Transmittance of visible and blue light through zirconia

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The aim of this study was to evaluate the transmittance of visible light (VL) (λ : 400–700 nm) and blue light (BL) (λ : 360–540 nm) through six CAD/CAM zirconia blanks (ZiB) in comparison to a lithium disilicate ceramic (LS2). Disks of the zirconia materials Bruxzir (BX), Cercon (CE), Lava Frame (LF), Lava Plus (LP), Prettau (PT), Zenostar (ZS) and LS2 (EM) were manufactured and the transmittance was measured in a spectrophotometer. ZS, followed by CE, PT, LP, LF, and BX showed the lowest transmittance of VL and BL. The highest transmittance was shown by EM. The transmittance of BL was lower than that of VL in all groups. EM ceramics showed higher transmittance than all zirconia materials and the thickness of zirconia materials influenced the transmittance values. Knowledge about VL and BL transmittance would help clinicians to individually tailor the selection of material to the specific indication and to make the right choice regarding the luting procedure and light curing duration.

Keywords: Transmittance, CAD/CAM, Zirconia, Optical properties

INTRODUCTION

All-ceramic restorations are regularly used in esthetic dentistry due to their capacity to mimic the natural tooth^{1–5}. Besides their excellent optical properties, ceramic materials present good biocompatibility, low thermal conductivity, high chemical resistance, low bacterial adhesion and satisfactory mechanical strength^{6–10}. In association with computer-aided-design/computer-aided-manufacturing (CAD/CAM) technology, these materials can be easily and rapidly fabricated with favorable mechanical properties¹¹.

Nowadays, a diverse range of ceramics is commercially available for the fabrication of copings and monolithic restorations, for example heat-treated glass-ceramic or zirconia^{10,12}. Lithium disilicate (LS2) glass ceramics present excellent optical properties combined with more favorable mechanical properties than conventional dental porcelain¹². Some disadvantages have been reported however, such as their lower fracture resistance compared to zirconia materials^{12,13}.

The most often used zirconia in dentistry is the tetragonal zirconia polycrystal (Y-TZP) stabilized through yttria (Y_2O_3). This has excellent mechanical properties (up to 1,200 MPa dependent on type), corrosion resistance, biocompatibility, low thermal conductivity, and higher flexural strength and hardness in comparison to other dental ceramics^{14–16}. These properties enable a huge range of uses in dentistry, from single crowns and fixed partial denture (FDP) framework fabrication to implant abutments and total screwed-retained prosthesis

substructures over implants¹⁴. Zirconia is, however, more opaque and white colored than LS2¹⁴. Less opaque ceramics that allow greater transmittance of light are preferable from the esthetic point of view^{13,14}. This holds true when zirconia is only used as a framework in the esthetic region.

Transmittance is generally defined as the relative amount of light passing through the material, with the remaining light being reflected or absorbed within the visible spectrum (400 to 700 nm)¹⁷. Moreover, it is one of the most important optical properties and enables the creation of a more natural appearance of dental restorations¹⁸. With the majority of light passing through a ceramic material, light is intensely scattered and diffusely reflected, leading to a more opaque appearance. When only some of the light is scattered and most is transmitted the material will have higher transmittance values¹⁹.

Light transmittance is also a crucial factor when choosing the specific luting procedure (light-cure, dual-cure), as it determines whether the light will pass through the restoration and reach the cement with sufficient effectiveness to perform the cure. The light used during polymerization is blue light, and therefore it is the amount of light within the blue spectrum (360–540 nm) passing through the restoration that is decisive and not the amount of light within the visible spectrum (400 to 700 nm)^{20,21}. The potential for additional light curing during cementation can even increase the conversion rate and therefore the mechanical properties of the luting material.

Several procedures can increase light transmittance through zirconia in order to improve the optical properties

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and allow adequate passage of blue light during polymerization¹³. One of these procedures involves reducing the amount of residual pores and impurities, for example the amount of alumina, which is added to zirconia to improve its mechanical properties and prevent low-temperature degradation¹³. The grain size and density of zirconia also influence transmittance¹⁴. A higher sintering temperature increases the grain size and density, consequently increasing transmittance¹⁴. However, these procedures result in a zirconia with greater susceptibility to low-temperature degradation due to the reduction in amounts of alumina and larger grains¹³. Additionally, monolithic restorations of zirconia are less esthetic than lithium disilicate restorations, as the manufacturing process uses CAD/CAM blocks, without any manual characterization during the veneering procedure by a dental technician. Thus, high transmittance zirconia monolithic restorations are more appropriate for posterior regions¹³.

Despite their widespread use, little information is available concerning the transmittance of regular zirconia materials. Therefore, the aim of this study was to evaluate the transmittance of visible (λ : 400–700 nm) and blue light (λ : 360–540 nm) through different types of zirconia in comparison with a LS2 control group.

