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LED and Halogen Light Transmission through a CAD/CAM Lithium Disilicate Glass-Ceramic

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The effect of thickness, shade and translucency of CAD/CAM lithium disilicate glass-ceramic on light transmission of light-emitting diode (LED) and quartz-tungsten-halogen units (QTH) were evaluated. Ceramic IPS e.max CAD shades A1, A2, A3, A3.5, high (HT) and low (LT) translucency were cut (1, 2, 3, 4 and 5 mm). Light sources emission spectra were determined. Light intensity incident and transmitted through each ceramic sample was measured to determine light transmission percentage (TP). Statistical analysis used a linear regression model. There was significant interaction between light source and ceramic translucency ($p=0.008$) and strong negative correlation ($R=-0.845$, $p<0.001$) between ceramic thickness and TP. Increasing one unit in thickness led to 3.17 reduction in TP. There was no significant difference in TP ($p=0.124$) between shades A1 ($\beta_1=0$) and A2 ($\beta_1=-0.45$) but significant reduction occurred for A3 ($\beta_1=-0.83$) and A3.5 ($\beta_1=-2.18$). The interaction QTH/HT provided higher TP ($\beta_1=0$) than LED/HT ($\beta_1=-2.92$), QTH/LT ($\beta_1=-3.75$) and LED/LT ($\beta_1=-5.58$). Light transmission was more effective using halogen source and high-translucency ceramics, decreased as the ceramic thickness increased and was higher for the lighter shades, A1 and A2. From the regression model ($R^2=0.85$), an equation was obtained to estimate TP value using each variable β_1 found. A maximum TP of 25% for QTH and 20% for LED was found, suggesting that ceramic light attenuation could compromise light cured and dual cure resin cements polymerization.

Key Words: halogen dental curing lights, LED dental curing lights, lithium disilicate, dental porcelain, glass ceramics

Introduction

Dentistry is going through the polymer and ceramic age. Metal-free ceramic restorations present excellent aesthetics, biocompatibility, long-term stability and ability to mimic the tooth shade (1,2). Nowadays, there is an extensive variety of systems available for the preparation of ceramic restorations using CAD/CAM technology (2-4). Lithium disilicate glass-ceramics have been proposed as an option for partial and all-ceramic restorations (4,5). Their good mechanical resistance (6), acid sensitivity (4), and translucency (2,7) allow the construction of esthetic and adhesively cemented crowns (6), inlays, onlays and veneer restorations (4,5).

An adequate polymerization of resin cement improves clinical performance of the ceramic restoration. This polymerization may be influenced by several factors, such as ceramic translucency (1,8), type and thickness (1,9,10), and the light-curing unit (LCU) (11,12). Until recently, conventional quartz-tungsten-halogen (QTH) light-curing units were the most common light source for inducing polymerization in resin based dental materials (13). However, their use decreased due their inherent drawbacks. Halogen bulbs have a limited effective lifetime of around 50 h. The bulb, reflector and filter degrade over time due to the high temperatures involved, leading to a reduction in light output. The result is a reduction of the light cure unit's effectiveness to cure dental composites (14). In the last years, light-emitting diodes (LED) are also available. LEDs have lifetimes of over 10,000 hours and present little degradation of light output over this time, a distinct advantage when compared with halogen bulbs. In addition, LEDs require no filters to produce blue light. LEDs are very resistant to shock and vibration and their relatively low power consumption make them suitable for portable use. The spectral output of these blue LEDs falls mainly within the absorption spectrum of camphorquinone (400 nm – 500 nm), photoinitiator of most dental composites. Although these systems present greater energy efficiency, QTH light transmission through ceramics has shown similar results to LED and some clinicians still use QTH to light cure resin cement during ceramic restorations cementation (12,15,16) because they still have success in their clinical practice.

The influence of the type of LCUs to polymerize dual-cured resin cement through ceramic restorations is not fully investigated and the clinicians are not sufficiently clarified whether they should keep their QTH or whether they should exchange for a LED source. The clinical significance of this topic is that the resin cement under ceramic restorations should receive enough light intensity to achieve proper polymerization and optimal properties. The objective of this study was to evaluate the effect of the thickness, shade and translucency of a CAD/CAM lithium disilicate glass-ceramic on the percentage of light transmission from both QTH and LED curing sources. The null hypothesis is that the percentage of light transmission through the ceramic is not influenced by ceramic thickness, translucency, shade or type of light source.

