Among dental ceramics, zirconia ceramics have shown the best mechanical characteristics.1–3 Monolithic zirconia restorations present some advantages, such as no need for veneering procedures and easy, short, and precise fabrication processes using computer-aided design/computer-assisted manufacturing (CAD/CAM) systems.4,5 However, monolithic zirconia restorations also present some difficulties achieving optimum esthetics.6,7

Both ceramic translucency and shade play essential roles in replicating a tooth-like appearance. The translucency of monolithic zirconia restorations is primarily affected by the type of zirconia ceramic used. Manufacturers have produced zirconia ceramics with different visible light transmittance percentages of between 20% and 50%.6 Low-translucency zirconia is usually employed for zirconia substructures, while high-translucency zirconia is routinely used for full-contour zirconia restorations.6 As the natural shade of zirconia is white,6,8 manufacturers have introduced pre-shaded zirconia blanks/blocks and color liquids for white zirconia blanks/blocks.9 However, esthetic problems with monolithic zirconia restorations still exist, especially in the esthetic zone, as zirconia optically differs from human dentin due to the inhomogeneity of the zirconia microstructure.10

Background, cement, and restoration thickness may affect the color of monolithic zirconia restorations.6 To gain optimum esthetics with these restorations, the...
Although an esthetic guideline on background-cement–ceramic shade harmony has been suggested for matching monolithic zirconia restorations according to the target shade, proper combinations of ceramic thickness and cement type for color matching of these restorations are unclear. Therefore, the purpose of this in vitro study was to assess the effect of ceramic thickness and cement type on the color matching of high-translucency monolithic zirconia restorations and to find proper ceramic thickness–cement combinations for achieving the color match. The null hypothesis was that the ceramic thickness and cement type would not influence the color match.

**MATERIALS AND METHODS**

Based on results of related studies (standard deviation [SD] = 0.4, mean difference = 0.7), α = .05, and β = 0.2, a sample size calculation was performed using a formula with an adjustment due to multiple comparisons of means for five experimental groups. Consequently, 10 specimens were allocated to each experimental group. Therefore, 300 monolithic zirconia disk specimens of six different thicknesses (0.7, 0.9, 1.1, 1.4, 1.6, and 1.8 mm) and 300 backgrounds were assigned to five cement groups in order to assess the color match of 30 different ceramic thickness–cement combinations.

Disk specimens with 10-mm diameter and the aforementioned thicknesses were milled from high-translucency monolithic zirconia ceramic (DD cubeX2, Dental Direkt) using a CAD/CAM system (CORiTEC 250i, imes-icore). The specimens were immersed in an A2 color solution (DD Bio ZX2 Monolith Zero LZDD, Dental Direkt) for 5 seconds and left for 30 minutes to dry. They were then sintered for 12 hours at a maximum temperature of 1,520°C with a sintering furnace (iSINT HT, imes-icore). A digital gauge (293 MDC-MX Lite, Mitutoyo) with high accuracy was applied for thickness.
measurements. A polishing kit for zirconia (BruxZir, Glidewell Direct) was used to adjust the specimens according to the specified thicknesses (± 0.02 mm). Specimens without acceptable thicknesses were removed from the research. All specimens were cleaned in an alcoholic solution for 20 minutes and then dried with air.

In order to prepare composite resin backgrounds, a cylindrical wax prototype (10-mm diameter, 10-mm height) with a superficial hollow space was fabricated. This space with 0.1-mm depth and 8-mm diameter was allocated for cement. An impression (Speedex, Coltène) was taken of the prototype to make a matrix. An A3.5-shade composite resin (Z100 restorative, Coltène) was taken of the prototype to make a matrix. An A3.5-shade composite resin (Z100 restorative, 3M ESPE) (L* = 62.1, a* = 1.4, b* = 19.2) was applied to the matrix and incrementally polymerized with a light-polymerizing device (Elipar FreeLight 2, 3M ESPE) at an intensity of 800 mW/cm² for 40 seconds. The light-polymerizing device (Elipar FreeLight 2, 3M ESPE) was used between specimens and backgrounds18,22) for spectrophotometry using an Optic Research) with acceptable precision and accuracy26,27 was employed for spectrophotometry using an illumination degree of 2 × 45 degrees (polarized, telecentric, monochromatic), a reading at 0 degrees (polarized, telecentric), a digital resolution of 640 × 480, and an optical resolution of c.a. 0.03 per 0.03 mm. A putty material (Speedex, Coltène) was formed to fix the distance between the specimens and the device and to isolate the specimens from the surrounding light.11,12 Therefore, specimens only received the light emitted from the device. Each zirconia disk specimen was allocated to a background, and color measurements were performed before cementation (a distilled water drop was used between specimens and backgrounds18,22) and after cementation. The device calibration was made with its green and white plates before measurements as instructed by the manufacturer. International Commission on Illumination (CIE) L*a*b* values (L* = lightness; a* = redness-greenness; b* = yellowness-blueness) were measured three times at the specimen’s center by a skilled operator, and average amounts were then recorded.

