

RESEARCH AND EDUCATION

## Effect of masticatory simulation on the translucency of different types of dental zirconia



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Ceramic dental restorations fabricated from various formulations of zirconia have greater fracture resistance than lithium disilicate. However, the absence of the amorphous glassy phase in zirconia leads to lower levels of translucency and may compromise the esthetics of the restoration.<sup>1-4</sup> Zirconia manufacturers have reported that recent formulations demonstrate adequate strength for anterior restorations and improve translucency. Conventional or low-translucency zirconia have a lower percentage of yttria (3 mol %). Improving the translucency of zirconia material has been accomplished by increasing the percentage of yttria from 3 to 5 mol%. The increased concentration of yttria leads to increased nonbirefringent cubic phase and so improves translucency. However, strength and toughness were diminished because cubic zirconia does not undergo stress-induced transformation.<sup>5-8</sup>

### ABSTRACT

**Statement of problem.** Translucent zirconia has been marketed to dentists seeking to provide esthetic monolithic dental restorations. Evidence on differences in translucency between recently introduced translucent zirconia and conventional zirconia before and after fatigue testing with thermocycling is lacking.

**Purpose.** The purpose of this in vitro study was to evaluate the effect of fatiguing and thermocycling on the translucency of 5 mol% yttria partially stabilized zirconia (5Y-PSZ) and 3 mol% yttria partially stabilized zirconia (3Y-PSZ) at clinically relevant thicknesses.

**Material and methods.** Translucent zirconia (BruxZir Anterior Solid Zirconia [5Y-PSZ]) and conventional zirconia (BruxZir Shaded Zirconia [3Y-PSZ]) were evaluated. Disk-shaped specimens were prepared to 0.7-mm and 1.2-mm thicknesses for each zirconia type. Four groups (n=10/group) were evaluated. Translucency parameter (TP), contrast ratio (CR), and light blockage percentage (Lb %) were recorded by using an integrating sphere spectrophotometer before and after fatiguing (1.2 million cycles at 110-N load with simultaneous thermocycling at 5 °C to 55 °C). Data were analyzed by repeated-measures analysis of variance for statistical significance ( $\alpha=.05$ ). CR values were compared with the reported 0.06 translucency perception threshold of the human eye.

**Results.** A statistically significant difference was found in TP, CR, and Lb% between 5Y-PSZ and 3Y-PSZ ( $P<.001$ ). Thickness had a statistically significant effect on TP, CR, and Lb% ( $P<.05$ ). The 0.7-mm thickness groups were more translucent and had lower Lb% than the 1.2-mm thickness groups ( $P<.001$ ). Baseline ranking from most to least translucent according to TP and CR measurements was as follows: 5Y-PSZ (0.7 mm), 3Y-PSZ (0.7 mm), 5Y-PSZ (1.2 mm), and 3Y-PSZ (1.2 mm). Lb% was 64% at the 1.2-mm and 56% at the 0.7-mm thickness in the 3Y-PSZ groups. Lb% was 61% at the 1.2-mm and 53% at the 0.7-mm thickness in the 5Y-PSZ groups. None of the groups, before and after fatiguing, had a CR value exceeding the clinically perceivable 0.06 translucency perception threshold value.

**Conclusions.** Translucent (5Y-PSZ) and conventional (3Y-PSZ) zirconias evaluated in this study displayed degrees of translucency that were inversely related to the zirconia thickness. 5Y-PSZ was more translucent and blocked less light than 3Y-PSZ, but this difference may not be perceivable to the human eye. Both 5Y-PSZ and 3Y-PSZ were optically stable after fatiguing and thermocycling. (J Prosthet Dent 2019;122:404-9)

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## Clinical Implications

Clinicians should be aware of the different zirconia types, the degree of translucency each type may offer, and the human ability to detect differences in translucency. The translucency of translucent and conventional zirconia is stable when exposed to masticatory simulation.

