Effect of thickness of monolithic zirconia ceramic on final color

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Monolithic zirconia restorations are a popular option in esthetic and restorative dentistry with excellent mechanical properties, including flexural strength and fracture toughness.1-4 However, achieving optimal esthetics with these restorations is still challenging.3,5-7 Replicating translucency and shade are important to attain a color match between a zirconia restoration and natural teeth.8,9 Zirconia ceramics have partial translucency, but various zirconia ceramics show differences in light transmission percentage.10-13 The color of zirconia ceramic can be affected by substrate,14-20 cement,21,22 zirconia type,11,12,15 zirconia thickness,11,23,24 coloring procedure,25 sintering conditions,26 and aging.7

The CIELab color system (L*, lightness; a*, red-green value; b*, yellow-blue value) has been widely used to quantify the color and to evaluate the color difference between a restoration and a tooth because of its simplicity, feasibility, and validity.27 A spectrophotometer measures CIELab values of the restoration and the tooth, and according to a formula, their color difference (ΔE) is determined.3,11,14-27 Then the ΔE value is compared with a threshold for acceptability to determine whether the color difference is clinically acceptable.27-29 Increasing the zirconia thickness decreases translucency11,13 and increases color masking ability.20 With a metal or dark substrate, an increase in the zirconia thickness is suggested,14,20 because substrate-induced color mismatches may not be correctable by changing the color of the luting agent.20 Moreover, the luting agent...
may compromise the final color of thin monolithic zirconia restorations. The reduction of zirconia thickness decreases the L* and b* values and increases the a* value. Additional staining has been proposed to match the color of precooled monolithic zirconia ceramic to natural teeth. A minimum thickness of monolithic zirconia restoration of 0.5 mm has been recommended for fracture resistance, but the minimum dimension terms of esthetics is unclear.

High-translucency zirconia has been introduced for anterior and posterior monolithic restorations. Nevertheless, difficulties of shade reproduction with these restorations remain. Ceramic thickness, which affects the translucency of the restoration, is an important factor for a successful shade reproduction. Therefore, the purpose of this in vitro study was to assess the effect of thickness of monolithic zirconia ceramic on its final color and to define the minimum thickness needed for an acceptable final color. The null hypothesis was that the thickness of monolithic zirconia ceramic would not affect its final color.

**MATERIAL AND METHODS**

A total of 60 zirconia disk specimens (N=60) were tested in 6 groups based on 3 zirconia thicknesses (0.7, 0.9, and 1.1 mm) and 2 zirconia brands (n=10 per group). The sample size was determined with consideration of α=.05, β=.1, and from the results of previous studies. Ceramic thicknesses were excluded from the study. The specimens were cleaned in an ultrasonic bath containing 98% ethanol for 20 minutes and dried.

To fabricate an A4 shade porcelain substrate to simulate human dentin, a cylindrical pattern of 10 mm in diameter and height of an acrylic resin (Duralay; Reliance Dental Mfg Co) was prepared. A silicone putty impression (Speedex; Coltène) was made of the pattern to make a mold. The mold was filled with a mixture of powder and liquid of an A4 shade porcelain (Ivoclar Vivadent AG) prepared according to the manufacturer’s instruction. The porcelain substrate was fired for 70 minutes with a heat rate of 60 from 500°C to 920°C, cooled to room temperature, and polished using a porcelain polishing laboratory kit (LUS41; Hager & Meisinger GmbH). CIELab values of this substrate (L*=67.0, a*=3.6, b*=26.0) were measured with a spectrophotometer (SpectroShade Micro; MHT Optic Research AG) with an acceptable reliability, repeatability, and validity. The illumination was 2×45 degrees (polarized, telecentric, monochromatic), the reading was at 0 degrees (polarized, telecentric), the digital resolution was 640×480, the optical resolution was approximately 0.03 per 0.03 mm, and the repeatability was ΔE<0.5 on teeth. The A4 shade of the substrate was confirmed by the spectrophotometer.

An A2 shade tab of a shade guide (VITA classical A1-D4 shade guide; VITA Zahnfabrik H. Rauter GmbH & Co KG) was selected. CIELab values of this shade tab were measured at the center of its middle third with the same spectrophotometer and considered as the CIELab values of final color (control) (L*=74.8, a*=0.7, b*=20.0).