The first null hypothesis was that the quantity of light passing through diverse types of zirconia and the LS2 control group is similar. The second hypothesis was that the light transmittance is similar independent of the zirconia thickness.

MATERIALS AND METHODS

Six different zirconia ceramics were analyzed in the present study and compared to one CAD/CAM glass-ceramic material as the control group (E.maxCAD, HT, Ivoclar Vivadent, Schaan, Liechtenstein). Table 1 shows the detailed specifications of all materials evaluated.

Fabrication of specimens

Disks of lithium disilicate ceramic (E.maxCAD, HT, Ivoclar Vivadent) were fabricated to be used as the control group ($n=20$, of 1.0 ± 0.05 mm thickness and 16 mm in diameter). Disk-shaped test specimens ($N=120$) from each zirconia material ($n=20$ per material) were manufactured with 1 mm thickness and also in the specific minimum thickness recommended by the manufacturer for each material (diameter: 16 mm). Ceramic blanks were cut using a low-speed diamond saw (Accutom, Struers, Ballerup, Denmark) under constant water cooling and were mechanically polished (Abramin, Struers) on both sides using a series of diamond grinding sheets (up to SiC P4000). Definitive thickness was determined using a digital micrometer (Mitutoyo IP65, Mitutoyo, Kawasaki, Japan). Each material was fabricated in two thicknesses: 1.0 mm (for comparison of the materials), and the minimum thickness recommended by the manufacturer (to show the maximum possible transmittance of each material). After polishing, the following thicknesses were obtained for each material: Bruxzir –0.5 and 1 mm; Cercon HT –0.4 and 1 mm; Lava Frame –0.3 and 1 mm; Lava

Table 1 Overview over abbreviations, thicknesses, Lot. No, manufacturers and compositions of the materials tested

Test Material	Abbreviation	Thickness (mm)	Lot No.	Manufacturer	Composition
Bruxzir	BX	0.5/1	B5437	Prismatik Dentalcraft, Irvine, CA, USA	ZrO ₂ >89 wt%, Y ₂ O ₃ <6 wt%, HfO ₂ <4 wt%, Al ₂ O ₃ <1 wt%
Cercon_HT	CE	0.4/1	18010959	Degudent, Hanau, Germany	ZrO ₂ , 5 wt% Y ₂ O ₃ , 3 wt% HfO ₂ , 1 wt% Al ₂ O ₃ , 1 wt% SiO ₂
Lava Frame	LF	0.3/1	473958	3M, Seefeld, Germany	92.27 wt% ZrO ₂ , 4.98 wt% Y ₂ O ₃ , 0.43 wt% Al ₂ O ₃ , 0.21 wt% SiO ₂ , 1.58 wt% HfO ₂
Lava Plus	LP	0.3/1	474144	3M	ZrO ₂ , 3 wt% Y ₂ O ₃ , 0.1 wt% Al ₂ O ₃
Prettau	PT	0.5/1	ZB0143C	Zirkonzahn, Gais, Italy	ZrO ₂ , 4–6 wt% Y ₂ O ₃ , 1 wt% Al ₂ O ₃ , 0.02 wt% SiO ₂ , 0.01 wt% Fe ₂ O ₃ , 0.04 wt% Na ₂ O
Zenostar	ZS	0.4/1	20110905-22	Ivoclar Vivadent, Schaan, Liechtenstein	ZrO ₂ >99 wt%, Y ₂ O ₃ >6.5–8 wt%, HfO ₂ ≤5 wt%, Al ₂ O ₃ <1 wt%
E.max CAD_HT	EM	1	P87637	Ivoclar Vivadent	57–80 wt% SiO ₂ , 11–19 wt% Li ₂ O, <13 wt% K ₂ O, <5 wt% MgO, <8 wt% ZrO ₂ , <8 wt% ZnO, <5 wt% Al ₂ O ₃ , <11 wt% P ₂ O ₅ and <8 wt% colouring oxides

Plus –0.3 and 1 mm; Prettau –0.5 and 1 mm; Zenostar –0.4 and 1 mm (Table 1). Subsequently, all specimens underwent ultrasonic cleaning in distilled water for 5 min (Sonorex RK102H, Bandelin Electronic, Berlin, Germany) and were wiped with cotton on both sides to remove residues.

