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Original Article

Effect of the thickness and translucency of the lithium disilicate veneer ceramic on the optical properties of bilayered zirconia

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Abstract

Aim: This study evaluates the effect of lithium disilicate veneer ceramics on the color difference (ΔE_{ab} and ΔE_{00}), translucency parameters (TP_{ab} and TP_{00}), and opalescence parameter (OP) of different thicknesses and translucencies.

Methodology: Ten 0.5 mm thick zirconia core specimens were prepared, and sixty veneer ceramics in A2 shade were prepared from high-translucence (HT) and low-translucence (LT) lithium disilicate glass-ceramics (IPS e.max CAD) in three different thicknesses (0.5 mm, 0.7 mm, and 1 mm). The specimens were evaluated as bilayered structures, and group names were assigned based on the thickness of the core-veneer combinations (n = 10): E1 = (0.5 + 0.5), E2 = (0.5 + 0.7), and E3 = (0.5 + 1). A spectrophotometer (Vita EasyShade V) was used to measure the Commission Internationale de l'Elcairage (CIE) color coordinates L*, a*, and b*, and the ΔE_{ab}, ΔE_{00}, TP_{ab}, TP_{00}, and OP values were calculated. A two-way analysis of variance (ANOVA) and Tukey HSD tests ($\alpha = 0.05$) and Pearson correlation tests ($\alpha = 0.01$) were applied for statistical analysis.

Results: The optical properties (ΔE_{76}, ΔE_{00}, TP_{76}, TP_{00}, and OP) of the bilayered zirconia-based ceramics were significantly affected by the thickness and translucency of the lithium disilicate veneer ceramics ($p<0.001$). However, the interaction between the thickness and translucency of the veneer ceramic was significant only for OP ($p<0.05$). For each thickness, the TP_{76} and TP_{00} values were significantly higher for the HT groups than for the LT groups. The HT groups demonstrated higher OP values than the LT groups, and there were strong correlations between ΔE_{76} and ΔE_{00} and TP_{76} and TP_{00}. Furthermore, there were significant correlations between the TP_{76} and TP_{00} values and the OP parameter.

Conclusion: The optical properties of the bilayered structures were significantly affected by the thickness and translucency of the veneer ceramics. Therefore, the thickness and translucency of the veneer ceramic must be taken into account to achieve a restoration with the desired shade and appearance.

Keywords: color, opalescence, spectrophotometry, translucence, zirconia

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Introduction

Presently, the demand for aesthetic restorations has increased, and ceramic restorations are constantly being developed to meet client expectations (1). Zirconia-based restorations have come to the fore, both for the aesthetic advantages of all-ceramic restorations and for strength comparable to that of metal-ceramic restorations (1, 2). The most common use of zirconia ceramic is as a core material beneath the veneering ceramic. Zirconia cores are covered with veneer ceramics to mask the white and opaque color of conventional zirconia, giving the restorations a natural appearance (3). Conventionally, the veneering process is done using layering or the pressing technique (2). In addition to these techniques, a new technique has been proposed that utilizes CAD (computer-aided design) and CAM (computer-aided manufacturing) to produce lithium disilicate glass-ceramic, which is composited with the zirconia core using a fusion ceramic (a CAD-on technique) or resin cement (4). In this way, it prevents porcelain chipping, which is the most common problem in zirconia-based restorations (5).

Color matching ceramic restorations with the desired shade and giving them a natural appearance remains a challenging process. The information provided by manufacturers is insufficient for achieving a color match between the selected color and the final color of the finished restoration (3). The veneering process plays a significant role in the target shade. The thickness of each layer and the ratio between the layers are critical to producing a suitable color match, contingent on the final thickness of the restoration (3).

In addition to color matching, a restoration should have ideal translucency and opalescence for a natural and vital appearance (6). Translucency refers to the scattering of a large portion of the light passing through a material (7) and is one of the primary factors that determines the aesthetics and choice of suitable restorative materials (8). When a restoration has sufficient translucency, it is in harmony with the surrounding tissues (8).

