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ORIGINAL ARTICLE

Light transmission of zirconia ceramics with different colors and thicknesses†,††

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KEYWORDS
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Abstract *Background/purpose:* It is clear that any reduction in the degree of conversion due to inadequate power output from a polymerization lamp will have an adverse effect on resin performance. The aim of this study was to evaluate the light transmission of zirconia ceramics with different zirconia core thicknesses and colors when irradiated with different types of light polymerization units.
Materials and methods: Zirconia core specimens, 11 mm in diameter, were made in three different thicknesses (0.5 mm, 0.8 mm, and 1.0 mm) for each of 16 color shades of the Vita Lumen Classical scale ($n = 240$). On zirconia core specimens of each color and thickness group, feldspathic dentin porcelain of the same color was added to reach a total veneer thickness of 1.5 mm. In total, 48 groups ($n = 5$) consisting of different zirconia core thicknesses and colors were glazed. Light transmission of all groups was measured by a radiometer and recorded as mW/cm^2 for a conventional halogen light (Hilux 200), LED 1 (Hilux LED-max 550), LED 2 (Hilux LED-max 1055), Bluephase LED 'curing light' (Ivoclar), and plasma arc light (Monitex SP-200). Data were statistically analyzed with three- and two-way ANOVAs. For multiple comparisons of mean values, Tukey's HSD test was used ($\alpha = 0.05$).
Results: According to the three-way ANOVA results, when comparing different light units, thickness, and color groups, there were statistically significant differences among groups ($P < 0.05$).
Conclusion: For any thickness, color, and polymerization unit tested, there did not appear to be adequate transmission of light through the zirconium ceramic samples to achieve effective resin polymerization.

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Introduction

An increasing number of all-ceramic materials and systems are currently available for clinical use. Bioceramics are known as ceramic materials that are especially developed for medical and dental use.[1] Over the course of time, esthetic demands of patients and clinicians have led to the development of all-ceramic crowns. Bonded all-ceramic restorations provide superior esthetics because ceramics allow diffuse transmission as well as diffuse and specular reflectance of light, reproducing a depth of translucency and color mimicking that of natural teeth.[2] Over the last decade, zirconia technology has propelled a rapid development of metal-free dentistry that may provide high biocompatibility, enhanced esthetics, and improved material strength. Nevertheless, considering the optical properties, it could be said that yttrium-stabilized zirconia has a high refractive index, low absorption coefficient, and high opacity in the visible and infrared spectra.[1] The increased opacity of zirconia ceramics could be useful in esthetically demanding clinical situations, such as in cases of masking dichromatic abutment teeth or metal post and cores, but low light transmission may cause inadequate polymerization of resin cement under zirconia ceramics. When comparing different ceramic restorative materials, zirconia ceramics have the highest relative translucency compared to metals.[3]

To obtain the most out of the mechanical and chemical properties of photoactivated or dual polymerization cements, the light should reach the porcelain subjacent cement in an intensity that is capable of polymerizing its light-activated components.[4] Dual-curing resin systems provide a higher degree of conversion of monomers compared to light-curing resin systems. However, use of a catalyst with anterior porcelain veneers is problematic because of the potential for discoloration.[5]

It is clear that any reduction in the degree of conversion due to inadequate power output from a polymerization lamp will have an adverse effect on resin performance. The thickness and shade of restorative material have the greatest influence on light transmission and affect the degree of polymerization of light-polymerized resin luting agents. Generally, the thicker the restoration or the darker its shade, the more critical the intensity of the incident light is to achieve optimal photopolymerization of the material.[6,7]

The International Organization for Standardization (ISO) recommends an intensity for polymerization lights of 300 mW/cm^2, and the standard depth-of-polymerization requirement is 1.5 mm. It was stated that "*polymerization lights with an intensity of 300 mW/cm^2 appear to effectively polymerize most resin-based composite materials when appropriate polymerization times are used, which, in some cases, are longer than those recommended by the manufacturers.*"[8]

