Effect of abutment tooth color, cement color, and ceramic thickness on the resulting optical color of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown

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Statement of problem. A dark-colored prepared abutment tooth may negatively affect the esthetic outcome of a ceramic restoration if the tooth is restored using translucent enamel-like ceramic materials.

Purpose. The purpose of this study was to evaluate the cumulative effect that the tooth abutment color, cement color, and ceramic thickness have on the resulting optical color of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown.

Material and methods. A CAD/CAM glass-ceramic lithium disilicate-reinforced monolithic crown (IPS e.max CAD LT) was fabricated. Three possible crown restoration variables were tested in vitro. The procedure examined 4 prepared abutment tooth colors (light, medium light, medium dark, and dark), 2 cement (Variolink II) colors (translucent and opaque), and 4 ceramic thickness values (1.0 mm, 1.5 mm, 2.0 mm, and 2.5 mm). The color of each combination was measured using a spectrophotometer, and the average values of the color difference (ΔE) were calculated. The data were analyzed with a 3-way ANOVA (tooth abutment color, ceramic thickness, and luting agent) and Tukey's HSD test (α=.05), which evaluated within-group effects of the tooth abutment color to the ΔE at each ceramic thickness.

Results. The ΔE values of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown were significantly influenced by the tooth abutment color (P<.001), cement color (P<.001), and ceramic thickness (P<.001). Significant interactions were present among these 3 variables (P<.001). A dark-colored abutment tooth demonstrated the greatest ΔE values relative to other variables tested. An increase in ceramic thickness resulted in a significant decrease in ΔE values (P<.01). The ΔE values were slightly decreased when the crowns were cemented using the opaque cement.

Conclusions. This study demonstrated that underlying tooth abutment color, cement color, and ceramic thickness all influence the resulting optical color of CAD/CAM glass-ceramic lithium disilicate-reinforced restorations. (J Prosthet Dent 2011;105:83-90)

Clinical Implications

The present study demonstrated that almost all of the ΔE values in a group with a dark-colored abutment tooth were higher than the perceptible difference (ΔE>2). For dark-colored abutment teeth, crowns with a ceramic thickness of 1.0 mm cemented using either translucent cement or opaque cement, and crowns with a ceramic thickness of 1.5 mm cemented with translucent cement fell within a clinically unacceptable range in terms of color change (ΔE>3.7).

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The optical properties of natural teeth are the result of light reflected from the enamel and dentin and scattered or reflected by the dental hard tissue.[1,2] A significant challenge in dentistry is to optimally match the optical properties of natural teeth with those of artificial teeth.[3,4] In clinical situations that require esthetic restorations, ceramic restorations have the potential to effectively replicate the appearance of the natural dentition. Various ceramic systems are commercially available. Among these, heat-pressed glass-ceramic lithium disilicate-reinforced structures have generated considerable interest, due to the material's adequate strength properties (350-450 MPa),[5] integration with the tooth structure from the bonding mechanism, fabrication process (lost wax technique), which is more practical than the layering technique, and excellent esthetic features.[6] The color of the heat-pressed ceramic restoration can be modified to match that of the natural tooth by layering it with veneering ceramic or by custom staining and glazing. With the development of computer-assisted design/computer-assisted manufacturing (CAD/CAM) technology, an individual ceramic restoration, such as an inlay, onlay, veneer, or crown, can be fabricated by milling a machinable glass-ceramic block. A machinable version of the lithium disilicate-reinforced ceramic blocks with low-translucency color was recently introduced. This glass-ceramic block was developed for the fabrication of fully contoured restorations; however, there is little information available regarding the optical properties of this ceramic.

Although ceramic systems improve color and translucency of the restorations, a perfect color result cannot be ensured. Dentin constitutes the bulk of a tooth and is largely responsible for its color. Ceramics that are more translucent allow more light to enter and scatter, which means that the underlying tooth has a significant influence over the resultant color. When a tooth with intensely discolored dentin requires a ceramic crown, and the adjacent natural tooth has high translucency, clinicians face a challenge in selecting restorative materials that can be used to achieve a good match (Fig. 1).

