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Dental zirconia generations: a comparative study of translucency parameters and light transmittance across varying thicknesses

Gerações de zircônia dentária: um estudo comparativo dos parâmetros de translucidez e transmitância de luz em diferentes espessuras

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ABSTRACT

Objective: This in vitro study evaluated the translucency and polymerization light transmission of zirconia discs, produced from different generations of dental zirconia materials and with a consideration of varying thicknesses. **Material and Methods:** Disc-shaped specimens (0.5mm, 1.0mm, 1.5mm, 2.0mm, and 3.0mm) were produced from three A1 pre-shaded monochrome zirconia generations: conventional (3Y-TZP (inCoris TZI C); high translucency 4Y-PSZ (Cercon HT) and super translucent 5Y- PSZ (Cercon XT). A total of 90 discs were prepared. Translucency measurements were conducted using an intraoral spectrophotometer on each specimen against white and black backgrounds. Polymerization light transmission was assessed by measuring the transmitted light through each specimen emitted from confirmed emission spectra light-polymerizing units using a digital optical power meter. Two-way ANOVA tests ($\alpha=0.05$) were utilized to evaluate the differences between the influences of the zirconia generation and thickness parameters. **Results:** Different zirconia generations and thicknesses displayed distinct TP and transmittance values, with 5Y-PSZ exhibiting the highest values, which decreased as thickness increased. A significant interaction was found between zirconia generation and thickness on TP and transmittance ($p\leq0.001$), with more pronounced differences at lower thicknesses and non-significant differences at 3mm thickness. **Conclusion:** The study demonstrates that the generations and thickness of zirconia, and their interactions, significantly impact light transmission and TP values. Extra translucent cubic zirconia (5Y-PSZ) exhibits the highest TP, making it a more preferable choice for achieving predictable aesthetic outcomes that mimic teeth translucency and high polymerization light transmittance, ensuring adequate photopolymerization of the underlying resin luting cement.

KEYWORDS

Ceramics; Polymerization; Translucency; Transmittance; Zirconia.

RESUMO

Objetivo: Este estudo avaliou in vitro a translucidez e a transmissão da luz de polimerização através de discos de zircônia, produzidos a partir de diferentes gerações de materiais de zircônia odontológica com variadas espessuras. **Material e Métodos:** Espécimes em forma de disco (0,5 mm, 1,0 mm, 1,5 mm, 2,0 mm e 3,0 mm) foram produzidos a partir de três gerações de zircônia monocromática pré-sombreada A1: convencional (3Y-TZP (inCoris TZI C); alta translucidez 4Y-PSZ (Cercon HT) e super translúcida 5Y-PSZ (Cercon XT). Um total de 90 discos foram preparados. As medições de translucidez foram conduzidas usando um espectrofotômetro intraoral em cada espécime contra fundos branco e preto. A transmissão de luz de polimerização foi avaliada medindo a luz transmitida através de cada espécime, emitida a partir de unidades de polimerização de luz de espectros de emissão confirmados usando um medidor de potência óptica digital. Testes ANOVA dois fatores ($\alpha = 0{,}05$) foram utilizados para avaliar as diferenças entre as gerações de zircônia e diferentes parâmetros de espessura. **Resultados:**

Diferentes gerações e espessuras de zircônia exibiram distintos valores de TP e transmitância, com a 5Y-PSZ exibindo os valores mais altos, que diminuíram conforme a o aumento da espessura. Uma interação significativa foi encontrada entre a geração de zircônia e a espessura em TP e transmitância ($p \leq 0,001$), com diferenças mais proeminentes em espessuras menores e diferenças não significativas em espessuras de 3 mm. **Conclusão:** O estudo demonstra que as gerações e a espessura da zircônia, e suas interações, impactam significativamente a transmissão de luz e os valores de TP. A zircônia cúbica extra translúcida (5Y-PSZ) exibe o TP mais alto, tornando-a uma escolha mais preferida para atingir resultados estéticos previsíveis que se assemelham a translucidez dos dentes e a alta transmitância de luz de polimerização, garantindo a fotopolimerização adequada do cimento resinoso.

PALAVRAS-CHAVE

Cerâmicas; Polimerizações; Translucidez; Transmitância; Zircônia.

INTRODUCTION

The field of prosthodontics underwent a significant transformation in the late 1990s with the introduction of zirconia [1]. This material, known for its remarkable mechanical properties and pure white color, rapidly became a popular alternative to metal framework materials in fixed dental prostheses (FDPs), which were often veneered with more translucent aesthetic ceramics [2].

Since then, a new generation of zirconia has emerged, offering pre-shaded options suitable for monolithic restorations. Although the optical properties and translucency of zirconia may not be ideal for anterior teeth, it has secured its position as the most prescribed material for fabricating posterior crown restorations [3-6].

Recent advancements have resulted in the development of highly and extra translucent zirconia, widening its applications in aesthetic zones of FDPs by providing optimal optical properties and translucency to match the appearance of adjacent natural teeth, especially when a high degree of translucency is desired [7-9]. This progress in zirconia's evolution is attributable to several strategies employed by manufacturers, such as reducing alumina content to 0.05 wt% or less, refining zirconia grain size, enhancing processing density, and controlling the manufacturing process to minimize air pockets and their density [10,11].