To replicate the conditions of spectrophotometry for all specimens and to exclude external light, a silicone putty material (Speedex; Coltène) was molded to the spectrophotometer. The A4 shade porcelain substrate was located at the center of this silicone mold, and the zirconia specimens were placed on it without an intermediary. The spectrophotometer was calibrated with plates, as instructed by the manufacturer. CIELab values of the specimens’ central area were measured with the spectrophotometer by an expert operator (E.M.) uninformed about the specimen material manufacturer. Color measurements were conducted 3 times for each specimen, and the average values were calculated to report thicknesses as follows:

**Table 1. Tested materials and their identifications**

<table>
<thead>
<tr>
<th>Zirconia Material</th>
<th>Manufacturer</th>
<th>Translucency</th>
<th>Flexural Strength</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD cubeX²</td>
<td>Dental Direkt GmbH</td>
<td>49%</td>
<td>&gt;750 MPa</td>
<td>&gt;6.0 g/cm²</td>
</tr>
<tr>
<td>CopraSmile</td>
<td>Whitepeaks Dental Solutions GmbH &amp; Co KG</td>
<td>&gt;40%</td>
<td>609 MPa</td>
<td>6.046 g/cm²</td>
</tr>
</tbody>
</table>

**Clinical Implications**

Zirconia thickness may influence the color of monolithic zirconia restorations. This study identified the minimum thickness required for a monolithic zirconia restoration and the related amount of tooth reduction to achieve optimum esthetics.
of the CIELab values was recorded. Color difference values were calculated to compare the CIELab values of a specimen with the CIELab values of the final color. The $\Delta E$ was calculated using the formula $\Delta E \text{ab} = \left( \frac{1}{2} \left( \Delta L^2 + \Delta a^2 + \Delta b^2 \right) \right)^{1/2}$. A threshold for acceptability ($\Delta E = 3.3$) was assumed to assess color differences.\textsuperscript{27,37}

Statistical software (IBM SPSS Statistics v21; IBM Corp) was used for data analysis. The results of the Kolmogorov-Smirnov test showed that the data were normally distributed ($P > .05$). Two-way ANOVA with the Bonferroni correction was used to assess effects of thickness and brand of zirconia and their interaction on the $\Delta E$. With statistical software (STATA; StataCorp LLC), a 1-sided 1-sample $t$ test was used to compare the $\Delta E$ values with the acceptability threshold ($\Delta E = 3.3$) ($\alpha = .05$ for all tests).

RESULTS

The means and standard deviations of the CIELab and $\Delta E$ values for the zirconia thickness groups of 0.7, 0.9, and 1.1 mm for the zirconia brands are presented in Figures 1 to 4 and Supplemental Table 1. The 2-way ANOVA showed that the thickness affected the $\Delta E$ ($P < .001$); however, the brand ($P = .059$) and the interaction of thickness and brand ($P = .905$) did not affect the $\Delta E$ (Table 2). Pairwise comparisons of the $\Delta E$ values were performed with the Bonferroni test with 2 orders: between different thicknesses in each brand (order 1) and between different brands in each thickness (order 2). According to order 1, significant differences were detected between 0.7 and 0.9 mm ($P < .001$), 0.9 and 1.1 mm ($P = .029$), and 0.7 and 1.1 mm ($P < .001$) in Dental Direkt, and significant differences were also found between 0.7

![Figure 1. Means and standard deviations of lightness (L*) values.](image1)

![Figure 2. Means and standard deviations of red-green (a*) values.](image2)

![Figure 3. Means and standard deviations of yellow-blue (b*) values.](image3)

![Figure 4. Means and standard deviations of color difference ($\Delta E$) values.](image4)
and 0.9 mm (P<.001) and 0.7 and 1.1 mm (P<.001) in Whitepeaks. However, no significant difference was found between 0.9 and 1.1 mm in Whitepeaks (P=.124). According to order 2, no significant difference was detected between Dental Direkt and Whitepeaks in 0.7 (P=.83), 0.9 (P=.1), and 1.1 (P=.4) mm.

The 1-sided 1-sample t test compared the means of the ΔE values with the acceptability threshold (ΔE=3.3). The null hypothesis of ΔE≤3.3 was rejected for 0.7 mm in Dental Direkt (P=.001) and Whitepeaks (P<.001) and was accepted for 0.9 and 1.1 mm in both brands (P>.05). Hence, the 0.7-mm-thick monolithic zirconia ceramics manifested significant color differences compared with the final color.

**DISCUSSION**

This study evaluated the effect of 3 different zirconia thicknesses on the final color of 2 different monolithic zirconia ceramics. The results showed significant differences in the CIELab and ΔE values related to zirconia thickness. Therefore, the null hypothesis of the study was rejected.

To interpret the results on color differences, a ΔE reference value (threshold) is necessary. Perceptibility and acceptability thresholds have been defined; however, different values have been reported. The perceptibility and acceptability thresholds are significantly different, and also observers and sites make differences in the measurement of both thresholds. Concerning the human eye's ability of different observers to recognize color differences, 3 intervals have been suggested for the thresholds: ΔE<1 undetectable by the human eye; 1<ΔE<3.3 detectable by skilled operators but clinically acceptable; ΔE>3.3 detectable by patients and untrained observers and regarded as clinically unacceptable. Accordingly, the present study considered the acceptability threshold of ΔE=3.3 to evaluate color differences.