In general, the optical behavior of a ceramic restoration is determined by the combination of the underlying tooth structure color, the thickness of the ceramic layers, and the color of the cement. Previous studies have demonstrated that underlying tooth structure is a primary influence on the appearance of definitive ceramic restorations.[7-11] If a ceramic restoration is placed on a dark underlying tooth structure, such as an endodontically treated tooth, the color beneath the crown might result in discoloration and shadowing of the restoration, particularly in the cervical areas. To eliminate this undesirable effect, such factors as the thickness of ceramic, ceramic shade, or cement color should be considered. It has been demonstrated that controlling the thickness of the ceramic might allow clinicians to manage the overall translucency of the restoration, while the choice of cement color had less effect.[7,9,12-14] It has been suggested that to mitigate the effect of the abutment tooth on the overall color, the thickness of the ceramic should be at least 2.0 mm.[7,13-15]

The color of a material is often expressed in CIE L*a*b coordinates.[16] These coordinates, obtained from spectral reflectance measurements with a spectrophotometer, provide a numerical description of the color's position in a 3-dimensional color space. The L* color coordinate ranges from 0 to 100 and represents lightness. The a* color coordinate ranges from -90 to 70 and represents greenness on the positive axis and redness on the negative. The b* color coordinate ranges from -80 to 100 and represents yellowness (positive b*) and blueness (negative b*). The color difference (ΔE) between 2 specimens that have colors expressed in L*, a*, and b* is derived from the following formula[17]:

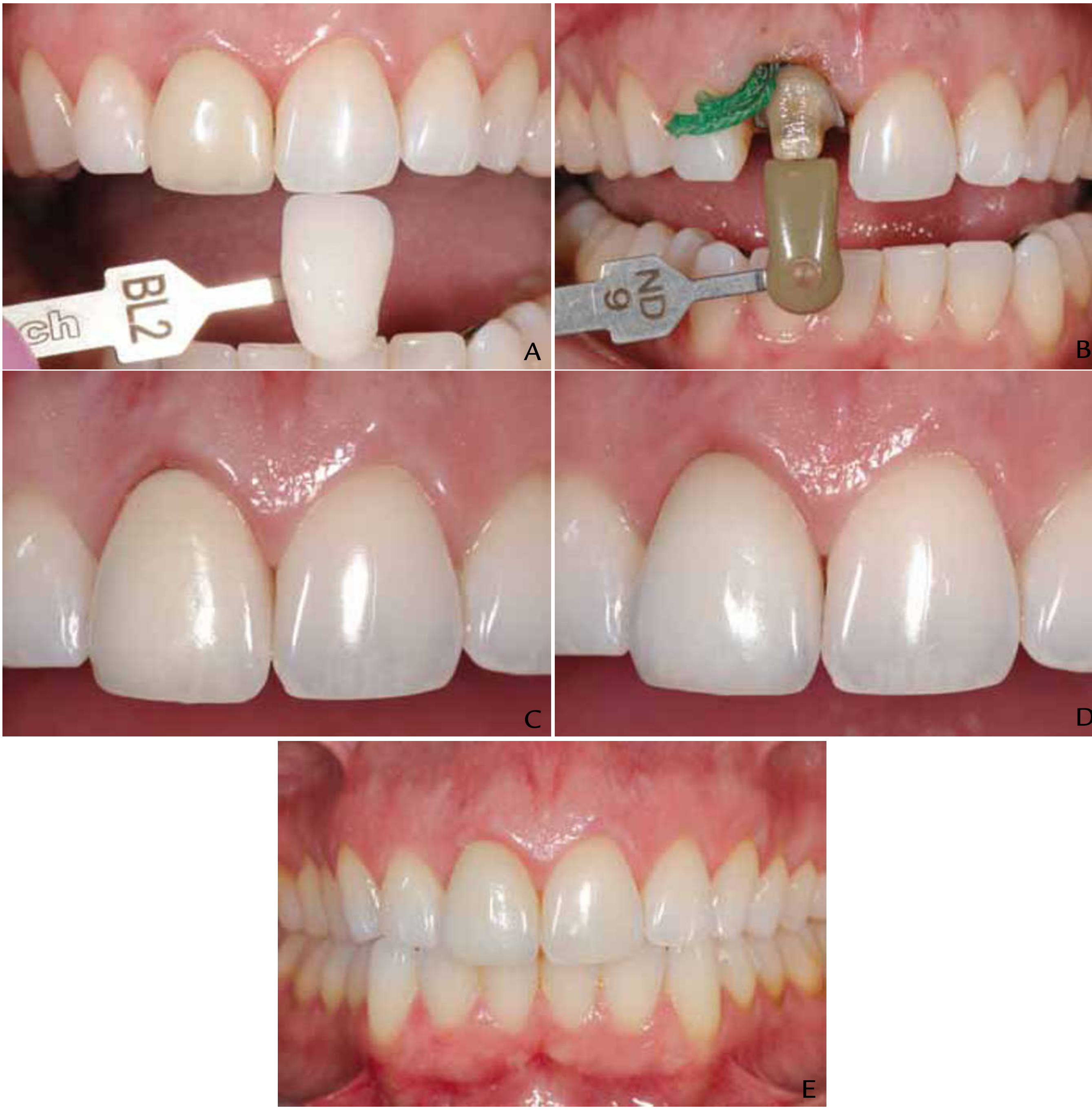
$$\Delta E\ (L^*a^*b^*) = [(L^*_1 - L^*_2)^2 + (L^*_1 - L^*_2)^2 + (L^*_1 - L^*_2)^2]^{1/2}$$

