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The influence of foundation restoration type and ceramic thickness on the final color of zirconia-reinforced lithium silicate ceramic

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ABSTRACT

Background: Similarity in the appearance of a monolithic restoration with the adjacent teeth is necessary. This study aims to influence the foundation material type and ceramic thickness on the final color of zirconia-reinforced lithium silicate (ZLS) ceramic.
Materials and Methods: In this experimental study, the A2 translucent blocks of ZLS were sectioned into rectangular specimens with thicknesses 1, 1.5, and 2 mm (n = 15). Substructure materials include resin composite (B1, D2, A2, A3, and C3), nickel chrome alloy, amalgam, and white and black substrate. Substructure material of resin composite with A2 color was proposed as the control group. The value of the color difference (ΔE_{00}) is calculated by the CIEDE2000 formula. Data analysis was accomplished by two-factor repeated measures ANOVA and one-sample t-test (α =0.05).
Results: The mean value of maximum ΔE_{00} with a black substrate (12.13 ± 0.17) at 1 mm ceramic thickness and the mean value of minimum ΔE_{00} with B1 resin composite foundation material (0.02 ± 0.17) at 2 mm ceramic thickness are visible. The significant effect of the foundation restoration type, thickness, and interaction between them is visible on ΔE_{00} (P < 0.001).
Conclusion: Different thickness is required to meet ideal esthetic outcomes with different substrates. Under the conditions of this investigation, zirconia-reinforced lithium silicate over black, white, nickel–chromium, and amalgam did not meet acceptable outcomes.

Key Words: Ceramics, color, permanent dental restoration

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INTRODUCTION

Today, esthetics is among the top priorities of dental patients. Ceramic restorations are widely used in esthetic regions owing to their better optical behaviors compared with porcelain fused to metal restorations.[1-3] There has been a surge in the fabrication of different types of ceramic restorations, such as inlay, onlay, veneer, and crown because of the developments in computer-aided design and computer-aided manufacturing (CAD/CAM) technology.[4] Monolithic CAD/CAM blocks have excellent fracture resistance, homogenous structure, and minor construction defects.[5-7] Zirconia-reinforced lithium silicate (ZLS) ceramics, with ten percent zirconia by weight, were proposed as a chairside CAD/CAM ceramic with better mechanical properties than the lithium disilicate ceramics.[4-8] Teeth under reconstruction with fixed prostheses have extensive fillings with composite resin or amalgam alloy. Some of these teeth have posts and cores with different alloys, such as nonprecious gold (NPG) colored (yellow-gold

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colored alloy for construction of type 2 restorations) or nickel–chromium. Furthermore, the appearance of a translucent fixed prosthesis could be affected by the optical properties of foundation materials.[9,10] The perfect color with ZLS materials may be challenging due to its translucency property.[1,10,11]

Several researchers have represented the optical behavior of ZLS ceramics. According to Passos *et al*., a 1.5 mm thickness for ZLS with a gold substrate and 2 mm with the C2 resin composite substrate is necessary for a clinically acceptable color. Finally, they did not obtain a perfect final color over the silver background.[10] Saad *et al*. reported that the translucency of ZLS ceramics was better than lithium disilicate. Improvement in the optical properties of both ZLS and lithium disilicate by veneering them was visible.[1] Abdelnaby *et al*. observed that ZLS ceramic had less translucency than lithium disilicate glass ceramic, particularly with the increase in ZLS thickness. They further reported that the darker background caused significant changes in the final color.[11]

The Commission Internationale de l`Eclairage L*a*b system (CIELAB) is used mainly in research into the optical parameters of dental tissues and materials, as it allows the expression of each color numerically along three coordinates. In these systems, L* is symmetrical to value or lightness. However, a* and b* are not exactly in line with Munsell's hue and chroma.[12] On the other hand, a* and b* are called "chromaticity coordinates."[13] Based on the color change (ΔE) value and the comparison with a perceptional threshold of the human eye, a slight color change was even ascertained.[14]

The influence of foundation materials and ceramic thickness on the appearance of monolithic restorations has been investigated.[10-12,15-21] However, there are inadequate data concerning the minimum required thickness of the translucent shade of ZLS restorations for achieving the ideal final color on different substrates. Furthermore, knowing the minimum required thickness will help minimize the amount of unnecessary reduction in tooth structure.

The current research aimed to determine the effect of foundation material type and ceramic thickness on the color of the ZLS ceramic. The null hypothesis was that there is no significant influence on the color of the ZLS ceramic with different foundation materials and thicknesses.

