An In-Vitro Study of Retentive Force for Prefabricated Posterior Zirconia Crowns Using Five Different Cements

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Abstract

Purpose: To assess retentive strengths of 5 commercially available cements with prefabricated zirconia crowns, and identify their cementation failure pattern.

Methods: EZ Pedo prefabricated primary molar zirconia crowns were cemented on extracted human teeth using Ketac Cem Maxicap, FujiCEM 2, BioCem, RelyX Unicem 2 and RelyX Luting Plus Automix (N = 15). Following thermocycling 5000 cycles from 5°C to 55°C, crown retentive strengths were determined and statistically analyzed using one-way ANOVA with LSD post hoc test (P < 0.05).

Results: Mean retentive strengths (Newtons): Ketac Cem 482.4 ± 87, FujiCEM 2 354.9 ± 121, BioCem 462.7 ± 138, RelyX Unicem 2 409.0 ± 171 and RelyX Luting 233.5 ± 170. Values among the 5 groups were statistically different (P = 0.014), but not the cement failure ranking differences (P = 0.47).

Conclusions: There is a significant difference in the retentive strengths among the 5 cements used to cement prefabricated primary zirconia crowns (ANOVA P = 0.014). Ketac Cem has the highest retention force, then BioCem, RelyX Unicem, Fuji CEM II, and RelyX Luting. The majority of cement failures (70.6%, N = 53) occurred between the cement and the tooth.

Keywords: Prefabricated; Zirconia Crowns; Retention; Cement

Introduction

Zirconia crowns have recently found favor as adequate restorations for permanent teeth [1], and in the past decade factors of esthetics, cost, toxicity and durability of tooth-colored restorative materials, including zirconia, have increasingly influenced treatment planning in pediatric patients [2,3]. Yttrium-oxide stabilized zirconia (Y-TZP) is chemically and dimensionally stable, has high mechanical strength and fracture-toughness, making it an attractive material for restorative dentistry [4–6]. When placing zirconia crowns for primary teeth, the tooth must be reduced to fit the crown only passively, causing less retention than custom made crowns. Furthermore, due to the non-adhesive characteristics of the material, cementation of zirconia crowns can be challenging [3].

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Zirconia crowns are made of a crystalline dioxide of zirconium with mechanical properties that are comparable to those of metals, but with greater esthetic quality [7]. Because zirconia crowns for primary teeth are non-adjustable, their manufacturers recommend a passive seating when cementing them [8]. Zirconia crowns that are custom-made can be cemented using conventional adhesive methods, with resin-based luting agents reportedly providing high retention and improved marginal adaptation [9]. Currently, some prefabricated zirconia crown manufacturers recommend either glass ionomer or resin modified glass ionomer cements, however no literature publications were found to support the use of any particular cement.

Retentive strength data are very important to predict the long-term clinical performance of zirconia crowns for primary teeth [10]. The objective of this study is to investigate the retentive strength of prefabricated zirconia crowns for primary teeth (EZ Pedo, Loomis, CA) with different types of cements (Ketac Cem Maxicap, FujiCEM 2, RelyX luting plus automix, RelyX Unicem 2 and BioCem) and identify their cementation failure pattern.

Methods

Seventy-five extracted human posterior permanent teeth were used, with 1-mm deep circumferential grooves placed around the roots for retention. Teeth were mounted in Ultradent plastic specimen molds (Ultradent products, Inc. South Jordan, UT) using office paper binder clips to hold them centered on each hole and maintaining the long axis of each tooth perpendicular to the base of the mold. The holes in the Ultradent molds were filled with self-cure EpoxyCure 2 epoxy resin (Buehler, Lake Bluff, IL). Each tooth was embedded with the cemento-enamel junction (CEJ) at least 1 mm above the level of the epoxy. Specimens were maintained in 100% humidity during the entire length of the study.

Teeth were prepared to fit zirconia crowns in accordance with the manufacturer’s recommended tooth reduction for the crowns (EZ Pedo, Loomis, CA). Seventy-five zirconia crowns (EZ Pedo size 4 for first primary molars) were used. To have a standard prep, a negative impression of the internal surface of the crown was made and the dimensions were taken directly from the impression. The measurements were ≤ 6 mm mesio-distally, ≤ 7 mm bucco-lingually, ≥ 2 mm axial height on the mesial and distal side and ≥ 4 mm axial height on the buccal and lingual surface. Final tooth dimensions after reduction had to suit these criteria so that the zirconia crown would fit onto the prepared tooth passively.

