

RESEARCH AND EDUCATION

Comparison of the mechanical properties of translucent zirconia and lithium disilicate

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ABSTRACT

Statement of problem. Three mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) possesses excellent mechanical properties but is relatively opaque. Five mol% yttria-stabilized zirconia polycrystal (5Y-ZP) offers improved translucency, but many of its clinical properties have not been compared with those of 3Y-TZP and lithium disilicate.

Purpose. The purpose of this in vitro study was to compare the flexural strength, translucency parameter, bond strength, and enamel and material wear of 5Y-ZP (Katana UTML) with 3Y-TZP (Katana HT) and lithium disilicate (e.max CAD).

Material and methods. Flexural strength bars were sectioned ($n=10$, $25 \times 4 \times 2$ mm), sintered or crystallized, polished, and fractured at 1 mm/min. Translucency specimens (1 mm thick) were fabricated ($n=10$). Their $L^*a^*b^*$ values were measured against a black-and-white background with a spectrophotometer, and ΔE_{00} was calculated. Zirconia bond strength specimens were airborne-particle abraded with $50 \mu\text{m}$ alumina followed by the application of a 10-methacryloxydecyl dihydrogen phosphate-containing primer (Clearfil Ceramic Primer). Lithium disilicate bond strength specimens were etched with 5% hydrofluoric acid followed by application of a silane-containing primer (Clearfil Ceramic Primer). A Tygon tube filled with resin cement (Panavia SA) was fixed to the surface of the ceramics and light-polymerized. After 1 day or 150 days of water storage, the resin cement was debonded in a macroshear test ($n=10$). The cusps of extracted human molars were isolated and mounted into the University of Alabama at Birmingham wear-testing device. Wear testing was performed with a 20-N load for 300 000 cycles in 33% glycerin. The volumetric wear of polished zirconia, lithium disilicate, and enamel were measured along with the wear of the opposing enamel cusps using a noncontact profilometer ($n=8$). The data were compared by ANOVA and Tukey-Kramer analysis ($\alpha=.05$).

Results. No statistical difference was seen between the bond strengths ($P=.155$) or the opposing enamel wear ($P=.533$) of different ceramics. A statistically significant difference was seen between the flexural strength ($P<.001$), translucency parameter ($P<.001$), and wear ($P<0.01$) of the materials. The flexural strength values (MPa) were 1194 ± 111 (Katana HT), 688 ± 159 (Katana UTML), and 450 ± 53 (e.max LT). The translucency parameter values were 6.96 ± 0.53 (Katana HT), 8.30 ± 0.24 (Katana UTML), 9.28 ± 0.36 (e.max LT), and 12.64 ± 0.48 (e.max HT). Bond strength values (MPa) at 1 and 150 days were 34.22 ± 5.14 and 28.37 ± 6.03 (Katana HT), 35.04 ± 5.69 and 25.03 ± 6.44 (Katana UTML), and 35.50 ± 3.45 and 22.32 ± 3.45 (e.max LT). Material and enamel wear (mm^3) were 0 and 0.24 ± 0.19 (Katana HT), 0 and 0.23 ± 0.09 (Katana UTML), 0.28 ± 0.13 and 0.31 ± 0.10 (e.max CAD), and 0.09 ± 0.03 and 0.31 ± 0.14 (enamel).

Conclusions. 5Y-TZP has a flexural strength and translucency parameter between those of 3Y-TZP and lithium disilicate. Both the short-term and long-term bond strength of 5Y-ZP and 3Y-TZP was shown to be similar to lithium disilicate. 5Y-ZP demonstrated no measurable material wear and opposing enamel wear similar to that of all the other materials tested. (J Prosthet Dent 2017;■■■■)

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Clinical Implications

5Y-ZP has improved translucency, which may allow its use for anterior restorations; however, its decreased mechanical properties may contraindicate its use for posterior fixed partial dentures. Bonding to 5Y-ZP is possible but will depend on alumina airborne-particle abrasion. 5Y-ZP is a wear-resistant and wear-friendly material.

Zirconia is a metastable ceramic that exists in 3 crystalline phases: monoclinic, tetragonal, and cubic. At room temperature, pure zirconia is stable in its monoclinic phase. Zirconia used in dentistry, however, has traditionally been doped with 3 mol% yttria to stabilize the tetragonal phase at room temperature. The advantage of 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) containing tetragonal zirconia is that the material may respond to a forming crack with transformation toughening, which is the ability to form a transformation zone that will shield the crack.¹ Transformation toughening gives dental zirconia its high fracture toughness.

