Translucency and strength of high-translucency monolithic zirconium oxide materials

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The purpose of this study was to evaluate the translucency and strength of highly translucent monolithic zirconia ceramic materials recently introduced to the market. Four monolithic zirconium oxide materials promoted as having high translucency (BruxZir Shaded 16, BruxZir HT, Lava Plus, and inCoris TZI C) were compared to a high-translucency, lithium disilicate monolithic glass-ceramic material (IPS e.max CAD HT). To evaluate translucency, the materials were sectioned into 0.5-, 1.0-, 1.5-, and 2.0-mm-thick specimens; all were sintered and polished. Translucency parameters were calculated with a spectrophotometer. To evaluate flexural strength and modulus, the ceramic materials were sectioned to create beams and fractured in a universal testing machine. The lithium disilicate had significantly greater translucency than the zirconia materials at each thickness. In general, the translucencies of the zirconia materials were similar at each thickness. However, at the manufacturers' recommended minimal thicknesses, 0.5-mm specimens of BruxZir Shaded 16, inCoris TZI C, and Lava Plus were more translucent than the 1.0-mm-thick specimens of IPS e.max CAD HT. Translucency significantly decreased for each material at each increase in thickness. The flexural strengths of the zirconia materials were similar to each other and significantly greater than that of IPS e.max CAD HT. Flexural moduli were more variable. Of the zirconia materials, BruxZir Shaded 16 had an overall better combination of translucency, strength, and modulus.

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The desire to develop highly esthetic permanent restorations is not new. In 1886, Land developed the first all-ceramic crown, which was the most esthetic full-veneer restorative material in dentistry for many years.[1] In the mid-1900s, dental materials researchers began marketing and manufacturing metal-ceramic restorations, which had strength and accuracy due to the cast metal but also provided esthetically pleasing results because of the ceramic.[1] For years, dentists have used metal-ceramic crowns to provide their patients with strong, long-lasting restorations while also taking the patient's esthetic concerns into account. Yet, despite these favorable results, researchers have intensified their research into all-ceramic restorations in order to address the increasing demands of dental patients for improved esthetics and metal-free dentistry.[2]

The all-ceramic preference is based on an inherent translucency associated with these materials, which allows dentists and laboratory technicians to fabricate restorations that are similar to natural teeth.[3] Translucency is one of the primary factors in improved esthetics, and this property is critical in the selection of materials. All-ceramic systems have different compositions, microstructures, crystalline contents, and phases, which may influence the optical and strength properties of the restoration. These ceramic systems can be divided into glass-containing materials (such as feldspathic porcelain), reinforced-glass materials (such as leucite and lithium disilicate), glass-infiltrated crystalline materials, and purely crystalline materials (such as zirconia and alumina). However, an increase in the crystalline content to achieve greater strength often results in greater opacity.[4]

To provide high strength and improved esthetics, zirconium oxide has been used as a core material; porcelain is then fused to the outer surface. Zirconium oxide has been shown to be more translucent than metal substructures when ceramic is fused to the outer surface.[5] The outer porcelain is more translucent and allows the zirconia core material color to show.[6] However, a common problem with veneered zirconium oxide compared to metal-ceramic crowns is an increased fracture rate, possibly caused by the mismatch of the coefficients of thermal expansion, surface grinding, inadequate core design, or overloading. To reduce the risk of veneering fracture and to simplify procedures, manufacturers have recently marketed monolithic zirconia restorations.[7]

Although relatively opaque, monolithic zirconium oxide crowns may have some advantages over metal-ceramic and zirconia ceramic restorations. The zirconium oxide does not require as much tooth reduction as glass-based all-ceramic crowns, yet the flexural strength and fracture toughness of the monolithic material reduce the potential for chips and fractures associated with the use of veneering porcelain.[8] They can be milled and shaded prior to sintering, which is a much faster and less expensive process than ceramic veneering. Kim et al found that, depending on sintering conditions, yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramics can be made more translucent while retaining their strength properties.[3] The authors concluded that less sintering time at the optimal temperature produces smaller grain sizes and enhanced translucency.[3]