The color of the middle third of an A2 shade tab of a shade guide (VITA classical A1–D4 shade guide; VITA Zahnfabrik) was regarded as a target color. CIE L*a*b* values of the target color were measured with the same device (L* = 74.8, a* = 0.7, b* = 20.0). The device additionally verified the tab’s color (A2).

Color differences were determined using the following formula:

\[
\Delta E_{00} = \sqrt{\left(\frac{\Delta L}{k_{LSL}}\right)^2 + \left(\frac{\Delta C}{k_{CSC}}\right)^2 + \left(\frac{\Delta H}{k_{HSH}}\right)^2}
\]

, considering \(k_L = 2, k_C = 1, \text{and} k_H = 1\), as recommended by investigators.28,29 The \(\Delta E_{00}\) values were calculated for a specimen with three orders:

1. Between before cementation and after cementation (\(\Delta E_{1}\)) (to evaluate cement-induced color changes)
2. Between the target color and the specimen before cementation (\(\Delta E_{2}\)) (to assess color matches before cementation)
3. Between the target color and the specimen after cementation (\(\Delta E_{3}\)) (to estimate color matches after cementation)\textsuperscript{15,21}

An acceptability threshold (\(\Delta E_{00} = 1.8\)) was hypothesized to interpret color differences.\textsuperscript{28,29} A color match could be obtained when the \(\Delta E_{3}\) value was ≤ 1.8.

Data were statistically analyzed with software (SPSS 21, IBM). Normal distribution of data was confirmed using Kolmogorov-Smirnov test (P > .05). The effects of ceramic thickness, cement type, and their interaction on the \(\Delta E_{3}\) were evaluated using two-way analysis of variance (ANOVA). Pairwise comparisons of the tested groups were made with Bonferroni adjustment. The \(\Delta E_{3}\) values of different ceramic thickness–cement combinations were compared with the acceptability threshold (\(\Delta E_{00} = 1.8\)) by using one-sided, one-sample \(t\) test and software (STATA, StataCorp LLC). P < .05 was considered for all tests.

**RESULTS**

The mean \(\Delta E_{1}\), \(\Delta E_{2}\), and \(\Delta E_{3}\) values for different combinations of the ceramic thickness (0.7, 0.9, 1.1, 1.4, 1.6, and 1.8 mm) and cement type (TB, ZP, RU, PS, GC) are demonstrated in Figs 1 to 3. The two-way ANOVA results revealed that the ceramic thickness, cement type, and their interaction significantly affected the \(\Delta E_{3}\) (P < .001) (Table 2). Pairwise comparisons of the tested groups in the \(\Delta E_{3}\) showed significant differences between some
ceramic thickness–cement combinations of 1.1-TB ($P = .969$), 1.4-TB ($P = 1$), 1.6-TB ($P = 1$), 1.8-TB ($P = 1$), 0.9-ZP ($P = .976$), 1.1-ZP ($P = 1$), 1.4-ZP ($P = .900$), 1.6-ZP ($P = .998$), and 1.8-ZP ($P = .917$). The null hypothesis of ceramic thickness–cement combinations of 1.1-TB ($P = .969$), 1.4-TB ($P = 1$), 1.6-TB ($P = 1$), 1.8-TB ($P = 1$), 0.9-ZP ($P = .976$), 1.1-ZP ($P = 1$), 1.4-ZP ($P = .900$), 1.6-ZP ($P = .998$), and 1.8-ZP ($P = .917$). The null hypothesis of

According to the one-sample $t$ test results, the
null hypothesis of $\Delta E_3 \leq 1.8$ was not rejected for the

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The cement-induced color change of A2-shade high-translucency monolithic zirconia cemented to an A3.5-shade background was evaluated by measuring the ∆E<sub>1</sub> (specimen’s color difference between before cementation and after cementation). According to Fig 1, RU and PS created minimum color changes, even less than the perceptibility threshold (∆E<sub>00</sub> = 0.8)<sup>[29]</sup>; however, opaque cements such as TB and ZP induced major color changes, and GC was in between. This shows that universal (A2-shade) resin cements generate slight color changes in monolithic zirconia restorations on A3.5-shade backgrounds. This may be due to the properties of universal resin cements such as shade (A2), high level of translucency, low thickness (0.1 mm), and weak masking ability.

