Purpose: To evaluate the retention of zirconia crowns on polyetheretherketone (PEEK) abutments using different luting agents, with and without PEEK primer. **Materials and Methods:** A total of 100 PEEK abutment replicas were fabricated, airborne particle–abraded with aluminum oxide, and divided into four groups (n = 25). A total of 100 zirconia crowns were fabricated and cemented using either adhesive resin cement or self-adhesive resin cement with and without PEEK primer; thus, the groups were: group AA-P (adhesive cement with primer); group AA-N (adhesive cement without primer); group SA-P (self-adhesive cement with primer); and group SA-N (self-adhesive cement without primer). The specimens were thermocycled and subjected to crown pull-out tests. The values were recorded and analyzed using analysis of variance and post hoc analysis ($\alpha = .05$). The mode of failure of debonded surfaces was evaluated using scanning electron microscopy. **Results:** The pull-out force values were 3.13 ± 0.31 MPa for group AA-P, 1.77 ± 0.20 MPa for group AA-N, 2.10 ± 0.12 MPa for group SA-P, and 1.49 ± 0.18 MPa for group SA-N. Statistically significant differences were found between all four groups ($P < .001$). The specimens with PEEK primer applied showed higher values compared to nonprimed specimens for both cements tested. Scanning electron microscopy analysis showed more mixed failures for adhesive cement and more adhesive failures for self-adhesive resin cement. **Conclusion:** The maximum pull-out forces were recorded for zirconia crowns bonded to PEEK abutments with adhesive cement. The use of PEEK primer increased the pull-out values for both resin cements. *Int J Prosthodont* 2022;35:453–459. doi: 10.11607/ijp.7177
An economic alternative to zirconia is polyetheretherketone (PEEK), a synthetic polymeric material with good workability and an elastic modulus similar to alveolar bone.\(^8^,^9\) This material can be easily customized to suit any implant system. One of the major drawbacks of PEEK material is that it is difficult to establish a strong durable bond to composite resin material due to its low surface energy.\(^10^,^11\) Various surface modifications and primers have been introduced to enhance the bonding of PEEK materials.\(^12^–^15\) Adhesive systems containing methyl methacrylate (MMA) monomers is one such modification.\(^12^,^15^,^16\)

Contamination of a primed abutment surface in the oral cavity with blood and saliva may interfere with bonding.\(^17^,^18\) This possibility necessitates priming of the PEEK surface immediately before cementation. Moreover, a special type of light-curing unit with a wavelength of 375 to 400 nm is required for the curing of a PEEK primer, creating an additional financial burden.\(^19\)

The selection of a luting agent is also important for cement-retained restorations. Resin cements are routinely used in the cementation of indirect restorations due to their superior mechanical properties, ease of use, and esthetic qualities.\(^20\) Commercially available resin adhesive systems are usually adhesive resins and self-adhesive resins. Some of the adhesive resins are MMA based, and since MMA monomers can bond directly to PEEK, the use of these resins should void the necessity of using a PEEK primer. Another type of commonly used resin cement is self-adhesive resin cement, which eliminates the need for a separate adhesive application regardless of the surface.\(^21\) Due to the presence of acidic functional monomers, these cements do not require any pretreatment or conditioning.\(^22\)

The present study evaluated and compared the bond strength of an adhesive resin cement (with and without PEEK primer) for cementation of a zirconia crown to a PEEK implant abutment. The null hypotheses were that (1) the type of cement does not influence the pull-out forces of zirconia crowns bonded to PEEK abutments; and (2) the use of a PEEK primer does not influence the pull-out forces of zirconia crowns bonded to PEEK abutments.

**MATERIALS AND METHODS**

The present in vitro study compared the pull-out forces of zirconia crowns cemented onto PEEK implant abutments with two different resin cements and the effect of surface conditioning with PEEK primer.