Most recently, dental manufacturers and laboratories have been marketing high-translucency monolithic zirconia restorative materials with claims of good esthetics and excellent strength properties. The manufacturer of BruxZir zirconia restorative materials, including BruxZir HT and BruxZir Shaded 16 (Glidwell Laboratories), claims that its zirconium oxide materials offer improved optical properties due to unique colloidal and pressed processing techniques that differ from other processing methods.[9] BruxZir HT milling blanks are used for the production of full-contour zirconia crowns, fixed partial dentures, and implant crowns. The material is chemically and physically reprocessed to reduce zirconia particle size and then shaped through a unique process. BruxZir HT requires staining or dipping to produce desired shades for a final restoration, which purportedly exhibits maximum strength and translucent pearlescence. BruxZir Shaded 16 is a series of 16 preshaded pressed zirconia blanks that match all of the VITA Classical shades (VITA North America), and no color dipping or staining is required. It is marketed as a "glaze-and-go" system that ensures complete and consistent shade penetration.[9]

The manufacturer of Lava Plus zirconium oxide material (3M ESPE) asserts that the improvement in the product's translucency was made possible by using a high-quality zirconia processing technique that reduces the number of impurities and structural defects.[10] Lava Plus also contains less aluminum (0.1% weight), which reportedly reduces light scattering and improves translucency.[10]

The ceramic inCoris TZI C (Dentsply Sirona) is marketed as preshaded, millable zirconia blocks that do not require a separate dipping and drying step.[11] According to the manufacturer, this preshaded, translucent zirconium oxide accelerates the production of esthetically pleasing, fully anatomical restorations while maintaining high strength, resistance to corrosion, and good biological compatibility, as well as offering 10 predyed VITA shades (A1-A4, B2, B3, C2, C3, and D3).[11]

With claims of greater translucency without a reduction in strength properties, these monolithic zirconia ceramic materials attempt to fulfill the desires of both patients and doctors. Limited research has been published evaluating the translucency and strength properties of these recently introduced high-translucency zirconia materials. The purpose of this study was to evaluate the translucency parameter, flexural strength, and flexural modulus of 4 monolithic zirconia ceramic materials and compare these properties to those of a lithium disilicate glass-ceramic material. The first null hypothesis was there would be no difference in translucency parameters based on ceramic material or thickness. The second null hypothesis was there would be no difference in flexural strength or flexural modulus among the ceramic materials.

Materials and methods

Four monolithic zirconia oxide materials marketed as having high translucency (BruxZir Shaded 16, BruxZir HT, Lava Plus, and inCoris TZI C) were compared to a high-translucency, lithium disilicate glass-ceramic material (IPS e.max CAD HT, Ivoclar Vivadent). The BruxZir Shaded 16, inCoris TZI C, and IPS e.max CAD HT blocks were all preshaded (A2) and did not require immersion in dye solution.

Translucency measurements

Translucency was evaluated by determining the translucency parameter of the ceramic materials. The ceramic materials were sectioned into 0.5-, 1.0-, 1.5-, and 2.0-mm-thick specimens using a precision saw (IsoMet 5000, Buehler). After sectioning, the specimens were prepared according to each manufacturer's specifications prior to sintering in a high-temperature furnace (inFire HTC, Dentsply Sirona).

The Lava Plus specimens were shaded according to the manufacturer's instructions prior to sintering.[10] An immersion container was selected that was dry, clean, and free of residual dyeing liquid. A bottle of Lava Plus Zirconia Dyeing Liquid shade A2 was shaken before use, and the immersion container was subsequently filled. The specimens were placed in the dyeing liquid for 2 minutes. Residual dyeing liquid was removed from each specimen with an absorbent paper towel, and then the specimens were allowed to air dry. Following the shading procedure, each specimen was sintered according to the manufacturer's specifications in the high-temperature furnace.[10]

The BruxZir HT specimens were shaded according to the manufacturer's instructions. A bottle of BruxZir Coloring Liquid shade A2 was selected and shaken prior to use. Coloring liquid was poured into the clean and dry immersion container to cover the specimens by at least 1.0 mm. The specimens were cleaned, dried, placed in the coloring liquid, and allowed to soak for 15 minutes. Each specimen was carefully removed, placed on a clean surface, and allowed to air dry under a light. Following the shading procedure, each specimen was sintered according to the manufacturer's specifications in the high-temperature furnace.[9]

Prior to translucency measurements, the thickness of the specimens was measured with a digital calipers (GA182, Grobet Vigor). Specimens were polished with 400- and 600-grit silicon carbide sandpaper (Sandblaster Pro, 3M ESPE) and deemed acceptable if within 0.05 mm of the thickness for that group. A pilot study was conducted to determine initial specimen thickness before sintering. Five specimens were prepared for each thickness of material.