This result can be explained by the optical behavior of monolithic zirconia ceramic, which is optically a partially translucent ceramic. According to Table 1, both examined zirconia ceramics had an absolute translucency of more than 40% in their 1-mm-thick specimens. Therefore, light transmission is expected through the tested ceramics, and subsequently a substrate's color can affect the resultant color. The substrate effect reduces when the ceramic thickness increases and the ceramic translucency decreases. This may be why the color match resulted from an increase in the thickness from 0.7 to 0.9 mm in the present study. To compensate for the effect of the A4 shade substrate for gaining the A2 shade final color, the thickness of the A2 shade monolithic zirconia ceramic should be increased. According to the results, the zirconia brand did not affect the final color because of using 2 zirconia ceramics with similar translucencies and the same coloring process.

Sulaiman et al showed an inverse relationship between translucency and thickness of monolithic zirconia that was brand dependent. Their finding on the zirconia thickness was supported by this study. However, the findings of the studies on the zirconia brand were dissimilar because of testing 2 highly translucent zirconia ceramics with similar translucencies in the present study.

Malkondu et al evaluated color changes of monolithic zirconia with 2 different thicknesses (0.6 and 1 mm) and 3 types of cement. They reported that the mean ΔE values for the 0.6-mm-thick zirconia were more than those for the 1-mm-thick zirconia. The effect of thickness on the color of monolithic zirconia was confirmed by the current study. The current investigation additionally defined a minimum thickness needed for optimal esthetics.

Basso et al reported that monolithic glass-ceramic could mask a C4-shaded substrate but could not mask metal substrates and had less color masking ability than glass-ceramic-layered zirconia. Moreover, increasing the thickness of monolithic structures from 0.7 to 2 mm decreased the ΔE value. This was supported by the present study, though the studies evaluated different types of ceramic.

Chang et al showed that a bleached substrate could change the color of Katana zirconia crowns in the cervical and body areas, and the color change could not be modified with various cement shades. To compensate for the substrate effect on the color of monolithic zirconia
crowns, the present investigation suggested an increase in zirconia thickness rather than a change in cement shade advised by the study of Chang et al.30 The increase in zirconia thickness seems to be a more practical solution.

Kim et al31 evaluated the effect of thickness reduction on the color and translucency of monolithic zirconia ceramics and found perceptible color differences (ΔE>3.7) when the thickness decreased from 2 to 1 mm. A similar result was derived from the current study; however, different thickness ranges were evaluated by the studies.

Kim and Kim32 compared the optical characteristics of precolored monolithic zirconia ceramics with those of veneered zirconia and lithium disilicate glass-ceramics, and observed the color differences ranging beyond the acceptability threshold. They concluded that precolored monolithic zirconia ceramics might induce color mismatches because of their high L* value and low a* and b* values. Although the present research did not use precolored monolithic zirconia ceramics, both studies showed the possibility of a color mismatch in monolithic zirconia restorations. However, the studies suggested different solutions including an increase in the thickness (the present study) and additional staining (the Kim and Kim32 study).

Wang et al11 surveyed the translucency parameter of glass and zirconia ceramics with different thicknesses. They indicated that both material and thickness affected the translucency, and the translucency decreased while the thickness increased. This result on the thickness effect was emphasized by the current study; however, Wang et al’s11 study result on the material effect was not consistent with the current study result. The use of 2 types of ceramic (glass and zirconia) with different translucencies in the Wang et al11 study may explain the inconsistency of the results.

Tabatabaian et al20 revealed that the minimum thickness of zirconia framework should be 0.8 mm to achieve a color match when a zirconia-based restoration is placed on a nickel–chromium substrate. Although the current study tested monolithic zirconia ceramics that were more translucent than the framework zirconia examined by Tabatabaian et al,20 both investigations suggested increasing the zirconia thickness to improve esthetics.

Nakamura et al32 indicated that a monolithic zirconia crown with a minimum thickness of 0.5 mm could be applied in the molar area without risking fracture. Respecting both mechanical and esthetic requirements for a restoration, this crown thickness defined by Nakamura et al32 should be increased in the esthetic zone based on the present study results.

According to the results of this study, when the treatment option is the placement of a monolithic zirconia restoration on an A4 shade foundation material or a prepared tooth (with dentin color), the amount of foundation and/or tooth reduction and the following restoration thickness should be at least 0.9 mm to achieve an acceptable final color.

Although an increase in the zirconia thickness will decrease the effects of both substrate and cement on the color, the cement effect was not evaluated in this study. This study’s results are limited to 2 ceramic brands with a specific shade and the substrate shade tested. Because the substrate shade may affect the final color and the following ceramic thickness needed, other substrate shades, especially dark ones, should be investigated. Therefore, more studies are required on cements, brands and shades of monolithic zirconia ceramics, and substrate shades to determine the minimum ceramic thicknesses required for particular foundation materials for the esthetic enhancement of monolithic zirconia restorations.

CONCLUSIONS

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

1. The thickness of monolithic zirconia ceramic affected its final color.
2. To achieve an acceptable final color, the minimum thickness of a monolithic zirconia ceramic should be 0.9 mm.

REFERENCES


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