MATERIALS AND METHODS

Determine the sample size

The present research is an experimental study. The Ethics Committee of the Hamadan University of Medical Sciences approved this research (IR.UMSHA.REC.1399.707). Based on the findings of the recent studies with 80% power and a 0.05 significance level, the present investigation determined 15 specimens for each thickness group (n = 15).[9]

Sample preparation

The A2 translucent blocks of VITA SUPRINITY (VITA Zahnfabrik, DeguDent, Germany) were sectioned into rectangular specimens of 1 mm, 1.5 mm, and 2 mm thickness. They sectioned via a diamond saw (series 15 LCU, BUEHLER) of a cutting machine (CUTLAM® micro 2.0, France) under a constant water flow. The mentioned samples were simulating monolithic restorations. The ZLS ceramic samples were purified with distilled water and ultrasound (EMAG, Germany) for 20 min under the manufacturer's guidance. A honeycomb tray was utilized to fix the samples on the firing tray in order to avoid the contamination of samples during crystallization. Afterward, the samples were crystallized entirely in a furnace (Programat P310, Ivoclar-Vivadent, Schaan, Liechtenstein) at 840°C for 8 min and adjusted by use of 1200-grit SiC paper with water cooling to establish the predesignated thicknesses (±0.02 mm). The thickness of each sample was measured by use of a stainless steel digital caliper (Absolute Digimatic Caliper, Mitutoyo, USA) with 0.01 mm accuracy. The samples with defects related to thickness and structure were removed from the investigation. The final dimensions of the samples were 14 mm × 12 mm × 1 mm, 14 mm × 12 mm × 1.5 mm, and 14 mm × 12 mm × 2 mm.

Foundation materials preparation

The colors of composite resin foundation materials included B1, D2, A2, A3, and C3. Furthermore, different alloy foundation materials included nickel–chromium (Ni-Cr), amalgam (AM), and NPG. Backgrounds with black and white colors also were used based on the literature. The characteristics of materials used in this study are visible in Table 1.

Resin composite foundation materials (GRADIA PLUS, GC, Germany GmbH) with B1, D2, A2, A3, and C3 shades were applied to a stainless steel mold with dimensions of 14 mm × 12 mm × 3 mm. After that, the resin composite was cured for 45 s by a light-curing device (Kerr, USA). Next, the surface polishing of the resin composite foundation materials was done with 600-grit SiC papers. The amalgam foundation material is prepared from an amalgam alloy (Solaloy, Trent Dent, UK). After trituration, the amalgam alloy was condensed into a stainless mold (14 mm × 12 mm × 3 mm). Then, the surface of it was burnished. For the cast metal foundation material, two rectangular patterns (14 mm × 12 mm × 3 mm) were formed with a dental inlay wax (Kerr, USA). The patterns were cast with a nickel–chromium alloy (Thermabond, USA) and an NPG-colored alloy, Albadent, USA; they were polished with a special polishing kit (Shofu Dental, Germany).

Polytetrafluoroethylene materials (Fluorotech, UK) were sectioned into 14 mm × 12 mm × 3 mm dimensions to prepare black and white backgrounds. All foundation materials were purified with 98% ethanol and ultrasound (EMAG, Germany) for 30 min. The CIELAB coordinates of the foundation materials and backgrounds were evaluated with a spectrophotometer (VITA Easyshade compact; VITA Zahnfabrik, GmbH) which was calibrated according to the recommendations of the manufacturer and employed for all measurements [Table 2].

Spectrophotometry of the samples

A customized positioning jig is used to prevent the external light, stabilizing the position of the ceramics, substrates, and a spectrophotometer. The positioning jig is visible in Figure 1.

The conditions are explained above, repeated for all measurements with a standard light source D65. One drop of optical liquid (Cargille Labs, Cedar Grove, NJ, USA) with a refraction index of 1.5 was applied to the surface of each foundation material to establish optical contact. The L*, a*, and b* of the specimens were assessed using a spectrophotometer in the middle of each sample. Then, for each sample, the mean value of three records was calculated and