Delta E represents the numerical distance between L*a*b* coordinates of 2 colors. When the ΔE value of 2 colors is less than 1 unit (ΔE<1), 2 colors can be judged to match in color.[18,19] When measured color differences are within the range of 1 to 2 ΔE, correct judgments are frequently made by observers. When ΔE values are greater than 2 ΔE units, all observers can apparently detect a color difference between the 2 colors.[18,19] Under uncontrolled clinical conditions, such small differences in color are not noticeable, because average color differences below 3.7 are rated as matches in the oral environment.[20,21]

The purpose of this study was to evaluate the cumulative effect of the tooth abutment color, cement color, and ceramic thickness on the optical resultant color of a glass-ceramic lithium disilicate-reinforced crown produced by CAD/CAM technology. The null hypothesis was that the color difference (ΔE) of a CAD/CAM glass-ceramic lithium disilicate-reinforced restoration would not be affected relative to the tooth abutment color, cement color, and ceramic thickness.

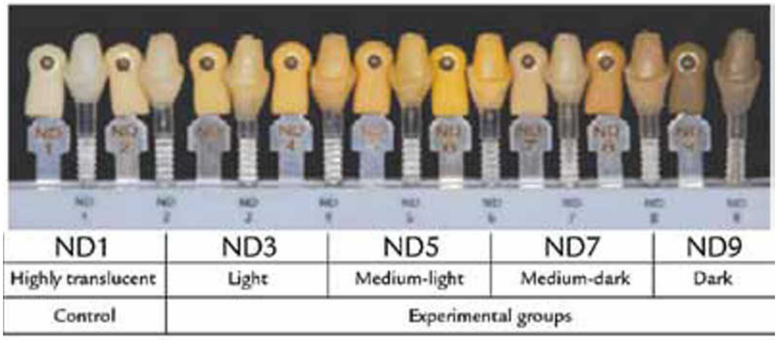
MATERIAL AND METHODS

A maxillary central incisor typodont model tooth (Model 1560; Columbia Dentoform Corp, Long Island City, NY) was prepared for a complete coverage ceramic crown with an incisal reduction of 1.5 mm, a convergence angle of 6 degrees, and a 1.0-mm rounded circumferential shoulder finish line.[22,23] An impression of the prepared tooth was made with light- plus medium-viscosity vinyl polysiloxane impression material (Aquasil Ultra; Dentsply Intl, York, Pa). This impression was poured with a vacuum-mixed die stone (FUJIROCK; GC America, Alsip, Ill), according to the manufacturer's recommendation. Crowns with facial thicknesses of 1.0 mm, 1.5 mm, 2.0