Levels of material translucency may be assessed by identifying the translucency parameter (TP), which is defined as the color difference ( $\Delta E$ ) between a uniform thickness of a material over a white and a black backing.<sup>9</sup> The smaller the TP value, the lower the translucency. Alternatively, translucency may be evaluated by identifying the contrast ratio (CR), which is the ratio of illuminance (Y) of the test material when placed over a black background (Y<sub>b</sub>) to the illuminance of the same material when it is placed over a white background (Y<sub>w</sub>). A CR of zero is transparent and 1 is opaque.<sup>10</sup> Also, measuring the amount of light transmitting through or blocked by an object has also been reported as a method of determining the translucency of a material. In a natural tooth, increased levels of translucency may be observed in the incisal and proximal regions because of the presence of a high proportion of enamel compared with the underlying dentin. Translucency is reduced in the cervical aspect of teeth because the enamel is thinner and the dental layer is thicker. Enamel allows approximately 70% light transmittance, whereas dentin allows less (approximately 53%).<sup>11</sup> The TP of 1-mm-thick enamel is 18.7, and the CR is 0.55. The TP of 1-mm-thick dentin is 16.4, and the CR is 0.60.<sup>12</sup> The color of the dentin has the greatest influence on the overall color of a tooth. Zirconia crowns essentially serve to replace the natural enamel of the dentition, and optimal esthetics require similar levels of translucency.

Dental materials vary in their translucency. The TP and CR of different ceramic material have been reported. According to 1 study, at a 1-mm thickness, the TP/CR values of different ceramics were as follows: IPS e.max CAD (17/0.64), IPS Empress CAD (19/0.59), Paradigm (21/0.53), and feldspathic porcelain (18/0.59).<sup>13</sup> Zirconia has low translucency and high opacity. The CR of zirconia was reported to be close to 1.<sup>14-16</sup> Heffernan et al<sup>4</sup> reported the CR of 0.5-mm-thick specimens of ceramic and nonceramic materials to be in the following order from the most to the least translucent: Vitadur Alpha (0.60)>Empress (0.64)>In-Ceram Spinell (0.67)=Empress 2 (0.68)>Procera (0.72)>In-Ceram Alumina (0.87)>In-Ceram Zirconia (1.00)=SF52 alloy (1.00). Another study reported a CR value of 0.76 for KATANA zirconia ultra-translucent multilayered EA2 and a value of 0.84 for IPS e.max CAD LT A2.<sup>17</sup>

Material color, thickness, and surface texture affect the translucency of the dental material. Darker restorations absorb more light and transmit less, which increases opacity.<sup>12</sup> Increased restoration thickness increases the opacity and decreases the TP.<sup>1,16,18,19</sup> In one in vitro study, all the zirconia ceramics evaluated showed some degree of translucency; however, it was less sensitive to thickness than that of glass-ceramics.<sup>1</sup> The thickness of zirconia attenuates light transmission, which may compromise the degree of double-bond conversion of resin-based cements, and more polymerizing time may be needed to deliver sufficient energy through zirconia restorations when adhesive cementation is used.<sup>20</sup>

Different equipment is available for measuring the color and translucency of dental and industrial materials. These include spectrophotometers, spectroradiometers, and colorimeters. Spectrophotometers are among the most accurate, useful, and flexible instruments for overall color matching and color matching in dentistry.<sup>21,22</sup> They measure the amount of light energy reflected from an object at 1- to 25-nm intervals along the visible spectrum.<sup>22-24</sup> The main components of the spectrophotometer are a source of optical radiation, a measure of dispersing light, an optical system for measuring, and a detector and means of converting the light obtained to a signal that can be analyzed and interpreted.<sup>22</sup> Spectrophotometers have been reported to have 33% more accuracy and objective matching in 93.3% of the evaluations than human interpretation of color.<sup>21,22</sup>

In vitro studies have been conducted to compare the translucency of 5 mol% yttria zirconia with 3 mol% yttria zirconia after aging with thermocycling.<sup>3,15,25,26</sup> Thermocycling combined with the fatiguing of zirconia at clinically relevant thicknesses using a mastication simulator may create fatiguing conditions that more closely approximate the oral environment. The authors are unaware of studies evaluating the translucency of zirconia after fatigue loading and thermocycling. This in vitro study compared 5 mol% yttria partially stabilized zirconia (5Y-PSZ) with 3 mol% yttria partially stabilized zirconia (3Y-PSZ) before and after fatiguing and thermocycling at clinically relevant thicknesses. The first null hypothesis was that no significant difference would be found between the translucency of 5Y-PSZ and 3Y-PSZ at different thicknesses. The second null hypothesis was that fatiguing and thermocycling would have no significant effect on the translucency of 5Y-PSZ and 3Y-PSZ.