Light-curing units (LCUs) and modes induce significant differences in most characteristics such as the degree of conversion of resin composite cements.[9] For example, high-intensity curing lights achieve adequate polymerization of resin cements through veneers in a markedly shorter time period than do conventional halogen lights.[10] Light curing is usually performed with quartz tungsten halogen (QTH) LCUs. Other technologies, such as xenon plasma arc (PAC) and light-emitting diodes (LEDs) are also available. In current dental resins, camphorquinone (CQ) is typically used as a visible light-activated free-radical photoinitiator. The absorption spectrum of CQ has a broad maximum at 468 nm in the blue region of the visible spectrum. Dental curing units are generally halogen sources with band-pass filters that transmit in the 400—540-nm visible region. The spectrum flux of LEDs and PACs peaks around 470 nm, and is concentrated over a much-narrower wavelength band than are halogen lamps. The peak wavelength of light absorption of the CQ photoinitiator is at 468 nm, which coincides with the peak of LEDs and PACs. Although these systems are still being developed, their application has grown considerably.

Given esthetic requirements for different ceramic systems, light transmittance should be considered by clinicians. Considering the previously mentioned circumstances, the aim of this study was to evaluate the light transmission of zirconia ceramics of different colors and thicknesses when different types of polymerization units are irradiated. The research hypothesis was that different thicknesses and core-colored zirconia ceramics affect the amount of transmitted light.

Material and methods

To prepare zirconium oxide (yttrium partially stabilized with tetragonal polycrystalline structure) ceramic samples, 1.1-mm-diameter brass molds were prepared. The Zirkonzahn polymerizing lamp (Quick Lamp, Zirkonzahn, Bruneck, Italy) for light curing the mock-up framework resin (Rigid) is a LCU used to photopolymerize resins. This unit is necessary for hardening the resin, T-Rigid, used for modeling. Then the T-rigid resin was placed on a pantograph machine (Zircograph E 025 ECO, city?, ST?, country?) and prepared for the milling process. Coloring and baking of the specimens were performed according to the manufacturer's instructions.

After these procedures, manual-aided design, manual-aided manufactured (MAD-MAM) zirconium core specimens (Zirkonzahn) of 11 mm in diameter were made in three different thicknesses (0.5 mm, 0.8 mm, and 1.0 mm $\pm$ 0.05 mm) for each of 16 color shades (A_1, A_2, A_3, $A_{3.5}$, A_4, B_1, B_2, B_3, B_4, C_1, C_2, C_3, C_4, D_2, D_3, and D_4) of the Vita Lumen Classical Shade scale according to the manufacturer's recommendations (n = 240). On zirconia core specimens of each color and thickness group, feldspathic dentin porcelain (Ceramco PFZ, Degudent, Hanau-Wolfgang, Germany) of the same color was added to

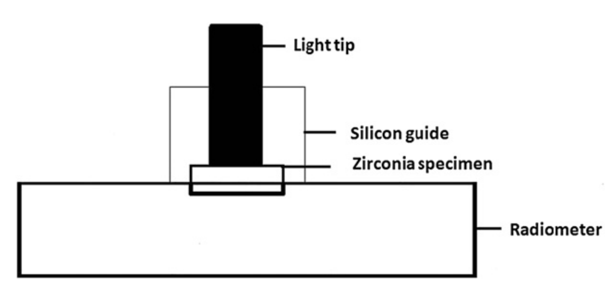

Figure 1 Experimental measurement of light transmission.

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Table 1 Three-way ANOVA table.

Source	d.f.	Sum of squares	Mean square	*F*	*P*
Thickness	2	803294.57	401647.29	8774.860	0.000*
Color	15	1052933.95	70195.596	1533.576	0.000*
Light unit	4	1477698.59	369424.647	8070.886	0.000*
Thickness × color	30	99987.40	3332.913	72.815	0.000*
Thickness × light unit	8	206443.58	25805.447	563.776	0.000*
Color × light unit	60	152764.00	2546.067	55.624	0.000*
Thickness × color × light unit	120	45847.92	382.066	8.347	0.000*
Error	960	43941.60	45.773		

*Differs significantly at $P < 0.05$.

reach a total veneer thickness of 1.5 ± 0.05 mm. All specimens were measured using digital calipers (C-master; Mitutoyo, Tokyo, Japan). In total, 48 groups consisting of different zirconia core thicknesses and colors and including 5 specimens were glazed according to the manufacturers' recommendations.

