A comparison of shear bond strength of brackets bonded to zirconia

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Purpose: The objective of this study was to compare the shear bond strength (SBS) of ceramic orthodontic brackets bonded to highly translucent zirconia surfaces following the use of two different primers.

Materials and methods: Three types of highly translucent zirconia crowns, Cercon xt ML, e.max ZirCAD, and STML-ML Katana Zirconia, were milled, sandblasted, and primed using two zirconia primers, Monobond Etch and Prime and Z-Prime Plus. A ceramic bracket (Radiance) was bonded onto the facial surface of each crown. Shear bond strength was evaluated using a universal testing machine.

Results: There was no significant overall difference across the six experimental groups regarding shear bond strength. The use of the two tested zirconia primers resulted in comparable and clinically acceptable shear bond strengths.

Conclusions: Both tested zirconia primers were associated with adequate bond strength when bonding a ceramic orthodontic bracket to the three highly translucent zirconia substrates.

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Introduction
Continuing advances in technology prompt dental practitioners to constantly seek new gold standards for their patients. Patients not only expect a cosmetic result, but also desire an aesthetic treatment option. Because of high aesthetic demands, more adolescents and adults request the use of more visually pleasing dental and orthodontic materials, such as porcelain crowns and ceramic brackets.1 As a result, clinicians may need to bond orthodontic brackets to teeth that have ceramic restorations. The variable surface conditioning treatments available for porcelain substrates are directly correlated to the bond strength of ceramic brackets.2 Consequently, there is a higher level of bond failure when bonding orthodontic brackets to porcelain restorations compared with bonding to enamel.3 With high aesthetic advantages, it would be desirable to establish an adequate method to achieve superior bond strength between ceramic orthodontic brackets and ceramic restorative materials.4

Patients often experience fixed prosthodontic treatment and may have full-coverage ceramic restorations, prior to seeking orthodontic treatment. Zirconia has become a popular ceramic material in dentistry.5,6 New highly-translucent zirconia ceramics have favourable optical properties and can be applied as monolithic full-contour restorations in appropriate clinical circumstances. The latest generation of zirconia materials has a significantly higher degree of translucency, providing greatly improved aesthetics.
The use of highly-translucency, zirconia materials provides a greater range of aesthetic possibilities, specifically for anterior teeth. However, due to the properties of the ceramic materials, bonding brackets to porcelain surfaces can be uncertain. Compared with tooth enamel, orthodontic brackets have a lower bond strength to zirconia, and, consequently, surface pre-conditioning by sandblasting and/or primer application is required. For this reason, it is necessary to establish a bonding protocol for clinicians that will achieve efficient and durable bracket-porcelain bonding.

Currently, hydrofluoric acid (HFA) is used to etch ceramic restorative materials prior to bonding brackets. It has been reported that since zirconia does not have a glass phase, hydrofluoric acid etching will not enhance bond strength. With the increasing aesthetic quality and popularity of ceramic restorative options, bonding to these restorations is becoming a more common consideration for clinicians. Therefore, finding an alternative mechanism to treat ceramic substrates prior to bonding orthodontic brackets would be advantageous for the clinician and the patient.

The objective of the present study was to compare the shear bond strength (SBS) of ceramic orthodontic brackets bonded to highly translucent zirconia surfaces following the use of a bonding resin and two different primers.

Materials and methods
Sixty anterior full-coverage maxillary central incisor crowns were milled from three different zirconia discs using the same maxillary incisor crown computer-aided design/computer-aided manufacturing (CAD/CAM) file (inLab CAM software, Dentsply Sirona, NC, USA) (in Lab MCX5, Dentsply Sirona, NC, USA).

Each zirconia crown was sandblasted (Basic Quattro IS, Renfert, Hilzingen, Germany) with 110 µm alumina particles (Cobra, Renfert, Hilzingen, Germany) for 20 seconds, at 1 psi at a distance of 5 cm. Crowns were cleaned in an ultrasonic bath (Soniclean M250, Midmark, OH, USA), utilising distilled water for 20 minutes. The glazed crowns were separated into three groups (N = 20), based on the specific type of zirconia utilised: Group 1: Cercon xt ML (Dentsply Sirona, NC, USA), Group 2: e.max ZirCAD (Ivoclar Vivadent, NY, USA), Group 3: STML-ML Katana Zirconia (Kuraray Noritake, Tokyo, Japan). All groups were bonded using Radiance ceramic brackets (American Orthodontics, St. Louis, MO, USA).

Each group was further subdivided into two subgroups (N=10), A and B, identified by the applied zirconia primer. The “A” sub-groups represented brackets bonded using Monobond Etch and Prime (Ivoclar Vivadent, NY, USA), while “B” sub-groups represented those using Z-Prime Plus (Bisco, Schaumburg, IL, USA) (Figure 1, Table I). Each primer was applied according to the manufacturers’ recommended protocol. Transbond XT (3M Unitek, Monrovia, CA, USA) light cure adhesive paste was applied to the bracket and light cured for 40 seconds, 10 seconds from each cardinal position around the bracket.