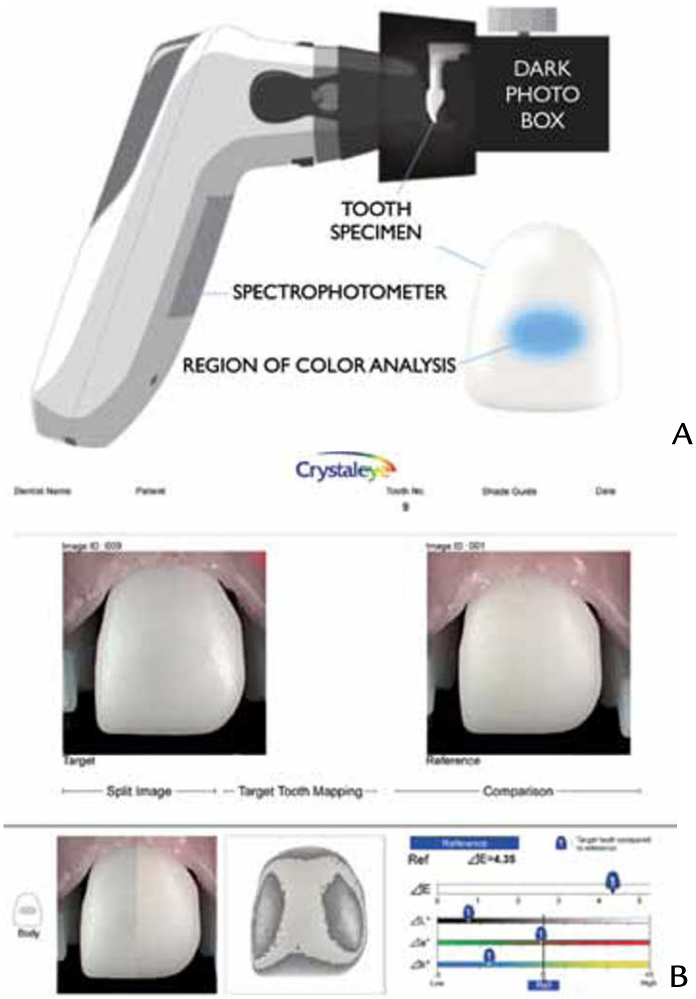


1 Representative photographs of: A, Shade selection for single crown on maxillary central incisor. B, Shade selection of prepared tooth using Natural Die Material Guide. C, Metal ceramic crown at trial insertion. D, Ceramic crown at trial insertion. Note: Crown made of heat-pressed lithium disilicate-reinforced core structure and layered veneering ceramic. E, Definitive ceramic crown 2 weeks after cementation.

mm, and 2.5 mm were waxed on the stone dies to obtain the contours of the definitive crowns. A scan spray (IPS Contrast Spray; Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied to the prepared tooth and the wax crown, and the prepared tooth and wax crown were each optically scanned using a digital scanner (Everest Scan Pro; KaVo Dental GmbH, Biberach, Germany). The images were uploaded into a computer to create a digital model. The CAD software program (KaVo Everest Energy Software; KaVo Dental GmbH) was used to create a cement space at 0.3 mm thickness[24,25] and to finalize the crown design. A lithium disilicate-reinforced monochromatic ceramic block with low-translucency color for CAD/CAM technology (IPS e.max CAD LT, Shade BL; Ivoclar Vivadent AG) was used to fabricate a single crown. This low-translucency (LT) color block was selected because it is suitable for fabricating a complete contour crown, according to the manufacturer's recommendation. The partially crystallized lithium disilicate glass-ceramic block was placed in the milling unit



2 Schematic representation of custom tooth abutment color guide used.



3 Schematic representation of: A, diagram of spectrophotometer device used to capture tooth color for each variable combination tested; B, color data and numerical data gathered by spectrophotometer at selected region.