**Fabrication of PEEK Abutment Replicas**

PEEK cylinders (BioHPP, Bredent) with brass metal cores of 2-cm length and 8-mm diameter were fabricated. A total of 100 specimens were then milled to a taper of 6 degrees with 5-mm height, 5-mm diameter at the top, and a 1-mm shoulder finish line at the base to simulate a custom PEEK implant abutment. The shaft portions of the specimens were then customized with retentive grooves.

**Fabrication of Zirconia Crowns**

PEEK abutments were optically scanned using an open technology scanner (Aoralscan-DS-Ex, Shining 3D Dental). Crowns with a standard cement gap, wall thickness, and occlusal geometry and with two lateral extensions (3 × 3 × 2 mm) (Fig 1) to facilitate attachment to the universal testing machine were designed with the help of a dental CAD software (DentalCAD, Exocad). A total of 100 zirconia specimens were then milled from CAD blocks (Ceramill Zolid FX, Amann Girrbach) using the CAD/CAM five-axis milling machine (Ceramill Motion 2, Amann Girrbach). The internal surfaces of all crowns were airborne particle–abraded with 50-µm aluminum oxide (Al\(_2\)O\(_3\)) (Cobra, Renfert) particles at a distance of 10 mm with an air pressure of 0.2 MPa and at an angulation of 45 to 90 degrees for 15 seconds.

**Mounting PEEK Abutment in Custom-Made Jig**

The PEEK abutments were attached to the surveying arm of a milling machine so that the long axis of the abutment was perpendicular to the platform. The PEEK implant abutment replicas were then embedded into a custom-made jig secured on the milling table (Fig 1) and filled with autopolymerizing acrylic resin (DPI RR Cold Cure, DPI).

**Cementation of Zirconia Crowns**

All of the PEEK abutments were airborne particle–abraded with 110-µm Al\(_2\)O\(_3\) particles at a distance of 10 to 15 mm with an air pressure of 0.2 MPa and an angulation of 90 degrees for 15 seconds. The abutments...
and crowns were ultrasonically cleaned in distilled water for 60 seconds and dried with oil-free air. Fifty PEEK abutments were coated with a thin layer of PEEK primer (Visio.link, Bredent) with the help of a composite applicator tip and polymerized in a light-polymerizing chamber (Bre.Lux Power Unit, Bredent) of wavelength 370 to 500 nm for 90 seconds. Surface priming was omitted for the remaining 50 specimens. The primed specimens were then divided into two groups (n = 25) based on the cement used for bonding the zirconia crowns: self-adhesive resin cement (G-CEM LinkAce, GC) or adhesive resin cement (RelyX Ultimate, 3M) with adhesive (Single Bond Universal, 3M). The unprimed specimens were also divided in a similar manner.

Thus, the four experimental groups were: Group AA-P (n = 25): Crowns cemented using adhesive cement and adhesive on primed PEEK abutment; Group AA-N (n = 25): Crowns cemented using adhesive cement and adhesive on nonprimed PEEK abutment; Group SA-P (n = 25): Crowns cemented using self-adhesive cement on primed PEEK abutment; Group SA-N (n = 25): Crowns cemented using self-adhesive cement on nonprimed PEEK abutment. For specimens in groups AA-P and AA-N, the adhesive was applied in a thin layer on both the PEEK and zirconia surfaces and gently air dried for 5 seconds. The cements were dispensed and loaded according to the manufacturer’s recommendations. Crowns were seated immediately, and finger pressure was maintained until the cement had set. Cements were tack cured for 1 second, and excess cement was removed with an explorer while maintaining finger pressure. Each surface was then light cured for 20 seconds. Self-adhesive resin cement was allowed to autopolymerize for 4 more minutes. Excess cement was removed using abrasive-impregnated rubber points at slow speed.

All cemented samples were stored at 37°C in distilled water for 24 hours according to ISO 11405. After complete polymerization, the specimens were thermocycled (THE-1100, SD Mechatronik) for 5,000 cycles at 5°C and 55°C with a 30-second dwell time in each bath according to ISO 10477.