The most successful strategy has been to increase the cubic crystalline form content in zirconia's microstructure [6,10,11]. The cubic polymorph of zirconia, which boasts superior translucency compared to its tetragonal counterpart, offers a constant refractive index in all directions due to its optically isotropic nature. Additionally, the larger grain size of the cubic polymorph in zirconia reduces light scattering at grain boundaries, reducing their visibility and allowing more light to pass through zirconia restorations [6,10]. However, this manufacturing strategy results in a trade-off: the cubic zirconia has lower strength and fracture toughness than its tetragonal counterpart due to the absence of transformation toughening mechanisms present in the metastable tetragonal phase and the relatively larger particle size of the cubic phase compared to the tetragonal phase [4,9,12]. To stabilize and maintain a polymorphic equilibrium favoring the cubic form as a major crystalline phase, additional stabilizing oxides such as yttria (Y_2O_3) are incorporated. Conventional zirconia contains about 3mol% yttria (3Y), which is insufficient for achieving the desired translucency [6,10,11]. By raising the yttria content to 4mol% (4Y) and 5mol% (5Y), the cubic form's presence increases to about 30% and 50% respectively. This enhancement in cubic zirconia content has led to improved translucency in zirconia-based dental restorations [8,9]. It is noteworthy that while the increase in cubic phase content by raising yttria concentration enhances translucency, it concurrently reduces mechanical properties. Specifically, 4Y-TZP zirconia exhibits a flexural strength of 600 to 900 MPa and fracture toughness of 2.5 to 3.5 $MPa \cdot m^{1/2}$, and 5Y-TZP zirconia shows a flexural strength of 700 to 800 MPa and fracture toughness of 2.2 to 4 $MPa \cdot m^{1/2}$. This is in contrast to more opaque zirconia, which has a flexural strength of 1,000 to 1,400 MPa and fracture toughness of 3.5 to 4.5 $MPa \cdot m^{1/2}$ [10,13,14].

The increased translucency of zirconia, coupled with advances in bonding zirconia to tooth structures using new generations of 10-Methacryloyloxydecyl Dihydrogen Phosphate (10-MDP)-containing adhesive luting resin cements, has expanded potential applications of zirconia in the aesthetic and minimally invasive bonded restoration field within fixed prosthodontics [15-17]. As zirconia usage continues to grow, it's crucial to further investigate its optical properties [18].

Specifically, the translucency of zirconia, a key optical property, plays a critical role in dental restorations [3,19,20]. Translucency is evaluated by measuring a material's translucency parameter (TP) and light transmittance. The TP represents the color difference between a material with a uniform thickness when placed against white and black backgrounds, which is important in predicting the aesthetic outcome of a restoration. This allows for the replication of natural teeth translucency or the concealment of underlying colors in cases with dark foundations or tooth shades [8,21,22].

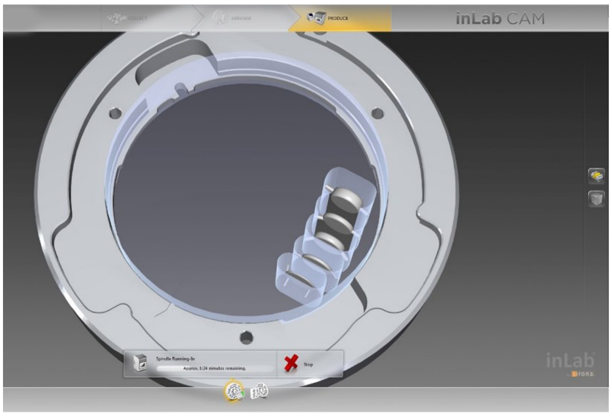
Light transmittance, defined as the ratio of light transmitted at a specific wavelength to the amount of light before transmission, is essential in indirect zirconia restorations. The process involves reflectance, internal scattering, and absorption of polymerization light before it reaches the luting cement, which is responsible for attenuating the polymerizing light after it passes through and exits the restoration. Previous research indicates that light transmission through ceramic materials impacts the photopolymerization of resin luting cement, potentially leading to inadequate polymerization of photopolymerizing or highly light-dependent dual polymerizing luting resin cements [22-24].

While the optical properties of zirconia ceramics are well-documented, research on these properties—specifically, light transmittance and translucency parameter (TP), which are essential for the aesthetic outcome of zirconia restorations and the effective photo-polymerization of underlying resin cement—remains limited in the context of the newest highly translucent cubic zirconia. To the best of my knowledge, no study has yet investigated the combined effects of generation type and thickness on light transmittance and TP. Furthermore, there is a significant gap in research using materials from the same manufacturer and shade, which is critical for accurately determining the impact of yttria content and thickness and for minimizing confounding factors that could affect transmittance and TP. Therefore, this study aimed to compare the TP and transmittance of zirconia discs (of the same shade and from the same manufacturer) fabricated from new generations of high and extra-high translucent zirconia at varying thicknesses with those made from conventional 3Y-TZP. The null hypothesis that was tested is that there would be no significant difference in the light transmittance and TP values between highly translucent cubic zirconia and 3Y-TZP.

MATERIALS AND METHODS

This study explored the optical properties of three generations of A1 pre-shaded monochrome dental zirconia materials from the same manufacturer (Dentsply Sirona Inc.; Charlotte, NC), outlined in Table I. The materials tested comprised a conventional 3mol% yttria-tetragonal zirconia polycrystal (3Y-TZP) (inCoris TZI C, mono L blocks), a high translucency 4mol% yttria-partially stabilized zirconia (4Y-PSZ) (Cercon HT, 98.5mm discs), and a super/extra translucent 5mol% yttria-partially stabilized zirconia (5Y-PSZ) (Cercon XT, 98.5mm discs).

Circular disc-shaped specimens with a uniform diameter of 10 mm and various thicknesses (0.5mm, 1.0mm, 1.5mm, 2.0mm, and 3.0mm) were designed using a 3D modeling software program (Meshmixer; Autodesk, Inc.; San Rafael, CA). The 3D digital images were exported as STL files and opened in a CAM software (inLab CAM SW16.1; Dentsply Sirona Inc.; Charlotte, NC) to nest the files within the respective zirconia CAD/CAM discs and blocks (Figure 1). The specimens were then milled using a 5-axis computer numerical control (CNC) dental milling machine (inLab MC X5; Dentsply Sirona Inc.; Charlotte, NC). In total, 90 discs



Spindle Running-In

Approx. 1:24 minutes remaining.

Figure 1 - Schematic representation of the process of virtually nesting a specimen's design files into a CAD/CAM zirconia disc in a software program.