(KaVo Everest Engine; KaVo Dental GmbH). The slow-speed milling mode for IPS e.max CAD materials was selected from the milling programs. A 1.0-mm diamond rotary cutting instrument (Grinding Pin G1; KaVo Dental GmbH) was used to mill the internal surface of the crown. The slow-speed milling mode and small cutting instrument were used in this study because it was found that these parameters produced CAD/CAM crowns with the best marginal integrity.[26]

Five crowns of each thickness were milled to test each combination of the groups. When the milling process was finished, the crown in the partially crystallized state was retrieved from the milling unit. Then the crown was fired in an oven (Zubler Vario 300; Jensen Dental, North Haven, Conn) for 5 minutes at 750°C and for 10 minutes at 850°C to complete crystallization, according to the manufacturer's recommendation.

To simulate the clinical situation and to create the different colors of the prepared tooth, light-polymerized materials that simulated the shade of the tooth preparation (IPS Natural Die Material Guide; Ivoclar Vivadent AG) were used. This shade guide is used in clinical practice to determine the tooth preparation shade that matches the original tooth shade when completing the definitive restoration. Five different colors of prepared teeth were fabricated as follows: a high-translucency color (ND1), a light color (ND3), a medium-light color (ND5), a medium-dark color (ND7), and a dark color (ND9) (Fig. 2). A high-translucency color (ND1) was used as a control to simulate the clinical situation in which the tooth has been bleached. Other colors (ND3, ND5, ND7, and ND9) were used to simulate an adjacent tooth that required a ceramic crown. CAD/CAM glass-ceramic lithium disilicate-reinforced crowns were seated with 2 different trial insertion cement colors, a translucent color (Variolink II Try-in, Shade Transparent; Ivoclar Vivadent AG) and an opaque color (Variolink II Try-in, Shade Opaque white; Ivoclar Vivadent AG). The trial insertion paste was used in this study as it helped predict the influence of resin cement shade on the definitive restoration.[7] A cement was applied on the crown, and then the crown was seated with finger pressure and the excess cement was removed.

For each of the test groups, the color difference (ΔE) was measured with a spectrophotometer (Crystaleye; Olympus America Corp, Center Valley, Pa) from 5 crowns for each variable combination tested. An artificial environment was used with a simulated gingiva (Baseplate wax; Carmel Dental Wax, Montreal, Quebec, Canada).

The manufacturer purports that this spectrophotometer measures the reflectance or transmittance factors of an object one wavelength at a time. This computer-aided tooth color determination used 7 LEDs (light-emitting diodes) as an illumination source with 45/0-degree geometry. At the beginning of each session and prior to data acquisition, the instrument was calibrated using a calibration plate, according to the manufacturer's recommendation. A plastic protective cap which acted as an aperture was placed on the spectrophotometer head, and then the spectrophotometer was positioned to capture the crown image (Fig. 3, A). The capture time was 0.2 seconds. Spectral data was acquired from the captured image of the tooth. The reflectance values, from 400 to 700 nm, with 1-nm intervals for each pixel, were transferred from the spectrophotometer to a computer. Spectral data of the experimental tooth (ND 3, ND5, ND7, and ND9 abutment) were analyzed and compared to the control tooth (ND1 abutment) using ΔE to determine the color difference in the body area (3.0 x 3.0 mm) of the crown. Determination of ΔE was based on the following equations[17]:

$$\Delta E = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2}$$

where $\Delta L^* = L^*_{\text{experimental tooth}} - L^*_{\text{control tooth}}$, $\Delta a^* = a^*_{\text{experimental tooth}} - a^*_{\text{control tooth}}$, $\Delta b^* = b^*_{\text{experimental tooth}} - b^*_{\text{control tooth}}$