The occlusal surfaces of the preparations were cut flat with the EZ-Prep 001 donut-shaped bur. Axial reduction was with the bur perpendicular to the occlusal table. The hand piece was secured in an apparatus to orient the bur parallel to the long axis of the tooth. An EZ-Prep 002 bur was used to create a chamfer margin equal to the full thickness of the bur tip. (This bur has a taper of 8 degrees giving a total convergence of 16 degrees). With the EZ-Prep 004 flame bur, the chamfer margin was then removed. Final axial tooth preparations ended with margins feathered as the manufacturer recommended (See Figure 1).

Figure 1: Tooth mounted in epoxy block, handpiece held by surveyor type positioning guide.
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After all 75 teeth were prepared, they were rinsed with water, dried with gauze to avoid excessive drying, then randomly divided into 5 groups (N = 15) for cementation. All cements were mixed and applied according to manufacturer’s instructions and seated with finger pressure by the same investigator. Group 1 was cemented with Ketac Cem Maxi Cap (glass ionomer cement by 3M ESPE St. Paul, MN). This cement comes in a capsule that requires being held in an activator for 4 seconds, then placed in an amalgamator for 10 seconds. The manufacturer recommends removing excess cement after 7 minutes from the beginning of the mix. Group 2 was cemented with FujiCem 2 (Resin Modified Glass Ionomer cement by GC America Inc. Alsip, IL). This cement and the following 3 cements come in an automix syringe. Working time for FujiCem 2 is 2 minutes 15 seconds, and finishing can be done 4 minutes 30 seconds after seating. Group 3 was cemented with BioCem (Resin Modified Glass Ionomer with added calcium and phosphates, by NuSmile, Ltd. Houston, TX). A flash light-cure for 5 seconds is required on facial and lingual surfaces before removing excess cement, then light-curing an additional 10 seconds on the facial and lingual after removing excess cement. Group 4 was cemented with RelyX Unicem 2 (Self-adhesive Resin Cement, 3M ESPE St. Paul, MN) for which the manufacturer recommended a flash light-cure of 2 sec, then removing the excess cement, followed by light-curing for an additional 20 sec on facial, lingual and occlusal aspects. Finally, group 5 was cemented with RelyX Luting plus Automix (Resin Modified Glass Ionomer by 3M ESPE St. Paul, MN). Tack light-curing for 5 seconds on buccal, lingual and occlusal surfaces was recommended by the manufacturer. After removing excess cement it had to set for 5 minutes per manufacturer recommendations.

Twenty-four hours following cementation, all specimens underwent 5,000 thermal cycles between water temperatures of 5o C and 55o C, in accordance with International Organization of Standardization (ISO) specifications [11,12]. Beading wax was placed as a seal around the margin (crown-tooth interface) and on the top part of the epoxy block. The crown part of each specimen was then embedded in self-cure epoxy resin blocks that adapted to the receiving fixture of the Instron E3000 (Instron®, Northwood, MA) (See Figure 2).

Each specimen was placed in the Instron E3000 for crown pull-off testing at a speed of 0.5 mm/min, and maximum forces (Newtons) of removal were recorded (See Figure 3).

Specimens were then analyzed for cement failure ranked as follows: 1- cement failure with > 75% of cement left on the tooth, 2- cement failure with 51-75% cement left on the tooth, 3- failure with 50% of cement left on the crown and 50% left on the tooth, 4- failure with 51-75% of the cement left on the crown, and 5- failure with >75% of cement left on the crown (See Figure 3).

In some cases there were substrate failures in which either the root fractured or the grip of the epoxy holding the root or zirconia crown failed. For tooth fracture cases a completely new specimen was made and the test repeated. For specimen grip failures, the crown or the root, whichever was involved, was remounted in the epoxy resin and the Instron tests repeated. When these second tests were done, the higher retention value of the two tests was used. If there was a dislodgement of the specimen from the epoxy in the second test, then the higher force from the 2 tests was used, assuming that the cement strength was the greater of those 2 forces.

**Statistical analysis**

Data were tabulated in Excel with means, medians, and standard deviations displayed in graphs and charts. One-way ANOVA with LSD post hoc tests (P < 0.05) were performed using IBM SPSS 22.0 (Chicago, IL).