Material and Methods

Forty ceramic blocks (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein), assigned according to translucency and shade (Table 1), were sectioned into approximately 1-, 2-, 3-, 4- and 5-mm-thick samples (n=5 for each thickness) using a diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA). The specimens with 1 to 4 mm varied up to 0.3 mm and 5 mm specimens varied up to 0.6 mm and were not polished as they had smooth and regular surfaces after cutting. The thickness of each specimen was measured with a digital caliper and several points were plotted on a thickness x light transmission curve. The greater the number of plotted points, the greater the reliability of the absorption coefficient calculation. Next, each sample was crystallized in a ceramic oven (EDG Titan 2000 Platinum, Equipamentos e Controles Ltd., São Paulo, SP, Brazil) at temperatures ranging from 403 to 850 °C, according to the manufacturer's specifications. During the crystallization process, two samples were lost: a 2-mm-thick LTA2 and a 3-mm-thick LTA3.

Analyses of QTH and LED emission spectra were performed using a spectrometer (USB 2000; Ocean Optics Inc., Dunedin, FL, USA) that measured the relative intensity of diffracted light (SpectraSuite software; Ocean Optics Inc.) with a 0.35-nm resolution linear array detector over a wavelength range from 340 to 1100 nm. The spectra were obtained at an elapsed time of zero and after ten consecutive activations to simulate continuous use and heating conditions, and any associated decrease in emitted light intensity .

The emitted baseline intensity of each curing light unit and the light intensity transmitted through each ceramic sample were recorded using a digital power meter (Newport Optical Power Meter, Model 835, Évry, France). Each sample was placed directly over the photosensitive crystal detector in contact with the light tip of the light curing unit. Considering that this sensor detects photons around a central value, the peaks obtained in the spectra analysis were used as reference for the wavelength range of each light source. From the light source characterization experiments, the initial emission spectra were similar for both QTH and LED illumination (Fig. 1) and remained unchanged up to 10 min after thermal stability of the lamp wire filament of each appliance, since after heating the power emitted by these lamps tended to be more stable.

The tip of each light source was coupled to a metallic ring attached to the power meter probe, containing the photosensitive crystal. For each ceramic sample, measurements were performed at 10, 20 and 30 s after the start of activation. The mean of three power measurements (mW/cm^2), with and without ceramic samples, was used to calculate the light transmission percentage (TP). The light intensity of each light source throughout the experiment was measured at the beginning and after every 5 samples using a radiometer (Radiometer for halogen light and LED; ECEL, São Paulo, SP, Brazil). Mean values were 1350 mW/cm^2 for LED source and 950 mW/cm^2 for QTH.

The independent effect of each factor and its

Table 1. Description, shade, translucency, batch numbers and composition of the ceramics

Ceramic	Shade	Translucency	Composition
IPS e.max CAD LT A1/C14	A1	Low	SiO_2, Li_2O, K_2O, MgO, ZnO_2, Al_2O_3, P_2O_5 and other oxides
IPS e.max CAD LT A2/C14	A2	Low	
IPS e.max CAD LT A3/C14	A3	Low	
IPS e.max CAD LT A3.5/C14	A3.5	Low	
IPS e.max CAD HT A1/C14	A1	High	
IPS e.max CAD HT A2/C14	A2	High	
IPS e.max CAD HT A3/C14	A3	High	
IPS e.max CAD HT A3.5/C14	A3.5	High	

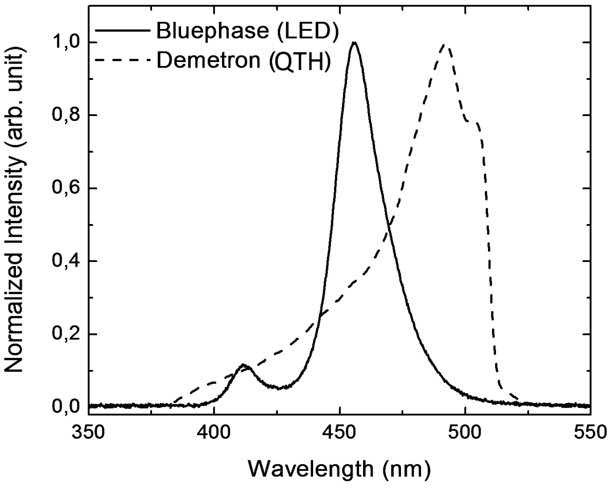

Figure 1. Spectra for Bluephase (LED) and Demetron (QTH) light sources.

interactions on the TP through each ceramic sample was evaluated using multiple linear regression (Stata, release 12, StataCorp LP, College Station, TX, USA). The coefficients $ß_0$ (intercept) and $ß_1$ were estimated for each level of the evaluated factors.