The translucency parameter was determined using a dental spectrophotometer (VITA Easyshade Compact, VITA North America) in single-tooth mode using techniques outlined in a recent study by Della Bona et al.[12] The tip of the spectrophotometer was held in contact with the surface of the specimen. Three measurements of L^*, a^*, and b^* were recorded for each specimen and averaged to obtain a value for the following calculations. In the color space, L^* indicates lightness, the a^* coordinate represents the green-red range, and the b^* coordinate represents the blue-yellow range. The translucency parameter (TP) of each

Table 1. Mean (SD) translucency parameter values for the tested ceramics, by material thickness.

	Material thickness			
Ceramic	0.5 mm	1.0 mm	1.5 mm	2.0 mm
IPS e.max CAD HT	34.2 (0.5)^{Aa}	23.2 (0.4)^{Ba}	17.9 (0.2)^{Ca}	13.3 (0.3)^{Da}
BruxZir Shaded 16	26.3 (0.8)^{Ab}	18.2 (0.3)^{Bb}	11.7 (0.7)^{Cb}	7.8 (0.2)^{Db}
inCoris TZI C	25.9 (1.1)^{Ab}	17.5 (0.7)^{Bb}	10.5 (0.5)^{Cbc}	6.3 (0.4)^{Dc}
Lava Plus	25.1 (0.7)^{Abc}	15.7 (0.4)^{Bc}	9.7 (0.5)^{Cc}	7.0 (0.5)^{Dbc}
BruxZir HT	23.2 (0.8)^{Ac}	14.6 (0.5)^{Bc}	9.2 (1.0)^{Cc}	7.0 (0.3)^{Dbc}

Groups with the same superscript uppercase letter per row or lowercase letter per column are not significantly different ($P > 0.006$).

specimen was determined by calculating the color difference between readings against black (B) and white (W) backgrounds for the same specimen, according to the following equation:

$$TP = [(L^*B - L^*W)^2 + (a^*B - a^*W)^2 + (b^*B - b^*W)^2]^{½}.$$

The greater the translucency parameter, the greater the translucency of the specimen.

A mean and standard deviation were determined for each of the ceramic materials at each thickness. Data were analyzed with a 2-way analysis of variance (ANOVA) to evaluate the effect of ceramic type and thickness on the translucency parameter ($\alpha = 0.05$).

Flexural testing

Flexural strength testing was completed in accordance with the international standard for ceramic materials.[13] Ten specimens were prepared for each ceramic material. To prepare each beam specimen, the ceramic materials were sectioned using the precision saw. The final size of the beam specimens was 4.0 mm in width, 1.3 mm in depth, and 15.0 mm in length. A pilot study was conducted to determine the size of the sectioned beam specimens necessary to result in the final beam size after the sintering of each ceramic block material in the oven as before.

Each beam specimen was fractured in a universal testing machine (model 5543, Instron). Each specimen was placed on a 3-point bending test device, which was constructed with a 13.0-mm span length between the supporting rods. The central load was applied with a head diameter of 2.0 mm at a crosshead speed of 1.0 mm/min. The flexural strength (FS) was obtained using the equation $FS = 3Fl/2bd^2$, where F is the loading force at the fracture point, l is the length of the support span (13 mm), and b is the width and d the depth of the beam specimen. Measurements were made using the electronic digital calipers. Flexural modulus was determined from the slope of the linear region of the load-deflection curve using analytical software (Bluehill, Instron).

The mean and standard deviation for flexural strength and flexural modulus were calculated for each of the ceramic materials. The data were examined with a 1-way ANOVA with Tukey post hoc tests to evaluate the effect of ceramic type on flexural strength or flexural modulus ($\alpha = 0.05$).

Table 2. Mean (SD) flexural strength (in MPa) and flexural modulus (in GPa) of the tested ceramics.

Ceramic	Flexural strength	Flexural modulus
IPS e.max CAD HT	387.4 (51.9)^{b}	147.7 (19.1)^{c}
BruxZir Shaded 16	921.7 (112.0)^{a}	290.8 (15.7)^{a}
inCoris TZI C	855.2 (119.7)^{a}	132.2 (11.4)^{c}
Lava Plus	880.0 (156.1)^{a}	270.1 (16.8)^{b}
BruxZir HT	953.9 (86.7)^{a}	270.1 (16.8)^{b}

Groups with the same superscript lowercase letter per column are not significantly different ($P > 0.05$).