**Results**

Descriptive statistics for the retentive strength for the different cement groups are summarized in table 1. One-way ANOVA showed a significant difference in retention load within the 5 groups (P = 0.014). The null hypothesis was rejected, and there was a significant difference in the retention strength among the 5 cements evaluated. LSD Post Hoc test showed there was a significant difference in the
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retention between Ketac Cem and FujiCem 2, Ketac Cem and RelyX Luting, FujiCem and BioCem, BioCem and RelyX Luting. RelyX Unicem had no significant difference with any of the other cements (Table 2).

<table>
<thead>
<tr>
<th>Cement Groups (I)</th>
<th>Cement Groups (J)</th>
<th>Mean Differences (I-J)</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketac Cem Maxicap</td>
<td>FujiCem 2</td>
<td>127.46</td>
<td>.016*</td>
</tr>
<tr>
<td>BioCem</td>
<td></td>
<td>19.71</td>
<td>.703</td>
</tr>
<tr>
<td>RelyX Unicem</td>
<td></td>
<td>73.38</td>
<td>.159</td>
</tr>
<tr>
<td>RelyX Luting</td>
<td></td>
<td>154.68</td>
<td>.004*</td>
</tr>
<tr>
<td>Fuji CEM 2</td>
<td>Ketac Cem Maxicap</td>
<td>-127.46</td>
<td>.016*</td>
</tr>
<tr>
<td>BioCem</td>
<td></td>
<td>-107.74</td>
<td>.040*</td>
</tr>
<tr>
<td>RelyX Unicem</td>
<td></td>
<td>-54.07</td>
<td>.298</td>
</tr>
<tr>
<td>RelyX Luting</td>
<td></td>
<td>27.22</td>
<td>.599</td>
</tr>
<tr>
<td>BioCem</td>
<td>Ketac Cem Maxicap</td>
<td>-19.71</td>
<td>.703</td>
</tr>
<tr>
<td>Fuji CEM 2</td>
<td></td>
<td>107.74</td>
<td>.040*</td>
</tr>
<tr>
<td>RelyX Unicem</td>
<td></td>
<td>53.07</td>
<td>.301</td>
</tr>
<tr>
<td>RelyX Luting</td>
<td></td>
<td>134.96</td>
<td>.011*</td>
</tr>
<tr>
<td>RelyX Unicem 2</td>
<td>Ketac Cem Maxicap</td>
<td>-73.38</td>
<td>.159</td>
</tr>
<tr>
<td>Fuji CEM 2</td>
<td></td>
<td>54.07</td>
<td>.298</td>
</tr>
<tr>
<td>BioCem</td>
<td></td>
<td>-53.67</td>
<td>.301</td>
</tr>
<tr>
<td>RelyX Luting</td>
<td></td>
<td>81.29</td>
<td>.119</td>
</tr>
<tr>
<td>RelyX Luting Plus</td>
<td>Ketac Cem Maxicap</td>
<td>-154.68</td>
<td>.004*</td>
</tr>
<tr>
<td>Automix</td>
<td>Fuji CEM 2</td>
<td>-27.22</td>
<td>.599</td>
</tr>
<tr>
<td>BioCem</td>
<td></td>
<td>-134.96</td>
<td>.011</td>
</tr>
<tr>
<td>RelyX Unicem</td>
<td></td>
<td>-81.29</td>
<td>.119</td>
</tr>
</tbody>
</table>

Table 2: LSD Post hoc test summary between the groups.

*P-value less than 0.05.

Cement failure rankings were recorded in table 3. Most of the failures are in categories 4 and 5. FujiCEM 2 had 100% of the specimens in category 5, BioCem had 78% in category 5, Ketac Cem Maxicap had 75% in category 4, RelyX Luting plus automix had 66% in category 4 and RelyX Unicem presented 58% in category 4. However, the Kruskal-Wallis test determined that there was no significant difference in cement ranking failure among the 5 cements ($P = 0.47$).

<table>
<thead>
<tr>
<th>Cement failure ranking</th>
<th>Ketac Cem Maxicap</th>
<th>FujiCEM 2</th>
<th>BioCem</th>
<th>RelyX Unicem 2</th>
<th>RelyX Luting Plus Automix</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. &gt; 75% cement left in the tooth</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. 51 - 75% cement left in the tooth</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. 50% in tooth 50% in crown</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4. 51 - 75% cement left in the crown</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>5. &gt; 75% cement left in the crown</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>5</td>
<td>4</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>11</td>
<td>14</td>
<td>12</td>
<td>12</td>
<td>57</td>
</tr>
<tr>
<td>Tooth fractured</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Dislodge from the epoxy block</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 3: Frequency table of cement failure Ranking.