Table I - Overview of the characteristics of the investigated zirconia generations

Brand	Type	Composition (wt%)	Manufacturer	Lot #	Shade	Flexural strength*
InCoris TZI C	Pre-shaded zirconium Oxide (3Y-TZP) 3Y-TZP (<15% *c*)	ZrO_2+HfO_2+Y_2O_3 ≥ 99.0% Σ Y_2O_3 + Er_2O_3 5.6% Al_2O_3 ≤ 0.35% Other oxides (except Er_2O_3) ≤ 0.2%	Dentsply Sirona Inc.; Charlotte, NC	2014373410	A1	> 900MPa
Cercon® HT	Pre-shaded zirconium Oxide 4-PSZ (>30% *c*)	ZrO_2 Y_2O_3: 5% HfO_2: <3% Al_2O_3, Other oxides including Silicon oxide: <1%	Dentsply Sirona Inc.; Charlotte, NC	18047811	A1	1200 MPa
Cercon® XT	Pre-shaded zirconium Oxide 5Y-PSZ (>50% *c*)	ZrO_2 Yttrium oxide (Y_2O_3): 9% HfO_2: <3% Al_2O_3, Other oxides including Silicon oxide: <1%	Dentsply Sirona Inc.; Charlotte, NC	18044893	A1	750 MPa

* According to manufacture data (three-point flexural testing). PSZ, yttria-partially stabilized zirconia; TZP, yttria-tetragonal zirconia polycrystal; *c*, Cubic.

were prepared, with six specimens for each combination of thickness and zirconia generation type. Sample size calculations were initially conducted using G*Power software (version 3.1.9.6, Heinrich Heine University Düsseldorf). An a priori power analysis, utilizing an effect size (f) of 0.91 derived from the findings of Supornpun et al. [8], determined that a total of 30 specimens would be required to achieve 80% power for detecting significant differences at an alpha level of 0.05 in an ANOVA test. Despite the initial calculations, the decision was made to fabricate 6 specimens for each material and thickness combination, consistent with the number of specimens used in related research, resulting in a total of 90 specimens to enhance the robustness of the study.

The specimens underwent conventional sintering in a high-temperature furnace (Sirona Infire HTC speed; Dentsply Sirona Inc., Charlotte, NC) following the manufacturer's recommendations, Post-sintering, they were cleansed in an ultrasonic cleaner and their thicknesses were confirmed using a digital caliper (Mitutoyo 500-180-30 Caliper, Mitutoyo Corp., IL, USA) with an accuracy of ±0.02 mm. Subsequently, each ceramic disc was then finished and polished in a standardized manner to achieve a smooth surface using diamond-impregnated, bullet-shaped zirconia polishing stones/burs (Zirconia Polishing Kit CA, SHOFU Dental Corporation, CA, USA).

Figure 2 - A specimen is shown being tested against a black background using a spectrophotometer. A 3D-printed alignment jig was utilized to precisely position the spectrophotometer at the center of the specimen.

The specimens' translucency was assessed using a calibrated clinical spectrophotometer (Vita Easyshade Advance, VITA Zahnfabrik; Bad Säckingen, Germany). This contact-type spectrophotometer features D65 illumination and a geometric 2°/0° observer angle and has been proven to be highly reliable for measuring the optical properties of dental materials in various studies [25,26]. With a small aperture size of 3mm within the measurement area and a probe tip size of 5mm, the device corresponds to the central area of the ceramic discs [27]. A custom-designed 3D-printed alignment jig, depicted in Figure 2, was employed to ensure consistent alignment of the probe tip with the same central area of the specimens. This jig facilitated the positioning of the probe at a precise 90-degree angle to the specimen surface, thereby promoting consistent measurement conditions [28,29]. Furthermore, the specimens were prepared with flat surfaces and were measured against opaque backgrounds to mitigate any potential edge-loss effects. Additionally, the selection of the specimen diameter was carefully considered in relation to the device's aperture to minimize the potential for edge-loss effects, ensuring the reliability of the translucency measurements [30,31].

The CIE Lab* values of each specimen were first obtained on a ColorChecker background (X-rite ColorChecker Passport, X-rite Inc.; MI, USA) on a black patch background (L* = 20.46, a* = -0.07, and b* = -0.97) and then on a white patch background (L* = 96.53, a* = -0.43, and b* = 1.19). The TP was calculated for each specimen based on the color differences against these backgrounds using the following equation:

$$TP = \Delta E76 = \sqrt{\left(\left(L_W * - LB^*\right)^2 + \left(a_W * - a_B *\right)^2 + \left(b_W * - b_B^*\right)^2\right)} \quad (1)$$

where L* refers to the brightness, a* to the redness-to-greenness, and b* to yellowness-to-blueness. The subscript B refers to the color coordination on the black background and W to those on the white background [19,21,32,33].

To measure the transmittance of the specimens, a digital optical power meter (Model 1830-C; Newport, CA, USA) was connected to an optical detector (818-SL/DB; Newport, CA, USA), capable of detecting wavelengths in the range of 400–1100 nm, along with an OD3 attenuation filter. The emission spectrum of the light-polymerizing units was verified using an integrating sphere connected to a fiber-optic spectrometer (USB 4000, Ocean Optics; Dunedin, FL, USA). This ensured compatibility between the spectral emission of the polymerization LED light unit (450 nm - 550 nm) and the range of the optical detector used. Ceramic disc specimens were carefully centered on the detector's attenuation filter lens, and the light guide of the verified light-polymerizing unit was aligned over the specimen using a silicone alignment jig (Figure 3). The intensity of transmitted and incident light was recorded after activating the light-polymerizing unit for 10 seconds, both with and without the interposition of zirconia disc specimens. Transmittance (T) was then calculated using the formula:

Figure 3 - Photograph of the alignment process of a light polymerizing unit over the zirconia specimen. The process involves the use of a silicone jig over the optical detector, which is connected to a digital optical power meter for the measurement of transmittance.

$$T = \left(I\_t / I\_0\right) \times 100\% \quad (2)$$

where I_t is the intensity of the transmitted light and I_0 is the intensity of the incident light [8,12,24].

