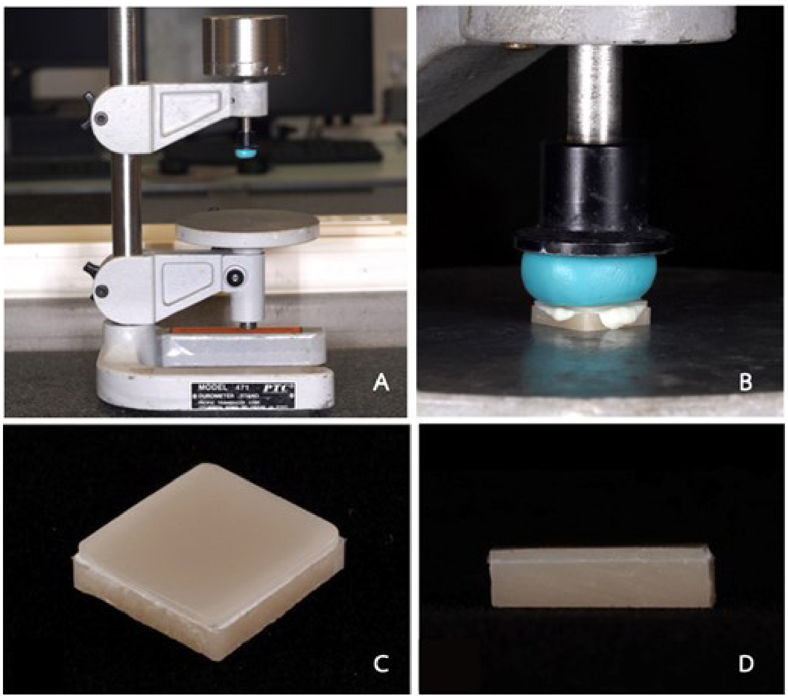

Figure 1 *A) Durometer (ASTM D 2240 Type A, PTC Instrument, USA) B) Cementation procedures C) a cemented ceramic specimen D) a cross-section of a cemented specimen*

Color measurements were performed at the center of each specimen using a spectrophotometer (Ultrascan PRO; Hunter Lab, USA) via a 7 mm size aperture. According to the International Commission of Illumination (CIE), the measurements were performed under the D65 CIE standard illuminant. Color coordinates were described numerically according to their positions in the 3-dimensional color space as L*, a*, and b* values. The L* color coordinates range from 0 to 100, representing value or brightness. The a* color coordinate represents redness on the positive axis and greenness on the negative axis, whereas the b* color coordinate represents yellowness on the positive axis and blueness on the negative axis. As recommended by the CIE, the CIEDE2000 (ΔE_{00}) formula was used to calculate color differences.[20,21] The perceptibility threshold (PT) of 0.8 and acceptability threshold (AT) of 1.8 were used in this study. PT represents the smallest color difference that can be noticed by 50% of the observers, while AT represents the smallest color difference clinically acceptable for 50% of the observers.[22-24]

Data was analyzed using statistical software (IBM SPSS statistics, v29). The Shapiro-Wilk test was used to determine the normality of the data, and Levene's test was used to test the homogeneity of variance. The three-way analysis of variance (ANOVA) was performed to statistically analyze the effects of ceramic thicknesses, ceramic translucencies, cement colors, and their interactions with the mean values of ΔE_{00}, L*, a*, and b* data. In addition, a Bonferroni post-hoc multiple comparison test was operated to determine differences among the mean values. The P value ≤ 0.05 was considered a statistically significant difference.

Results

The Shapiro-Wilk test showed a normal distribution of data, and Levene's test showed homogeneity of variance. The three-way ANOVA revealed that the final color of CAD-CAM lithium disilicate veneers was significantly influenced by ceramic translucency (HT, MT, and LT), ceramic thickness (0.5 and 1.0 mm), and cement color (neural and light plus) ($P < 0.001$). Means and standard deviations of ΔE_{00} values are presented in Table 1. Statistically significant interactions of ΔE_{00} values were also present among groups. The final colors of most combinations were within the acceptable range since their mean ΔE_{00} values fell below 1.8. An exception was a group using 0.5 mm HT ceramic with light plus cement, whose mean ΔE_{00} value (1.85 ± 0.14) exceeded the AT and was the highest value in the study. The lowest mean ΔE_{00} value was obtained from a group using 1.0 mm LT ceramic with light plus cement (0.35 ± 0.15). Most groups with a 1.0 mm ceramic thickness demonstrated mean ΔE_{00} values within the perceptibility threshold ($\Delta E_{00} \leq 0.8$), except for the 1.0 mm HT ceramic with light plus cement (0.90 ± 0.14) (Fig. 2).