Origin Pro 7.0 data analysis software (Origin Lab Corporation, Northampton, MA, USA) was used to obtain the coefficient of absorption (α) according the Lambert-Beer equation:

$$I/I_0 = e^{-\alpha d} \qquad [1]$$

where I is the light intensity transmitted through the sample, I_0 is the intensity of the incident light, d is the thickness of the sample, and *e* is Napier's constant. To determine the coefficient of absorption for each ceramic as a function of translucency and shade, the transmission percentage (TP) values obtained at each thickness were converted into Naperian logarithms and fitted to linear models for both QTH and LED data series.

Results

The variation coefficient obtained for initial measurements without ceramic was 3.5% for the QTH source and 3.7% for the LED source, indicating low range throughout the experiment, with no additional intervals between irradiances. TP results obtained for each ceramic sample as a function of thickness, shade, and translucency are in Figures 2 and 3 for QTH and LED sources, respectively. There was a decrease in TP with an increase in thickness, as well as a decrease in translucency. There was a strong negative correlation between ceramic thickness and TP (Pearson's correlation coefficient: R=-0.845, p<0.001). The linear regression model explained 85% of the TP variance (R^2=0.85). There was significant interaction only between light source and ceramic translucency (p=0.008). The adjusted model, combining light source and translucency is in Table 2, which presents the $ß_1$ coefficients of investigated factors.

Based on $ß_1$ values, increasing the thickness in one unit, TP reduced a mean of 3.17. Considering shades, there was no statistical difference between effects of A1 and A2 (p=0.124). Light transmission was significantly lower

Table 2. Adjusted linear regression model for ceramic thickness and shade, combining the factors of light source and translucency

Parameter	$ß_1$	Sig.	95% Confidence interval	
			Lower bound	Upper bound
Intercept	19.480	.000	18.791	20.170
LED / Low translucency	-5.583	.000	-6.157	-5.010
LED / High translucency	-2.924	.000	-3.494	-2.353
QTH / Low translucency	-3.756	.000	-4.330	-3.182
QTH / High translucency	0^b	.	.	.
Thickness	-3.165	.000	-3.312	-3.019
Shade A3.5	-2.183	.000	-2.754	-1.612
Shade A3	-.833	.005	-1.406	-.259
Shade A2	-.450	.124	-1.024	.123
Shade A1	0^b	.	.	.

$ß_1$: TP coefficient for each parameter evaluated. QTH: quartz-tungsten-halogen lamp. LED: light-emitting diode. R-square adjusted: 0.85. [b]: reference for each factor.

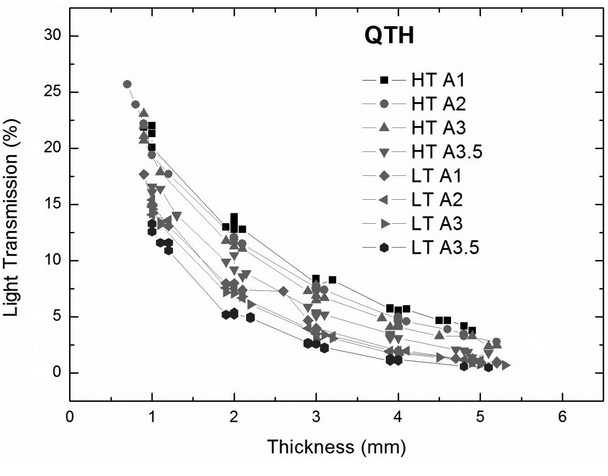

Figure 2. Graphic presentation of percent light transmission as function of ceramic thickness, shade, and translucency obtained using QTH light source.