The disadvantage of the first iteration of 3Y-TZP dental zirconia was its opacity. One source of opacity of dental zirconia is the presence of alumina. Alumina is added as a sintering aid to help prevent the formation of pores when green-state zirconia is placed in the furnace. Alumina also segregates to grain boundaries and helps stabilize tetragonal zirconia. Zirconia and alumina have different indices of refraction, and alumina content can therefore decrease the in-line light transmission when it is added to zirconia.² In the second iteration of 3Y-TZP used in dentistry, the alumina content was decreased from 0.25wt% to 0.05wt%. This 0.05wt% alumina-containing 3Y-TZP is more translucent than 0.25wt% alumina-containing 3Y-TZP; however, it is more susceptible to low-temperature degradation because there is less alumina to stabilize the tetragonal phase.^{3,4}

More recently, dental zirconia has been fabricated with increased yttria content. Doping zirconia with 8 mol% yttria will completely stabilize the cubic phase,⁵ whereas the third iteration of dental zirconia is doped with 5 mol% yttria, which creates a partially stabilized zirconia with approximately 50% cubic phase zirconia.⁴ The cubic phase of zirconia is isotropic in different crystallographic directions, which decreases the light scattering that occurs at grain boundaries. As a result, the cubic zirconia appears more translucent.⁴⁻⁷ Stabilized cubic zirconia does not transform at room temperature, and cubic zirconia will therefore not undergo transformation toughening or low-temperature degradation. In other words, it has reduced mechanical properties but

will not transform over time.⁴ Some confusion in nomenclature has occurred as both 0.05wt% alumina-containing 3Y-TZP and 5 mol% yttria-stabilized zirconia polycrystal (5Y-ZP) have been called “translucent zirconia”; however, these zirconia materials have different mechanical and optical properties.⁴

In a survey conducted in 2015, monolithic zirconia was reported as the most prescribed material for posterior single crowns, and lithium disilicate as the most prescribed material for anterior single crowns.⁸ These prescription preferences can be attributed to the favorable mechanical properties of zirconia and the esthetic properties of lithium disilicate. The advent of 5Y-ZP promises the strength of zirconia with translucency closer to that of lithium disilicate, but these claims need to be evaluated directly. Additionally, several of the clinical properties of 5Y-ZP need to be evaluated to determine whether this material will perform similarly to previous iterations of dental zirconia in terms of bonding ability with the use of airborne-particle abrasion and primers containing 10-methacryloxydecyl dihydrogen phosphate (MDP)⁹⁻¹¹ and wear compatibility with opposing enamel.^{12,13}

The first aim of this project was to compare the flexural strength and translucency parameters of 5Y-ZP with those of 3Y-TZP and lithium disilicate. The second aim was to compare the early and long-term bond strength of 5Y-ZP and that of resin cement with 3Y-TZP and lithium disilicate. The third aim was to compare material and opposing enamel wear of 5Y-ZP with 3Y-TZP, lithium disilicate, and enamel. The null hypotheses were that no difference would be found between 5Y-ZP and the reference materials for the properties tested.

MATERIAL AND METHODS

The 5Y-ZP material selected for this study was Katana UTML shade A1 (Kuraray Noritake Dental). As it is a multilayer shaded material, the bottom (cervical) surface of the disk was selected for the bonded surface of the bond strength specimen, and the top (occlusal) surface of the disk was selected to receive all other experimental conditions (tensile surface of flexural strength bars, face of translucency parameter specimens facing spectrophotometer, and worn surface of wear specimens). The reference 3Y-TZP material selected was Katana HT shade HT10. The reference lithium disilicate material selected was e.max CAD LT shade A1 (Ivoclar Vivadent AG). For the translucency parameter, e.max CAD HT shade A1 was also included.