Opalescence is an optical phenomenon involving the scattering of light in short wavelengths of the visible spectrum. Natural tooth enamel is opalescent, which gives tooth a bluish color in reflected light and an orange or brown color in transmitted light (9). Opalescence solves aesthetic problems related to color and translucency in ceramic systems. Thus, it is possible to produce restorations that cannot be recognized as artificial (10).

Studies have reported significant color differences between ceramic systems and shade guides in the same nominal shade (1, 11-13). It has been reported that high-translucence (HT) lithium disilicate CAD/CAM glass-ceramics exhibit more color differences than low-translucence (LT) glass-ceramics when compared with the shade guide as a reference (12). Although HT lithium disilicate ceramics exhibit a higher translucency parameter (TP) than LT lithium disilicate, LT ceramics have been reported to have a superior masking effect to that of HT lithium disilicate glass-ceramics (14, 15). Information on the color and translucency of zirconia systems veneered with lithium disilicate ceramics of different thicknesses and translucency is limited (14). Furthermore, no study in the literature examines the opalescence of zirconia ceramics veneered with lithium disilicate at different thicknesses and translucency. Therefore, this study investigates the effect of lithium disilicate veneer ceramics of different thicknesses and translucencies on the optical properties—including shade reproduction (ΔE_{76} and ΔE_{00}), translucency parameters (TP_{76} and TP_{00}), and the opalescence parameter (OP)—of zirconia-based ceramics. The null hypothesis is that the thickness and translucency of the veneer ceramic would not affect the optical properties of lithium disilicate veneered zirconia ceramics.

Materials and Methods

The materials used in this study are presented in Table 1. Ten zirconia core specimens were cut from pre-sintered zirconia blocks (IPS e.max ZirCAD, Ivoclar Vivadent AG, Schaan, Liechtenstein) using a slow-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) under water cooling. The specimens were polished with abrasive papers (3M Wetordry TriMite, Minnesota, USA) from #1200 to #1500 grits under water cooling. The sintering process was performed on the pre-sintered zirconia specimens in a furnace (Zirkonofen 700, Zirkonzahn GmbH, South Tyrol, Italy) at 1500 ℃ for 8 hours, per the manufacturer's instructions. The final thickness of the zirconia core was 0.5 ± 0.02 mm.

Using a slow-speed diamond saw (Isomet, Buehler) under water cooling, 60 veneer ceramics were cut from lithium disilicate blocks (IPS e.max CAD, Ivoclar Vivadent AG) in A2 shade, three different thicknesses (0.5 mm, 0.7 mm, and 1 mm), and two different levels of translucency (HT and LT) (n = 10). The core–veneer thickness ratio and combinations were labeled as follows: E1HT and E1LT (0.5:0.5), E2HT and E2LT (0.5:0.7), and E3HT and E3LT (0.5:1). The lithium disilicate veneer ceramics were polished with silicon carbide abrasive paper under water cooling. The final thickness of the veneer ceramics was measured using a digital caliper (MX10103 Digital Caliper, Max Extra, China). The total thicknesses of the core–veneer combinations for E1, E2, and E3 were 1 mm, 1.2 mm, and 1.5 mm, respectively. All specimens were cleaned in distilled water using an ultrasonic machine. To create an optical connection between the zirconia cores and the veneer ceramics, a drop of glycerin gel (Glycerin Pure, Oro Medical, İstanbul, Turkey) was applied between the zirconia and the lithium disilicate veneer ceramic (12, 14).

Regarding optical measurements, the L*, a*, and b* Commission Internationale de l'Eclairage (CIE) color coordinates were measured over 18% neutral gray, white, and black backgrounds (MQ-DGC-Z, Micnova, Guangdong, China). The measurements were made using a portable spectrophotometer (Vita EasyShade V, Vita Zahnfabrik GmbH, Bad Säckingen, Germany), which was calibrated before each measurement, per the manufacturer's recommendations. Three measurements were made from the middle of each specimen against each background, and the average values were recorded. A shade tab in A2 color (Vitapan Classical, Vita Zahnfabrik GmbH) was used as the reference. The measurement tip of the spectrophotometer was placed over the middle third of the shade tab over the gray background, a measurement was made five times, and the average value was recorded. This operation was repeated for each specimen. The L*, a*, and b* values of the shade tab were as follows: L* = 82.2, a* = 1.6, and b* = 24.23. The color difference between the specimens and the reference was calculated using both CIEDE2000 (ΔE_{00}) and CIEDE76 (ΔE_{ab}) formulas.