Three different types of LED were used called LED 1 (Hilux LED-max 550; Benlioğlu Dental, city?, Turkey, with an output power of 620 mW/cm^2), LED 2 (Hilux LED-max 1055; Benlioğlu Dental, with an output power of 1100 mW/cm^2), and a Bluephase LED 'curing light' (Ivoclar Vivadent, Schaan, Liechtenstein, with an output power of 1400 mW/cm^2), as well as a type of QTH lamp (Hilux 200; Benlioğlu Dental, with an output power of 500 mW/cm^2), and a PAC polymerization unit (Monitex SP 200; Monitex, San-Chung City, China, with an output power of 1700 mW/cm^2).

The incident light power given by the five LCUs and the transmitted light power through each zirconia ceramic sample were registered using a digital radiometer device (Hilux LEDMAX; Benlioğlu Dental). Each polymerization light had a light guide with 7-mm-diameter tips. The light polymerization units were connected to a voltage stabilizer before the measurements. The power irradiated by the LCUs without the interposition of the porcelain and the distance (1.5 mm) between the light tip of the unit and the radiometer were the same as those of the sample groups. Light transmission by zirconia ceramic was determined by placing it on the radiometer and irradiating the specimen for 10 s at the highest setting for each light polymerization. The sample diameter was the same length from the radiometer's optic eye. To avoid light escaping, appropriate silicon impression materials were prepared around the light tips, and specimens were embedded in silicon (Fig. 1). Over the irradiation period of 10 s, the highest and lowest values of the transmitted light were recorded. For each sample, measurements were made in this way three times, and averages were recorded as mW/cm^2.

Data were statistically analyzed with three- and two-way analyses of variance (ANOVAs). For multiple-comparison of mean values, Tukey's honest significant difference (HSD) test was used ($\alpha = 0.05$).

Table 2 Tukey's HSD test of mean light intensities (mW/cm^2) for different core thicknesses.

Zirconia ceramic core thickness (mm)	*n*	Amount of light passing through the sample (mW/cm^2)	Group differences[a]
1.0	400	36.817	A
0.8	400	50.085	B
0.5	400	97.120	C

[a] Different letters indicate a statistically significant difference between groups ($P < 0.05$).

Results

According to the three-way ANOVA results, when comparing different light units, color groups, and thicknesses, there were statistically significant differences among the groups. Interactions of thickness × color, color × light unit, thickness × light unit, and thickness × color × light unit significantly differed ($P < 0.05$; Table 1).

When comparing different core thicknesses for transmitted light power (mW/cm^2) with Tukey's HSD test, specimens with a 1-mm core thickness demonstrated the

Table 3 Tukey's HSD test of the mean light intensities (mW/cm^2) for different colors of zirconia ceramics.

Color	*n*	Light intensity (mW/cm^2)	Group differences[a]
A4	75	19.2133	A
C4	75	24.6000	B
D4	75	29.2133	C
A3,5	75	30.3067	C
B4	75	31.2800	C
A3	75	47.2400	D
C3	75	49.4933	D
B3	75	54.1733	D
D3	75	63.6933	E
A2	75	64.8400	E
C2	75	75.0267	F
B2	75	85.0933	G
D2	75	95.0667	H
C1	75	96.9867	H
A1	75	98.5200	H
B1	75	116.7067	I

[a] Letters indicate a statistically significant difference between groups ($P < 0.05$).

Table 4 Tukey's HSD test of mean light intensities (mW/cm^2) for different light sources.