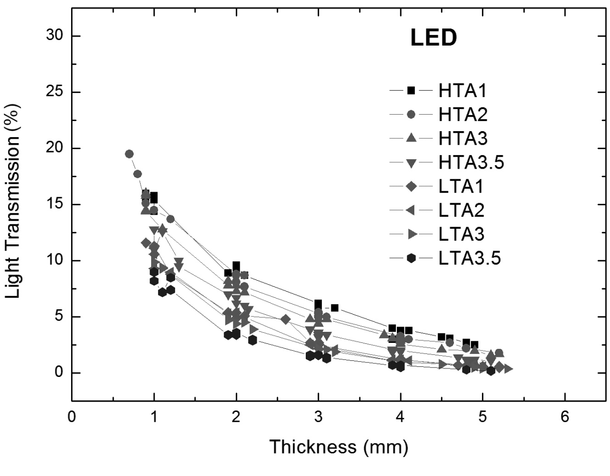

Figure 3. Graphic presentation of percent light transmission as function of ceramic thickness, shade, and translucency obtained using LED light source.

for A3 (β_1=-0.83) and A3.5 (β_1=-2.18) compared to A1. Considering the light source and translucency interaction, the highest TP resulted from QTH and high-translucency (HT) ceramic, the reference value. A mean reduction of 2.92 in TP was observed for LED and HT ceramics. When QTH and low-translucency (LT) ceramic factors were combined, a mean reduction of 3.75 was observed, whereas LED and LT ceramics had the greatest impact on TP reduction (β_1=-5.58). From these data, an equation for the estimated light transmission percentage (ETP) was constructed:

$$ETP \approx \beta_{1\ Intercept} + \beta_{1,d} . d + \beta_{1,shade} + \beta_{1,s*t} \qquad [2]$$

where $\beta_{1\ Intercept}$=19.48; $\beta_{1,d}$=-3.17; d=sample thickness (mm); $\beta_{1,shade}$=0 for A1, -0.45 for A2, -0.83 for A3 or -2.18 for A3.5; s*t=(interaction between light source and translucency) and $\beta_{1,ls*t}$=0 for QTH/ HT, -2.92 for LED/HT, -3.76 for QTH/LT, or -5.58 for LED/LT, according to Table 2.

Figures 4 and 5 show the Naperian logarithm of TP as function of ceramic thickness, considering all combinations of translucency and color for QTH and LED sources, respectively. Figure 6 shows the absorption coefficients as function of ceramic shade for each combination of translucency and light source.

Discussion

The null hypothesis that light transmission through ceramic is not influenced by ceramic thickness, translucency, shade, or light source was rejected, as light transmitted by LED was lower than by QTH. Evaluating light sources, light emission spectra showed an explicit peak for the LED source and a broad region of intensity for the QTH source in visible blue light spectrum. The detector, placed immediately behind the sample, prevented loss of any light during the analysis, which provided more accurate transmission readings. The low coefficient of variation observed for both the QTH (3.5%) and LED (3.7%) sources in the readings without any interposing sample suggests that the intensity of light emitted by the devices was predictable, even after continuous use. However, this finding differs from studies where a decrease in light intensity with prolonged use was reported (20). This is important since inadequate power provided by the light unit may have an adverse effect on the clinical performance of ceramics that rely on light cured or dual cured resin cements (12,17,18).

Figures 2 and 3 demonstrate that QTH light transmission was more effective than LED transmission, particularly for 1 mm samples and for high-translucency 2 mm ceramic samples. However, these factors should not be analyzed separately because the regression analysis results showed an interaction between the light source and ceramic translucency. This could be related to the pattern of each light source. During the experiments, LED focused directly on the ceramic generated a narrower and collimated beam following the tip diameter, while for QTH scattering of light through the entire sample was observed. Besides that, lithium disilicate crystalline structure probably contributes to refraction, dispersion and diffraction of the QTH light, making its total transmission more effective than the LED light. Though it was stated previously that the light transmission through ceramic restorations is influenced by the light curing unit and the ceramic type, ceramic thickness provides the main effect (10,12).

The absorption coefficient of ceramic is theoretically an intrinsic property of the material. However, the light absorption of ceramics exposed to a QTH source was lower than that for a LED source, suggesting the influence of wavelength range on the optical performance of lithium disilicate glass-ceramics. It has been demonstrated that direct light transmission through glass ceramics increased

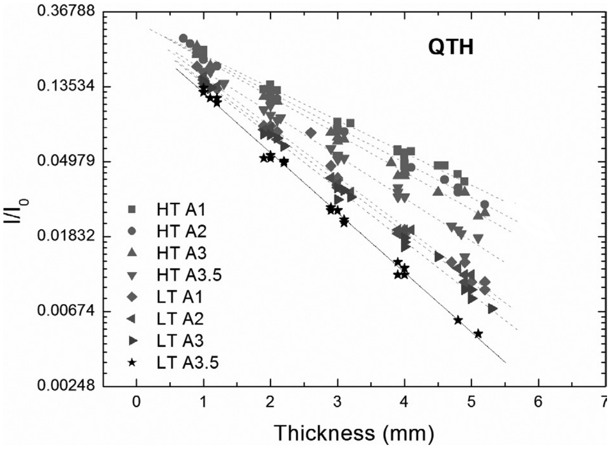

Figure 4. Graphic presentation of l_n of QTH light transmission as function of ceramic thickness for all combinations of translucency and shade.