A two-way analysis of variance (ANOVA) was conducted to determine the effects of zirconia generation and thickness on translucency and transmittance. Data were presented as mean ± standard deviation. Normality and homogeneity of variances were assessed using the Shapiro-Wilk test and Levene's test for equality of variances ($p>0.05$). Statistical analysis was performed using the IBM SPSS statistical software program (IBM SPSS Statistics, v20.0; IBM Corp) ($\alpha = 0.05$).

RESULTS

Distinct TP and transmittance values were exhibited by the various zirconia generations and thicknesses, as shown in Figure 4. The 5Y-PSZ demonstrated the highest overall TP and transmittance values, followed by the 4Y-PSZ, and lastly, the 3Y-TZP. Furthermore, the TP and transmittance values for all zirconia generations decreased as the thickness of the specimens increased.

A significant interaction was observed between zirconia generation type and thickness on both TP and transmittance, with $p \leq .001$ for both. As a result, an analysis of simple main

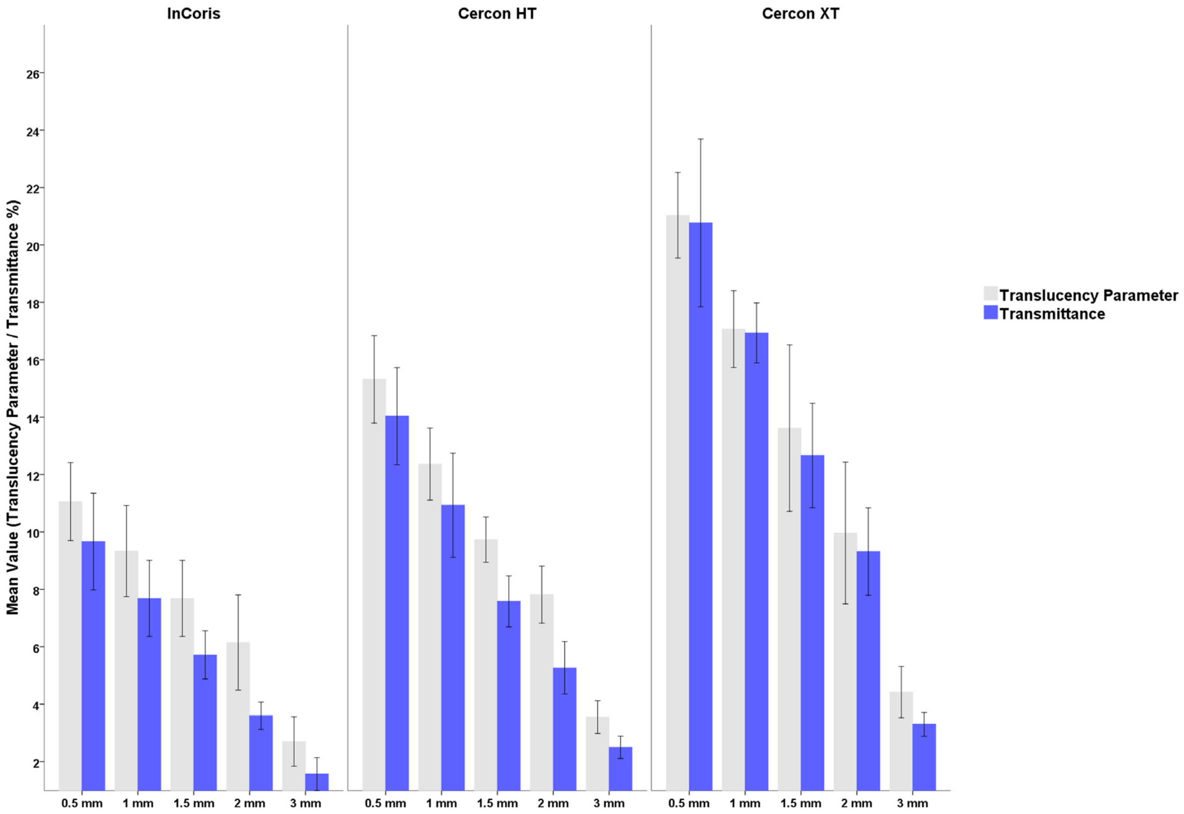


Figure 4 - Bar chart illustrating the variation in translucency parameter and transmittance across different specimen thicknesses for each of the three generations of zirconia.

effects was conducted, with statistical significance receiving a Bonferroni adjustment and being accepted at the $p < .025$ level. Statistically significant differences in the mean of both TP and transmittance values were identified among the three zirconia generations for all thicknesses, except for the 3 mm thickness (Table II).

Pairwise comparisons were carried out for each simple main effect, with reported 95% confidence intervals and p-values Bonferroni-adjusted within each simple main effect. Differences in both TP and transmittance values among the three zirconia generations were more pronounced in lower thicknesses and diminished as thickness increased. The difference between inCoris TZI C and Cercon HT in both TP and transmittance values became insignificant for thicknesses greater than 1 mm, but the difference was significant for 0.5 and 1 mm thicknesses. Furthermore, there were no significant differences among the three zirconia generations in TP and transmittance values at a 3 mm thickness (Table III). The effect of varying thickness on both TP and transmittance values was more noticeable in the extra translucent 5Y-PSZ zirconia than in the other two zirconia generations (Figure 4).

DISCUSSION

This study's findings highlight that both the type and thickness of zirconia, along with their interactions, significantly affect light transmission and TP values, leading to the rejection of the null hypothesis. Specifically, the TP values of extra translucent cubic zirconia (5Y-PSZ) were noticeably higher than those of 4Y-PSZ and conventional 3Y-TZP. Furthermore, 5Y zirconia demonstrated the highest translucency nearing the human enamel translucency (TP of 18) at a 1 mm thickness [34]. This superior optical resemblance to natural teeth can be attributed to successful strategies employed in zirconia manufacturing technology [35]. On the other hand, 4Y zirconia exhibited a TP of approximately 12.4 at 1 mm thickness, significantly less than human dentin TP at similar thicknesses [34]. The lowest translucency was observed in conventional 3Y zirconia with a TP of 9 at 1 mm thickness, underscoring the influence of the zirconia generation and the effects of reducing Al_2O_3 content and increased cubic polymorph content via elevated Y_2O_3 stabilizing content on zirconia translucency [9,10].

