Retention Force of Glass Ionomer Based Luting Cements with Posterior Primary Zirconium Crowns – A Comparative *in Vitro* Study

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Objective: *To determine the retentive force of three glass-ionomer luting cements used with prefabricated primary zirconium crowns (PPZCs) and to assess whether the retentive force was dependent on cementation material or different PPZCs brands.* ***Study design****: Four mandibular right second molar PPZCs were selected, one each from four manufacturers–NuSmile®ZR, Sprig Crowns, Cheng Crowns and Kinder Krowns. Silicone impressions of the outer surface of crowns were taken; stone dies prepared and reduced to fit the corresponding brand. 24 alginate impressions of each die obtained and filled with core buildup flowable composite. 96 composite tooth-replicas thus achieved were divided into four groups and further categorized into three subgroups of eight samples based on luting cements used – BioCem, FujiCEM®2 and KetacCem. Samples were thermocycled, placed in artificial saliva for one week followed by assessment of retentive force for crown dislodgment and failure mode.* ***Results:*** *Data was statistically evaluated using two-way ANOVA, HSD (P <0.05). KetacCem had the lowest retentive force while BioCem showed comparatively higher value to FujiCEM®2. Adhesive failure modes were predominant with cement mainly adhering to crown's internal surface.* ***Conclusions:*** *Resin-based GI cements offered superior retention than conventional GI cements for PPZCs and retentive force was dependent on cement type.*

Keywords*: Primary zirconia crowns, luting cement, retentive force*

INTRODUCTION

Owing to increased esthetic demands, the popularity of prefabricated primary zirconium crowns (PPZCs) has significantly increased in the last decade.[1, 2] These full-coverage crowns have proven clinical acceptability and provides excellent esthetics, which is crucial for the satisfaction of both children and their parents. They also exhibit high strength, biocompatibility, minimal gingival irritation and insignificant wear of opposing tooth.[3, 4] Apart from non-adhesive nature of the zirconia material, the limitations associated with PPZCs includes non-crimping of crown margins[5], micro-leakage due to open cervical margins [6] and gingival hemorrhage as the preparation of abutment tooth is sub-gingival. In comparison to tooth preparation for stainless steel crowns (SSCs), PPZCs require greater tooth reduction [7] leading to increased cement thickness between the crown and prepared tooth. Consequently, these restrictions can challenge the cementation of primary zirconium crowns. The retention and bond strength of the luting material hence becomes an important aspect in their clinical performance.

The desired characteristics of luting cement for pediatric full coverage crowns includes proper adhesion to tooth/restoration, stability over time, low solubility, biocompatibility, appropriate marginal seal with high tensile, compressive and retentive strength.[8,9]

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Resin cements, resin modified glass ionomer cement (RMGIC), conventional glass ionomer cement (GIC) and relatively new bioactive cements are luting materials available to cement PPZC's.[9,10] These cements have contrasting properties like resin cements being moisture intolerant, while RMGIC's are comparatively less moisture sensitive. [11,12] Bioactive cements have the property to form hydroxyapatite (HA) on their surface by the release of Ca^{2+}, $PO4^{2-}$ and hydroxyl groups. The principle behind the bioactive property has been connected to its negatively charged surface and release of ions required for HA formation.[13] Manufacturers of PPZC's have recommended using glass ionomer based luting materials for cementation but with limited scientific support.

The inner surface of zirconium crowns can also have a significant effect in their retention.[10, 14] Commercially, four different brands of PPZCs are available namely: NuSmile® ZR Crowns, Sprig EZ Crowns, formerly known as EZ-Pedo crowns, Cheng Crowns and Kinder Krowns. These companies have described different techniques of increasing PPZC's adhesion and stability in their product specifications. The NuSmile® ZR kit contains try in crowns for trial fitting and preparation refinement that ensures cementation success.[15] Sprig EZ crowns have a specially designed Zir-Lock® system that helps to increase their retention[16] while Cheng Crowns feature simulated knife-edge crimped margins to allow for better retention.[17] The Kinder Krowns have internal retention threads that offer mechanical retention of restoration. [18] Finally, the performance of the primary zirconium crowns also depends on the remaining occluso-cervical height (OCH) of the preparation. A decrease in clinical crown height and increase in occlusal convergence angles would result in significant loss of retention of the extra-coronal restoration.[19]

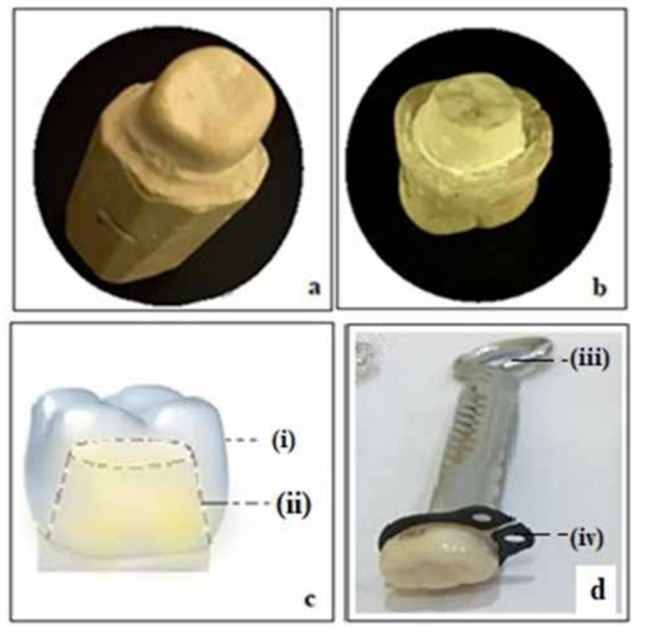
Majority of the studies on zirconium crowns have been reported for permanent dentition in adult patients. Literature addressed to PPZC's performance is limited to mainly clinical studies and has not compared commercially available PPZCs. The bond strength of commonly used luting materials with different PPZC brands is currently unknown. This data is essential to determine the long-term success of these crowns. The objectives of the present in-vitro study are to evaluate the retentive force of glass ionomer based luting cements on standardized abutment preparations for posterior PPZC's and to determine whether the type of cement or different variations of crown's internal surface has any effect on their retention.