Mounting Specimens in Universal Testing Machine

The maxillary and mandibular jig assemblies were tightly fixed with screws and then mounted on the universal testing machine (AG-X Plus, Shimadzu) for measuring the retentive force. The cylinder in the mandibular jig assembly was filled with acrylic resin, and the maxillary jig assembly with the mounted crown was lowered into the resin until the lateral extensions of the crowns were fully embedded (Fig 3).

Pull-out Test

The maxillary jig assembly was pulled with a crosshead speed of 0.5 mm/minute. The pull-out force required to debond the specimens was recorded in Newtons. For retentive strength calculation, the values were then converted into megapascals by dividing by the surface area of the cemented surface of the PEEK abutment (105.47 mm²). The surface area of the abutment was calculated as $A = \pi r^2 + \pi (r+R) \sqrt{(R-r)^2+h^2}$, where $r$ is the radius at the top, $h$ is the height, $R$ is the radius at base, and $\pi = 3.14$. The data were statistically analyzed using two-way ANOVA and post hoc analysis.

Failure Mode Analysis

After the crowns were debonded, the failure mode of cement was recorded as whether the cement remained on the crown, the abutment, or both. The debonded surface was examined under scanning electron microscopy (SEM; SU 6600 FESEM, Hitachi) at x100 magnification without any surface preparation, and the mode of failure was designated as (1) cement
remains on PEEK, (2) cement remains on zirconia, or (3) a mixed failure.

**Statistical Analysis**
Data were statistically analyzed using software (SPSS version 20, IBM). The pull-out test results were subjected to two-way analysis of variance (ANOVA) followed by Tukey post hoc tests ($\alpha = .05$). No statistical analysis was performed for mode of failure.

**RESULTS**
The mean pull-out and SD forces are listed in Table 1. Statistical analysis using two-way ANOVA showed a statistically significant difference ($P < .001$) in the mean retentive strength between the tested groups (Table 2). Post hoc analysis showed a significant difference between the groups ($P < .001$).

Higher mean retentive forces were recorded when resin cements were used with PEEK primer (Fig 4). Also, the mean retentive forces were higher for adhesive resin cement than for self-adhesive resin cement.

SEM analysis showed a mixed type of bond failure in group AA-P and group SA-P, whereas group AA-N and group SA-N showed more adhesive failure with cement retained on zirconia crowns (Figs 5 and 6, Table 3).

**DISCUSSION**
The results of the present study showed that the pull-out bond strength of PEEK abutment with zirconia crown was influenced by the type of luting cement used. Hence, the first null hypothesis was rejected. In general, adhesive cement compared to self-adhesive cement showed higher bond strength values both with and without primer. This finding is consistent with previous studies demonstrating adhesive systems that contain MMA monomers showed slightly higher strength values.$^{12,15,16}$

The higher bond strength values obtained for adhesive resin cement compared to self-adhesive resin cement may be due to the differences in viscosity and bonding mechanism. There are studies suggesting that the diffusive capacity of self-adhesive cements is less than adhesive cements. This may be due to the rapid increase

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**Table 1** Mean and SD (MPa) Pull-Out Force in Each Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (MPa)</th>
<th>SD (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA-P</td>
<td>3.13</td>
<td>0.31</td>
</tr>
<tr>
<td>AA-N</td>
<td>1.77</td>
<td>0.20</td>
</tr>
<tr>
<td>SA-P</td>
<td>2.10</td>
<td>0.12</td>
</tr>
<tr>
<td>SA-N</td>
<td>1.49</td>
<td>0.18</td>
</tr>
</tbody>
</table>

AA-P = adhesive resin cement and adhesive with PEEK primer; AA-N = adhesive resin cement and adhesive without PEEK primer; SA-P = self-adhesive resin cement with PEEK primer; SA-N = self-adhesive resin cement without PEEK primer.