Table II - Table demonstrating the distinct main effects of zirconia specimen thickness on both Translucency Parameter and Transmittance for the three zirconia generations

Specimen Thickness		Translucency Parameter						Transmittance					
		Sum of Squares	df	Mean Square	F	*p-Value*	Partial Eta Squared	Sum of Squares	df	Mean Square	F	*p-Value*	Partial Eta Squared
0.5 mm	Contrast	300.629	2	150.314	71.372	<0.001*	.656	375.231	2	187.616	106.037	<0.001*	.739
	Error	157.956	75	2.106				132.700	75	1.769			
1 mm	Contrast	182.191	2	91.096	43.254	<0.001*	.536	264.250	2	132.125	74.675	<0.001*	.666
	Error	157.956	75	2.106				132.700	75	1.769			
1.5 mm	Contrast	108.974	2	54.487	25.871	<0.001*	.408	155.254	2	77.627	43.874	<0.001*	.539
	Error	157.956	75	2.106				132.700	75	1.769			
2 mm	Contrast	43.934	2	21.967	10.430	<0.001*	.218	103.721	2	51.861	29.311	<0.001*	.439
	Error	157.956	75	2.106				132.700	75	1.769			
3 mm	Contrast	8.876	2	4.438	2.107	.129	.053	9.031	2	4.516	2.552	.085	.064
	Error	157.956	75	2.106				132.700	75	1.769			

df: degrees of freedom.

Table III - A comprehensive pairwise comparison of the mean changes in both Translucency Parameter and Transmittance among the three zirconia generations, considering different specimen thicknesses

Specimen Thickness	(I) Zirconia Generation	(J) Zirconia Generation	Translucency Parameter					Transmittance				
						95% CI					95% CI	
			Mean (I-J)	Std. Error	*p-Value*	Lower Bound	Upper Bound	Mean (I-J)	Std. Err	*p-Value*	Lower Bound	Lower Bound
0.5mm	InCoris	Cercon HT	-4.258*	.838	<0.001	-6.310	-2.207	-4.367*	.768	<0.001	-6.247	-2.486
		Cercon XT	-9.975*	.838	<0.001	-12.02	-7.923	-11.100*	.768	<0.001	-12.981	-9.219
	Cercon HT	InCoris	4.258*	.838	<0.001	2.207	6.310	4.367*	.768	<0.001	2.486	6.247
		Cercon XT	-5.717*	.838	<0.001	-7.768	-3.665	-6.733*	.768	<0.001	-8.614	-4.853
	Cercon XT	InCoris	9.975*	.838	<0.001	7.923	12.027	11.100*	.768	<0.001	9.219	12.981
		Cercon HT	5.717*	.838	<0.001	3.665	7.768	6.733*	.768	<0.001	4.853	8.614
1mm	InCoris	Cercon HT	-3.033*	.838	.002	-5.085	-.982	-3.250*	.768	<0.001	-5.131	-1.369
		Cercon XT	-7.733*	.838	<0.001	-9.785	-5.682	-9.250*	.768	<0.001	-11.131	-7.369
	Cercon HT	InCoris	3.033*	.838	.002	.982	5.085	3.250*	.768	<0.001	1.369	5.131
		Cercon XT	-4.700*	.838	<0.001	-6.752	-2.648	-6.000*	.768	<0.001	-7.881	-4.119
	Cercon XT	InCoris	7.733*	.838	<0.001	5.682	9.785	9.250*	.768	<0.001	7.369	11.131
		Cercon HT	4.700*	.838	<0.001	2.648	6.752	6.000*	.768	<0.001	4.119	7.881
1.5mm	InCoris	Cercon HT	-2.050	.838	.050	-4.102	.002	-1.867	.768	.052	-3.747	.014
		Cercon XT	-5.933*	.838	<0.001	-7.985	-3.882	-6.950*	.768	<0.001	-8.831	-5.069
	Cercon HT	InCoris	2.050	.838	.050	-.002	4.102	1.867	.768	.052	-.014	3.747
		Cercon XT	-3.883*	.838	<0.001	-5.935	-1.832	-5.083*	.768	<0.001	-6.964	-3.203
	Cercon XT	InCoris	5.933*	.838	<0.001	3.882	7.985	6.950*	.768	<0.001	5.069	8.831
		Cercon HT	3.883*	.838	<0.001	1.832	5.935	5.083*	.768	<0.001	3.203	6.964
2mm	InCoris	Cercon HT	-1.667	.838	.151	-3.718	.385	-1.667	.768	.099	-3.547	.214
		Cercon XT	-3.817*	.838	<0.001	-5.868	-1.765	-5.717*	.768	<0.001	-7.597	-3.836
	Cercon HT	InCoris	1.667	.838	.151	-.385	3.718	1.667	.768	.099	-.214	3.547
		Cercon XT	-2.150*	.838	.037	-4.202	-.098	-4.050*	.768	<0.001	-5.931	-2.169
	Cercon XT	InCoris	3.817*	.838	<0.001	1.765	5.868	5.717*	.768	<0.001	3.836	7.597
		Cercon HT	2.150*	.838	.037	.098	4.202	4.050*	.768	<0.001	2.169	5.931
3mm	InCoris	Cercon HT	-.850	.838	.941	-2.902	1.202	-.933	.768	.684	-2.814	.947
		Cercon XT	-1.720	.838	.131	-3.772	.332	-1.733	.768	.081	-3.614	.147
	Cercon HT	InCoris	.850	.838	.941	-1.202	2.902	.933	.768	.684	-.947	2.814
		Cercon XT	-.870	.838	.907	-2.922	1.182	-.800	.768	.903	-2.681	1.081
	Cercon XT	InCoris	1.720	.838	.131	-.332	3.772	1.733	.768	.081	-.147	3.614
		Cercon HT	.870	.838	.907	-1.182	2.922	.800	.768	.903	-1.081	2.681

*Based on estimated marginal means. Std. Err, Standard Error; CI, Confidence Interval.; Mean difference significant at .05 level.; Adjustment for multiple comparisons: Bonferroni.