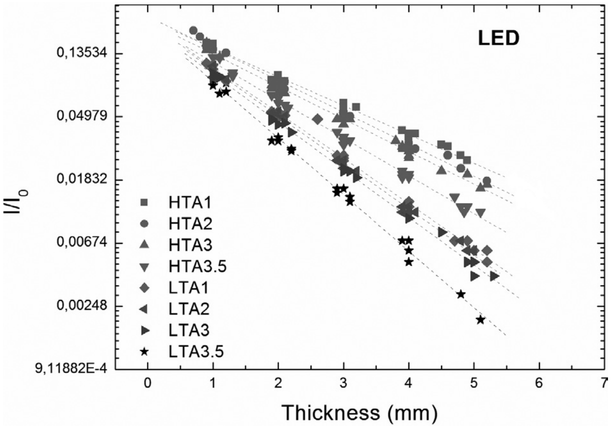

Figure 5. Graphic presentation of l_n of LED light transmission as function of ceramic thickness for all combinations of translucency and shade.

with increase in wavelength from 400 to 700 nm (19).

The correlation between the Naperian logarithm of the absorption coefficient and the ceramic thickness shows a linear relationship between the variables of shade and translucency, not only for QTH but also for LED. The higher coefficient of absorption for darker and low-translucency ceramics confirmed the findings of lower TP values for these ceramic specimens exposed to LED. This is probably because of the different emission spectra obtained from the two light sources; the LED source exhibited a narrower spectrum. This suggests that coefficient of absorption is also related to the wavelength range of each light source (20).

Dose-response gradient of light transmission beneath lithium disilicate glass-ceramic with progressively lower TP for darker and low-translucency ceramics, may be explained by the homogeneity of variance in residuals for shade and translucency, confirming the low variability among pre-manufactured ceramic blocks after crystallization procedure. It is probably a result of lithium disilicate glass-ceramic crystalline structure. This study also demonstrated an exponential increase in TP with decrease in thickness. It was previously reported that light transmission through ceramic is more affected by its thickness than by its shade (7,21,22).

In spite of different used parameters , the TP behavior of lithium disilicate glass-ceramics was in agreement with another study (7), and suggests that it is more favorable than those reported for feldspathic and pressed lithium disilicate glass-ceramics (21,22) or zirconia ceramics (23). Figures 2 and 3 show that light transmission was exponentially higher for light-shade and high-translucency-ceramic samples, as well as for low-thickness ceramics, confirming other studies (7,10,16). Coefficients of absorption obtained from the Lambert-Beer equation confirm these trends, demonstrating an exponential relationship between TP and ceramic thickness (7,21) and a more favorable performance of QTH. Besides the absorption, the scattering should also be considered in light transmission when ceramic materials are investigated.

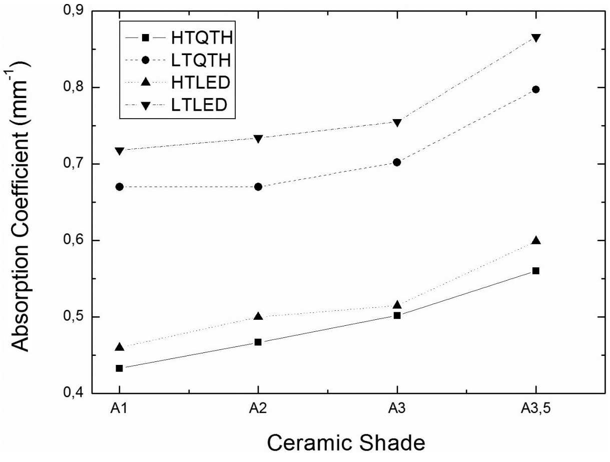

Figure 6. Graphic presentation of absorption coefficients as function of ceramic shade according to each combination of translucency and light source.