The 3-point bend flexural strength of the zirconia and lithium disilicate materials were tested according to ISO 6872. Specimens (n=10) were prepared by sectioning the ceramic into 25×4×2 mm bars, sintering or crystallizing according to the manufacturer's

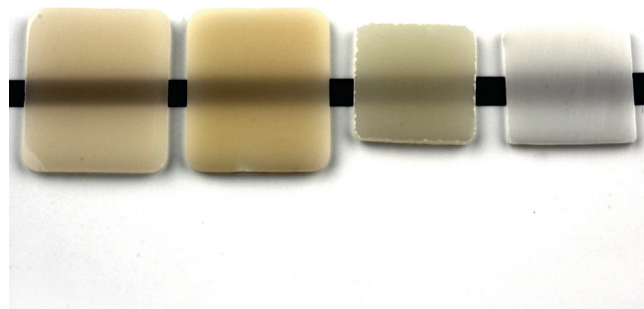


Figure 1. Specimens (1 mm thick) of (left to right) e.max CAD HT, e.max CAD LT, Katana UTML, and Katana HT.

recommendations, and polishing all specimens with 1200-grit silicon carbide paper. All dimensions were confirmed to be accurate within 0.1 mm with digital calipers. The specimens were placed in a universal testing machine on 20-mm separated supports and loaded to failure at 1 mm/min.

Specimens for testing translucency ($n=10$) were prepared by sectioning the ceramic into 1.1-mm (lithium disilicate) or 1.5-mm (zirconia) thick blocks with a circular sectioning blade and silicon carbide abrasive paper, sintering or crystallizing according to the manufacturer's recommendations, and polishing (both sides) to a final thickness of 1 mm with 1200-grit silicon carbide paper. Lithium disilicate specimens were wet-sectioned, and zirconia specimens were dry-sectioned to replicate the manufacturing process performed in a dental laboratory. All dimensions were confirmed to be accurate within 0.1 mm with digital calipers. $L^*a^*b^*$ values were obtained with a spectrophotometer (CM-700d; Konica Minolta) against a white background and a black background ($n=10$). A 400- to 700-nm specular output and 10-degree geometry were used, with each specimen measured twice and averaged. The translucency parameter was measured using ΔE_{00} calculated with the CIEDE2000 color difference formula¹⁴⁻¹⁶:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{1/2},$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are differences in lightness, chroma, and hue; R_T (rotation function) accounts for the interaction between hue and chroma in the blue region; S_L , S_C , and S_H adjust for variation in the $L^*a^*b^*$ coordinate system; and K_L , K_C , and K_H correct for experimental conditions ($K_L=1.0$, $K_C=1.0$, $K_H=1.0$ for this

study). The translucency parameter was measured by determining the color difference (ΔE_{00}) between the $L^*a^*b^*$ values against a white and a black background. Representative specimens were photographed (Fig. 1).

Specimens for testing shear bond strength ($n=10$ /group) were prepared by sectioning the ceramic into blocks, sintering or crystallizing according to the manufacturer's recommendations, and polishing with 1200-grit silicon carbide paper. The lithium disilicate specimens were etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar Vivadent AG) for 20 seconds. The zirconia specimens were airborne-particle abraded for 10 seconds with 50- μ m alumina at 0.2 MPa.

A primer containing silane and MDP (Clearfil Ceramic Primer; Kuraray Noritake Dental) was applied to all pretreated ceramic surfaces for 20 seconds, followed by air thinning for 10 seconds. A transparent Tygon tube (internal diameter=1.5 mm) was filled with resin cement (Panavia SA shade A2; Kuraray Noritake Dental), affixed to the surface of each ceramic specimen, and light-polymerized (Elipar S10, 1200 mW/cm²; 3M ESPE) on 4 sides for 20 seconds each side. After storage in deionized water at 37°C for either 1 day or 150 days, the specimens were subjected to flat blade shear loading at 1 mm/min until failure by using a universal testing machine (5565; Instron).

Ceramic specimens ($n=8$) were prepared for wear testing by sectioning the ceramic into blocks, sintering or crystallizing according to the manufacturer's recommendations, and polishing with 1200-grit silicon carbide paper. Enamel specimens ($n=8$) were fabricated from the flat labial enamel surface of freshly extracted maxillary central incisors. Opposing enamel cusps (antagonists) were prepared from extracted caries-free mandibular molars. Their mesiobuccal cusps were standardized to a cone (diameter=5 mm, height=2 mm) with a diamond rotary instrument (Sintered diamond part #5014006OU; Brasseler).