TP values of zirconia were assessed across a broad range of thicknesses, specifically 0.5mm to 3.0mm. An exponential relationship was discerned between thickness and TP, displaying significant increases in translucency as thickness decreased, echoing findings from previous studies [8,21,36]. Notably, variations in thickness had a more pronounced impact on the TP of 5Y translucent zirconia, whereas the TP of the least translucent zirconia was less influenced by changes in thickness. Even at a thickness of 3.0mm, all tested zirconia demonstrated some degree of translucency, presenting TP values surpassing the 2.0 threshold [21,37]. Below this threshold, a material is considered sufficiently opaque to obscure a black background. As a result, the pre-shaded conventional 3Y zirconia at A1 shade examined in this study may be unsuitable for cases requiring the masking of a very dark underlying tooth structure or foundation restoration, suggesting the need for a less translucent zirconia material or the use of masking luting cement [19].

Transmittance and TP, while closely related, describe distinct aspects of light interaction with materials. The TP measurements in this study accounted for the full visible light spectrum of Illuminant D65 emitted by the spectrophotometer. However, the polymerization of resin cement in dental applications typically employs blue light, which matches the absorption spectrum of the camphorquinone photo-initiator [38]. The polycrystalline structure of zirconia, comprised of varying grain sizes, orientations, and optical properties, influences its interaction with light, resulting in light attenuation coefficients that change as a function of wavelength. Additionally, the presence of air pockets/pores, anisotropic nature, large birefringence, and high refractive index in tetragonal zirconia significantly impact translucency, particularly at the short wavelengths used for polymerization [5,7.10]. Thus, separate measurements of polymerization light transmittance were conducted to account for these factors.

The study results demonstrated that the transmittance of incident polymerizing light varied depending on the thickness and type of zirconia used, with the highest transmittance reported for 5Y and lower thicknesses. For 4Y zirconia, a 10% transmittance was observed at a 1 mm thickness and 14% at a 0.5 mm thickness. These values align with those reported by Liebermann et al. [24], who found 8% and 15% transmittance at 1 mm and 0.4 mm thicknesses, respectively. The transmittance value for 5Y zirconia was slightly lower than the values reported by Harada et al. [3] for an ultra-translucent zirconia brand containing Y_2O_3 at 9.32 wt%. This is similar to the yttria content for the 5Y zirconia used in this study. However, the transmittance values reported in Harada's study were for the full spectrum of light, with a wavelength range of 380 to 780 nm.

This implies that if a 1mm-thick 5Y zirconia restoration is cemented using a second-generation LED light curing unit with an average high-intensity irradiance of 1500 mW/cm^2, the irradiance reaching the composite luting cement will be approximately 300 mW/cm^2. The resulting calculated radiant energy will be 6 J/cm^2 following a 20-second polymerization duration. In contrast, for 1mm-thick 3Y and 4Y zirconia restorations, only 150 to 195 mW/cm^2 of irradiance will reach the cement, respectively, and the energy will fall short of the 6 J/cm^2 required within the 20-second timeframe [39]. This data, along with the impact of both zirconia type and thickness on light transmittance, can assist clinicians in selecting the appropriate cement type and polymerization protocols [15,22]. Furthermore, the choice of a polymerization light unit with sufficient irradiance and/or an extended polymerization duration should be considered in line with the reciprocity principle when applicable [40,41].

This study presents several limitations due to the inherent properties of zirconia as a polycrystalline material [5]. The translucency of zirconia is significantly influenced by manufacturing factors such as grain size, air pockets and their density, which contribute to its optical properties, including TP and transmittance [10,42,43]. Although the grain size is a crucial factor in determining the optical properties of zirconia ceramics, SEM (Scanning Electron Microscopy) analysis was not conducted in this research, representing a limitation that warrants consideration. Furthermore, elements such as zirconia shade, chromaticity, as well as surface treatments and characterizations, significantly influence these properties [8,14,44,45]. In this research, only one brand of zirconia and a single shade were examined, without the application of glaze or surface characterization. These limitations underscore the need for further investigations to better comprehend the effects of different brands, shades, and surface characterizations on the TP and transmittance of zirconia-based dental restorations. Expanded research in this area will provide a more clinically relevant understanding of expected aesthetic outcomes and the impact of light transmittance during polymerization. Ultimately, this knowledge will support the selection of the most appropriate luting cement materials and protocols, ensuring long-term success in dental restorations and more predictable optimal aesthetic outcomes.

CONCLUSIONS

1. The study reveals that both the type and thickness of zirconia, as well as their interactions, significantly influence light transmission and TP values. Among the tested zirconia types, 5Y exhibited the highest values.
2. An exponential relationship was observed between zirconia thickness and both TP and light transmission values, with these values increasing as thickness decreased. The impact of thickness variations was more pronounced in the case of 5Y zirconia.
3. To predict material translucency and achieve optimal aesthetic outcomes, clinicians should take into account both the type and thickness of zirconia. Furthermore, clinicians should consider these factors when selecting the appropriate cement type and polymerization protocols.

Author's Contributions

Farah RI: Conceptualization; Methodology; Investigation; Data Curation; Formal Analysis; Software; Writing – Original Draft Preparation; Writing – Review & Editing; Validation; Visualization; Supervision; Project Administration.

Conflict of Interest

The author declares no conflict of interest.

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Regulatory Statement

Given that this study did not involve any human or animal subjects, it did not necessitate formal ethical approval. However, it has been granted an exemption from requiring such approval by the Ethical Committee of Qassim University.