Resin cements are the usual choice for bonding of CAD/CAM restorations, as the preparations cannot present frictional retention (24). Reduction of light transmission through the ceramic restoration affects the polymerization of dual-cure resin cements (9), especially for restoration thicknesses above 2 mm (17) or 3 mm (10). In the present study, TP was lower than 10% for samples with thicknesses above 2 and 3 mm for LED and QTH, respectively, regardless of shade and translucency. TP values were lower than 5% for low-translucency and dark shade samples above 3-mm thickness for both light sources. A significant decrease in irradiance of QTH and LED light sources through ceramics was observed when 1.5 to 6 mm-thick IPS e.max CAD LT A3 was reported (11).

Equation [2] was proposed to estimate QTH and LED light transmission, considering $ß_1$ coefficients of each evaluated parameter from the multivariate regression. As an example, the estimated light transmission can be calculated (using $ß_1$ values shown in Table 2) for a 1-mm thick lithium disilicate glass-ceramic restoration , A1 shade and a high-translucency using QTH light source as follow:

$$ETP \approx ß_{1\ \mathrm{Intercept}}+ß_{1,d}.d+ß_{1,\mathrm{shade}}+ß_{1,s*t} \qquad [2]$$
$$ETP=19.48+(-3,17\ .\ 1)+0+0$$

In these conditions, ETP would be 16.31%. Based on $ß_1$ data, it is possible to estimate the efficiency of light transmission through the restoration and, consequently, its potential effect on the photo activation of resin cement. This equation is effective for lithium disilicate glass-ceramics and QTH (≈950 mW/cm^2) or LED (≈1350 mW/cm^2). Further studies are under way to determine the effect of light transmission attenuation on the conversion degree and microhardness of different resin cements.

Within the limitation of this *in vitro* study, it may be concluded that both light sources were effective, but light transmission through lithium disilicate glass-ceramic is more effective using a halogen source and high-translucency ceramic; light transmission decreased as the ceramic thickness increased and was higher for A1 and A2 ceramic shades than for A3 and A3.5 shades, for both QTH and LED. Besides, the proposed equation allows estimation of light transmission percentage through an IPS e.max CAD ceramic from clinical data of thickness, shade, translucency and light source.

The emission spectra of the evaluated light sources are compatible with the absorption peak of camphorquinone, a common photoinitiator in photoactivated and dual resin cements (12). Although the proposed equation does not consider the wavelength of each device, the attenuation of light by ceramic may be compensated by the concept of energy density. It considers the product of total intensity of the emitted light by the exposure time (25). The clinical significance of the present study is that the less translucent, darker and thicker the ceramic, the greater should be the exposure time on each face of the restoration, aiming to provide enough power for proper polymerization of the underlying resin cement.

Resumo

Avaliou-se o efeito da espessura, cor e translucidez de uma cerâmica vítrea a base de dissilicato de lítio para CAD / CAM sobre a transmissão da luz de unidades de diodos emissores de luz (LED) e de quartzo-tungstênio-halogênio (QTH). Cerâmica IPS e.max CAD nas cores A1, A2, A3, A3.5 de translucidez alta (HT) e baixa (LT) foram cortadas (1, 2, 3, 4, 5 mm). Os espectros de emissão das fontes de luz foram determinados. A intensidade da luz incidente e transmitida através de cada espécime de cerâmica foi medida para determinar a percentagem de transmissão de luz (TP). Um modelo de regressão linear foi utilizado para a análise estatística. Houve interação significativa entre a fonte de luz e translucidez cerâmica ($p = 0.008$) e forte correlação negativa ($r = -0.845$, $p < 0.001$) entre a espessura da cerâmica e TP. O aumento da espessura em uma unidade levou a uma redução média de 3.17 em TP. Não houve diferença significativa em TP ($p = 0.124$) entre as cores A1 ($ß1 = 0$) e A2 ($ß1 = -0.45$), mas ocorreu redução significativa para as cores A3 ($ß1 = -0.83$) e A3.5 ($ß1 = -2.18$). A interação QTH/HT proporcionou maior TP ($ß1 = 0$) do que LED/HT ($ß1 = -2.92$), QTH/LT ($ß1 = -3.75$) e LED/LT ($ß1 = -5.58$). A transmissão de luz foi mais eficaz utilizando QTH e cerâmica de alta translucidez, diminuiu à medida que a espessura de cerâmica aumentou, e foi maior para as cores A1 e A2. A partir do modelo de regressão ($R2 = 0.85$), obteve-se uma equação para estimar o valor de TP utilizando os valores de ß1 encontrado. Foi observada TP máxima de 25% para QTH e 20% para LED, sugerindo que a atenuação promovida pela cerâmica pode comprometer a ativação de um cimento resinoso fotoativado e de ativação dupla.

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