**Table 2** Results of Two-way ANOVA for Studying Conditions

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III sum of squares</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>F</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected model</td>
<td>38.779</td>
<td>3</td>
<td>12.926</td>
<td>175.423</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Intercept</td>
<td>452.553</td>
<td>1</td>
<td>452.553</td>
<td>6141.535</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Type of resin cement vs use of primer</td>
<td>35.247</td>
<td>2</td>
<td>17.623</td>
<td>239.165</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Error</td>
<td>7.074</td>
<td>96</td>
<td>.074</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>498.407</td>
<td>102</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Mean difference significant.
in the viscosity following the acid base reaction during setting.\textsuperscript{22,23}

As the application of PEEK primer enhanced the bond strength, the second null hypothesis was also rejected. PEEK primer, such as Visio.link, contains pentaerythritol triacrylate (PETIA) solution, MMA monomers, and additional dimethacrylate. The MMA monomers can cause swelling in the PEEK surface dissolved by PETIA, and the two methyl groups in the dimethacrylate monomers facilitate the bonding between the resin and PEEK.\textsuperscript{16}

Similarly, both the self-adhesive resin cement and the adhesive in the adhesive resin cement system contain 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), which is capable of producing good bond strength to a zirconia surface. The bond strength is attributed to the chemical interaction between the phosphate ester of 10-MDP and the hydroxyl group of the passive zirconia surface.\textsuperscript{24,25}

The observations of the present study were supported by the failure mode analysis using SEM. All groups luted with adhesive resin cement exhibited predominantly mixed failures, whereas those cemented with self-adhesive resin cement showed more failures with the cement retained on the zirconia crown. The presence of more adhesive failures when cemented without a PEEK primer may be due to reduced bond strength at the cement-PEEK interface.

The bond strength values obtained in this study were similar to or greater than the values obtained in a previous study comparing the retention strength of zinc phosphate cement, glass-ionomer cement, and resin-modified glass-ionomer cement.\textsuperscript{26} The values were also comparable to the retention strength values obtained in similar studies conducted to evaluate the retention strength of zirconia crowns on natural teeth using resin-modified glass-ionomer cement, self-adhesive resin cement, and adhesive resin cement.\textsuperscript{27,28}

Thus, according to the present study, in clinical situations, it is highly recommended to use PEEK primer when luting zirconia crowns to PEEK abutments. In the absence
of PEEK primer, adhesive resin cement with adhesive is a better alternative to self-adhesive resin cement. However, this study does have a few limitations. As the pull-out test conducted in this in vitro study was a pure tensile test, it does not take into consideration the other forces acting on the crown intraorally. Also, the specimens underwent only thermal aging, and mechanical loading was not done to simulate chewing. Hence, further clinical studies are needed to establish the present results.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn: (1) The pull-out bond strength values obtained were higher when PEEK primer was

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**Table 3** Failure Mode According to Scanning Electron Microscopy

<table>
<thead>
<tr>
<th>Group</th>
<th>Cement completely separated from PEEK</th>
<th>Cement completely separated from zirconia</th>
<th>Cement remained on PEEK and zirconia</th>
<th>Bond failure within cement layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group AA-P</td>
<td>0</td>
<td>2</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>Group AA-N</td>
<td>15</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Group SA-P</td>
<td>2</td>
<td>8</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Group SA-N</td>
<td>20</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

All data are reported as number of specimens. AA-P = adhesive resin cement and adhesive with PEEK primer; AA-N = adhesive resin cement and adhesive without PEEK primer; SA-P = self-adhesive resin cement with PEEK primer; SA-N = self-adhesive resin cement without PEEK primer.
used compared to nonprimed PEEK surfaces; (2) adhesive resin cement was a better choice than self-adhesive resin cement regardless of the use of PEEK primer; and (3) in the absence of PEEK primer, adhesive resin cement can be considered a better choice than self-adhesive resin cement for the cementation of a zirconia crown to a PEEK abutment.

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