Ceramic restorations have become an essential treatment option, especially in the anterior region, because of their favorable optical properties.\(^1\)-\(^6\) The natural appearance of a dental restoration depends not only on size, shape, and surface form but also on translucency and color.\(^4\)-\(^7\) Many ceramic systems are available with different mechanical and physical properties. Ceramic systems with greater strength typically have a less natural and more opaque appearance as a result of increased crystalline content.\(^5\),\(^8\) The more translucent ceramic systems like lithium disilicate permit greater light transmission through the core material and provide a life-like appearance.\(^3\),\(^6\) However, the translucency of ceramic materials increases the complexity of color matching, and the final color may easily be affected by different factors. The color of underlying tooth, abutment, and luting cement may affect the final color of a ceramic restoration as much as the material itself.\(^3\)-\(^6\),\(^9\)-\(^16\)

Resin luting cements provide adequate esthetics, low solubility with oral fluids, excellent mechanical properties, and strong integrity between tooth and ceramic restoration, thus increasing clinical success.\(^5\),\(^11\) They are
available in different shades for final color management of ceramic restorations. The color match of a ceramic restoration to the adjacent natural dentition is a complex process, and matching errors may cause a remake of the restoration. The shade of resin cement may cause difficulties in color matching with ceramic restorations during the luting process. Previous studies have reported that, if the underlying tooth color and the thickness of the ceramic restoration are optimum, concerns regarding luting cement color would be minimal. However, the cement color may become influential when the thickness of ceramic restoration decreases to less than 1.5 mm or the restoration is placed on a dark underlying tooth or abutment to mask the color and prevent undesirable results. Additionally, resin cements may appear brighter after the polymerization process. Detectable color differences may also occur between some composite resin materials and their nominal shade guide color. For these reasons, the effect of luting cement on final color may be tested using clinical evaluation pastes.

Instrumental color matching has become essential to quantifying color in dentistry because of better accuracy with objective, standardized results, and the mathematical expression of color parameters. The color parameters are usually recorded using the International Commission on Illumination \( L^*a^*b^* \) (CIELab) color space system, which allows a color determination in 3-dimensional space. \( L^* \) represents the coordinates for lightness, with values ranging from 0 (black) to 100 (white), and \( a^* \) and \( b^* \) are the coordinates for the red-green axis and yellow-blue axis, respectively. The CIELab color difference formula (\( \Delta E_{ab} \)) has been used for visual or instrumental evaluations since it was first described in 1976. The CIEDE2000 color difference formula (\( \Delta E_{00} \)) is a more recent formula and was introduced to improve the correlation between visual judgments and instrumental color difference values.

The purpose of this study was to evaluate the effect of different shades and brands of resin cement on the color of lithium disilicate ceramic. The null hypothesis was that the effect of different brands of resin cement in the same shade on the color of lithium disilicate ceramic would be similar. The second null hypothesis was that resin cements in different shades from the same manufacturer would not affect the color of lithium disilicate ceramic differently.

### MATERIAL AND METHODS

Ten disk-shaped ceramic core specimens were fabricated (Vita A2 shade) from a heat-pressed lithium disilicate ceramic with high-core translucency (Lds.ht) (IPS e.max press; Ivoclar Vivadent AG), according to the manufacturer’s instructions (Table 1). One side of each core disk was sequentially ground with 600-, 800-, 1000-, and 1200-grit silicon carbide papers (Wetordry; 3M ESPE) using a sanding machine (Phoenix Beta; Buehler) at 100 rpm/min for 15 seconds under water cooling. The thicknesses of specimens were controlled with a digital micrometer (Digimatic Caliper; Mitutoyo), and the dimensions were adjusted to 11×0.8 ±0.01 mm. Core specimens were placed in a mold with a disk-shaped cavity (11×1.5 mm), and A2 shade veneering ceramic (IPS e.max Ceram; Ivoclar Vivadent AG) was layered onto the nonground surfaces. Layering and firing procedures were repeated until each ceramic specimen’s final thickness was adjusted to 1.5 ±0.01 mm; the specimens were then autoglazed.