ΔE_{00} was calculated using the following equation: (16, 17)

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2}$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue, respectively, between the shade tab and the bilayered specimens measured over a gray background. S_L, S_C, and S_H are weighting functions for the lightness, chroma, and hue components, respectively. K_L, K_C, and K_H are the parametric factors to be adjusted based on the different configurations, which are set to 1 in this study. R_T is a rotation function that accounts for the interaction between the chroma and hue differences in the blue region. In this study, ΔE_{00} = 0.8 units was adopted as the CIEDE2000 50% perceptibility threshold, with ΔE_{00} = 1.8 units as the 50% acceptability threshold, based on values used in the study by Paravina et al. (18).

ΔE_{ab} was calculated according to the following formula:

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

where ΔL*, Δa*, and Δb* are the differences between the CIELAB color parameters of the specimens and the reference. It has been reported that 50% of observers can perceive a color difference of 2.6 ΔE units, and 5.5 ΔE is a clinically unacceptable color match (19).

For TP measurements, the color difference between the reference and the same specimen over the black background and white background were calculated using both the CIE2000 (TP_{00}) and CIELAB (TP_{ab}) formulas.

The values from the a* and b* coordinates recorded when the specimens were placed on black (B) and white (W) backgrounds were also used to calculate OP using the following formula (8, 20, 21):

$$OP = \sqrt{(a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2}$$

Statistical analysis

Analysis of the data was carried out with IBM SPSS Version 22 (IBM SPSS Inc., Armonk, NY, USA). The normality of the data was analyzed using Shapiro-Wilk tests. The data was analyzed using two-way analysis of variance (ANOVA) and post hoc Tukey HSD tests with Bonferroni adjustments (α = 0.05). Pearson correlation tests were performed to check for any existing correlations (α = 0.01).

Results

The means, standard deviations, and the two-way ANOVA results for ΔE_{ab} and ΔE_{00} are presented in Table 1 and Table 2. The two-way ANOVA results reveal significant differences in ΔE_{ab} and ΔE_{00} between the test groups for different thicknesses and translucencies of the veneer ceramics. However, the interaction between thickness and translucency for ΔE_{ab} and ΔE_{00} was insignificant ($p>0.05$) (Table 2). In both the HT and LT veneer ceramics, the E1 and E2 groups had the highest ΔE_{ab} and ΔE_{00} values. The color difference between the specimen and the shade guide tends to decrease as the thickness of the veneer ceramic increases. The lowest color difference values were observed in the E3 groups, which were comprised of 1 mm thick veneer ceramics. Considering the translucency of the veneer, the LT groups had lower color difference mean values than the HT groups at all tested thicknesses. Only the E3LT group had an ΔE_{ab} value below the acceptability threshold. However, all the other groups had ΔE values above the acceptability threshold for both ΔE_{ab} (>5.5) and ΔE_{00} (>1.8).

Table 1. Means and standard deviations of groups for the ΔE_{ab} and ΔE_{00} parameters in each thickness and translucency.

	ΔE_{ab}			ΔE_{00}		
	Thickness			Thickness		
	0.5 mm (E1)	0.7 mm (E2)	1 mm (E3)	0.5 mm (E1)	0.7 mm (E2)	1 mm (E3)
HT	13.49±0.24^{a,A}	13.47±0.47^{a,A}	12.08±0.31^{b,A}	8.91±0.16^{a,A}	8.85±0.28^{a,A}	7.77±0.24^{b,A}
LT	6.06±0.81^{a,B}	6.05±0.31^{a,B}	4.36±0.74^{b,B}	4.05±0.51^{a,B}	4.06±0.19^{a,B}	2.92±0.48^{b,B}

Different superscript capital letters in the same column indicate statistical differences between groups. Different superscript lowercase letters in the same row indicate a statistical difference between groups (p<0.05).

Table 2. Two-way ANOVA results of the ΔE_{ab} and ΔE_{00} parameters.