Table 1: Characteristics of materials used in this study

Materials used		Composition	Manufacturer	Preparation technique
Foundation materials	Resin composite (B1, D2, A2, A3, C3)¶	1%–5%: Bisphenol A-glycidyl methacrylate 5%–10%: Triethylene glycol dimethacrylate 1%–5%: Urethane dimethacrylate, ceramic filler	GC, Germany GmbH	Using layering technique, resin composite was applied into a stainless steel mold of 14 mm × 12 mm × 3 mm and light cured for 45 s
	AM	45%: Ag 31%: Sn 24%: Cu	Solaloy; Trent Dent, England	Trituration and condensation into a stainless mold of 14 mm × 12 mm × 3 mm
	Ni-Cr	75%: Ni 14%: Cr 5%: Mo 1.6%: Be	Thermabond alloy super cast, CA, USA	Wax pattern was cast (dimensions of the wax pattern were 14 mm × 12 mm × 3 mm)
	NPG	80.7%:Cu 7.8%: Al 4.3%: Ni 7.2%: Fe, Zn, Mn	NPG; Aalba Dent, Inc.	Wax pattern was cast (dimension of the wax pattern were 14 mm × 12 mm × 3 mm)
	Black and white	PTFE	AFT Fluorotech, Welwyn Garden City, United Kingdom	Sectioned into 14 mm × 12 mm × 3 mm dimensions
Ceramic samples	ZLS	56%–64%: SiO_2, 15%–21% : Li_2O, 8%–12%: ZrO_2, 3%–8%: P_2O_5, 1%–4%: K_2O, 1%–4%: Al_2O_3, and other oxides	VITA Zahnfabrik, DeguDent, Germany	Sectioned through a diamond saw to rectangular samples (dimensions of the samples were 14 mm × 12 mm × 1 mm, 14 mm × 12 mm × 1.5 mm, and 14 mm × 12 mm × 2 mm)

¶Different shades of the resin composite materials. Ni-Cr: Nickel–chromium alloy; NPG: Nonprecious gold-colored alloy; AM: Amalgam; ZLS: Zirconia-reinforced lithium silicate

Table 2: CIELAB coordinates of different foundation materials in this study

Foundation materials¶	B1	D2	A2	A3	C3	Ni-Cr	NPG	AM	Black	White
L*,†	81.4	80	79.6	72.4	68.1	10.8	13.5	27.8	7.5	94.7
a*,‡	−2.5	0.7	0.9	3.1	1.1	−2.7	−0.7	−1.2	−1.1	−2.7
b*,§	13.5	18.7	18.5	23.1	18.5	2.9	6.8	5.7	−3.5	1.4

†L* is lightness or darkness; ‡a* is chromaticity coordinate; §b* is chromaticity coordinates; ¶Resin composite foundation materials are B1, D2, A2, A3, and C3. Alloy foundation materials are Ni-Cr; NPG; AM. Backgrounds are black; white. Ni-Cr: Nickel–chromium alloy; NPG: Nonprecious gold-colored alloy; AM: Amalgam, CIELAB: Commission Internationale de l`Eclairage L*a*b system

reported. CIELAB values of the ceramic samples on the A2 composite substrate are regarded as control values (L^*_i, a^*_i, b^*_i), and CIELAB values on the other substrate are considered as tested values (L^*_j, a^*_j, b^*_j).

The following formula was used to calculate the changes in the final color:[22]

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \frac{\Delta C'}{K_C S_C}\frac{\Delta H'}{K_H S_H}}$$

In this investigation, ΔE_{00} values were compared with a 50:50% acceptability threshold (ΔE_{00} = 1.8), and a 50:50% perceptibility threshold (ΔE_{00} = 0.8).[22] Therefore, ΔE_{00} values were 0.8 and ΔE_{00} <1.8, considered as a clinically acceptable color difference. On the other hand, ΔE_{00} values were 1.8, and ΔE_{00} >1.8, designated as a clinically unacceptable color difference.

Statistical analysis

Statistical analysis of the data was done by IBM SPSS Statistics version 22.0 ((SPSS Inc., Chicago, Illinois, United States)). The normal distribution of the data was analyzed by Kolmogorov–Smirnov and Shapiro–Wilk tests. Two-factor repeated-measures ANOVA was used to investigate the influence of substrate type, thickness, and interaction among the groups. Afterward, the pairwise comparison for the color change (ΔE_{00}) between different subgroups was made by Bonferroni's *post hoc* test. For pairwise comparison, two sequences were designed: (1) each thickness group among different foundation materials and (2) each foundation material among different thicknesses.