∆E<sub>3</sub> ≤ 1.8 was rejected for the other ceramic thickness–cement combinations tested (<i>P</i> < .05).

**DISCUSSION**

Based on the results, the ceramic thickness, cement type, and their interaction significantly affected the ∆E<sub>3</sub> and color match, and therefore the null hypothesis of the study was rejected. TB in combination with the ceramic thickness of ≥ 1.1 mm and ZP in combination with the ceramic thickness of ≥ 0.9 mm produced color matches; however, RU, PS, and GC in combination with any ceramic thicknesses tested did not create color matches for high-translucency monolithic zirconia specimens.

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The color match of A2-shade high-translucency monolithic zirconia on an A3.5-shade background without cement was evaluated by measuring the ΔE (color difference between the target color and the specimen after cementation). According to Fig 2, all specimens (with any thicknesses) showed color mismatches (ΔE > 1.8). High-translucency zirconia of decreased thicknesses cannot solely mask an A3.5-shade background because of zirconia’s high level of translucency. The color mismatch of zirconia of increased thicknesses may be due to the inherent color, structural inhomogeneity, and optical properties of zirconia. This reemphasizes the optical differences between zirconia and tooth structures and feldspathic/glass-ceramics.

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Bacchi et al showed that a white opaque resin cement improved the masking ability of 1.8-mm–thick monolithic glass-ceramic and zirconia restorations on discolored backgrounds. Although Bacchi et al and the current study obtained similar results on the use of opaque cements for monolithic zirconia restorations on discolored backgrounds, the current study additionally introduced the minimum zirconia thicknesses for color matching.

Malkondu et al evaluated the color of 0.6- and 1-mm–thick monolithic zirconia ceramics in combination with three types of cement: conventional glass-ionomer, resin-modified glass-ionomer, and resin cements. They reported that zirconia thickness and cement type influenced the color and translucency of the monolithic zirconia. Although both studies showed the impact of cement type and zirconia thickness on the color, the present study assessed a wider range of zirconia thickness and also introduced proper cements and minimum zirconia thicknesses needed for color matching.

Tabatabaian et al assessed color changes of a 0.5-mm–thick low-translucency zirconia ceramic following application of different cements and advocated glass-ionomer and resin cements due to their lower color changes compared to opaque cements. To the authors’ knowledge, the color match may be more crucial than the color change, because if a factor makes a color match even with a greater color change, it is advantageous (eg, opaque cements for a discolored background in the present study). Conversely, tooth-shaded resin cements for a discolored background may induce less color changes but may not lead to a color match, as shown in this study. The disagreement between the results of Tabatabaian et al and this study may be due to the issue discussed.

With discolored backgrounds, increasing the ceramic thickness and choosing a cement with proper color and opacity may be solutions for color matching in high-translucency monolithic zirconia restorations. Because zirconia ceramics fundamentally differ from dentin and enamel, an increase in the zirconia thickness alone may not lead to a color match (Fig 2). Therefore, a corrective effect of cement may be needed for esthetics in monolithic zirconia restorations on discolored backgrounds. According to the results of this study, TB with a minimum ceramic thickness of 1.1 mm and ZP with a minimum ceramic thickness of 0.9 mm are recommended to achieve the color match for high-translucency monolithic zirconia restorations on an A3.5-shade background (a discolored background). On the other hand, tooth-shaded cements, such as universal resin cements, may be advantageous for these restorations when minimum background color coverage/correction is required. Also, the ceramic thickness needed for esthetics should be considered during tooth preparation for these restorations.
The limitations of this study were the use of one brand of zirconia, one background color, and five types of cement with specified shades. Thus, evaluation of different zirconia brands, background colors, and different luting agents with different shades is suggested for further studies.

CONCLUSIONS

Within the limitations of this study, the subsequent conclusions were made:
- Ceramic thickness and cement type influenced the color match of high-translucency monolithic zirconia restorations.
- Opaque cements with sufficient ceramic thicknesses created better esthetics than glass-ionomer and universal resin cements for high-translucency monolithic zirconia restorations cemented to A3.5-shade backgrounds.
- TB combined with a minimum ceramic thickness of 1.1 mm and ZP combined with a minimum ceramic thickness of 0.9 mm created the color match.

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