Results

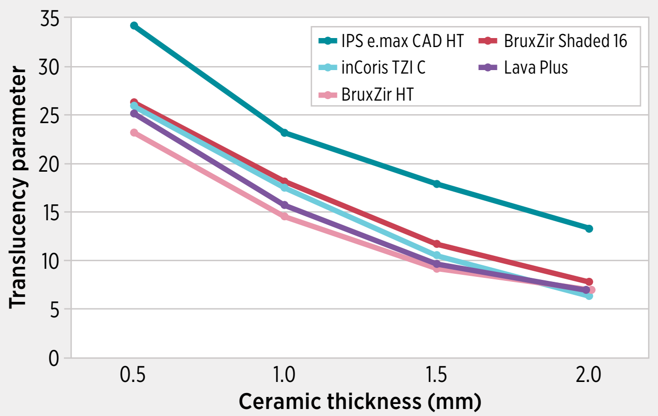
The 2-way ANOVA found a significant difference in translucency parameter values based on ceramic material ($P < 0.001$) and thickness ($P < 0.001$), but there were significant interactions ($P > 0.05$). The data were further analyzed with 1-way ANOVAs and Tukey post hoc tests to evaluate the effect of ceramic material on translucency parameter for each thickness, and the effect of thickness on translucency parameter for each ceramic material. A Bonferroni correction was applied because multiple comparison tests were completed ($\alpha = 0.006$). Significant differences in translucency parameter were found among groups based on material or thickness ($P < 0.006$). IPS e.max CAD HT had significantly higher translucency than the other zirconia materials at each thickness (Table 1).

Significant differences in flexural strength and flexural modulus were found among groups ($P < 0.001$). IPS e.max CAD HT had significantly lower flexural strength than the zirconia materials, which were not significantly different from each other. IPS e.max CAD HT and inCoris TZI C each had a significantly lower flexural modulus than the other 3 materials, while BruxZir Shaded 16 had a significantly higher modulus than all other materials (Table 2).

Discussion

The first null hypothesis was rejected. Differences were found in the translucency parameter based on type of ceramic material or thickness. IPS e.max CAD HT had significantly higher

Chart. Translucency parameters of tested ceramic materials.



translucency than the zirconia materials at each thickness. Corresponding results were shown by Baldissara et al, who found that the lithium disilicate glass ceramic showed significantly greater translucency than zirconia-based core materials.[14] In the present study, the translucencies of the zirconia materials were fairly similar at each thickness. However, translucency significantly decreased for each material at each increase in thickness. In 2 recent studies of the translucency parameter of zirconia materials, the translucency decreased significantly as the thicknesses of sintered zirconia specimens increased.[15,16]

Translucency is one of the primary factors in controlling esthetics, and it is critical in the selection of dental materials.[12] Yet there are other factors that must be taken into consideration, such as underlying tooth structure, cement opacity and shade, necessary thickness of the restoration, and the location of the tooth in the arch to be restored.[16] However, knowledge of a material's translucency allows for the fabrication of natural-looking, esthetic restorations that mimic the transition between the higher opacity of dentin and the relative translucency of enamel. One of the disadvantages of zirconia restorations is the relatively opaque nature of the material compared to other ceramic materials; this opacity is due to the size of the crystalline particles, which leads to greater light scattering and less translucency because less light is transmitted through the material.[16] As stated previously, the current study evaluated zirconia materials marketed as being highly translucent and compared these to a commonly used, high-translucency lithium disilicate material.

The manufacturer of IPS e.max CAD HT advises that the material should not be used for posterior full-coverage crowns with less than 1.0 mm in thickness/occlusal reduction due to the functional stress such restorations must withstand.[17] On the other hand, the manufacturers of the zirconium oxide materials used in the current study recommend minimal thicknesses as low as 0.5 mm.[10,11,18]