	Source	Type III Sum of Squares	df	Mean Square	F	p
ΔE_{ab}	Thickness (A)	31.896	2	15.948	60.495	<.001
	Translucency (B)	849.010	1	849.010	3220.525	<.001
	A * B	.279	2	.139	.528	0.593
ΔE_{00}	Thickness (A)	16.845	2	8.422	74.978	<.001
	Translucency (B)	350.890	1	350.890	3123.674	<.001
	A * B	0.014	2	0.007	0.061	0.941

Table 3 and Table 4 present the means, standard deviations, and the two-way ANOVA results for TP_{ab} and TP_{00}. The two-way ANOVA test reveals significant differences in thickness and translucency between the groups for TP_{ab} and TP_{00} (p<0.001). However, the interaction between thickness and translucency was not significant for TP_{ab} (p<0.001) and TP_{00} (p<0.001). The E1 groups had the highest TP_{ab} and TP_{00}values, while the E3 groups had the lowest TP_{ab} and TP_{00} values for both HT and LT veneer ceramics (p<0.05). The HT groups had higher TP_{ab} and TP_{00} values for all thicknesses (Table 3).

Table 4 and Table 5 present the means, standard deviations, and two-way ANOVA results for OP. The OP values were significantly affected by thickness, translucency (p<0.001), and the interaction between thickness and translucency (p<0.001). HT groups had significantly higher OP values than the LT groups, except for the E3 group. Regarding thickness, the LT groups had similar OP values for each thickness (p>0.05). The E1 and E2 groups had significantly higher OP values than the E3HT group (p<0.05).

Based on the results of the Pearson correlation tests (Fig. 1 and Fig. 2), there are significant correlations (p<0.001) and a strong positive linear relationship between ΔE_{ab} and ΔE_{00} (r = 0.999) and TP_{ab} and TP_{00} (r = 0.987) (p<0.001).

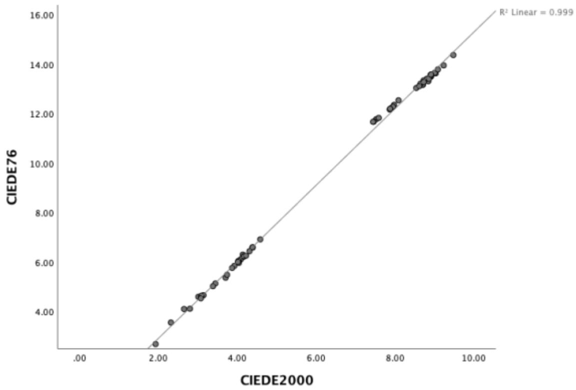

Figure 1. Correlation diagram between the ΔE_{ab} and ΔE_{00} values of the groups.

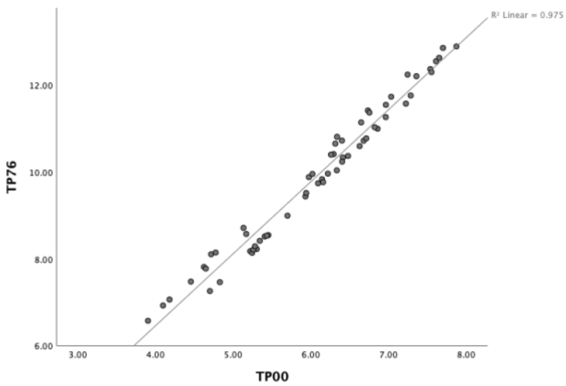

Figure 2. Correlation diagram between the TP_{76} and TP_{00} values of the groups.

There is a moderate correlation between ΔE_{ab} and the translucency parameters: TP_{ab} ($r = 0.436$) and TP_{00} ($r = 0.426$). Similarly, ΔE_{00} has significant and moderate correlations with TP_{ab} ($r = 0.457$) and TP_{00} ($r = 0.445$).

Furthermore, significant and moderate correlations ($p<0.001$) were found between OP and ΔE_{ab} ($r = 0.519$), and between OP and ΔE_{00} ($r = 0.538$). Significant positive correlations ($p<0.001$) were found between OP and TP_{ab} ($r = 0.725$) (Fig. 3) and between OP and TP_{00} ($r = 0.634$) (Fig. 4).