Discussion

Results of this study indicate a significant difference in the retentive strengths among the 5 cements tested. Rippe, et al. [13] evaluated the tensile retention of custom made crowns made of YTZP with different types of cements. They used self-cured resin cement, dual-cure Bis-GMA-based resin cement, resin modified glass ionomer cement, self-adhesive cement, and zinc phosphate. They found that resin cements (Multilink and RelyX ARC) demonstrated significantly higher retention values relative to those obtained for the self-adhesive resin cement, glass ionomer, and zinc phosphate cements; with mean tensile strengths of 200.9 N for Multilink and 223.44 N for RelyX ARC respectively [13]. The results in the present study were higher for all the cements used, with the mean tensile strength ranging between 327.22 N and 482.45 N.

Palacios, et al. evaluated resin cement with adhesive agent, resin modified glass ionomer, and self-adhesive resin cement. They measured removal strength of custom-made zirconium oxide ceramic copings designed with CAD/CAM technology for permanent teeth, and found the 3 cements had no statistical difference, with 647.78 N for RelyX Unicem, 652.68 N for Panavia and 782.04 N for RelyX Luting [14]. The values on that study were higher than those in the present study. However, it is important to remember that the crowns used in the present study are prefabricated crowns retrofitted to primary teeth.

Another study by Ernst, et al. evaluated the retentive strength of zirconium oxide ceramic crowns on extracted teeth. They studied 8 different cements including resin cements, compomer, resin modified glass ionomer cement, glass ionomer cement, and a self-adhesive resin luting cement. When the materials were evaluated without pretreatment of the ceramic, RelyX Unicem (4.9 MPa), Superbond (4.8 MPa), RelyX Luting (4.7MPa), Panavia (4.0 MPa) and Dyract Cem (3.3 MPa) showed the highest median retentive strength values and were not significantly different from each other. The values in the present study were converted into megapascals (MPa) using a surface area of $0.000118 \, m^2$ for comparison with other studies. Ketac Cem had a relatively low retentive strength of 1.9 MPa [15].

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However, in the present study Ketac Cem had the highest retentive strength with a mean of 4.6 MPa, which was in the same range as the resin cements in the study conducted by Ernst., et al. In the present study, RelyX Unicem with 3.4 MPa and RelyX Luting with 2.7 MPa had retention strengths lower than the compared study. The main difference between the 2 studies is the thickness of the cement since the present study used prefabricated crowns.

In 2010, Heintze conducted a systematic review evaluating laboratory studies of the adhesive properties of luting agents in crown retention tests [16]. He chose 18 studies that reflected clinical situations. These studies involved human teeth in which the occlusal surfaces were trimmed flat, a dental surveyor was used for mounting the teeth and a pre-set taper used to standardize the preparations [17-19]. In general, these studies reported that the resin luting agents had higher stress failure limits than glass ionomer cements. However, in some cases there was no statistically significant difference [16]. This differs from the present study because there was a statistically significant difference among the cements studied, with glass ionomer (Ketac Cem) having the highest tensile strength, followed by the RMGI with calcium phosphate (BioCem). There was no statistically significant difference between Ketac Cem and BioCem.

Zirconia crowns for primary teeth cannot be adjusted, and require only a passive seating for their cementation, which can compromise their retention [9]. The cement thickness when cementing these prefabricated crowns is not uniform and may be greater than the thickness of a custom made crown. Thus, the excess space needs to be compensated by the cement. Mehl., et al. [20] evaluated the influence of glass ionomer, polycarboxylate or resin cement film thicknesses on the crown retention after tensile testing. Their results showed a significant difference in retention between cement thickness of 14.4 ± 3 μm and cement thickness of 50 μm [20]. Other studies associated a decreased test load failure with increased resin cement thickness [21,22]. These data suggest that the cement film thickness could have affected the retentive strength of the crowns in the present study.

Several manufacturers currently fabricate zirconia crowns for pediatric dentistry: EZ Pedo, Cheng, Kinder Krown and NuSmile. Their retentive strengths may be affected by the various internal surface designs of each manufacturer. For this study EZ Pedo crowns were chosen. EZ Pedo crowns have a feature called Zir-Lock Ultra, which are mechanical undercuts designed to double the internal surface area and provide mechanical undercuts to help lock the crowns in place. In addition to the grooves, the company explains that aluminum oxide blasted on inner surfaces creates surface roughness to further enhance adhesive properties. EZ Pedo zirconia crowns also have a margin lock feature to prevent cement washout [23], and may help cement to remain bonded to the crown.