## MATERIAL AND METHODS

BruXZir Anterior Solid Zirconia (5Y-PSZ) and BruXZir Shaded Zirconia (3Y-PSZ) (Glidewell Laboratories) were used in this study (Table 1). Presintered cylinders were milled from each zirconia type. A diamond separating

**Table 1.** Zirconia materials used

Material	Manufacturer	Batch Number	Composition
BruXZir Anterior Solid Zirconia (5Y-PSZ)	Glidewell Laboratories	Z0696371	ZrO <sub>2</sub> >89 wt%, Y <sub>2</sub> O <sub>3</sub> <12 wt%, HfO <sub>2</sub> <4 wt%, Al <sub>2</sub> O <sub>3</sub> <0.05 wt%
BruXZir Shaded Zirconia (3Y-PSZ)	Glidewell Laboratories	B123848	ZrO <sub>2</sub> >89 wt%, Y <sub>2</sub> O <sub>3</sub> <6 wt%, HfO <sub>2</sub> <4 wt%, Al <sub>2</sub> O <sub>3</sub> <1 wt%

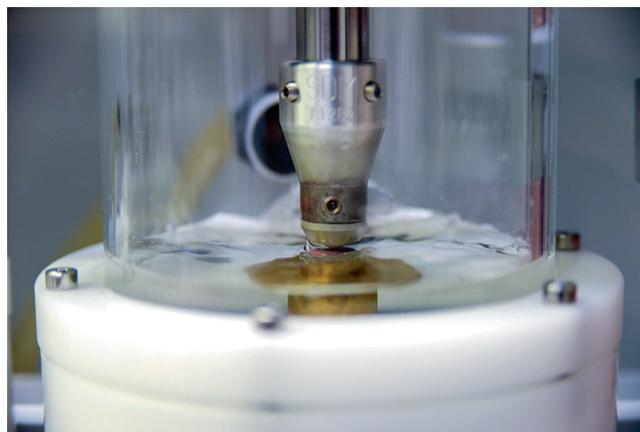
3Y-PSZ, 3 mol% partially stabilized zirconia; 5Y-PSZ, 5 mol% yttria partially stabilized zirconia.

disk under controlled speed and load was used to slice the cylinders into disks of 2 different thicknesses (1.5 mm and 0.9 mm). The final thickness ( $\pm 0.05$  mm) of the specimens was obtained by sequentially grinding each specimen by using silicon carbide grinding papers 380, 600, 800, and 1200 (Silicon Carbide Grinding Paper; Buehler) and was measured by using a precision digital caliper (Digimatic Micrometer; Mitutoyo Corp). Specimens were sintered by the manufacturer of the zirconia. The sintering parameters were as follows: temperature 1580 °C for the 3Y-PSZ and 1530 °C for the 5Y-PSZ, first holding time 60 minutes at 1200 °C, second holding time 150 minutes at 1580 °C for the 3Y-PSZ and 1530 °C for the 5Y-PSZ, and cooling rate 15 °C/min for both zirconia types.

After sintering, the final thicknesses were 1.2 mm and 0.7 mm ( $\pm 0.05$  mm). The specimens were polished by using sequential diamond polishers (BruXZir Polishing and Adjustment Kit; Glidewell Laboratories) connected to a latch contra-angle handpiece (Volvere Vmax; NSK) at a speed of 15 000 rpm, a time of 30 seconds, and a force of 150 to 200 N in the same direction by a single operator (I.A.A.). The pressure was standardized by using a custom force-indicating device controlled by using a computer software program (ToothAbrasion). The specimens were ultrasonically cleaned in distilled water for 5 minutes and air-dried for 20 seconds and allocated to 4 groups (n=10/group): 5Y-PSZ, 1.2 mm; 5Y-PSZ, 0.7 mm; 3Y-PSZ, 1.2 mm; and 3Y-PSZ, 0.7 mm.