Two cement colors exhibited a statistically significant difference in their mean ΔE_{00} values. The values were significantly higher for light plus cement for most groups, except for 1.0 mm LT ceramics. Regarding the effect of ceramic thickness, a statistically significant color difference was found between 0.5 mm and 1.0 mm thicknesses, with the latter being lower. However, no significant difference was found between 0.5- and 1.0-mm -thick LT ceramics using neutral cement. The effect was also present for ceramic translucency when light plus shade cement was applied, and the ΔE_{00} values decreased as less translucent ceramics were used. However, in neutral cement groups, HT and MT ceramic veneers with the same thickness showed no significant difference in their ΔE_{00} values (Table 1).

Concerning brightness, the mean L* values were significantly higher in groups using light plus than those using neutral shade cements. The data showed that when ceramic thickness was increased from 0.5 mm to 1.0 mm, no significant difference was found in HT and MT ceramics, except for MT with light plus shade cement. Meanwhile, the L* values for LT ceramics were significantly higher in thicker veneer groups, regardless of the medium used (Table 2). Additionally, L* values increased as ceramic translucency decreased.

Table 1 *ΔE_{00} values (mean ± SD) and statistical comparison of different groups*

Translucency	Thickness (mm)	Cement color			P value (Neutral vs Light plus)
		Glycerine	Neutral	Light plus	
HT	0.5	-	0.86^{ab} ± (0.12)	1.85^{a} ± (0.14)	< 0.001
	1.0	-	0.49^{c} ± (0.12)	0.90^{b} ± (0.14)	< 0.001
MT	0.5	-	0.93^{a} ± (0.20)	1.69^{a} ± (0.20)	< 0.001
	1.0	-	0.40^{c} ± (0.07)	0.64^{c} ± (0.10)	< 0.001
LT	0.5	-	0.72^{b} ± (0.14)	1.40^{d} ± (0.23)	< 0.001
	1.0	-	0.74^{ab} ± (0.05)	0.35^{e} ± (0.15)	< 0.001

Different small letters indicate significant differences within the same column for each cement color. HT, High translucency; MT, Medium translucency; LT, Low translucency. α=.05.

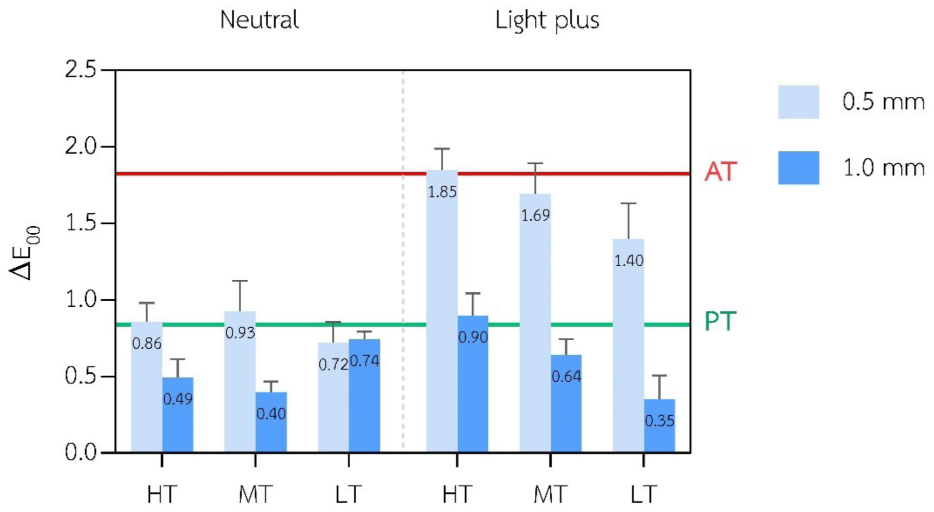

Figure 2 *ΔE_{00} values of veneers resulted from combinations of different ceramic translucencies, ceramic thicknesses, and cement colors. Green and red horizontal lines represent the perceptibility threshold, PT, and acceptability threshold, AT, respectively. HT, High translucency; MT, Medium translucency; LT, Low translucency*