The mechanisms and testing parameters of the University of Alabama at Birmingham wear machine have been described previously.¹⁷ The machine operates by applying a vertical load from the antagonist onto the specimen, sliding horizontally, and then repeating the cycle. The specific parameters for this test were a 20-N load, 0.4-Hz frequency, 2-mm sliding distance, 33% glycerin lubricant, and 300 000 testing cycles. The cone-shaped enamel cusps were used as the antagonist to oppose the polished ceramic and flat labial enamel surfaces. The ceramic and enamel specimens and the antagonists were scanned at 20- μ m resolution in a noncontact light profilometer (Proscan 5000; Scantron Ltd). The scans obtained from baseline and 300 000 cycles of wear were superimposed, and volumetric material loss was measured with software (Proform; Scantron Ltd). A representative specimen from each group was

imaged with scanning electron microscopy. The enamel specimen was examined in an environmental chamber at 0.67 kPa pressure.

The measurements were examined using normal probability plots and the Kolmogorov-Smirnov test, and the measurements were determined to be approximately normally distributed. The means of the flexural strength, translucency parameter, material wear, and opposing enamel wear for each material were compared by using ANOVA, and the mean bond strength for each material and each storage time (1 or 150 days) were compared by using 2-way ANOVA. The Tukey-Kramer multiple-comparisons test was then used to determine which specific pairs of means were significantly different. Statistical tests were 2-sided ($\alpha=.05$). Statistical analyses were performed using statistical software (SAS v9.4; SAS Institute Inc).

RESULTS

A statistically significant difference was seen between the flexural strength ($P<.001$) and translucency parameter ($P<.001$) for different ceramics. The flexural strength of Katana HT (1 194 \pm 111 MPa) was significantly greater than that of Katana UTML (688 \pm 159 MPa) ($P<.001$), which was significantly greater than that of e.max CAD LT (460 \pm 53 MPa) ($P<.001$). The translucency parameter of Katana HT (6.96 \pm 0.53) was significantly lower than that of Katana UTML (8.30 \pm 0.24) ($P<.001$), which was significantly lower than that of e.max CAD LT (9.28 \pm 0.36) ($P<.001$), which was significantly lower than that of e.max CAD HT (12.64 \pm 0.48) ($P<.001$).

No statistical difference was seen between the bond strengths to different ceramics ($P=.155$), and no significant interaction was noted between ceramic type and aging time (1 day or 150 days) ($P=.238$). Water storage of 150 days produced lower bond strength values than water storage of 1 day ($P<.001$). The bond strength to Katana HT was 34.22 \pm 5.14 MPa (1 day) and 28.37 \pm 6.03 MPa (150 days), Katana UTML was 35.04 \pm 5.69 MPa (1 day) and 25.03 \pm 6.44 MPa (150 days), and e.max CAD LT was 35.50 \pm 3.45 MPa (1 day) and 22.32 \pm 3.45 MPa (150 days).

No measurable wear could be detected on the zirconia materials. E.max CAD LT wear (0.28 \pm 0.13 mm³) was significantly greater than the wear of flat labial enamel (0.09 \pm 0.03 mm³) ($P<.001$). No statistical difference was seen between different materials for the wear to opposing enamel cusps ($P=.533$). The volumetric wear measured on enamel cusps opposing Katana HT was 0.24 \pm 0.19 mm³, Katana UTML was 0.23 \pm 0.09 mm³, e.max CAD LT was 0.31 \pm 0.10 mm³, and natural labial enamel was 0.31 \pm 0.14 mm³.

Due to the low sample size, post hoc power analyses which determined that the F-tests were all powered at

99% were performed to detect group differences for flexural strength, translucency parameter, and material wear based on 8 or 10 specimens per group at $\alpha=.05$.

The material wear demonstrated in Figure 2 shows no evidence of wear for Katana HT or Katana UTML. The e.max CAD specimen shows fine scratches parallel with the direction of antagonist sliding. The worn enamel specimen shows some signs of chipping of enamel rods.

DISCUSSION

The first null hypothesis was rejected because the results of this study demonstrate that 5Y-ZP is between 3Y-TZP and lithium disilicate in terms of strength and translucency. We failed to reject the second null hypothesis that no difference would be found in bond strength among all materials. Following airborne-particle abrasion and MDP-containing primer application, 5Y-ZP displayed similar short- and long-term bonding capability to that of 3Y-TZP and lithium disilicate (treated according to manufacturer's recommendations). The final null hypothesis was partially rejected because 5Y-ZP and 3Y-TZP did not experience material wear, unlike lithium disilicate or enamel-enamel contact. However, 5Y-ZP caused opposing enamel wear like the other materials tested.