Light source	n	Light intensity (mW/cm^2)	Group difference[a]
Halogen	240	16.9542	A
LED1	240	30.8875	B
LED2	240	60.1375	C
Bluephase	240	85.8208	D
Plasma	240	112.9042	E

[a] Letters indicate a statistically significant difference between groups ($P < 0.05$).

lowest light transmission (36.82 mW/cm^2), and specimens with a 0.5-mm core thickness demonstrated the highest light transmission (97.12 mW/cm^2) among all groups. There were statistically significant differences among the 0.5-mm, 0.8-mm, and 1-mm groups (Table 2). For all polymerization light units, according to the two-way ANOVA results, there was a statistically significant difference between color and thickness, and their interactions ($P < 0.05$).

When comparing the effect of different colors on the transmitted light power according to Tukey's HSD test, while the lowest light transmission (19.21 mW/cm^2) was generally observed with the A_4 color, the highest light transmission (116.71 mW/cm^2) was observed with the B_1 color groups (Table 3). There were no significant differences among the A_1, C_1, and D_2 color groups. For all light units except the PAC light polymerization unit, there was no significant difference between the A_4 and C_4 colors. But for PAC light, C_4 exhibited the lowest light transmission, and there was a statistically significant difference between C_4 and A_4 ($P < 0.05$).

When comparing different light polymerization units according to Tukey's HSD test, there were statistically significant differences among the transmitted light powers of the conventional halogen light, LED 1, LED 2, Bluephase LED light, and PAC light. The highest light transmission of all groups was observed with the PAC, and the lowest was observed with the halogen lamp. Bluephase was higher than LED 2, and LED 2 was higher than LED 1 (Table 4). The PAC light polymerization unit exhibited a light power value of 269.8 mW/cm^2 for the 0.5-mm zirconia core thickness and B_1 color, which was the highest value observed among all groups. The halogen light polymerization lamp exhibited no light transmission with zirconia ceramic samples with a 1-mm core thickness for the $A_{3.5}$, A_4, B_4, C_4, D_3, and D4 color groups. For different thicknesses, color groups, and light units, amounts of transmitted light (mW/cm^2) are presented in charts (Figs. 2–4).

Light transmission through zirconia ceramic specimens was reduced with increased thicknesses for all five light sources. The decreased intensity of the light transmitted through the three specimen thicknesses was significant ($P < 0.05$).