Eighty disk-shaped (11×0.2 mm) cement specimens were prepared in shades of translucent (Tr) and universal-A2 (Un) from 4 different brands of dual-polymerizing resin cements (Table 1). A hard plastic plate was pierced with a sharp punch, and 10 disk-shaped cavities were obtained to standardize the shape and dimensions of the specimens. Each brand and shade of resin cement material was mixed and prepared according to the manufacturer’s recommendations. The mixed cements were placed in the cavities between 2 polyester strips under glass sheets and polymerized with a polymerizing light unit (Hilux LED 550; Benlioglu Dental) at 750 mW/cm² for 20 seconds on each side. Ten specimens were obtained for each brand and shade of resin cement material. The cement specimens were then immersed in distilled water at 37°C ±1°C for 24 hours for complete polymerization.

Color coordinates of ceramic specimens were measured with a digital spectrophotometer (Vita Easy

### Table 1. Materials used

<table>
<thead>
<tr>
<th>Material</th>
<th>Code</th>
<th>Type</th>
<th>Manufacturer</th>
<th>Shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPS e.max Press</td>
<td>Lds.ht</td>
<td>Heath pressed lithium disilicate ceramic</td>
<td>Ivoclar Vivadent AG</td>
<td>A2</td>
</tr>
<tr>
<td>IPS e.max Press</td>
<td>Lds.ht</td>
<td>High-translucency</td>
<td>Ivoclar Vivadent AG</td>
<td></td>
</tr>
<tr>
<td>IPS e.max Press</td>
<td>Max_Un</td>
<td>Dual polymerized self-etch, self-adhesive resin luting cement</td>
<td>Kerr Haue Universal (A2)</td>
<td>Tr</td>
</tr>
<tr>
<td>IPS e.max Press</td>
<td>Max_Un</td>
<td>Dual polymerized self-adhesive resin luting cement</td>
<td>Kerr Haue Universal (A2)</td>
<td>Tr</td>
</tr>
<tr>
<td>IPS e.max Press</td>
<td>Rel_Un</td>
<td>Dual polymerized self-adhesive resin luting cement</td>
<td>3M ESPE</td>
<td>Tr</td>
</tr>
<tr>
<td>IPS e.max Press</td>
<td>Rel_Un</td>
<td>Dual polymerized self-adhesive resin luting cement</td>
<td>3M ESPE</td>
<td>Tr</td>
</tr>
<tr>
<td>IPS e.max Press</td>
<td>Var_Un</td>
<td>Dual polymerized self-adhesive resin luting cement</td>
<td>Ivoclar Vivadent AG</td>
<td>A2</td>
</tr>
</tbody>
</table>

Cle, Clearfil; Lds. ht, lithium disilicate high-translucency; Max, Maxcem; Rel, RelyX; Ub/Tr, universal/translucent; Var, Variolink.

### Clinical Implications

Clinicians should keep in mind that different brands of resin cement in the same shade may have different effects on the color of translucent lithium disilicate ceramic restorations.

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Shade; Vita Zahnfabrik). A polytetrafluoroethylene (PTFE; Teflon) mold was used to standardize the position of the specimens and the measuring tip of the spectrophotometer (6 mm) at the center of the specimens (11 mm). The mold also served as the standard white background for all measurements. The device was calibrated with the white calibration apparatus before the color measurements of each specimen group. The spectrophotometer recorded the measurements in the CIELab color space system. Initial color measurements were repeated 3 times for each specimen, and the means were set at the location of the color difference pair in \( \text{L}^* \), \( \text{a}^* \), and \( \text{b}^* \). After the initial color measurements, the color coordinates of the ceramic specimens were measured again with each brand and shade of cement, and the data were recorded as \( \text{L}_{1*}, \text{a}_{1*}, \) and \( \text{b}_{1*} \). (Table 2). To provide a good optical connection between the tested specimens, 1 drop of optical fluid (Cargille Optical Gel; Cargille Labs) with a refractive index of 1.52 was used.