The results of the current study show similar trends as those from previous studies. The 4-point bend flexural strength of 5Y-ZP (485 MPa) has previously been shown to be nearly half that of 3Y-TZP (854 MPa) when the specimens are fabricated from raw Tosoh powder.⁴ In another study, the total transmittance of light was reported as 20.18% for Katana HT, 23.37% for Katana UTML, and 27.05% for e.max CAD LT.⁶ The intermediate strength and translucency of 5Y-ZP in comparison with 3Y-TZP and lithium disilicate raises questions as to its clinical indications. According to ISO standard 6872,¹⁸ because Katana UTML has a flexural strength greater than 500 MPa but less than 800 MPa, it is graded as a class 5 material; therefore, it should be suitable as a "substructure ceramic for three-unit prostheses involving molar restorations." This clinical recommendation, however, should be regarded with caution, as 5Y-ZP does not have the same potential to undergo transformation toughening. This has been demonstrated by the lower fracture toughness of 5Y-ZP than 3Y-TZP.⁶ As a result, 5Y-ZP may not be as tolerant to the surface damage introduced during the fabrication, adjustment, and airborne-particle abrasion of a zirconia restoration.¹⁹

The translucency of 5Y-ZP is slightly less than that of lithium disilicate (e.max CAD LT), so its use for monolithic anterior restorations will still be limited for highly translucent restorations. For reference, the translucency parameter (ΔE) has been reported as 18.7 for 1 mm of human enamel and 16.4 for dentin.²⁰ If the $L^*a^*b^*$ values