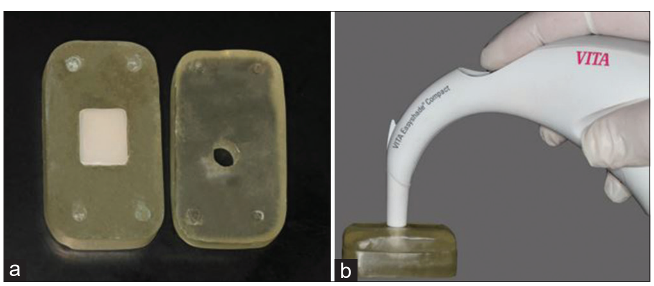

Figure 1: Positioning a ceramic sample and the foundation material in the customized jig (a). Spectrophotometry of the sample (b).

The one-sample *t*-test was used to (α =0.05) compare the color change values (ΔE_{00}) with the perceptibility ($\Delta E_{00} < 0.8$) and acceptability ($\Delta E_{00} < 1.8$) threshold.

RESULTS

Figure 2 shows the average results of color change (ΔE_{00}) in the thickness groups of 1, 1.5, and 2 mm over different foundation materials.

Based on two-factor repeated-measures ANOVA, the foundation material type, thickness, and interaction had a statistically significant effect on the mean values of color change (ΔE_{00}) [$P < 0.001$, Table 3].

The results of the two sequences are illustrated in Table 4.

Under sequence two, significant differences were visible between different thickness groups in all foundation materials except for the D2 and the B1 resin composite.

Based on the results of the one-sample *t*-test, clinically unacceptable ($\Delta E_{00} \geq 1.8$) color changes were detected in all thicknesses of the tested ceramic over black, white, Ni-CR, amalgam, and C3 resin composite foundation materials ($P < 0.001$). However, imperceptible ($\Delta E_{00} < 0.8$) color changes existed in all thicknesses of SUPRINITY over the resin composite foundation materials with D2 and B1shades ($P < 0.001$). Moreover, the final color of SUPRINITY with 2 mm thickness on A3 resin composite and 1.5 mm on NPG was acceptable ($P < 0.05$).

Table 3: Results of the statistical analysis with Greenhouse–Geisser test for the impact of the foundation material type, thickness, and interaction on the mean color change of zirconia-reinforced lithium silicate ceramic

Dependent factor	Fixed factor	Df	Mean square	*F*	*P*
ΔE_{00}†	Foundation material type	3.015	883.682	621.281	0.0001
	Thickness	1.965	187.352	270.331	0.0003
	Foundation material type × thickness	4.939	62.971	47.418	0.0001
	Error		1.3258		

†ΔE_{00}, color change according to CIEDE 2000. Df: Degree of freedom; CIEDE: CIE colour-difference equation (a color-difference formula recommended by the International Commission on Illumination in year 2001)

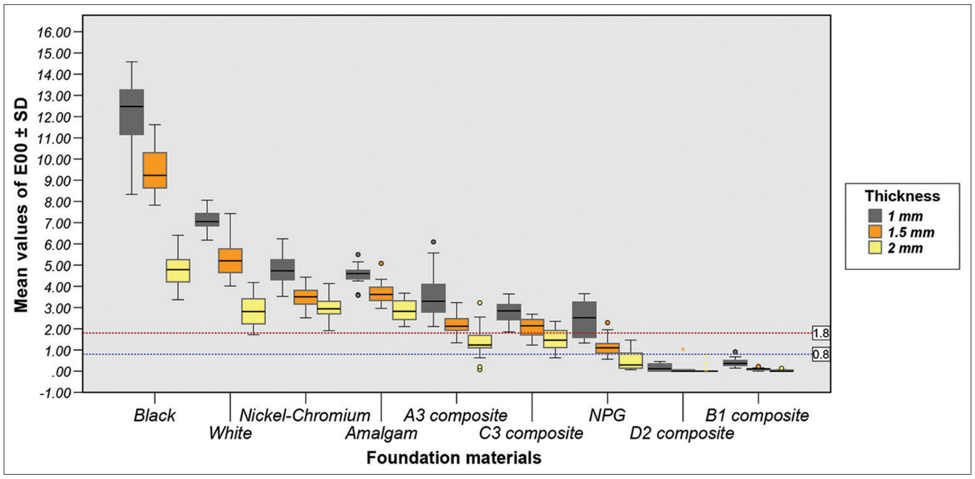

Figure 2: Average values of ΔE_{00} and comparison of it with acceptability and perceptibility thresholds. NPG: Nonprecious gold.