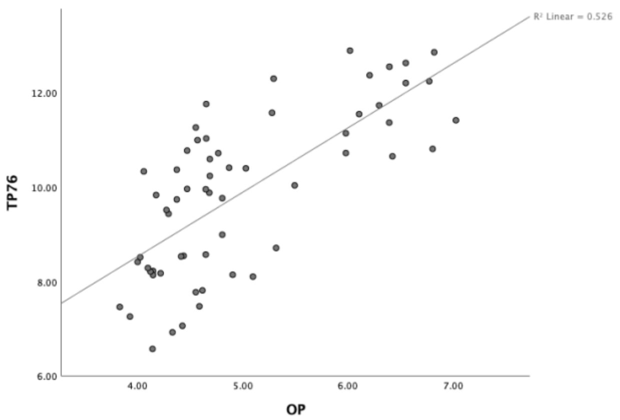

Figure 3. Correlation diagram between the TP_{76} and OP values of the groups.

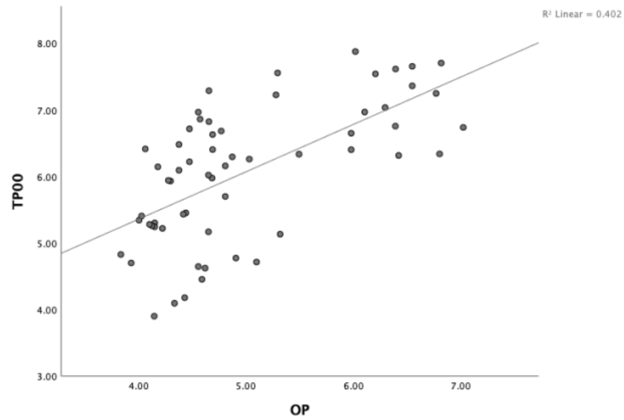

Figure 4. Correlation diagram between the TP_{00} and OP values of the groups.

Table 3. Means and standard deviations of groups for the TP_{ab} and TP_{00} parameters in each thickness and translucency.

	TP_{ab}			TP_{00}		
	Thickness			Thickness		
	0.5 mm (E1)	0.7 mm (E2)	1 mm (E3)	0.5 mm (E1)	0.7 mm (E2)	1 mm (E3)
HT	$11.94 \pm 0.86^{a,B}$	$11.07 \pm 0.92^{b,B}$	$8.13 \pm 0.43^{c,A}$	$7.19 \pm 0.61^{a,B}$	$6.64 \pm 0.53^{b,B}$	$5.21 \pm 0.25^{c,B}$
LT	$10.86 \pm 0.58^{a,A}$	$9.70 \pm 0.64^{b,A}$	$7.72 \pm 0.71^{c,A}$	$6.77 \pm 0.34^{a,A}$	$6.09 \pm 0.36^{b,A}$	$4.57 \pm 0.42^{c,A}$

Different superscript capital letters in the same column indicate a statistical difference between groups. Different superscript lowercase letters in the same row indicate a statistical difference between groups ($p<0.05$).

Table 4. Means and standard deviations of groups for the OP parameters in each thickness and translucency.

	OP		
	Thickness		
	0.5 mm (E1)	0.7 mm (E2)	1 mm (E3)
HT	$6.30 \pm 0.45^{a,B}$	$5.79 \pm 0.90^{a,B}$	$4.10 \pm 0.17^{b,A}$
LT	$4.75 \pm 0.40^{a,A}$	$4.45 \pm 0.21^{a,A}$	$4.67 \pm 0.36^{a,B}$

Different superscript capital letters in the same column indicate a statistical difference between groups. Different superscript lowercase letters in the same row indicate a statistical difference between groups ($p<0.05$).

Table 5. Two-way ANOVA results of the TP_{ab}, ΔE_{00}, and OP parameters.