Transmittance (T) analyses

To measure transmittance, the disks were placed at the entrance port of a spectrophotometer (Lamda 35 Perkin Elmer, Perkin Elmer, Waltham, MA, USA) in front of an integrating sphere with a measuring geometry D/8°, diffuse light at 10°, light with a wavelength between 200 to 800 nm (1 nm intervals), opening width of 2 mm and scan speed of 460 nm/min. A black barium sulfate standard was used to complete the integrating sphere. Measurements were conducted in two different wavelength spectra:

(a) λ from 360–540, representing the blue light equivalent to the emission spectra of standard polymerization units²¹⁾ and

(b) λ from 400–700, representing the spectrum of visible light.

The total transmittance was measured for each material. The transmittance mode was used and luminance values were obtained. Total transmittance (T) was calculated according to:

$$T (\%) = (L_{\text{specimen}} / L_{\text{source}}) \times 100$$

L is the luminance of the specimens and of the source, respectively. L_{source} was obtained by making one measurement of L without any specimen placed in

the optical path, which resulted in an L value (about 30.000) corresponding to 100% of transmittance. This baseline value was calculated from 40 measurements of light transmittance without any sample in the spectrophotometer.

The transmittance of all groups was recorded and compared to each other. Only disks of 1 mm thickness were subject to statistical analyses.

Statistical analyses

Descriptive statistics including mean and standard deviations (SD) were calculated for all materials. To test the normality of data distribution, the Kolmogorov-Smirnov test was applied. To evaluate differences between single groups within one wavelength spectrum, one-way ANOVA, followed by Tukey-HSD *post hoc* test was applied given the normality of the samples ($p=0.20$). Additionally, the transmittance through blue light was compared with the transmittance through visible light. As these data did not satisfy the assumption of normality, the Wilcoxon-Test was performed. SPSS Version 22.0 (IBM, Armonk, NY, USA) was used. Differences with p -values smaller than 0.05 were interpreted as being statistically significant.

RESULTS

Transmittance is reported as percentage values between 0% (totally opaque) and 100% (totally transparent) for visible (400–700 nm) and blue light (360–540 nm).

Table 2 shows the mean value (mean), SD, and the

Table 2 Mean values ($\pm$ SD) and 95% confidence interval of light transmittance for all tested materials with 1 mm thickness and the less thickness recommended from manufacturing at visible (400–700 nm) and blue light (360–540 nm)

Material	Visible light (400–700 nm)				Blue light (360–540 nm)			
	95% conf.interval				95% conf.interval			
	Mean%	Max.	Min.	SD	Mean%	Max.	Min.	SD
E.max_HT 1 mm	44.72 ^a	44.94	44.49	0.005	23.50 ^a	23.60	23.39	0.002
Lava Frame 0.3 mm	40.70	41.89	40.19	0.004	16.00	16.23	15.78	0.004
Prettau 0.5 mm	33.54	34.41	32.94	0.005	12.50	12.82	11.90	0.003
Bruxzir 0.5 mm	39.59	41.54	38.54	0.008	18.20	19.83	17.36	0.007
Cercon_HT 0.4 mm	38.52	39.20	37.28	0.006	15.28	15.73	14.50	0.004
Zenostar 0.4 mm	33.95	34.72	32.90	0.005	12.27	12.59	11.89	0.002
Lava Plus 0.3 mm	41.15	42.26	39.66	0.006	16.00	17.07	15.83	0.003
Bruxzir 1 mm	31.61 ^b	31.97	31.24	0.008	12.00 ^b	12.32	11.78	0.006
Lava Frame 1 mm	26.26 ^d	26.35	26.17	0.002	7.54 ^e	7.59	7.48	0.001
Lava Plus 1 mm	28.09 ^c	28.24	27.93	0.003	8.44 ^c	8.54	8.32	0.002
Prettau 1 mm	25.94 ^d	26.60	25.28	0.014	8.11 ^d	8.46	7.74	0.008
Zenostar 1 mm	19.64 ^f	19.76	19.51	0.003	4.80 ^f	4.84	4.75	0.001
Cercon_HT 1 mm	25.30 ^e	25.60	24.98	0.007	7.67 ^e	7.82	7.52	0.003

Statistical similarity between the groups (Tukeys test, *post hoc*) are displayed as letters following the mean values.

Fig. 1 Transmittance measurement within visible-light of the materials presenting 1 mm thickness (light red) and the less thickness recommended from manufacturing (dark red).

confidence interval (CI) of each material tested for both spectra separately. The Kolmogorov-Smirnov test found that 80% of the data showed a normal distribution. One-way ANOVA, followed by Tukey-HSD *post hoc* test was used to carry out statistical comparisons between different samples of 1 mm thickness within the light spectrum. The data used to compare blue light and visible light were not normal and thus the Wilcoxon test was performed.