A comparison group consisting of 10 extracted, human maxillary central incisor teeth which were etched for 20 seconds with 35% phosphoric acid, rinsed with water for 10 seconds and had Transbond Plus...
self-etching primer (3M Unitek, CA, USA) applied for 5 seconds and air-thinned. Transbond XT light cure adhesive paste (3M Unitek, CA, USA) was applied to each bracket, placed on the tooth and light cured for 40 seconds, 10 seconds from each cardinal position around the bracket.

Following the ISO technical report 11405 for adhesion testing, all bonded samples were thermocycled using a thermocycling machine (Sabri Dental Enterprises, IL, USA) for 500 cycles between 5°C and 55°C, and a dwell time of 30 seconds in each bath plus a transition time of 15 seconds. Each group was secured to a 0.021” × 0.025” stainless steel orthodontic wire using stainless steel ligatures around the bracket tiewings and embedded into epoxy resin. The orientation was such that the tooth’s facial surface was perpendicular to the floor to support the later debonding process.
Each sample was mounted in a universal testing machine (Model 5566, Instron, MA USA) to enable the application of a bracket shear force at a cross-head speed of 1 mm/min until failure. Maximum force at debond was recorded. The SBS of each sample was calculated in MPa by dividing the force (N) recorded at bracket debond by the surface area of the bracket base (13.94 mm²). The data were statistically analysed using the Kruskal Wallis test.

### Results

The SBS of all groups are shown in Table II. The non-parametric method, Kruskal Wallis test (Table III) showed no significant difference across the seven groups with a \( p \)-value of 0.07. From the pairwise comparisons, there was no significant difference between each pair of groups (Table IV). Group 3, the Katana + Monobond group, demonstrated the lowest SBS (7.46 MPa) and the comparison group (bond to enamel) demonstrated the highest SBS (20.0 MPa), which was still not significantly different from other groups due to the large standard deviation.

### Discussion

In dentistry today, clinicians often seek ways to satisfy their patients’ high aesthetic demands. By the advent and use of ceramic orthodontic brackets and zirconia crowns, these demands can be met. However, brackets bonded to ceramic restorations historically have a high degree of bond failure.\(^{14,16}\) Therefore, attaining adequate bond strength of orthodontic brackets to ceramic restorative materials is crucial.

Bracket bond failure is a challenging orthodontic treatment concern. The average bond failure rate for practitioners in the United States is reported to be approximately 5%.\(^ {17}\) Bond failure affects many aspects of an orthodontic practice as it is an inconvenience to the practitioner and the patient. Bond failure is costly and results in a loss of chair time and increased treatment time. Studies have reported that a single bond failure can result in a 20 – 30 minute loss in chair time and a cost of $70 – $80 to the practice.\(^ {18,19}\)

In addition, if the shear bond strength (SBS) is too low, brackets may debond between appointments, which delays treatment and increases practice cost. An extended treatment time can be costly to a practice due to a negative perception generated within the community.\(^ {18,19}\)

The zirconia products and the primers chosen for this study are relatively new to the market and are gaining popularity. A PubMed search found little published information concerning the impact on orthodontic bonding of aesthetic ceramic brackets. Cercon is milled from a monolithic block of solid yttria-stabilised zirconia and is claimed by the manufacturer to have high strength and excellent translucency and colour matching.\(^ {20}\) IPS e.max is a zirconium oxide product that the manufacturer claims has high strength and high fracture toughness without a compromise in translucency.\(^ {21}\) Katana is promoted as a multi-layer zirconia product that has excellent translucency and high strength.\(^ {22}\) Z-Prime Plus utilises a combination of two active monomers, MDP, a phosphate monomer, and BPDM, a carboxylate monomer reported to produce high bond strengths.\(^ {23}\) Monobond E & P is blend of a new ceramic conditioner and a silane coupling agent that is also advertised to produce high bond strength.\(^ {24}\)

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### Table II. Shear bond strength.

| Group                  | N Obs | Mean (MPa) | Std Dev | Coeff of Variation |
|------------------------|-------|------------|---------|--------------------|
| Comparison (Enamel)    | 8     | 20.0       | 14.1    | 70.14              |
| 1A Cercon + Monobond   | 10    | 11.5       | 3.02    | 26.3              |
| 1B Cercon + ZPrime Plus| 10    | 9.24       | 3.50    | 37.91              |
| 2A ZirCAD + Monobond   | 10    | 11.6       | 4.06    | 35.03              |
| 2B ZirCAD + ZPrime Plus| 10    | 11.4       | 4.48    | 39.27              |
| 3A Katana + Monobond   | 9     | 7.46       | 3.36    | 45.06              |
| 3B Katana + ZPrime Plus| 8     | 8.34       | 1.99    | 23.87              |

### Table III. Kruskal-Wallis test.

| Chi-Square | DF | P-value |
|------------|----|---------|
| 11.6391    | 6  | 0.0705  |

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In an effort to simulate the clinical application of the products, a maxillary incisor crown shape was chosen because all of the zirconia products promoted the high translucency of their product, which is important in the quality and acceptance of an anterior fixed prosthesis. The maxillary central incisor ceramic bracket was chosen as the bracket base would most closely match the facial contour of the crown. Thermocycling was employed to simulate aging by inducing thermal stresses at the bonding interface resulting from different thermal conductivities and expansion coefficients of the various materials. While the appropriateness of laboratory studies of clinical products are sometimes questioned, it has been reported that orthodontic bonding can be studied in a laboratory setting to obtain valid information concerning the adherence of a new product.