In the present study, cement failures were evaluated to assess their nature. The majority of crown dislodgements occurred as an adhesive failure with 23.3% having > 75% of cement left on the crown. There were no cases with >50% of cement left on the tooth. The “Zir-Lock Ultra” feature in the EZ-Pedo prefabricated crowns was possibly a factor improving the cement retention.

Further studies are recommended to evaluate relative retention strengths among the several different brands of prefabricated zirconia crowns.

Surface treatment and exposure to wetness can affect the physical properties of zirconia [24]. A recent systematic review found that loss of retention caused 19% of the clinical failures of custom made zirconia crowns [25]. Since it followed the cement manufacturer’s recommendations, the present study did not perform any surface treatment to the tooth or to the crown. A study by Rippe., et al. [13] tested 3 different types of surface treatments: cleaning with isopropyl alcohol, tribochemical silica coating, or application of a layer of glass porcelain plus silanization.13 However, the tensile strength values of the cements in that study were lower than the values in the present study, which did not employ any crown surface treatment.

An earlier study by Palacios., et al. [14] evaluating the retention of zirconium oxide ceramic crowns, treated the internal surface of the copings with aluminum oxide abrasion followed by ultrasonic bath cleaning with isopropyl alcohol. Their results indicated greater retention dislodgement forces than the present study, which is likely attributable to the surface treatment. A study by Ernst., et al. [15] found that the pretreatment with Rocatec tribochemical coating did not significantly improve the retentive strength of the cements studied.

To avoid any significant changes in the zirconia crowns’ properties, the present study was challenged to find a way to retain the crown portion of the specimen for a pull-off test. Retention of the crown to the epoxy was mainly due to the undercut area near the gingival margin of the crown. There were specimens in which the crown dislodged from the epoxy before dislodging from the tooth. When this occurred and the retentive strength was higher than those of the other specimens in the same group, that value was recorded as the retention load for that specimen. In cases where the load before crown dislodgment from the epoxy was low, the crown was mounted again in an epoxy block and the higher value was recorded. The cement that had the greatest crown dislodgement from epoxy was Ketac Cem, which was also the cement with the greatest mean retention load. It can be reasonably assumed that crown dislodgment from the epoxy was because the retentive strength of the cement to the crown was in excess of the retentive strength of epoxy to the crown.

The present in vitro study tried to simulate mouth conditions by using human teeth, maintaining all specimens at 100% humidity and using thermocycling for aging. With the design of the prefabricated crowns it was expected that some cement washout would inherently occur. However, in this study, cement remained bonded to the crown even after artificial aging.

Palacios, et al. [14] had added retention bars to the zirconia crowns to help with the mounting of the crown to the epoxy block. But since the pediatric zirconia crowns available in the market are prefabricated, adding the bars was not considered a feasible option for the present study. Embedding the crown in epoxy resin in this study was considered an effective method that might be used for follow-on prefabricated zirconia crown studies.

It is recognized that the present in vitro study was free of oral conditions like gum bleeding and saliva contamination at the time of cementation. These factors potentially affect retention strengths of the zirconia crowns clinically. Future investigations might test with known contamination agents, or assess the relative retentiveness with the same cement but different commercially available crowns.

Instead of using the first molar zirconia crown as done in this study, the authors would recommend choosing the second molar crown because of its more pronounced exterior buccal undercut contour that can allow better retention of the crown to the epoxy block. Long-term clinical studies are also recommended.

Conclusions

1. There is a significant difference in the retentive strengths among the 5 cements used to cement prefabricated primary zirconia crowns (ANOVA P = 0.014). Ketac Cem has the highest retention force, followed by BioCem, RelyX Unicem, Fuji CEM II, and RelyX Luting.
2. Among the cement types studied, glass ionomer (Ketac Cem Maxicap) has the greatest retentive strength followed by RMGI (BioCem) and resin cement (RelyX Unicem 2).
3. Dual-cure RMGI (RelyX Luting Plus Automix) showed the lowest retentive strength of the cements studied, next to reinforced RMGI (FujiCEM 2).
4. The type of cement did not affect the cement-failure ranking in these prefabricated zirconia crowns. In the majority of specimens (70.6%) cement material remained 100% to 75% on the crown.

Acknowledgments

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Bibliography


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