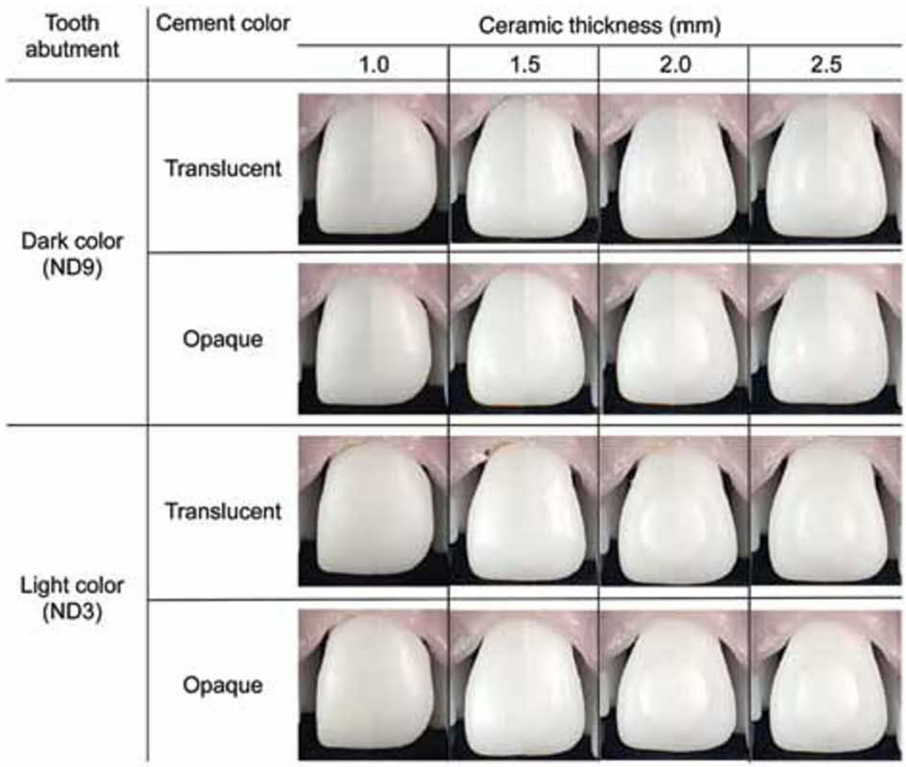
Color data of the control tooth images (ND1 abutment) and the experimental tooth images (ND 3, ND5, ND7, and ND9 abutment) were recorded (Fig. 3, B). The mean and standard deviation of ΔE values were calculated. The power of a statistical test from all data was computed with a significance level of α=.05, and the estimated power of 0.82 was detected. Three-way analysis of variance (ANOVA) was used to analyze the effect of the 3 parameters (tooth abutment color, cement color, and ceramic thickness) for the ΔE values using statistical software (SPSS 17.0; SPSS, Inc, Chicago, Ill). The Tukey Honestly Significant Difference (HSD) test was performed to evaluate within-group effects of the tooth abutment color on the ΔE values of each cement shade and ceramic thickness.

RESULTS

The means and standard deviations of the ΔE values in each combination test group are presented in Table I. As the intensity of the dentin color of the prepared tooth increased, increases in ΔE values were observed. These increases represent color mismatches and visually darker definitive crowns compared to the control crowns (Fig. 4). The greatest ΔE values were obtained from the 1.0-mm-thick ceramic crowns cemented with translucent cement on a dark-colored abutment tooth (ND9) (4.67 (SD 0.17)), followed by the 1.5-mm-thick ceramic crowns cemented with translucent cement on a dark-colored abutment tooth (4.08 (SD 0.11)). As the ceramic thickness increased, a significant decrease in ΔE values was recorded (P<.01). The lowest mean of ΔE values was obtained from the 2.5-mm-thick ceramic crowns cemented with translucent cement (0.38 (SD 0.16)) on a light-colored abutment tooth (ND3), followed by the 2.5-mm-thick ceramic crowns cemented with opaque cement (0.51 (SD 0.10)) on a

Table I. Mean (SD) of ΔE values recorded in experimental groups. Note that different uppercase superscript letters represent significant differences in tooth abutment color at same ceramic thickness (P<.05). Different lowercase superscript letters represent significant differences in ceramic thickness for same tooth abutment color (P<.05)