Before and after fatiguing the TP, CR, and percentage of light blockage (Lb%) measurements were recorded for each specimen by using an integrated sphere spectrophotometer (Ci7600 Benchtop Spectrophotometer; X-Rite) according to the CIE 1976 L\*a\*b\* color scale relative to the CIE standard illuminant D65. The spectrophotometer was calibrated according to the manufacturers' instructions over a standard illuminant with a white background ( $L^*=95.86$ ) and a black background ( $L^*=24.99$ ). Measurements were made through a 6-mm aperture and d/8-degree measurement geometry. An average was taken from 2 measurements for each specimen. Using the L\*a\*b\* values obtained, the TP and CR were calculated according to the following equations:

$TP = [(LB^* - LW^*)^2 + (aB^* - aW^*)^2 + (bB^* - bW^*)^2]^{1/2}$ , where B=color coordinates over a black background, W=color coordinates over a white background CR=YB/YW; YB=spectral reflectance over a black background; and YW=spectral reflectance over a white background.



**Figure 1.** Specimen mounted in mastication simulator chamber undergoing fatiguing with simultaneous thermocycling.

The spectrophotometer was calibrated to measure the transmission of light according to the manufacturers' instructions by using the specified transmission kit. The Lb% was recorded for each specimen. Data were recorded by using a color measurement software program (Color iQC and Color iMatch software; X-Rite).

Specimens were then coated with a separator (Rubber-Sep; Kerr Corp) and fixed on a glass slab by using denture wax (Surgident Periphery Wax Sticks; Kulzer GmbH). The glass slab and holders were then coated with petroleum jelly (Vaseline; Unilever) to facilitate the separation of the glass slab from the epoxy resin. Epoxy resin (EpoxiCure 2 Epoxy Resin; Buehler) was mixed according to the manufacturers' instructions and poured into the holders of the mastication simulator (CS-4.8; SD Mechatronik) (Fig. 1). The glass slab with the specimen was seated horizontally over the epoxy resin before hardening. After 24 hours, the glass slab was removed, and the epoxy resin was inspected for air bubbles underneath the mounted specimen. Specimens were remounted in epoxy resin when bubbles were noticed underneath the specimen. The holders with fixed specimens were mounted for fatiguing in the mastication simulator. A steatite head was used as opposing material. Fatiguing was performed for 1.2 million cycles at 1.4 Hz, 110 N, to represent approximately 5 clinical years.<sup>27</sup>

Thermocycling was performed simultaneously between 5 °C and 55 °C in distilled water with a 30-second dwell time. The fatiguing process created a distinct visually different area in the middle of the specimens, possibly due to wear. The translucency measurements

**Table 2.** Mean  $\pm$  standard deviation (SD) of translucency parameter (TP), contrast ratio (CR), and Lb% of different groups

Group	Before Fatiguing and Thermocycling (Mean $\pm$ SD)			After Fatiguing and Thermocycling (Mean $\pm$ SD)		
	TP	CR	Lb%	TP	CR	Lb%
5Y-PSZ/1.2	11.9 $\pm$ 0.36	0.70 $\pm$ 0.01	61 $\pm$ 0.97	11.9 $\pm$ 1.17	0.69 $\pm$ 0.03	59 $\pm$ 1.01
5Y-PSZ/0.7	14.4 $\pm$ 0.53	0.65 $\pm$ 0.01	53 $\pm$ 1.45	16.9 $\pm$ 0.78	0.63 $\pm$ 0.02	53 $\pm$ 1.53
3Y-PSZ/1.2	10.5 $\pm$ 0.56	0.75 $\pm$ 0.01	64 $\pm$ 0.94	11.1 $\pm$ 0.30	0.76 $\pm$ 0.01	65 $\pm$ 0.63
3Y-PSZ/0.7	13.8 $\pm$ 0.25	0.65 $\pm$ 0.05	56 $\pm$ 0.71	14.9 $\pm$ 0.30	0.66 $\pm$ 0.01	59 $\pm$ 0.39

3Y-PSZ, 3 mol% partially stabilized zirconia; 5Y-PSZ, 5 mol% yttria partially stabilized zirconia; Lb%, light blockage percentage.