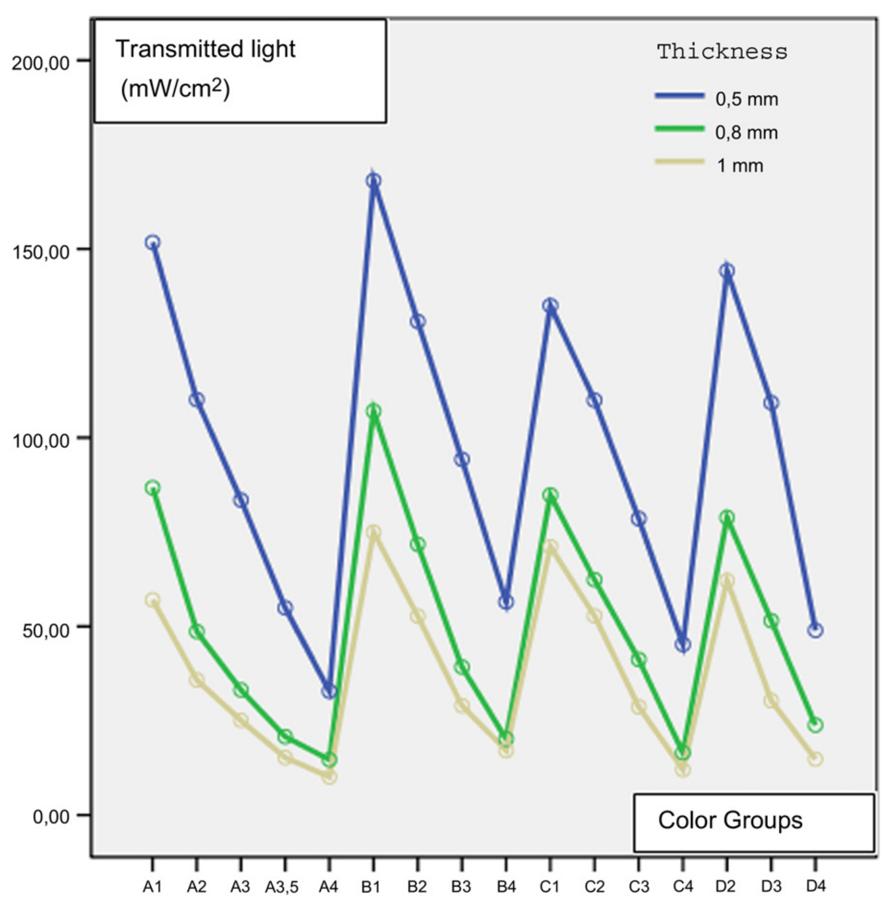

Figure 2 Light transmission with different color groups and thicknesses.

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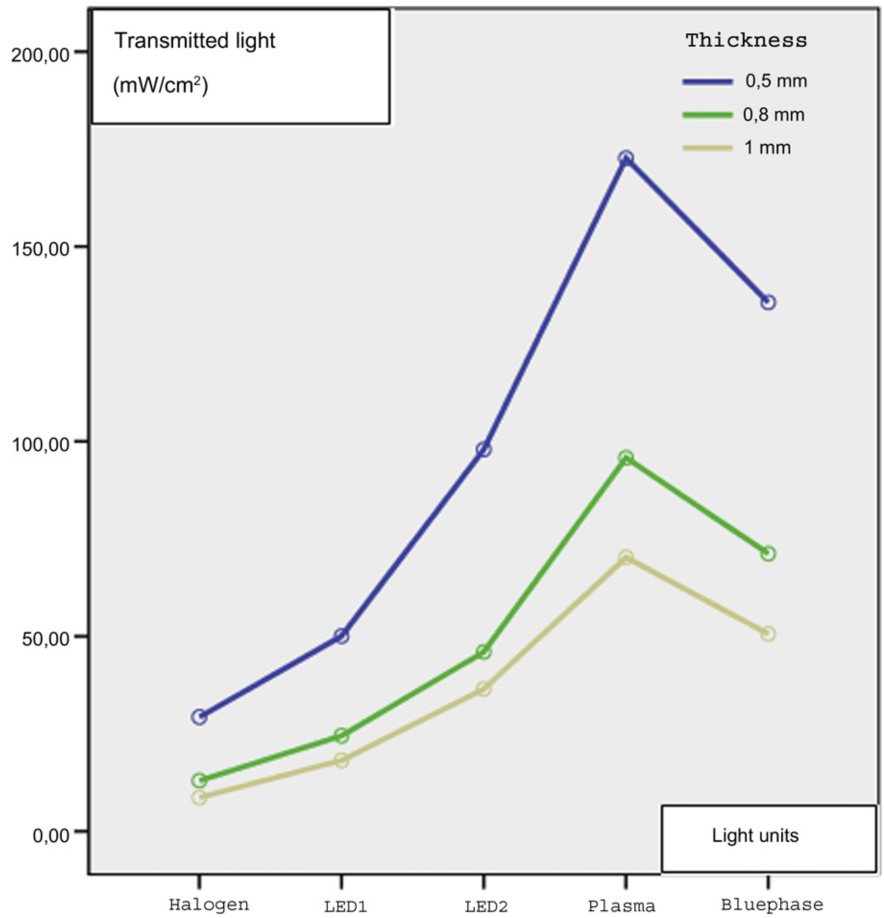

Figure 3 Light transmission with different thicknesses and light units.

Discussion

In the present study, the color, thickness, light source parameters, and their interactions were evaluated. Considering different light sources, light transmission varied with different colors and thicknesses of the zirconia ceramics. According to the results of the present study, the hypothesis was accepted. The degree of conversion in a polymerization reaction is dependent on the energy delivered during light curing, characterized as the product of the light intensity and exposure time.

The intensity of light transmitted through ceramic veneers is dictated by the polymerization unit and the type and thickness of the ceramic. With conventional halogen polymerization units, there may be insufficient light transmission through thicker veneers or all-ceramic crowns for adequate light polymerization. Rasetto et al[10] indicated that there did not appear to be sufficient transmission of light through thicker copings to achieve effective resin polymerization when the resin was lightly polymerized with conventional and lower-output high-intensity polymerization lights.