Table 4: The mean values of ΔE_{00}±SD§ and pairwise comparison results (*n*=15 in each thickness group)

Foundation materials¶ (thickness) (mm)	B1	D2	A3	C3	Ni-Cr	NPG	AM	Black	White
1	0.41±0.17^{F,a,*}	0.18±0.17^{F,a}	3.58±0.17^{D,a}	2.81±0.17^{E,a}	4.76±0.17^{C,a}	2.47±0.17^{E,a}	4.53±0.17^{C,a}	12.13±0.17^{A,a}	7.11±0.17^{B,a}
1.5	0.09±0.17^{F,a}	0.08±0.17^{F,a}	2.23±0.17^{D,b}	2.04±0.17^{D,b}	3.5±0.17^{C,b}	1.17±0.17^{E,b}	3.69±0.17^{C,b}	9.50±0.17^{A,b}	5.32±0.17^{B,b}
2	0.02±0.17^{D,a}	0.07±0.17^{D,a}	1.35±0.17^{C,c}	1.51±0.17^{C,c}	3.01±0.17^{B,c}	0.51±0.17^{D,c}	2.85±0.17^{B,c}	4.79±0.17^{A,c}	2.86±0.17^{B,c}

*Significant difference between foundation materials in each ceramic thickness group (comparison between results in a row) with different uppercase letters is visible (P<0.001); §ΔE_{00}, color change according to CIEDE 2000; ¶Resin composite foundation materials are B1, D2, A3, and C3. Significant difference between thickness groups in each foundation material (comparison between results in a column) with different lowercase letters is visible (P<0.001). Alloy foundation materials are Ni-Cr; NPG; AM. Backgrounds are black; white. SD: Standard deviation; NPG: Nonprecious gold-colored alloy; Ni-Cr: Nickel–chromium alloy; AM: Amalgam; CIEDE: CIE colour-difference equation (a color-difference formula recommended by the International Commission on Illumination in year 2001)

DISCUSSION

Based on the results of the current study, the foundation material type and the ceramic thickness and interaction had a significant statistical influence on the ZLS color. As a result, the null hypothesis of this research declined. The minimum ceramic thickness for clinically acceptable color was 1.5 mm for NPG and 2 mm for A3. The minimum thickness for the best final color was 1 mm for B1 and D2.

Technology made proper instruments to study color in dentistry by quantifying the color properties. To ascertain the color difference value, spectrophotometry compared to other conventional methods (such as the human eye) leads to more accurate measurements.[23,24] Researchers use a color difference formula to assess color change value after the CIELAB coordinates measurement through the instruments. Therefore, the accuracy of color studies is dependent on the ability of the color difference formula to generate values that correlate with the average visual responses of observers.[23] The first formula to calculate color difference was presented in 1976. The CIE76 color difference formula is defined as:

$$\Delta E_{76} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

Values of the color change calculated by the CIE76 color difference formula vary and depend on chromaticity.[24] Hence, the new CIEDE2000 (ΔE_{00}) color difference formula was introduced.

Accordingly, in the current research, the value of ΔE_{00} was computed after the spectrophotometry of the samples by recording L*, a*, and b* . Based on different reports, the CIEDE2000 formula exhibits superior balancing for determining color changes. The superiority in the color change evaluation with the CIEDE2000 is related to the uniformity in the evaluations compared to the CIELAB formula.[22,23,25,26] Furthermore, different investigations have reported that the CIEDE2000 ensures an excellent correlation between the perceived and evaluated color changes.[25-28]

Considering the above, the CIEDE2000 formula was used to specify the color change values in the current study.