Table 2 *L*, a*, and b* values (mean ± SD) and statistical comparison of different groups*

Translucency	Thickness (mm)	Cement color		
		Glycerine	Neutral	Light plus
*L**				
HT	0.5	65.56^{aA} ± (0.15)	64.97^{aB} ± (0.17)	67.11^{aC} ± (0.27)
	1.0	65.33^{aA} ± (0.40)	65.01^{aB} ± (0.24)	66.79^{aC} ± (0.18)
MT	0.5	67.88^{bA} ± (0.27)	67.57^{bA} ± (0.27)	69.93^{bB} ± (0.38)
	1.0	67.87^{bA} ± (0.36)	67.85^{beA} ± (0.18)	69.27^{cB} ± (0.26)
LT	0.5	68.73^{cA} ± (0.13)	68.09^{ceB} ± (0.33)	69.98^{bC} ± (0.37)
	1.0	70.61^{dA} ± (0.27)	69.52^{dB} ± (0.36)	70.45^{dA} ± (0.17)
*a**				
HT	0.5	1.36^{aA} ± (0.04)	1.42^{aA} ± (0.07)	1.18^{aB} ± (0.06)
	1.0	0.82^{bA} ± (0.06)	0.96^{bB} ± (0.08)	0.80^{bA} ± (0.04)
MT	0.5	1.08^{cA} ± (0.06)	1.05^{bdA} ± (0.05)	0.81^{bB} ± (0.10)
	1.0	0.26^{dA} ± (0.05)	0.49^{cB} ± (0.04)	0.29^{cA} ± (0.05)
LT	0.5	0.96^{eA} ± (0.03)	1.14^{dB} ± (0.25)	0.61^{dC} ± (0.08)
	1.0	0.29^{dA} ± (0.06)	0.20^{eAB} ± (0.03)	0.12^{eB} ± (0.10)
*b**				
HT	0.5	10.34^{aA} ± (0.32)	9.19aB ± (0.18)	7.90^{abC} ± (0.18)
	1.0	8.50^{bA} ± (0.22)	7.97bB ± (0.22)	7.58^{acC} ± (0.19)
MT	0.5	9.90^{cA} ± (0.50)	8.60cB ± (0.27)	7.97^{bC} ± (0.27)
	1.0	7.93^{dA} ± (0.22)	7.69bAB ± (0.16)	7.54^{cB} ± (0.16)
LT	0.5	9.58^{cA} ± (0.24)	8.93acB ± (0.37)	7.85^{abcC} ± (0.30)
	1.0	8.44^{bA} ± (0.18)	7.66bB ± (0.21)	8.12^{bC} ± (0.20)

Different small letters indicate significant differences within the same column for each cement color. Different capital letters indicate significant differences within the same row for each pair of ceramic translucency and thickness. HT, High translucency; MT, Medium translucency; LT, Low translucency. α*=.05.*

Discussion

The null hypothesis was rejected because different ceramic translucency, ceramic thickness, and cement color had statistically significant effects on the final color of the veneer restorations. The results showed that the final color of restorations was modified by luting resin cement, especially for the light plus shade. It was found that most of the light plus cement groups demonstrated significantly higher mean ΔE_{00} values compared to the neutral shade cement. An exception was a group using 1.0 mm LT ceramic (Table 1); however, according to the L*a*b* data, the light plus groups were optically brighter (higher L* value), less red (lower a* value), and less yellow (lower b*value), in which a similar pattern was also seen in HT and MT ceramics (Table 2). Light plus shade cement was more effective at modifying color than neutral shade cement because of its higher opacity and brightness value. Based on our observations, the neutral shade cement (Variolink Esthetic LC; Ivoclar Vivadent) might be comparable to other luting resin systems, such as translucent shade by RelyX Veneer (3M ESPE) and clear shade by Nexus 3 LC (Kerr), which represented highly translucent shades with minimal color effects. In contrast, the light plus shade cement (Variolink Esthetic LC; Ivoclar Vivadent) might be comparable to other systems such as white opaque shades by RelyX Veneer (3M ESPE) and Nexus 3 LC (Kerr), which also represented opaquer shades with more lightening effects. The findings agreed with other previous studies that resin luting cement could influence the final color of restorations, and a more opaque white cement shade was more effective in color modification than a highly translucent shade.[3,10,25] Due to an increase in the mean ΔE_{00} values, some previous studies perceived the color-modifying ability of opaque white cement as undesirable; however, it was found more favorable when a dark background coverage was necessary.[26-29] To exclude the effects of cement color, glycerine was used in the control group because of its colorlessness and comparable refractive index to that of resin cement.[30,31]