Light transmittance in the visible light spectrum

Within the visible light spectrum, all values ranged between 19.6 and 44.7%. The lowest transmittance was shown by ZS, followed by CE, PT, LP, LF, and BX. Significantly higher transmittance in comparison to all test materials was found for the glass-ceramic material EM. In general, the transmittance of visible light by the thicker specimens (1 mm) was reduced by around a third of the value for the lowest possible zirconia thickness (Fig. 1).

Light transmittance in the blue light spectrum

Within the blue light spectrum, all values ranged between 4.8 and 23.5% for both material thicknesses and were almost half those for visible light. The lowest transmittance was shown by ZS, followed by LP, CE, PT, LF and BX. The transmittance of the control group EM was significantly higher than that of all zirconia materials with 1 mm thickness. In general, the transmittance values of blue light of the 1 mm specimens were reduced by around a third of the values for the lowest zirconia thickness (Fig. 2).

Comparison of light transmittance in the blue and visible light spectrum

The transmittance of blue light was significantly lower than that of visible light ($p=0.000$) for all materials tested. Significantly higher transmittance of both visible and blue light was shown by the control group EM (Fig. 3).

Fig. 2 Transmittance measurement within blue-light of the materials presenting 1 mm thickness (light blue) and the less thickness recommended from manufacturing (dark blue).

Fig. 3 Transmittance measurement of all material (1 mm thickness) within visible-light (red) and blue-light (blue).

DISCUSSION

The present study analyzed the transmittance of visible and blue light through different zirconia ceramics using LS2 as a control group. In previous studies the overall transmittance of glass ceramic was higher than that of zirconia materials²²⁻²⁴. The present results confirm that high translucency zirconia (BX=31.61) showed higher transmittance than the traditional zirconia (PT=25.94), but still significantly lower transmittance of visible light than LS2 (EM=44.72). For both, the visible light and the blue light spectrum, the transmittance through LS2 was higher than through all zirconia materials tested.

The amount of light passing through the zirconia is generally determined by a complex combination of parameters, including residual porosity, grain size, primary particle size, additives such as alumina and sintering²³⁻²⁶. The higher transmittance of BX, followed by LF and LP, is related to the concentration of alumina. BX, LF and LP contain a concentration of $\text{Al}_2\text{O}_3 \leq 1\%$, which, according to previous studies²³⁻²⁶ improves

the transmittance of the material. Furthermore, the concentration of Y_2O_3 in BX is 6%. This high amount of Y_2O_3 is necessary to avoid the low-temperature degradation of the zirconia that occurs more frequently when the amount of alumina is lower²³⁻²⁶. Further comparisons of the zirconia materials were not possible, due to the lack of detailed information concerning composition.

The literature shows that the transmittance of zirconia materials is also significantly influenced by their thickness. Transmittance is inversely related to the thickness of the ceramic layer to be traversed by the light beam. The thicker the material is, the lower the transmittance is²³. Thicker materials appear more opaque. In previous studies^{22,23}, the transmittance of blue light through glass ceramic was higher than for the tested zirconia materials. However, at thicknesses of 2.5 mm or more, there was almost no difference between glass ceramics and monolithic zirconia^{22,23}. In the present study, there were significant differences in transmittance between the thinner zirconia recommended by the manufacturers, ranging from 0.3 to 0.5 mm (*i.e.* BX 0.5 mm=18.2%), and the 1-mm thick zirconia (BX 1 mm=12%).

Likewise, there were differences in the amount of light passing through the specimens depending on the wavelength, *i.e.* BX showed 32% compared to 12% of transmittance and ZS showed 20% *versus* 5% for visible and blue light respectively. For the zirconia samples, transmittance varied from 4.8% to 12% within the blue spectrum and all materials showed significantly different overall transmittance in comparison to visible light. In general, BX transmitted 12% of blue light through a restoration of 1 mm thickness. Therefore, the curing time would need to be twice as long as that for the tested glass ceramic EM. Moreover, the curing time for ZS, which showed 4.8% transmittance of blue light, would have to be about five times longer than that for the glass ceramic EM.

Due to the long polymerization time required for zirconia restorations using light-curing luting resins, dual-cure resins would be the optimal alternative with a lower risk of incomplete polymerization. Furthermore, the impact of light on the polymerization process of dual-cured composite cements is dependent on the type of luting material, with a large number of luting materials showing high sensitivity to blue light²⁷.

Therefore, the optical properties of each zirconia material within the visible and blue light spectrum should be known and considered by dental practitioners. Clinicians should also be aware of the individual light irradiance of their curing devices.

CONCLUSION

Lithium disilicate ceramics showed higher transmittance than all zirconia materials tested. There were also significant differences between zirconia materials themselves and between the different thicknesses of zirconia tested. Zirconia materials containing lower

amounts of alumina showed higher transmittance. Knowledge about visible and blue light could help clinicians to individually tailor the material selected to the specific indication.

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