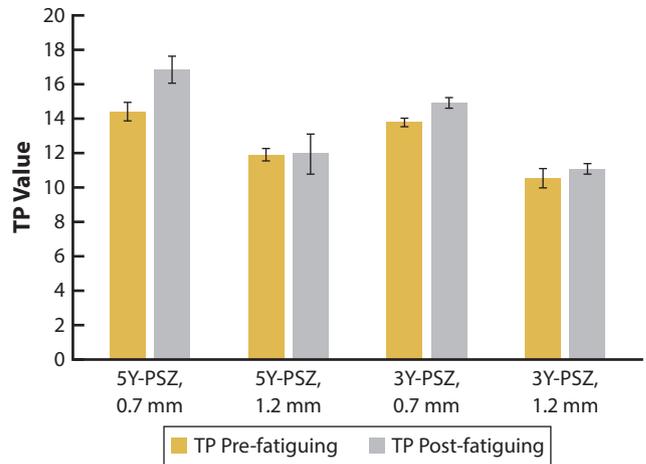
were made at those visually different areas of the specimen disks after fatiguing.

A repeated-measures analysis of variance was used to assess the TP, CR, and Lb% ( $\alpha=.05$ ) by using a within specimen factor (paired comparison before and after fatiguing of the same specimen) and between specimen factors (according to zirconia type and thickness). Pair-wise interactions of material by intervention and thickness by intervention were initially included in the model. Neither interaction was statistically significant ( $P=.09$  and  $P=.15$ , respectively), and both were therefore removed from the statistical model. All statistical analyses were performed by using a statistical software program (IBM SPSS Statistics, v24; IBM Corp).

**RESULTS**

The mean and standard deviation of the TP, CR, and Lb % of the different zirconia types and thicknesses are shown in (Table 2). The pattern of change of the TP over time with fatiguing was not significantly different for the 2 zirconias ( $P=.25$ ). The overall difference in the TP between the 2 zirconias was significant, with 5Y-PSZ having a higher TP on average than 3Y-PSZ before and after fatiguing ( $P<.001$ ). For 5Y-PSZ, the mean TP before fatiguing was 13.2  $\pm$ 0.11, and the mean TP after fatiguing was 14.4  $\pm$ 0.18. For 3Y-PSZ, the mean TP before fatiguing was 12.2  $\pm$ 11, and the mean TP after fatiguing was 13.0  $\pm$ 0.18. A significant difference was found in the pattern of change in the TP for the 2 thicknesses ( $P<.001$ ). Before fatiguing, the mean difference between the 2 thicknesses was 2.88 (95% confidence interval [CI]: 2.57, 3.18), with 0.7 mm having a mean TP of 14.1  $\pm$ 0.11 and 1.2 mm having a mean TP of 11.2  $\pm$ 0.11. After fatiguing, the average difference between the 2 thicknesses was 4.33 (95% CI: 3.82, 4.83), with the 0.7-mm thickness showing a slight increase in TP to 15.8  $\pm$ 0.18, whereas the 1.2-mm thickness did not change (11.51  $\pm$ 0.18) (Fig. 2).

The overall difference between the 2 zirconias was significant, with 5Y-PSZ having a lower CR on average than 3Y-PSZ before and after fatiguing ( $P<.001$ ). The pattern of change with fatiguing was significantly different for the 2 materials ( $P=.04$ ). The mean CR for



**Figure 2.** Mean translucency parameter values according to zirconia type, thickness, and fatiguing. 3Y-PSZ, 3 mol% partially stabilized zirconia; 5Y-PSZ, 5 mol% yttria partially stabilized zirconia; TP, translucency parameter.

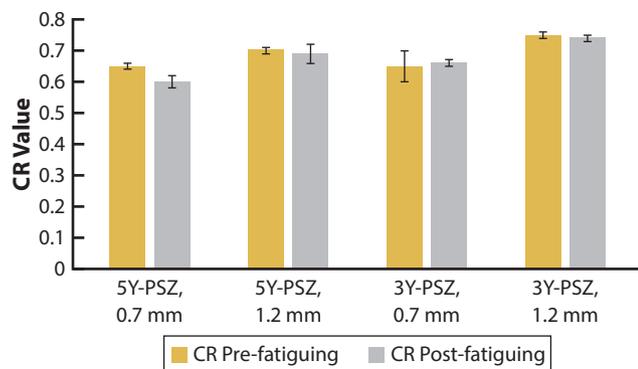
5Y-PSZ before fatiguing was 0.68  $\pm$ 0.01, whereas the mean CR for 3Y-PSZ was 0.70  $\pm$ 0.006. Although the difference between the means was small, it was significant ( $P=.004$ ). The mean CR for 5Y-PSZ after fatiguing was 0.65  $\pm$ 0.004, whereas the mean CR for 3Y-PSZ after fatiguing was 0.70  $\pm$ 0.004. The difference after fatiguing was significant ( $P<.001$ ).