	Ceramic Thickness (mm)	Tooth Abutment Color: Light (ND3)	Medium Light (ND5)	Medium Dark (ND7)	Dark (ND9)
Translucent Cement	1.0	0.92 (0.20)^{Aa}	1.27 (0.14)^{Ab}	2.10 (0.15)^{Bc}	4.67 (0.17)^{Cb}
	1.5	0.71 (0.12)^{Aa}	1.04 (0.01)^{Ab}	1.52 (0.23)^{Bc}	4.26 (0.24)^{Cb}
	2.0	0.54 (0.13)^{Aa}	1.05 (0.13)^{Ab}	1.17 (0.08)^{Bb}	2.63 (0.27)^{Ca}
	2.5	0.38 (0.16)^{Aa}	0.54 (0.07)^{Ba}	0.67 (0.09)^{Ba}	2.49 (0.07)^{Ca}
Opaque Cement	1.0	0.98 (0.12)^{Ab}	1.34 (0.06)^{Bb}	1.47 (0.17)^{Bb}	4.08 (0.11)^{Cc}
	1.5	0.60 (0.08)^{Aa}	1.14 (0.40)^{Bb}	1.39 (0.14)^{Bb}	2.80 (0.31)^{Cb}
	2.0	0.56 (0.13)^{Aa}	0.99 (0.09)^{Aa}	1.06 (0.05)^{Ba}	2.01 (0.07)^{Ca}
	2.5	0.51 (0.10)^{Aa}	0.68 (0.07)^{Aa}	0.87 (0.05)^{Ba}	1.71 (0.14)^{Ca}



4 Schematic representation example of color data evaluation for crowns cemented on different colors of prepared tooth. Rows 1 and 2 represents crown cemented on dark-colored prepared tooth. Rows 3 and 4 represent crown cemented on light-colored prepared tooth. Each picture illustrates different color between experimental tooth (ND9 or ND 3 abutment) (left) and control tooth (ND1 abutment) (right) at same ceramic thickness.

Table II. Results of 3-way ANOVA for mean ΔE values of combinations tested

Source	Sum of Squares	*df*	Mean Square	F	*P*
Tooth abutment color	139.8	3	46.6	1732	<.001
Ceramic thickness	26.1	3	8.7	324	<.001
Luting agent	2.1	1	2.1	79	<.001
Abutment color × ceramic thickness	13.8	9	1.5	57	<.001
Ceramic thickness × luting agent	0.76	3	0.25	9.4	<.001
Abutment color × luting agent	5.5	3	1.85	69	<.001
Abutment color × ceramic thickness × luting agent	4.5	9	0.5	18	<.001
Error	3.4	128	0.03		
Total	553.8	160			

light-colored abutment tooth (ND3). The ΔE values were slightly decreased when the crowns were cemented using the opaque cement.

The results of the 3-way ANOVA are presented in Table II. Statistically significant interactions of ΔE values were present among these 3 variables: the tooth abutment color, cement color, and ceramic thickness (P<.001). The data indicate that the ΔE values of CAD/CAM glass-ceramic lithium disilicate-reinforced materials were significantly influenced by the tooth abutment color (light, medium light, medium dark, or dark) (P<.001), cement colors (translucent or opaque color) (P<.001), and ceramic thickness (1.0, 1.5, 2.0, or 2.5 mm) (P<.001).

DISCUSSION

The results of the present study support rejection of the null hypothesis, since the color difference (ΔE) of a CAD/CAM glass-ceramic lithium disilicate-reinforced restoration is affected relative to the tooth abutment color, cement color, and ceramic thickness. Findings of the study are in agreement with previous reports in the literature.[7,12,14] Changing the underlying color of the abutment tooth from a lighter color (ND3 or ND5) to a darker color (ND7 or ND9) resulted in increased ΔE values. As demonstrated, almost all of the ΔE values in the group with the dark-colored abutment tooth (ND9) were higher than the perceptible difference (ΔE>2).[18,19] If a ΔE value of greater than 3.7 is regarded as a clinically unacceptable color change,[20,21] 3 of 32 combinations fell within this clinically unacceptable range. Those three combinations included the crowns with a ceramic thickness of 1.0 mm, cemented using either translucent cement or opaque cement on dark-colored abutment teeth, and crowns with a ceramic thickness of 1.5 mm, cemented with translucent cement on a dark-colored abutment tooth.