REFERENCES

1. McLaren EA, White SN. Glass-infiltrated zirconia/alumina-based ceramic for crowns and fixed partial dentures. Pract Periodontics Aesthet Dent. 1999;11(8):985-94, quiz 996. PMid:10853604.
2. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent. 2007;98(5):389-404. http://doi.org/10.1016/S0022-3913(07)60124-3. PMid:18021828.
3. Harada K, Raigrodski AJ, Chung KH, Flinn BD, Dogan S, Mancl LA. A comparative evaluation of the translucency of zirconias and lithium disilicate for monolithic restorations. J Prosthet Dent. 2016;116(2):257-63. http://doi.org/10.1016/j.prosdent.2015.11.019. PMid:26994676.
4. Kwon SJ, Lawson NC, McLaren EA, Nejat AH, Burgess JO. Comparison of the mechanical properties of translucent zirconia and lithium disilicate. J Prosthet Dent. 2018;120(1):132-7. http://doi.org/10.1016/j.prosdent.2017.08.004. PMid:29310875.
5. Pekkan G, Pekkan K, Bayindir BÇ, Özcan M, Karasu B. Factors affecting the translucency of monolithic zirconia ceramics: a review from materials science perspective. Dent Mater J. 2020;39(1):1-8. http://doi.org/10.4012/dmj.2019-098. PMid:31406098.
6. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater. 2014;30(10):1195-203. http://doi.org/10.1016/j.dental.2014.08.375. PMid:25193781.
7. Kim HK. Optical and mechanical properties of highly translucent dental zirconia. Materials (Basel). 2020;13(15):3395. http://doi.org/10.3390/ma13153395. PMid:32751942.
8. Supornpun N, Oster M, Phasuk K, Chu TG. Effects of shade and thickness on the translucency parameter of anatomic-contour zirconia, transmitted light intensity, and degree of conversion of the resin cement. J Prosthet Dent. 2023;129(1):213-9. http://doi.org/10.1016/j.prosdent.2021.04.019. PMid:34116838.
9. McLaren EA, Maharishi A, White SN. Influence of yttria content and surface treatment on the strength of translucent zirconia materials. J Prosthet Dent. 2023;129(4):638-43. http://doi.org/10.1016/j.prosdent.2021.07.001. PMid:34452741.
10. Zhang Y, Lawn BR. Novel zirconia materials in dentistry. J Dent Res. 2018;97(2):140-7. http://doi.org/10.1177/0022034517737483. PMid:29035694.
11. Cho MH, Seol HJ. Optical properties, microstructure, and phase fraction of multi-layered monolithic zirconia with and without yttria-gradient. Materials (Basel). 2022;16(1):41. http://doi.org/10.3390/ma16010041. PMid:36614380.
12. Inokoshi M, Shimizu H, Nozaki K, Takagaki T, Yoshihara K, Nagaoka N, et al. Crystallographic and morphological analysis of sandblasted highly translucent dental zirconia. Dent Mater. 2018;34(3):508-18. http://doi.org/10.1016/j.dental.2017.12.008. PMid:29325861.
13. Jung JM, Kim GN, Koh YH, Kim HE. Manufacturing and characterization of dental crowns made of 5-mol% yttria stabilized zirconia by digital light processing. Materials (Basel). 2023;16(4):1447. http://doi.org/10.3390/ma16041447. PMid:36837076.