The C*ab values of the test groups were calculated by using the formula \( [(a^2+b^2)^{1/2}] \). The color differences between the \( \text{L}^*, \text{a}^*, \text{b}^* \) color coordinates of the ceramic specimens at the initial and second measurements were calculated by using the CIEDE2000 (\( \Delta \text{E}_{00} \)) color difference formula:

\[
\Delta \text{E}_{00} = \sqrt{\left( \frac{\Delta \text{L}^*}{\text{K}_{1\text{L}} \text{S}_\text{L}} \right)^2 + \left( \frac{\Delta \text{C}^*}{\text{K}_{1\text{C}} \text{S}_\text{C}} \right)^2 + \left( \frac{\Delta \text{H}^*}{\text{K}_{1\text{H}} \text{S}_\text{H}} \right)^2 + \text{R_T} \left( \frac{\Delta \text{C}^*}{\text{K}_{1\text{C}} \text{S}_\text{C}} \right) \left( \frac{\Delta \text{H}^*}{\text{K}_{1\text{H}} \text{S}_\text{H}} \right),
\]

where \( \Delta \text{L}^*, \Delta \text{C}^*, \) and \( \Delta \text{H}^* \) are the differences in lightness (\( L \)), chroma (\( C \)), and hue (\( H \)) for a pair of specimens in \( \Delta \text{E}_{00} \), and \( \text{R_T} \) is the function (the so-called rotation function) that accounts for the interaction between chroma and hue differences in the blue region. Weighting functions \( S_L, S_C, \) and \( S_H \) adjust the total color difference for variation in the location of the color difference pair in \( L', a', b' \) coordinates, and the parametric factors \( K_L, K_C, \) and \( K_H \) are correction terms for experimental conditions. The parametric factors of the CIEDE2000 color difference formula were set to 1. Also, the perceptibility threshold was set at \( \Delta \text{E}_{00} \leq 1.30 \) units, and the clinical acceptability threshold was set at \( \Delta \text{E}_{00} > 2.25 \) units.

Color variation data were statistically analyzed. The Levene test of homogeneity was used for evaluating the normal distribution of the variables, and a normal distribution was found \( (P<.001) \). The \( \Delta \text{E}_{00} \) results were then analyzed using 2-way ANOVA and subsequent pairwise testing to address the stated hypotheses, involving comparisons of differences between the 2 shades for every brand and between every pair of brands for each shade. Each selected comparison was performed using the Student \( t \) test, and all \( P \) values were corrected by using the step-down Bonferroni procedure \( (a=.05) \). All computational work was performed with statistical software (IBM SPSS Statistics v20.0; IBM Corp).

### RESULTS

The \( \text{L}^* \) and \( \text{C}^*_{ab} \) values of the test groups are shown in Figure 1. All of the \( \text{L}^* \) and most of the \( \text{C}^*_{ab} \) values of the test groups were lower than those of the control group. The 2-way ANOVA results are shown in Table 3, and the mean ±SD values, and Student \( t \) test comparison results of the \( \Delta \text{E}_{00} \) values for the test groups are presented in Table 4.

Two-way ANOVA results showed that both resin cement shade \( (P=.016) \) and brand \( (P<.001) \) were significant for color differences. The Student \( t \) test comparisons of \( \Delta \text{E}_{00} \) values for different brands of resin cements in the same shade showed significant differences between RelyX universal (Rel_Un) and Un shades of other brands and Rel_Tr and Tr shades of other brands, and Rel’s \( \Delta \text{E}_{00} \)

### Table 2. Mean ±SD of L*, a*, b* values

<table>
<thead>
<tr>
<th>Cement Brand</th>
<th>Cement Shade</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Un</td>
<td>88.07 ±0.91</td>
<td>-0.26 ±0.48</td>
<td>20.80 ±1.48</td>
</tr>
<tr>
<td>Maxcem</td>
<td>Tr</td>
<td>87.12 ±0.92</td>
<td>0.43 ±0.25</td>
<td>23.46 ±1.71</td>
</tr>
<tr>
<td>Maxcem</td>
<td>Un</td>
<td>86.52 ±1.05</td>
<td>0.33 ±0.32</td>
<td>22.18 ±1.28</td>
</tr>
<tr>
<td>Variolink</td>
<td>Un</td>
<td>87.34 ±1.54</td>
<td>-0.26 ±0.20</td>
<td>20.47 ±1.76</td>
</tr>
<tr>
<td>Variolink</td>
<td>Tr</td>
<td>87.16 ±1.05</td>
<td>-0.48 ±0.42</td>
<td>21.81 ±1.71</td>
</tr>
<tr>
<td>Clearfil</td>
<td>Un</td>
<td>86.52 ±1.05</td>
<td>0.33 ±0.32</td>
<td>22.18 ±1.28</td>
</tr>
<tr>
<td>Clearfil</td>
<td>Tr</td>
<td>87.12 ±0.92</td>
<td>0.43 ±0.25</td>
<td>23.46 ±1.71</td>
</tr>
<tr>
<td>Relyx</td>
<td>Un</td>
<td>89.21 ±1.37</td>
<td>0.79 ±0.39</td>
<td>22.82 ±2.27</td>
</tr>
<tr>
<td>Relyx</td>
<td>Tr</td>
<td>87.98 ±0.85</td>
<td>0.13 ±0.55</td>
<td>21.77 ±1.76</td>
</tr>
</tbody>
</table>