The main effect of thickness, controlling for material, was significant ( $P<.001$ ), with 0.7 mm having a higher CR than 1.2 mm, both before and after fatiguing. For 0.7 mm, the mean CR before fatiguing was 0.65  $\pm$ 0.006, and the mean CR after fatiguing was 0.64  $\pm$ 0.004. For 1.2 mm, the mean CR before fatiguing was 0.73  $\pm$ 0.006, and the mean CR after fatiguing was 0.72  $\pm$ 0.004 (Fig. 3).

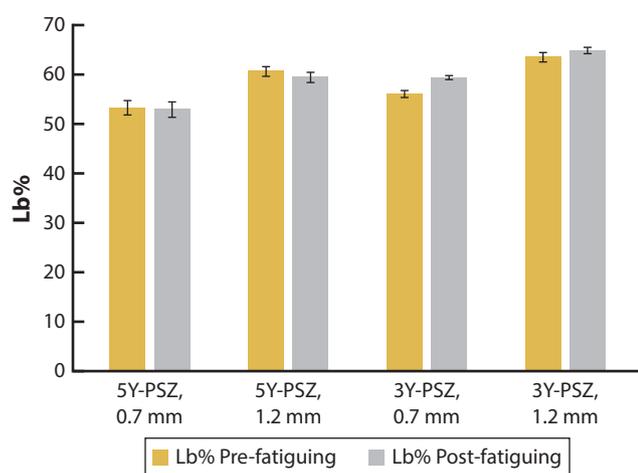
The pattern of change with fatiguing over time was significantly different for the 2 materials ( $P<.001$ ) and for the 2 thicknesses ( $P<.01$ ). The before-fatigue difference in mean Lb% for the 2 materials was 2.59 (85% CI: 1.69, 3.49), with 5Y-PSZ having a mean Lb% of 57  $\pm$ 0.31% and 3Y-PSZ having a mean Lb% of 60  $\pm$ 0.32%. The after-fatigue difference in the mean Lb% was 6.10 (95% CI: 5.49, 6.71), with 5Y-PSZ having a mean Lb% of 60%  $\pm$ 0.21 and 3Y-PSZ having a mean Lb% of 62%  $\pm$ 0.22. The before-fatigue difference in the mean Lb% for the 2 thicknesses was 7.11 (95% CI: 6.22, 8.01). The after-fatigue difference in the mean Lb% was 5.88 (94% CI: 5.28, 6.49) (Fig. 4).

**DISCUSSION**

Based on the results of this study, the first null hypothesis was rejected because a significant difference was found between the translucency of 5Y-PSZ and 3Y-PSZ at different thicknesses. The second null hypothesis was partially rejected because fatiguing and thermocycling



**Figure 3.** Mean contrast ratio values according to zirconia type, thickness, and fatiguing. 3Y-PSZ, 3 mol% partially stabilized zirconia; 5Y-PSZ, 5 mol% yttria partially stabilized zirconia; CR, contrast ratio.



**Figure 4.** Mean Light blockage % according to zirconia type, thickness, and fatiguing. 3Y-PSZ, 3 mol% partially stabilized zirconia; 5Y-PSZ, 5 mol% yttria partially stabilized zirconia; Lb%, light blockage percentage.

produced a significant difference in the CR and Lb% but not the TP.

The effect of the stabilization level (5 mol% versus 3 mol% yttria) and thickness of different zirconia types on their translucency was evaluated. Increased cubic phase in zirconia increased the translucency. The cubic phase represents approximately 15% of the content of 3Y-PSZ and greater than 50% of the 5Y-PSZ.<sup>8</sup> The 3Y-PSZ has 3 mol% of yttria and is predominantly tetragonal phase, whereas the 5Y-PSZ has 5 mol% yttria and is predominantly cubic phase. The 2 thicknesses (1.2 and 0.7 mm) were also considered to represent clinically relevant thicknesses.