Pazin et al[11] showed that the ceramic thickness is a critical factor in developing the hardness in indirectly activated dual-cured resin luting agents. Light transmission through a ceramic crown can be affected by a number of clinical and technical parameters. For example, the veneer thickness may be >1 mm near the incisal edge but only 0.3 mm in the gingival one-third. So the region where the light source is applied is important for the polymerization efficiency. In addition, the wavelength of the light source, characteristics of the guiding wand, composition of the ceramic veneers, and voltage should be taken into consideration.

As mentioned earlier, "*polymerization lights with an intensity of 300 mW/cm² appear to effectively polymerize most resin-based composite materials when appropriate polymerization times are used.*"[6] Linden et al[5] indicated that a chemical catalyst and prolonged curing times might be essential for clinical success. It should be considered that the light intensity beneath ceramic material might be insufficient for adequate polymerization of light-cured resin cement.

For single crowns, copings must be at least 0.5 mm thick, or 0.7 mm thick in areas of high stress.[12] Oztürk et al[13] evaluated the effects of various dentin ceramic thicknesses and repeated firings on the color of lithium disilicate glass-ceramic and zirconium-oxide with a 1-mm core thickness. In parallel with those studies, 0.5-mm, 0.8-mm, and 1-mm zirconia ceramic coping thicknesses were used in the present study.

In the present study, a conventional halogen lamp, different generation LED lights, and PAC polymerization lamp systems were tested. Compared to other light

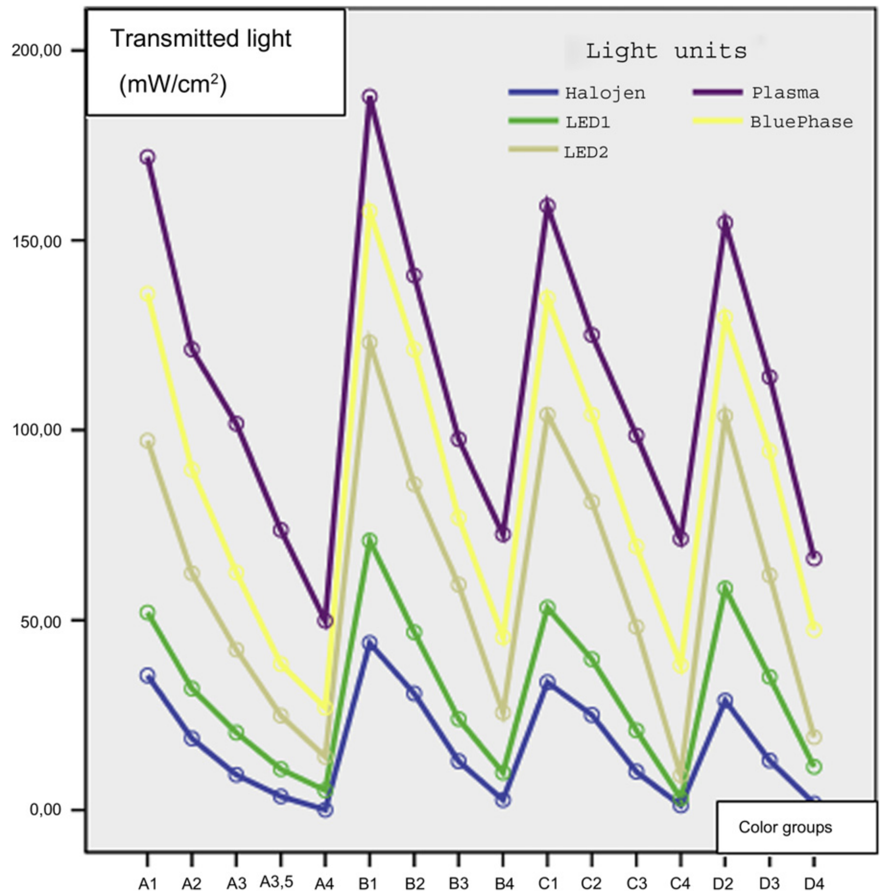

Figure 4 Light transmission with different color groups and light units.