The effect of thickness was seen in this study that thicker ceramics provided lower ΔE_{00} values, except no difference was shown for LT ceramics with neutral shade cement (Table 1). The results agreed with previous studies that thicker ceramics could lessen color effects from the underlying substructure and cement layer.[32-34] Other previous studies also found that ceramic opacity was increased along with an increase in ceramic thickness, thus achieving better background coverage.[34,35] An explanation for the better coverage was that, with an increase in ceramic opacity, more internal light scattering occurred within the ceramic layer, and less light was transmitted toward cement and substrate layers; subsequently, less diffused light was reflected from the underlying substructure, therefore, less influence to the overall final color.[36,37] It was speculated that even though the two thicknesses of LT ceramics on neutral shade cement were indifferent in their ΔE_{00} values, the thicker ceramic group, using both cement colors, showed significantly higher L* values. In HT and MT groups, it was found that even though thicker specimens could provide more background coverage, the thicker ceramics could not significantly raise the L* values. Therefore, according to this study, it was possible to raise brightness by adding more thickness to relatively opaque ceramic, such as LT, but it was not applicable to more translucent ceramics, such as HT and MT.

The effect of translucency was prominent in groups using light plus cement color. The data were consistent with previous studies that ΔE_{00} values decreased when ceramic translucency decreased, indicating better background coverage in opaquer ceramics.[3,14,15,38] Nevertheless, HT and MT ceramics showed no color difference for their ΔE_{00} values in neutral shade cement groups. Translucency also clearly affected brightness values, as it was seen that L* values increased along with an increase in ceramic opacity. Moreover, the data showed that even 0.5 mm MT ceramics were optically brighter than 1.0 mm HT ceramics; likewise, 0.5 mm LT were brighter than 1.0 mm MT ceramics (Table 2). Hence, increasing ceramic thickness may not be as effective as selecting a less translucent ceramic when aiming for a bright restoration.

In the current study, it was found that all levels of ceramic translucency exhibited color differences (ΔE_{00}) within the acceptable range, AT ≤ 1.8, except for 0.5-mm-thick HT veneers cemented with light plus shade cement (Fig. 2). From the results, in which the background color was in shade A3, it might be inferred that high, medium, or low translucency IPS e.max CAD ceramics, A1 shade, could be used interchangeably according to the translucency of the existing adjacent teeth in clinical contexts.

There were some limitations in this study. Only one ceramic shade, A1, was used, and the results may not apply to other shades with different optical properties.[29] Also, the ceramic specimens were fabricated to have flattened surfaces; therefore, they might not reflect the actual shape of veneers, which might be curved and angular. Additionally, composite substrates were substituted for extracted natural teeth to standardize each background substrate to be closest in color; nevertheless, biological tissues may influence the final color of the restoration differently. Moreover, the study investigated only one adhesive resin procedure, which might be irrelevant to other luting systems. Therefore, further studies may explore different ceramic shades and luting systems as well as integrating better simulation of clinical situations.

Conclusion

Based on the limitations of this *in vitro* study, the following conclusions were drawn.

1. Ceramic translucency, ceramic thickness, and cement color influenced the final color of CAD-CAM lithium disilicate veneer restorations. Decreasing ceramic translucency and increasing ceramic thickness could lower color differences.

2. Brightness was influenced mainly by the levels of ceramic translucencies followed by cement colors and ceramic thicknesses.

3. A white, opaquer shade cement provided better color modification and more brightness enhancement than a highly translucent shade cement.

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