One possible reason for the high ΔE values may be the optical properties of the material itself. The material has a high translucency due to the optical combination of a glass matrix and the lithium disilicate crystalline phase that reduces internal scattering of the light as it passes through the material.[3] As a result, the underlying color of the tooth structure may influence the resulting optical color of the crown. In general, the thickness of a typical ceramic crown is approximately 1.0 mm at the cervical and gradually increases to 2.0 mm near the incisal edge.[22,23] It must be noted that, when the underlying abutment tooth discoloration is too intense, the application options of a CAD/CAM glass-ceramic lithium disilicate-reinforced with a low-translucency (LT) ceramic block may be limited. Ceramic blocks of medium opacity (MO) or high opacity (HO) that are designated for fabrication of core structures might be suitable for this situation. Since the opaque color core structure is of high opacity, it is suggested that the core structure be veneered with veneering ceramic to enhance esthetic results.

It is known that ceramic opacity is increased with increasing thickness.[7,9,12] As the thickness of ceramic increases, the diffused reflection effects of the underlying abutment tooth diminish, and the majority of diffused reflection occurs in the ceramic crown. The current study confirmed that increasing ceramic thickness could affect the overall color of a restoration, as the decreased ΔE values demonstrated. The smallest ΔE values were recorded for the 2.5-mm ceramic thickness in all of the test groups. The optimal resulting color that is achieved with this thickness, however, would likely compromise the structural integrity of the restored tooth and endanger pulpal health. With respect to cement color, lower ΔE values were demonstrated in the group with opaque cement color. This is inconsistent with a previous report.[5] A possible explanation is that the previous study[5] evaluated the cement thickness at 0.2 mm, while the current study evaluated the cement thickness at 0.3 mm, which may make the cement more opaque. The color of the cement does, however, seem to have less influence on the overall color of the definitive restoration than the other variables. Clinicians should be deliberate in determining these values during the shade selection and fabrication processes for restorations.

There are limitations to the present study. The results are applicable only to the ceramic and luting system evaluated. A CAD/CAM glass-ceramic monochromatic ceramic block with low-translucency color and a single shade was used. Therefore, the external validity of these results, in evaluating this material for veneers of other ceramic shades, is limited. The influence of different ceramic shades or different ceramic block colors, such as medium opacity (MO) or high opacity (HO), on color difference must be considered in future research. To prevent an uneven ceramic thickness due to the geometry of the anatomical crown contour, the color difference in this study was evaluated only in the body area of the crown. Future research should consider color differences not only in the body area, but also in the cervical and incisal areas.

CONCLUSIONS

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

1. The underlying tooth abutment color, cement color, and ceramic thickness significantly influenced the resulting optical color of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown. Changing the underlying color of the abutment tooth from a lighter to a darker color resulted in increased ΔE values.
2. On dark-colored abutment teeth, the crowns with a ceramic thickness of 1.0 mm, cemented using translucent cement or opaque cement, and the crowns with a ceramic thickness of 1.5 mm, cemented with translucent cement, were within a clinically unacceptable color change range (ΔE>3.7).

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Noteworthy Abstracts of the Current Literature

Low temperature degradation –aging– of zirconia: A critical review of the relevant aspects in dentistry

Lughi V, Sergo V.
Dent Mater 2010;26:807-20.

This review presents a critical survey of all experimental data about the low temperature degradation of zirconia (often referred to as "aging") due to the tetragonal-to-monoclinic transformation, which have been collected at temperatures of interest for dental application (room temperature to about 100 °C). It is shown that the main factors affecting the aging phenomenon are (i) the stabilizer type and content, (ii) the residual stress and (iii) the grain size. It is also shown that extrapolating the low temperature degradation rate from accelerated aging tests can lead to unacceptable conclusions about the lifetime of the zirconia-based components. Finally, based on the experimental evidence, a set of engineering guidelines for the use of zirconia in restorative and prosthetic dentistry is proposed.