	Source	Type III Sum of Squares	df	Mean Square	F	p
TP_{ab}	Thickness (A)	127.869	2	63.940	127.752	<.001
	Translucency (B)	13.713	1	13.713	27.400	<.001
	A * B	2.477	2	1.238	2.474	.094
TP_{00}	Thickness (A)	46.178	2	23.089	123.437	<.001
	Translucency (B)	4.380	1	4.380	23.415	<.001
	A * B	.109	2	.055	.293	.748
OP	Thickness (A)	13.324	2	6.662	29.338	<.001
	Translucency (B)	9.021	1	9.021	39.728	<.001
	A * B	13.614	2	6.807	29.976	<.001

Discussion

The findings of this study demonstrate that the optical properties (ΔE_{76}, ΔE_{00}, TP_{76}, TP_{00}, and OP) of the lithium disilicate veneered zirconia ceramics are significantly affected by the thickness and translucency of the lithium disilicate veneer ceramic. Therefore, the null hypothesis of this study is rejected.

Most all-ceramic crowns have a recommended reduction thickness of 1.5 mm because 1 to 1.5 mm of tooth reduction is required to provide an aesthetically acceptable restoration (22). In studies evaluating the color of restorations, the preferred thickness was 1–1.5 mm for bilayered ceramics (1, 2, 14, 15, 23-26). Therefore, total thicknesses of 1 mm, 1.2 mm, and 1.5 mm were selected for evaluation in this study.

An optical fluid is preferred for use between the core and the veneer ceramic to create an optical connection (1, 14, 24, 27). The use of a coupling medium such as glycerin is needed to prevent undesirable effects (e.g., scattering and refraction of light) that may be caused by differences in the refractive indices of air and the ceramic (12, 14). The coupling medium can also prevent light scattering from occurring at the interface (28). Consequently, in this study, a glycerin gel was applied between the core and the veneer ceramic.

Notwithstanding the use of digital color measurement devices, clinicians, and dental technicians prefer to use conventional shade guides when selecting the desired tooth shade for a restoration. However, achieving the target shade in restorative materials remains a challenging process (11). In this study, none of the test groups matched the color in the shade guide except the E3LT group, which has a color difference value below the acceptability threshold ($\Delta E_{ab} < 5.5$). Similar results were reported in a recent study, which concluded that the low-translucent IPS e.max Press, a lithium disilicate based glass-ceramic, reproduces the A2 shade better than the high-translucent varieties (15). However, various studies that have used a shade guide as a reference have found significant color differences between the tested ceramics and the shade guide (1, 8, 11, 13). Lee et al. (1) reported that the color difference (ΔE_{ab}) between the Vita A2 shade tab and A2 bilayered ceramics was in the range of 8.5 to 13.1. In this study, the ΔE_{ab} values for the test groups are in the range of 4.36 to 13.49, and the ΔE_{00} values are between 2.92 and 8.91. This result shows that it is a challenging process to achieve a color match with the shade guide, even though the ceramics used were of the same nominal shade. Therefore, clinicians and dental technicians should be capable of adjusting the individual color parameters to achieve a specified target color. In addition, ceramic manufacturers should prepare special schemes that specify how their materials should be used to achieve the desired shade at the final thickness of the restoration (3).

The thickness of the ceramic affects the color and translucency of the final restorations (1). Among the groups with the same translucency in this study, the E3 groups had significantly smaller color differences than the E1 and E2 groups, while the E1 and E2 groups had similar color difference values. However, the LT groups had significantly lower color difference values than the HT groups in each thickness. Similar findings have been reported by various researchers, with the conclusion that high-translucent lithium disilicate ceramics exhibit larger color differences from the target shade (12, 14). Furthermore, some studies have reported that LT lithium disilicate ceramics exhibit a superior masking ability to HT ceramics (14, 29, 30).

Ceramic systems comprising core and veneer combinations should exhibit variable translucency to ensure a natural appearance in the oral environment (31). In this study, the translucency of the veneer ceramic was significantly affected by both TP_{ab} and TP_{00}. The HT lithium disilicate groups recorded higher TP_{ab} and TP_{00} values than the LT groups at all thicknesses. Although both HT lithium disilicate and LT lithium disilicate are essentially the same material, their crystalline content is different (8). LT ceramic has crystals of 0.8 ± 0.2 µm interlocked in a high-density matrix, while HT ceramic has larger crystals of 1.5 ± 0.8 µm interlocked in a glassy matrix (32). The difference in the crystalline form of these materials may produce different TP values in specimens of the same thickness. Furthermore, thickness had a significant effect on the TP values. The TP_{00} and TP_{ab} values decreased as the thickness of the veneer ceramics increased for both the HT and LT ceramics. This finding concurs with well-established studies in the literature (11, 14, 23, 25, 29).