In vitro testing has limitations. To maximize the clinical relevance of this study, zirconia specimens were artificially aged through cyclic loading for 1.2 million cycles accompanied by thermocycling, which is equivalent to 5 years of clinical use.<sup>27</sup> The simulator can apply dynamic loads to zirconia specimens submerged in

water while simultaneously allowing thermocycling. The visual change in the contact area of the mastication simulator may represent the wear of the surface of the zirconia.

Three different methods of evaluating translucency (TP, CR, and Lb%) were used and showed a high level of agreement. According to these research results, the first null hypothesis was rejected. The 5Y-PSZ is better than 3Y-PSZ in terms of translucency values and less Lb%. The ranking of the zirconias from the most to the least translucent according to the TP and CR values is as follows: 5Y-PSZ (0.7 mm) > 3Y-PSZ (0.7 mm) > 5Y-PSZ (1.2 mm) > 3Y-PSZ (1.2 mm). Higher Lb% was recorded in the 3Y-PSZ groups (62% at 1.2-mm and 56% at 0.7-mm thickness) than that in the 5Y-PSZ (60% Lb% at 1.2 mm and 53% at 0.7 mm). Reducing the thickness of the specimens increased the translucency and light transmission for both types of zirconia, which is consistent with previous findings.<sup>1,16,19</sup>

When zirconia restorations are under occlusal load, fatiguing may introduce superficial microcracks. These cracks induce phase transformation that transforms tetragonal particles to monoclinic, with the latter being larger in size and thus more prone to light blockage.<sup>26</sup> The translucency values and Lb% reported in this study support this explanation. With 3Y-PSZ possessing more tetragonal particles, the phase transformation is more likely to occur, and the monoclinic particles will block light and decrease the translucency. However, 5Y-PSZ has more cubic phase, and the likelihood of phase transformation is less, meaning the fatiguing process has a smaller impact on translucency and Lb% (Table 2).

The statistically significant differences noted may not be clinically significant or perceivable by the eye. It has been reported that 50% of humans are able to perceive differences in translucency less than the 0.06 CR value.<sup>28</sup> None of the groups had more than a 0.06 CR difference, either before or after fatiguing measurements, between the different types of zirconia of the same thickness. This indicates that some people may not be able to detect the difference in translucency between 5Y-PSZ and 3Y-PSZ. Moreover, the translucency was not perceivably different before and after fatiguing in the same group, which is a good clinical indication that zirconia translucency can remain stable and resistant under occlusal loads in a moist environment.

When the recently introduced translucent 5Y-PSZ is used to restore teeth in the esthetic zone, the inherent limitation in translucency of this type of zirconia is a limitation. The translucency of 5Y-PSZ, even in thin sections, is not comparable with that of enamel. Furthermore, minimal tooth preparation to attempt to benefit from the increased translucency of 5Y-PSZ may be contraindicated because of the biomechanical properties of the material. Manufactures have reported and

independent research studies have verified that 5Y-PSZ has significantly lower strength than 3Y-PSZ.

Limitations of this study include its in vitro design and that only 1 brand of zirconia was evaluated. The materials 5Y-PSZ and 3Y-PSZ from different manufacturers have different formulations and chemical composition, giving different optical properties. In future studies, the differences in translucency between different brands of zirconia with different yttria concentrations should be evaluated.

## CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Different types of zirconia according to yttria concentration displayed different degrees of translucency. The material 5Y-PSZ was more translucent than 3Y-PSZ.
2. The translucency of 5Y-PSZ and 3Y-PSZ was stable over the masticatory simulation equivalent of 5 years of use. The translucency of both types of zirconia was inversely related to thickness.

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### Acknowledgments

The authors would like to express their sincere gratitude to Ms Safaa Dali and Jessica Joy for their laboratory support, Dr Ceib Phillips for conducting the statistical analysis, and Glidewell Laboratories for their material support.

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<https://doi.org/10.1016/j.prosdent.2019.02.002>