When the manufacturer's recommendations are considered and the translucency parameter at each minimal thickness is compared, the results are more comparable (Chart). At 0.5-mm thickness, BruxZir Shaded 16, inCoris TZI C, Lava Plus, and BruxZir HT were less translucent than IPS e.max CAD HT at the same thickness but similar to or more translucent than IPS e.max CAD HT at the latter's recommended minimum 1.0-mm thickness. With 1.0 mm of thickness, BruxZir Shaded 16 and inCoris TZI C were more translucent than Lava Plus and BruxZir HT but similar in translucency to the 1.5-mm-thick specimens of IPS e.max CAD HT. At clinically recommended thicknesses, the translucency parameters of the translucent zirconia materials were not only similar to those of the lithium disilicate ceramic material but also comparable to the translucency parameters reported for 1.0 mm of dentin or enamel.[19]

In terms of translucency, the studied zirconia materials could satisfactorily replace dentin within a restoration, but, in order to produce a clinically acceptable match, it is necessary to carefully adjust the color of these systems.[20] Two main techniques are available for coloring. Either zirconia metal oxides are added to the Y-TZP powder, or the milled restoration is dipped in chloride solutions before sintering.[21] The coloring method may affect the intensity of the shade and the translucency of the zirconia. A laboratory study by Tuncel et al found that coloring liquids decreased the translucency of zirconia frameworks.[22] This agrees with the results of the present study, which found that the translucency of the dipped zirconia (BruxZir HT) was significantly less than the translucency of the precolored zirconia (BruxZir Shaded 16). A study by Kurtulmus-Yilmaz & Ulusoy, however, found that the coloring liquid did not have a significant effect on the translucency of zirconia cores. Instead, darker shades of the precolored zirconia were found to have less translucency.[21]

An advantage to polycrystalline ceramic restorations is that, due to their high strength properties, they can be cemented using a variety of luting agents, including conventional cements. However, for preparations with limited retentive features, the use of resin cements, in particular dual-cure resin cements, may be advisable to increase adhesion. Yet studies have shown that light activation of dual-cure resin cement produces better mechanical properties than relying on self-cure activation alone.[8] Thus, the translucency of zirconia ceramic materials may play a role in the adhesive strength of the restoration when a dual-cure resin cement is utilized.

The use of zirconia materials has increased in recent years, in part because of its superior strength properties when compared to other ceramic materials. However, to achieve a good esthetic outcome, porcelain may be veneered to the outer surface of the zirconia. A commonly encountered problem from these kinds of restorations involves the fracture of the porcelain from the underlying zirconia material. The clinical concern with fractures is one of the main reasons that monolithic zirconia restorations have become popular and manufacturers have subsequently tried to develop more translucent zirconia that can be used in more clinical situations.[7] In the present study, differences in flexural strength and modulus based on the type of ceramic material were found, and thus the second null hypothesis was also rejected. Flexural strength estimates a material's resistance under bending, which is a common form of stress in prosthetic dentistry.[23] The results of the present study found that the flexural strengths of the tested zirconia materials were similar to each other and significantly greater than those of IPS e.max CAD. A recent study by Homaei et al found similar mean flexural strengths of a zirconium oxide framework material (886.9 MPa) and IPS e.max CAD HT (356.7 MPa).[23]

Differences among groups were also found in the flexural modulus, but the results were more variable. The flexural moduli of the majority of the zirconia materials tested were nearly double that of the lithium disilicate material tested, which also agrees with a recent laboratory study.[23] These findings illustrated that the force necessary to deform the zirconia is much greater than that needed to deform commonly used glass-ceramic materials. Because of the many variables related to bite forces in the human dentition, including off-axis loading and fatigue over time, intraoral situations can be only estimated by in vitro testing. However, there are many situations where a strong material may be indicated, such as with a patient who has a history of fractured restorations or bruxism.

The highly translucent zirconia materials were shown in the current study to be as translucent as lithium disilicate at clinically recommended thicknesses and to be far stronger than lithium disilicate when compared at similar thicknesses, which indicates that restorations using these materials may have a promising future. Of the zirconia materials tested, BruxZir Shaded 16 had an overall better combination of translucency, flexural strength, and flexural modulus. However, more studies are necessary to evaluate the long-term cyclic fatigue resistance and wear against opposing dentition of these new high-translucency zirconia materials.

Conclusion

Within the limitations of the current study, the results indicated that, at similar thicknesses, highly translucent zirconium oxide materials are not as translucent as lithium disilicate. At clinically recommended minimum thicknesses, however, highly translucent zirconia materials are as translucent as lithium disilicate. In addition, the flexural moduli and flexural strengths of highly translucent zirconia materials are significantly greater than those of lithium disilicate.

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