The TP_{ab} values of the test groups range between 7.72 and 11.94, while the TP_{00} values range between 4.57 and 7.19 units. Basso et al. (14) reported TP_{ab} values for bilayered ceramics in the range of 11.1 to 13.8 for veneered zirconia with a core thickness of 0.5 mm, and veneered with 0.7 mm and 1 mm thick HT and LT lithium disilicate ceramic, respectively. Another study reported a TP_{ab} of 9.95 ± 0.3 for a veneered zirconia ceramic which had an 0.9 mm HT lithium disilicate veneer over its 0.5 mm zirconia core (13). It is quite difficult to make a comparison because of the limited number of studies that have reported TP_{ab} and TP_{00} values of zirconia systems veneered with lithium disilicate. Furthermore, because of the different thicknesses, materials, methodologies, measurement protocols, and geometries used in these studies, a direct comparison is impracticable.

Opalescence is necessary for a restoration to exhibit a natural and vital appearance (33). The OP values of zirconia core veneered ceramics have been reported in the range of 1.3 to 7.07 in the literature (13, 34). Della Bona et al. (8) reported the OP values of 1 mm thick HT and LT IPS e.max CAD ceramics as 4.86 ± 0.08 and 6.58 ± 0.51 units, respectively. In this study, the OP values of the test groups range between 4.10 and 6.30 units, which is in agreement with the aforementioned studies. In a US patent, it was reported that opalescence is not observed when the OP value is less than 4. However, if the OP value is in the range of 4 to 9, the restoration is accepted as being opalescent, and its presence is only slightly noticeable to the naked eye (33). The OP values of the test groups in this study are in the range of 4 to 9. Therefore, it can be concluded that both the HT and LT groups exhibit opalescence at all the tested thicknesses.

In this study, a strong correlation was found between ΔE_{ab} and ΔE_{00}. A similar finding was reported by Lee (35), who proposed that the two formulas for color difference may be used alternately for color difference evaluation. Other studies, however, have found that the CIEDE2000 formula reflects the color differences perceived by the human eye more accurately than the CIELAB formula (36, 37). Strong correlations were observed between TP_{ab} and TP_{00}, which also have the same formulas as color difference. In addition, OP values had significant correlations with the TP_{ab} and TP_{00}. Similarly, some studies have revealed a strong correlation between TP and OP values (9, 13, 38).

In this study, the in vitro conditions and the geometry of the specimens could not reflect the oral environment, which can be counted as a limitation. Furthermore, although the coupling medium could limit the light reflection between the layers, it could not mimic the optical effects of the connection layer (glass-fusion ceramic or composite resin cement) between the lithium disilicate veneer ceramic and zirconia (14). Therefore, future studies can focus on optical properties at different zirconia core thicknesses and different shades of the core and veneer, as well as comparisons of the different connection layers between the lithium disilicate and the zirconia cores.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. The optical properties (ΔE_{76}, ΔE_{00}, TP_{76}, TP_{00}, and OP) of zirconia-based bilayered ceramics are significantly affected by the thickness and the translucency of the lithium disilicate veneer ceramic. The effects of veneering material thickness and translucency on optical properties should be considered during the shade reproduction of ceramic restorations.
2. Regarding ΔE_{76}, only the 1.5 mm thick ceramic group (comprising 1 mm LT veneer ceramics) has a color difference below the acceptability threshold. Regarding ΔE_{00}, none of the test group shades were able to match the target Vita A2 shade. There is a strong correlation between ΔE_{76} and ΔE_{00}.
3. For each thickness, the TP_{76} and TP_{00} values of the HT groups were significantly higher than those of the LT groups. Furthermore, in both the HT and LT groups, the TP_{76} and TP_{00} values decrease significantly as the thickness of the veneer ceramic increases. In addition, there is a strong correlation between TP_{76} and TP_{00}.
4. The HT groups exhibit higher OP values than the LT groups, and there is a significant correlation between the OP parameter and TP_{76} and TP_{00}.

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