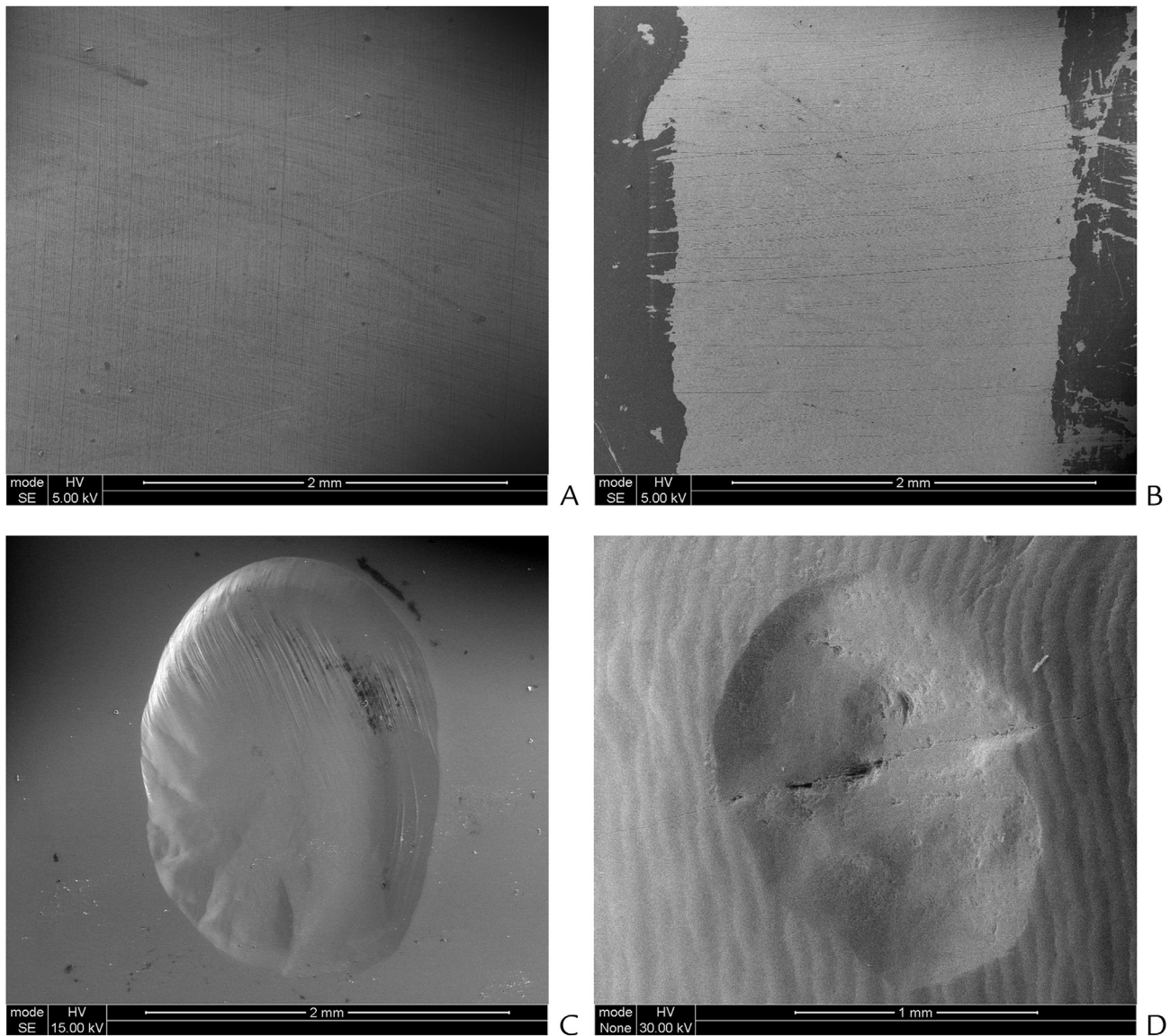


Figure 2. Scanning electron microscope images showing material wear (original magnification, $\times 50$). A, Katana HT. B, Katana UTML. C, e.max CAD. D, Enamel.

from the current study are converted to the translucency parameter in ΔE , the mean values would be 9.86 for Katana HT, 11.28 for Katana UTML, 13.68 for e.max CAD LT, and 16.89 for e.max CAD HT. As demonstrated by these values, even lithium disilicate may benefit from the addition of more translucent porcelain to mimic the translucency of enamel. The improvement in translucency from 5Y-ZP to 3Y-TZP, however, will make this material a more viable option for monolithic anterior restorations. In some clinical situations, the opacity of the material may help mask discolored substructures or cement.

The process of translucency testing revealed several nuances related to the manufacturing of zirconia restorations. Initial specimens of the zirconia were wet

sectioned, which increased the opacity of the material. Therefore, care should be taken to ensure that zirconia crowns are not exposed to water before sintering. Additionally, a batch of specimens were produced that were sintered at an incorrect firing temperature, which also increased the opacity of the specimens.

Like previous studies with 3Y-TZP, an effective bond to resin cement was achieved to 5Y-ZP after alumina airborne-particle abrasion and the application of an MDP-containing primer.⁹⁻¹¹ Moreover, the bond strength to zirconia was shown to be similar to that of lithium disilicate at both the early and late time points, as all materials showed a reduction in bond strength after water storage. The clinical implication of this bond strength value is the possibility of using zirconia

restorations in preparations with minimal retention. One potential complication of bonding to 5Y-ZP, however, is that alumina airborne-particle abrasion of its intaglio surface may decrease its strength as it does not undergo transformation toughening.⁶ A limitation of this study is that shear bond strength values do not represent true shear stress, but may actually represent tensile failure derived from contact of the cylinder of composite and the loading device.²¹ Therefore, values of shear bond strength have little quantitative meaning and should only be used for comparisons within this study.

Finally, 5Y-ZP maintained the excellent wear properties reported with 3Y-TZP.^{12,13} The mechanism of ceramic wear typically occurs as the ceramic material fractures through contact with opposing tooth structure and roughens. The rough asperities of the worn ceramic will then roughen the opposing enamel and start a cycle abrasive wear.¹³ Some of this surface fracturing could be seen on the surface of the lithium disilicate material (Fig. 2C). Despite the lower strength and fracture toughness of 5Y-ZP, no surface fracturing or roughening was observed during the wear process (Fig. 2B). As the zirconia specimen remained smooth throughout the wear process, limited wear was seen on the opposing enamel. The wear resistance of both 3Y-TZP and 5Y-ZP is a clinical advantage for patients with bruxism or other destructive habits.

Future studies should be conducted to compare the strength of these materials in clinically relevant geometries with actual bonding procedures. These studies will help elucidate the minimum recommended restoration thickness and allowable bonding procedures for 5Y-ZP. Ultimately, only clinical experience will reveal the clinical applications and shortcomings of this new iteration of translucent zirconia.

CONCLUSIONS

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

1. 5Y-ZP has a flexural strength and translucency parameter intermediate to those of 3Y-TZP and lithium disilicate.
2. Both short- and long-term bond strength of 3Y-TZP and 5Y-ZP were similar to those of lithium disilicate.
3. 5Y-ZP demonstrated no measurable material wear and opposing enamel wear similar to that of all other materials tested.

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