**Un/Tr**, universal/translucent.
results were significantly smaller (P=.001). The Tr shade of Variolink (Var) cement was significantly higher than Tr shades of other brands (P.<.001). When 2 shades of resin cements were compared for the same brand, a significant difference was observed between the Un and Tr shades of only Rel cement (P<.05).

When the mean ΔE<sub>00</sub> values were evaluated, the Var_Tr cement (2.36) resulted in a clinically unacceptable value (ΔE<sub>00</sub>=2.25) for Lds.ht ceramic. The ΔE<sub>00</sub> value of Rel_Un (1.15) was within the visually imperceptible limits (ΔE<sub>00</sub>≤1.30) (Fig. 2). The ΔE<sub>00</sub> values of other groups were in the range of visual perceptibility but clinical acceptability (1.30<ΔE<sub>00</sub>≤2.25).

**DISCUSSION**

This in vitro study evaluated different brands and shades of resin cement for lithium disilicate ceramic restorations and compared their effects on the optical properties and final color of the ceramic. Both null hypotheses were rejected because the brand and shade parameters of resin cements significantly affected the color of lithium disilicate ceramic.

Resin cements in translucent or universal shades are commonly selected to lute translucent ceramic restorations. The results of the present study showed that using various brands and shades of resin cement not only led to differences in the CIELab color coordinates but also influenced the final color of lithium disilicate ceramic. The use of all tested resin cements resulted in a decrease in the lightness value of the ceramics, and most also caused a change in chroma. However, Var_Un and Rel_Un resin cements slightly increased the chroma of the ceramics (Fig. 1). Additionally, the use of the universal shade of resin cement caused a change toward yellow, and the translucent shade of cement caused a change toward blue in the color of ceramics (Table 2). The experimental design of the present study simulated a controlled clinical condition that does not involve a discolored or dark underlying background. Unacceptable color difference (ΔE<sub>00</sub>=2.25) was determined for only Var_Tr (2.36) and visually perceptible differences for other test groups (1.30<ΔE<sub>00</sub>≤2.25). Using Rel-Un resin cement may result in an imperceptible (ΔE<sub>00</sub>≤1.30) color difference for lithium disilicate ceramic under these conditions. These findings were in agreement with those of a previous study<sup>12</sup> which reported that resin cements in the same shade but of different brands exhibited different color parameters. The translucent (RelY Veneer; 3M ESPE; Maxcem Elite, Kerr Hawe; Variolink II, Ivoclar Vivadent AG), and A1 (Un) (RelY Veneer, Maxcem Elite) shades of resin cements led to visually perceptible color differences (2.0<ΔE<sub>ab</sub>≤3.5) for the A1 shade of leucite-reinforced glass ceramic (IPS Empress Esthetic, Ivoclar Vivadent AG) of 1 mm in thickness.<sup>12</sup> The results of another study also reported that the yellow (Un) shade of 2 different resin cements (Variolink II, Nexus II; Kerr Hawe) did not match in the CIELab color space.<sup>3</sup> Previous studies and the present study reached a similar conclusion in that similar color reproduction with ceramic restorations may not always be possible when resin cements in the same nominal shade, but from different manufacturers are used.<sup>3,6,12</sup> However, another study indicated that similar shades of resin cements for 3 cement materials (Variolink Veneer; Ivoclar Vivadent AG,
Panavia F; Kuraray Medical Inc, RelyX; 3M ESPE) had similar effects on the color of lithium disilicate ceramic (IPS e.max Press) in 1.4-mm thickness. The discrepancy may be explained by the variations in the studies’ experimental designs, including specimen preparation methods or the background materials and shades used.