14. Zhang F, Inokoshi M, Batuk M, Hadermann J, Naert I, Van Meerbeek B, et al. Strength, toughness and aging stability of highly-translucent Y-TZP ceramics for dental restorations. Dent Mater. 2016;32(12):e327-37. http://doi.org/10.1016/j.dental.2016.09.025. PMid:27697332.
15. Butler S, Santos GC, Santos MJC. Do high translucency zirconia shades contribute to the degree of conversion of dual-cure resin cements? Quintessence Int. 2021;53(1):8-14. PMid:34410074.
16. Le M, Larsson C, Papia E. Bond strength between MDP-based cement and translucent zirconia. Dent Mater J. 2019;38(3):480-9. http://doi.org/10.4012/dmj.2018-194. PMid:31105161.
17. Kanout C. Evaluation of the translucency properties for CAD/CAM full ceramic crowns fabricated from glass ceramics (E.max) or high translucency zirconia (Lava Plus): a clinical study. Cureus. 2023;15(2):e34935. http://doi.org/10.7759/cureus.34935. PMid:36938259.
18. Mekled S, Elwazeer S, Jurado CA, White J, Faddoul F, Afrashtehfar KI, et al. Ultra-translucent zirconia laminate veneers: the influence of restoration thickness and stump tooth-shade. Materials (Basel). 2023;16(8):3030. http://doi.org/10.3390/ma16083030. PMid:37109865.
19. Park JH, Bang HJ, Choi NH, Park EJ. Translucency and masking ability of translucent zirconia; comparison with conventional zirconia and lithium disilicate. J Adv Prosthodont. 2022;14(5):324-33. http://doi.org/10.4047/jap.2022.14.5.324. PMid:36452362.
20. Wang J, Yang J, Lv K, Zhang H, Huang H, Jiang X. Can we use the translucency parameter to predict the CAD/CAM ceramic restoration aesthetic? Dent Mater. 2023;39(3):e1-10. http://doi.org/10.1016/j.dental.2023.01.002. PMid:36841746.
21. Wang F, Takahashi H, Iwasaki N. Translucency of dental ceramics with different thicknesses. J Prosthet Dent. 2013;110(1):14-20. http://doi.org/10.1016/S0022-3913(13)60333-9. PMid:23849609.
22. Cekic-Nagas I, Egilmez F, Ergun G, Kaya BM. Light transmittance of zirconia as a function of thickness and microhardness of resin cements under different thicknesses of zirconia. Med Oral Patol Oral Cir Bucal. 2013;18(2):e212-8. http://doi.org/10.4317/medoral.18181. PMid:23385497.
23. Tuncel İ, Turp I, Üşümez A. Evaluation of translucency of monolithic zirconia and framework zirconia materials. J Adv Prosthodont. 2016;8(3):181-6. http://doi.org/10.4047/jap.2016.8.3.181. PMid:27350851.
24. Liebermann A, Freitas Rafael C, Colle Kauling AE, Edelhoff D, Ueda K, Seiffert A, et al. Transmittance of visible and blue light through zirconia. Dent Mater J. 2018;37(5):812-7. http://doi.org/10.4012/dmj.2016-287. PMid:29998937.
25. Ziyad TA, Abu-Naba'a LA, Almohammed SN. Optical properties of CAD-CAM monolithic systems compared: three multi-layered zirconia and one lithium disilicate system. Heliyon. 2021;7(10):e08151. http://doi.org/10.1016/j.heliyon.2021.e08151. PMid:34712853.
26. Liu YC, Lin TH, Lin YY, Hu SW, Liu JF, Yang CC, et al. Optical properties evaluation of rapid sintered translucent zirconia with two dental colorimeters. J Dent Sci. 2022;17(1):155-61. http://doi.org/10.1016/j.jds.2021.05.014. PMid:35028033.
27. AlGhazali N, Burnside G, Smith RW, Preston AJ, Jarad FD. Performance assessment of Vita Easy Shade spectrophotometer on colour measurement of aesthetic dental materials. Eur J Prosthodont Restor Dent. 2011;19(4):168-74. PMid:22645803.
28. Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. J Prosthet Dent. 2009;101(3):193-9. http://doi.org/10.1016/S0022-3913(09)60028-7. PMid:19231572.
29. Dagg H, O'Connell B, Claffey N, Byrne D, Gorman C. The influence of some different factors on the accuracy of shade selection. J Oral Rehabil. 2004;31(9):900-4. http://doi.org/10.1111/j.1365-2842.2004.01310.x. PMid:15369473.
30. Dozić A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, Khashayar G. Performance of five commercially available tooth color-measuring devices. J Prosthodont. 2007;16(2):93-100. http://doi.org/10.1111/j.1532-849X.2007.00163.x. PMid:17362418.
31. Lehmann KM, Igiel C, Schmidtmann I, Scheller H. Four color-measuring devices compared with a spectrophotometric reference system. J Dent. 2010;38(Suppl 2):e65-70. http://doi.org/10.1016/j.jdent.2010.07.006. PMid:20659526.
32. Bayindir F, Koseoglu M. The effect of restoration thickness and resin cement shade on the color and translucency of a high-translucency monolithic zirconia. J Prosthet Dent. 2020;123(1):149-54. http://doi.org/10.1016/j.prosdent.2018.11.002. PMid:31027961.
33. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont. 1995;8(1):79-86. PMid:7710631.
34. Yu B, Ahn JS, Lee YK. Measurement of translucency of tooth enamel and dentin. Acta Odontol Scand. 2009;67(1):57-64. http://doi.org/10.1080/00016350802577818. PMid:19037822.
35. Ghodsi S, Jafarian Z. A review on translucent zirconia. Eur J Prosthodont Restor Dent. 2018;26(2):62-74. PMid:29797847.
36. El-khayat H, Katamish H, El-Etreby A, Aboushahba M. Effect of varying thickness and artificial aging on color and translucency of cubic zirconia and lithium disilicate ceramics. Braz Dent Sci. 2021;24(3). http://doi.org/10.14295/bds.2021.v24i3.2623.
37. Chaiyabutr Y, Kois JC, Lebeau D, Nunokawa G. Effect of abutment tooth color, cement color, and ceramic thickness on the resulting optical color of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown. J Prosthet Dent. 2011;105(2):83-90. http://doi.org/10.1016/S0022-3913(11)60004-8. PMid:21262405.
38. Leprince JG, Hadis M, Shortall AC, Ferracane JL, Devaux J, Leloup G, et al. Photoinitiator type and applicability of exposure reciprocity law in filled and unfilled photoactive resins. Dent Mater. 2011;27(2):157-64. http://doi.org/10.1016/j.dental.2010.09.011. PMid:21067803.
39. Li Q, Lin HL, Zheng M, Ozcan M, Yu H. Minimum radiant exposure and irradiance for triggering adequate polymerization of a photo-polymerized resin cement. Materials (Basel). 2021;14(9):2341. http://doi.org/10.3390/ma14092341. PMid:33946389.
40. Selig D, Haenel T, Hausnerová B, Moeginger B, Labrie D, Sullivan B, et al. Examining exposure reciprocity in a resin based composite using high irradiance levels and real-time degree of conversion values. Dent Mater. 2015;31(5):583-93. http://doi.org/10.1016/j.dental.2015.02.010. PMid:25804190.
41. Wydra JW, Cramer NB, Stansbury JW, Bowman CN. The reciprocity law concerning light dose relationships applied to BisGMA/TEGDMA photopolymers: theoretical analysis and experimental characterization. Dent Mater. 2014;30(6):605-12. http://doi.org/10.1016/j.dental.2014.02.021. PMid:24674341.
42. Uasuwan P, Juntavee N, Juntavee A. Optical characteristics of monochrome and multilayer fully stabilized zirconia upon sintered cooling speed. Eur J Dent. 2023;18(1):196-207. http://doi.org/10.1055/s-0043-1764233. PMid:37059447.
43. Mourouzis P, Tolidis K. Effects of milling method and artificial ageing on optical properties of high translucent zirconia for chairside restorations. Dent Mater. 2022;38(1):108-20. http://doi.org/10.1016/j.dental.2021.10.015. PMid:34823879.
44. Manziuc MM, Gasparik C, Burde AV, Dudea D. Color and masking properties of translucent monolithic zirconia before and after glazing. J Prosthodont Res. 2021;65(3):303-10. http://doi.org/10.2186/jpr.JPR_D_20_00039. PMid:33116028.
45. Wahba MM, Sherif AH, El-Etreby AS, Morsi TS. The effect of different surface treatments on color and translucency of bilayered translucent nano-crystalline zirconia before and after accelerated aging. Braz Dent Sci. 2019;22(2):203-12. http://doi.org/10.14295/bds.2019.v22i2.1622.

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