Owing to characteristics such as translucent shade and comparable mechanical properties with lithium disilicates (flexural strength is 435 Mpa), ZLS ceramic (flexural strength is 494.5 Mpa) was used in this research. ZLS ceramics have significantly contributed to the development of ceramics science thanks to the combining zirconia and glass-ceramic specifications.[11] The main difference between ZLS and lithium disilicate ceramics is in their final crystallization phase.[29] Besides, the results can be explained by the translucent shade of the ZLS ceramics and the color characteristics of the foundation materials in the present investigation. Light transmission for high- and low-translucent ZLS is significantly more than lithium disilicate ceramics with the same translucency.[1] The final result of a restoration in esthetics can be affected by two factors: the first is the optical properties of the foundation materials, and the second is the optical properties of the restoration. Since different foundation materials have different optical properties [Table 2], the final color of a sample depends on the color changes between the control foundation material and the tested one. According to Figure 2, at higher thicknesses, the mean value of ΔE_{00} decreases. Based on our results, B, W, Ni-Cr, AM, and C3 had a greater ΔE_{00} value and did not have the ideal and clinically acceptable color under the tested conditions. The thickness required to achieve the perfect color for B1 and D2 was the lowest among all foundation materials due to their significant similarity to the A2 shade regarding optical properties. This is in agreement with the results of Tabatabaian *et al*.[9] They reported that the required thickness for A1 and A3.5 was the lowest due to their slight differences with A2. Moreover, in Tabatabaian *et al*., black background did not result in ideal and clinically acceptable masking.[9] However, according to Tabatabaian *et al*.,[9] the minimum required thickness to get a superior masking ability was 0.6 mm for AM and 0.8 mm for Ni-Cr. The disagreement in Ni-Cr and AM between the present investigation and Tabatabaian *et al*. is most probably due to the different types of tested ceramic. In addition, Tabatabaian *et al*. used the CIELAB formula to evaluate the color difference value, which did not deliver accurate results. This problem was corrected in the present study using the most accurate color change evaluation method (CIEDE 2000).

Based on the results of the present investigation, a shift in the thickness of ZLS from 1 mm to 2 mm reduced the ΔE_{00} values, which is in line with Passos *et al*.,[10] who concluded that thickness predominated over translucency and firing protocol. Thus, thickness is a contributing factor in achieving ideal clinical standards. Passos *et al*. reported that for ideal results, the thickness of ZLS should be 1.5 mm over a gold foundation material. Furthermore, in their study, the minimum thickness for the acceptable clinical color of the NPG-colored foundation material was 1.5 mm following the results of the current investigation.

The A2 shade of ZLS was used in the current study as it is the most commonly employed shade tab.[30,31]

An optical liquid with a refraction index of approximately 1.5 was also added to improve the accuracy of spectrophotometric evaluation through reducing "edge loss."[11,12] Edge loss is a phenomenon in which light scattered through a translucent material ordinarily would be seen by the eye but is simply not measured by the instrument. This happens when the light is scattered in the translucent object away from the aperture and does not return through the aperture to the sensor; the phenomenon is wavelength dependent.[11,12]

Abdelnaby *et al*. reported 1.5 mm as the required thickness for achieving sound masking of C3 by ZLS glass ceramics.[11] In the current study, C3 was not properly masked with an A2 translucent shade of ZLS at either thickness. This disagreement can be explained based on CIEDE 2000 formula and the more acceptable and perceptible thresholds considered in the current investigation compared to Abdelnaby *et al*. They also did not use an exact and valid threshold to conclude regarding the color change value. Therefore, the use of a valid threshold according to the studies to compare the values of color change can be considered as one of the best points of our study. In the literature, there is no consensus on the suitable background in experimental studies to mimic intraoral conditions. Several researchers have shown that background has a wide range of effects on color perception.[32-35] Ardu *et al*. reported that a black background could be ideal for "*in vitro*" research owing to its ability to simulate the intraoral situation.[33] Furthermore, Zhang *et al*. used a white background to evaluate veneer color in their experimental study.[36] Therefore, the present *in vitro* study used black and white backgrounds to assess L*, a*, and b* coordinates.

Based on the findings of the present investigation, for a perfect final color for the ZLS crown, endocrown, onlay, inlay, and veneer, cosmetic dentists should primarily select an appropriate foundation material suitable for the final shade of the restorations. In complicated cases where a customized post and core are required, an NPG alloy has superiority over Ni-Cr or AM alloy as a foundation for a ZLS restoration [Figure 2]. Furthermore, the application of appropriate opaque porcelain on a metal post and core may reduce the color differences.

The present investigation is aimed to overcome the esthetical problems of ZLS material, such as a different substrate exists.

The limitations of the present investigation include the color of the ceramic and the fact that the influence of opaque cement was not considered. In addition, future studies are suggested to focus on different colors of ZLS material and emphasize the influence of opaque cement.

CONCLUSION

Under the conditions of this investigation, it is concluded that the increase in the thickness of ZLS ceramics could reduce the color change with a darker background. ZLS ceramics with a translucent shade over black, white, nickel–chromium, amalgam, and C3 resin composite foundation materials did not achieve a clinically acceptable color. The minimum thickness for clinically acceptable color of ZLS ceramics was 1.5 mm for NPG colored, and 2 mm for A3. The minimum thickness for a perfect final color was 1 mm for B1 and D2.

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Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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