The present study attempted to minimize the variations regarding the tested material itself. The experiment was designed to make reliable comparisons with previous investigations. Standardized ceramic and cement specimens were used to compose all test groups. Therefore, potential variations on the optical properties of specimens were aimed to be prevented/minimized during fabrication procedures. The ceramic and cement specimens were connected by using a refractive index solution (Optical Gel) to provide a good light transmission and eliminate the light scattering through the cement-ceramic specimen interface. As the thickness of the ceramic and cement specimens also plays a critical role in the final color of restorations, the ceramic and cement specimen thicknesses were adjusted to 1.5 and 0.2 mm respectively in present study. Similar studies have shown that using digital devices for color measurements may increase the accuracy of measurements 94% more than visual determination techniques. Therefore, all color measurements in the present study were performed with a spectrophotometer, positioning the specimens on a standardized white background. A strength of the present study was the use of the most recently developed CIEDE2000 color difference formula for calculating color change values. This formula can help ensure a more appropriate clinical interpretation of color variations in dentistry.

The effect of the shape, direction, and quantity of a luting cement on the CIELab color coordinates of ceramic materials mostly relates to the composition and content of the cement. The color and optical properties of composite resin materials are determined by the resin matrix, filler composition, and supplemental additives, including pigments and photoinhibitors. That the Tr shade of each brand of resin cement caused higher color differences than the Un shade for lithium disilicate ceramic may be explained by variations in their compositions. In addition, the white background of the PTFE mold used during color measurements may have closer color coordinates to the Un than the Tr shades. The refractive index characteristics of composite resins are important factors that influence the color coordinates. The light transmittance characteristics also affect the color of composite resin materials. The amount of absorbed, scattered, and transmitted light of composite resins are substantially determined by the filler, pigment, and opaque content of the material.

In the present study, the significantly different effects of resin cements in same shades from different manufacturers and also the differences between the 2 shades of RelyX cement may be explained by variations in their refractive index and light transmittance characteristics. This finding emphasizes the necessity of common shade classifications or industrial standardization for different manufacturers’ resin cements, something which has also been mentioned in previous studies. Therefore, evaluating the optical properties of resin cements with clinical evaluation pastes is recommended.

The esthetic advantages of ceramic systems depend largely on their core translucency. The structure and amount of crystal content within the core matrix, the chemical nature, and the size of the particles affect the incident light wavelength (λ) and determine the translucency/opacity character of a ceramic material. The influence of cement and background shades on the color of ceramic material systems has been mostly associated with the translucency of the core materials. While more translucent ceramics chiefly transmit incoming light and reflect from the underlying color, the luting cements tested made only imperceptible ΔE00 values (>1.30) for lithium disilicate ceramic.

This study did not compare the thicknesses and shade parameters of the ceramic material or the effect of clinical evaluation pastes on color coordinates. These variables and other optical properties such as translucency, chroma, and hue angle should be evaluated in future in vitro and in vivo studies.

**CONCLUSIONS**

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

1. Resin cements of the same nominal shade from different manufacturers had different effects on the color of lithium disilicate ceramic disks.
2. The effect of translucent and universal shades of RelyX Unicem resin cement was significantly smaller than the effect of other tested resin cements in the same shade.
3. The effect of translucent shade of Variolink II resin cement was significantly higher than the effect of other tested resin cements in the same shade.
4. A significant difference was observed between universal and translucent shades for only RelyX Unicem cement. This effect was also clinically different, the effect of RelyX Un being visually imperceptible and that of Tr being visually perceptible, although clinically acceptable.
5. The effect of the tested resin cements on the color of lithium disilicate ceramic was mostly visually perceptible but clinically acceptable (1.30<ΔE00≤2.25), except for the universal shade of RelyX and translucent shade of Variolink II. When the translucent shade of Variolink II was used under lithium disilicate
ceramic, the color change with the ceramic was not clinically acceptable. The effect of the universal shade of RelyX cement on the color of lithium disilicate ceramic was not visually perceptible.

REFERENCES


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