sources, in all colors and thicknesses, the PAC polymerization unit showed high values of light transmission. However, PAC has higher output power (1700 mW/cm^2) among the polymerization units, and measurements showed 269.8 mW/cm^2 as an average value for 0.5-mm thickness and B_1 color groups which was the expected maximum of light transmission. This value is lower than the 300 mW/cm^2 accepted as a standard by the ISO. Additionally, it should be considered that for PAC, the application time (3 s) proposed by the manufacturer is questionable, because it may be insufficient for adequate resin polymerization. Polymerizing lamps with an output power of 800 mW/cm^2 are widely used in clinics.[14] This may seem an adequate output power to clinicians, but it is clear that under these conditions, applying visible light-cure resin systems beneath zirconia ceramics would be inappropriate. Given the hardness of the resin, also dual-cure resin systems may reveal some clinical problems. As Valentino et al stated, inadequate polymerization can cause early failure of full-ceramic cementation.[15]

Peixoto et al[16] evaluated the effects of the shade and thickness of the porcelain on light transmission, and Cardash et al[17] cured visible light- and dual-curing composite resin luting cements under porcelain disks of different colors to examine the effects of porcelain color on the surface hardness. In both studies, lower light transmission was observed with A_4 and C_4 shades. These results are in concordance with the findings of the present study. Low light transmission was observed for the conventional halogen unit in the A_4, C_4, and D_4 color groups, and there was no statistically significant difference among these groups ($P < 0.05$). For LED light units, the lowest light transmission was observed with groups A_4 and C_4, and there was no significant difference between those groups. For the PAC polymerizing unit, the lowest light transmission was observed with C_4 color groups. Depending on these results, it could be said that when the output power of the light polymerization unit decreases, increasing numbers of color groups are affected by light transmission. In other words, this result indicates that the greater the thickness, the greater the number of shades that have statistically equivalent percentages of transmitted light; that is, the light blockage is more associated with the thickness than to the porcelain shade in thicker samples.

Based on this investigation, it could be said that high output power (mW/cm^2) of polymerization lamps results in greater light transmission. However, the type of light source and output power also influence heat generation in light-cured systems. Heat adds kinetic energy to a curing system and increases conversion.[18] On the contrary, the effects of heat on biological tissues include arteriole vasodilatation, exudation, coagulative necrosis of cells, and excessive temperature rises, which can cause pulp inflammation. In the genesis of thermal damage, the extent of the damage depends on the quality of heat transferred to biological tissues. Heat transmission is influenced by factors such as the thermal conductivity of the target, the duration of the thermal impulse, the contact surface, the temperature, and the thermal capacity of the source.[19,20]

It is clear that increasing the core thickness reduces light penetration.[3] In the present study, a 1-mm zirconia core ceramic thickness had the lowest light transmission. We know that zirconia ceramic cores have the lowest light transmission compared to other ceramic restorative materials.

Zirconia ceramics with various chemical compositions and production techniques probably exhibit different light transmission properties. For example, some zirconia-based systems utilize a white-colored core, which may limit their indications from an esthetic standpoint. Some systems use a Y-TZP core that is relatively translucent and may simultaneously mask underlying discolored abutments.[21] Based on this, the use of zirconia ceramics with different chemical compositions may be significant for clinicians. Additionally, measuring the degree of conversion of different resin luting agents beneath zirconia ceramic materials may produce better clinical situations. Future studies should be expanded to include other dental light polymerization units, particularly PAC polymerization units with a minimum intensity of 2500 mW/cm^2.

In conclusions, none of the polymerization light units through zirconia ceramics used in the present study demonstrated an average value of 300 mW/cm^2, which is known as the standard for resin composite polymerization. This resulted in insufficient light polymerization for light-cured resin systems of various colors and thicknesses of zirconia ceramics used. Based on this investigation, for any thickness, color, and polymerization unit tested in the present study, there did not appear to be adequate transmission of light through the zirconia ceramic samples to achieve effective resin polymerization.

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