The present study results were slightly higher but consistent with those reported by Ju et al., who found a SBS ranging from 5.16 to 13.85 MPa when a ceramic primer was used to bond ceramic brackets to zirconia.

Utilising the specific materials of the present study, it was found that the SBS of the two tested zirconia primers were comparable. In addition, confirmation that the SBS between the three types of zirconia tested were statistically comparable to one another, was determined. Although there were no significant differences in the SBS between the six experimental groups, the mean SBS for all experimental groups ranged from 7.46 MPa to 11.59 MPa, which is clinically acceptable. These values were lower than the mean SBS of the comparison group of brackets bonded to enamel but not statistically different. The comparison group also showed the largest coefficient of variation or dispersion of the data, which may have resulted from operator error in either the preparation or testing of the samples. Previous studies have suggested that bond strength values in the range of 6 to 8 MPa are adequate for orthodontic force application and the present results fall within or above that range.

Table IV. Pairwise two-sided multiple comparison analysis.

| Group                                      | Wilcoxon Z | DSCF Value | p-value |
|--------------------------------------------|------------|------------|---------|
| ZirCAD + ZPrime Plus vs. Katana + ZPrime Plus | 1.5993     | 2.2618     | 0.6828  |
| ZirCAD + ZPrime Plus vs. Cercon + ZPrime Plus | 1.2095     | 1.7105     | 0.8908  |
| ZirCAD + ZPrime Plus vs. ZirCAD + Monobond  | -0.3780    | 0.5345     | 0.9998  |
| ZirCAD + ZPrime Plus vs. Katana + Monobond  | 2.2045     | 3.1177     | 0.2929  |
| ZirCAD + ZPrime Plus vs. Cercon + Monobond  | -0.2268    | 0.3207     | 1.0000  |
| ZirCAD + ZPrime Plus vs. Comparison        | -1.0662    | 1.5079     | 0.9379  |
| Katana + ZPrime Plus vs. Cercon + ZPrime Plus | -0.2666    | 0.3770     | 1.0000  |
| Katana + ZPrime Plus vs. ZirCAD + Monobond  | -2.0436    | 2.8901     | 0.3870  |
| Katana + ZPrime Plus vs. Katana + Monobond  | 1.0585     | 1.4969     | 0.9400  |
| Katana + ZPrime Plus vs. Cercon + Monobond  | -2.3990    | 3.3927     | 0.1988  |
| Katana + ZPrime Plus vs. Comparison        | -1.0502    | 1.4852     | 0.9422  |
| Cercon + ZPrime Plus vs. ZirCAD + Monobond  | -1.2095    | 1.7105     | 0.8908  |
| Cercon + ZPrime Plus vs. Katana + Monobond  | 1.0614     | 1.5011     | 0.9392  |
| Cercon + ZPrime Plus vs. Cercon + Monobond  | -1.6630    | 2.3519     | 0.6409  |
| Cercon + ZPrime Plus vs. Comparison        | -1.0662    | 1.5079     | 0.9379  |
| ZirCAD + Monobond vs. Katana + Monobond    | 1.9596     | 2.7713     | 0.4407  |
| ZirCAD + Monobond vs. Cercon + Monobond    | 0.3024     | 0.4276     | 0.9999  |
| ZirCAD + Monobond vs. Comparison           | -1.0662    | 1.5079     | 0.9379  |
| Katana + Monobond vs. Cercon + Monobond    | -2.6944    | 3.8105     | 0.0996  |
| Katana + Monobond vs. Comparison           | -1.3472    | 1.9052     | 0.8296  |
| Cercon + Monobond vs. Comparison           | -0.8885    | 1.2566     | 0.9744  |
The limitations of this study may relate to the number of materials tested and human error when mounting the teeth in epoxy resin or in the universal testing machine. Future studies may utilise a larger number of individual samples as well as sample diversity (more primers) to measure the success or failure of these bonding protocols.

Based on the results of this laboratory study, both Monobond Etch and Prime and Z-Prime Plus, when following the respective manufacturers’ protocols, provide the clinician with acceptable materials to bond ceramic orthodontic brackets to the three tested zirconia materials.

**Conclusions**

The tested zirconia primers produced clinically acceptable shear bond strengths when bonding a ceramic orthodontic bracket to the three high translucency zirconia substrates. The results of this laboratory study showed no contraindication to using these primers with these crown materials. Therefore, using the specific materials and following the manufacturers’ protocols provide a practical method to bond ceramic brackets to zirconia crowns.

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**Conflict of interest**

The authors declare no conflicts of interest in this study.

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