MATERIALS AND METHOD

No ethical approval was required from the institutional research ethics committee as the study neither involved human subjects/animals nor teeth. A total of 96 primary mandibular right second molar prefabricated zirconium crowns, size three were chosen as a test from the four brands; 24 NuSmile® ZR Crowns (Houston, Texas, USA), 24 Sprig EZ Crowns, (Loomis, Calif., USA), 24 Cheng Crowns (Exton, PA., USA) and 24 Kinder Krowns (St. Louis Park, Minn., USA).

A light body silicone (Zhermack SpA, Badia Polesine, Italy) impression of the outer surface of four selected PPZCs, one each from four commercial brands was taken. This created negative replicas of the crowns which were then poured with type III dental stone (Dentify GmbH, Engen, Germany) (Figure 1 a). The resulting four abutment dies were prepared and reduced according to manufacturer instructions with a remaining OCH of 4 mm and a total convergence angle of 16 degrees. To standardize all the samples, the OCH was measured with vernier calipers while the axial reduction was carried out using a bur of tip diameter of 0.85 mm with 8-degree taper by the same investigator. All sharp line angles were rounded to ensure a passive fit for the corresponding zirconium crowns (Figure 1 b). The abutment portion inside the PPZCs closely approximated the inner shape of selected crowns. There was enough reduction of gypsum abutment for a standard thickness of cement at the crown margins.

Figure 1- Steps involved in composite tooth replica for cementation of zirconium crowns. (a) Gypsum die (b) Preparation of gypsum die following the guidelines of crown preparation. (c) Tooth replica made from composite core-build up material with passive fit of zirconia crowns (i) PPZC (ii) composite tooth replica. (d) Sample after cementation (iii) zinc screw (iv) steel washer.



Twenty-four alginate (Cavex Holland BV, Haarlem, Holland) impressions were taken for each corresponding abutment die and were poured with dual-cure core buildup flowable composite (Spident, Incheon, Republic of Korea) material. This material was used instead of natural tooth due its similarity to tooth structure in hardness and fracture toughness. A total of 96 composite tooth replicas were prepared to fit each crown type and the replicas were narrower than the crest of PPZCs (Figure 1c). Zinc screw eye was placed into the bottom end of the composite replica and cured to attach it inside (Figure 1d).

Each brand of PPZC group (consisting of 24 samples) was further divided into 3 subgroups consisting of eight crowns. The crowns were then cemented on ideally prepared composite tooth model with three different glass ionomer luting cements- FujiCEM® 2(GC America, Alsip, IL, USA), Ketac™ Cem Maxicap (3M ESPE, St.Paul, MN, USA) and BioCem (NuSmile, Houston, TX, USA). The storage, mixing and cementation method for each luting material was followed according to the manufacturer's guidelines. The crowns were filled with 1ml of test cement and cemented onto the corresponding composite tooth replica with finger pressure. Excess cement was removed by a probe around the crown margin. Cementation of the crowns occurred one week before testing. The crowns were cemented over a steel washer with a tight fit around crestal contours of PPZCs which provided the circumferential leverage to pull-off for the crowns (Figure 1 d).

All samples underwent thermocycling at temperatures of 5° C and 55° C for 5000 cycles after cementation. The exposure time in each bath was 30 seconds with a transfer time of 5-10 seconds. This process of thermocycling corresponded to samples being placed five-years intraorally and each cycle represented one meal. [20] The samples were then stored in artificial saliva (Pickering Laboratories, Mountain View, CA, USA) at 37° C in thermo-incubator for one week. To mimic the true oral conditions, artificial saliva used had a composition similar to commercially available products indicated to treat dry mouth and other conditions. This formulation was stored at room temperature with a pH of 6.8.

The retentive force required to dislodge the zirconium crown from the composite tooth replica was tested with the universal testing machine, M350-5CT (Testomatric, Rochdale, UK). The Win-Test analysis 4.4.2 software was used to analyze the amount of force required to dislodge the crown from the cement. The upper grip consisted of an S-shaped metal hook (stainless steel, 8 mm diameter) that attached to the screw eye in composite tooth model. The lower grip comprised of four screws screwed to a metal base that was tightened around the center of the test samples. The standard distance between the grips during testing was 20.7 cm (Figure 2). The standardized speed used to pull the crown was 5 mm/sec. A tensile force was applied to dislodge each crown and was recorded in Newton's (**N**) (Figure 3). The specimens were also evaluated for failure modes using a stereomicroscope EZ4 HD (Leica, Leitz-Park, Wetzlar, Germany).

Figure 2. Schematic representation of universal testing machine and experimental set-up to measure the retentive force (a) Screw hooks for attaching the tooth replica to the universal testing machine. (b) Composite tooth replica. (c) PPZC. (d) Lower grip screws for holding the zirconia crown. (e) Sample held for testing the retentive force for PPZCs.

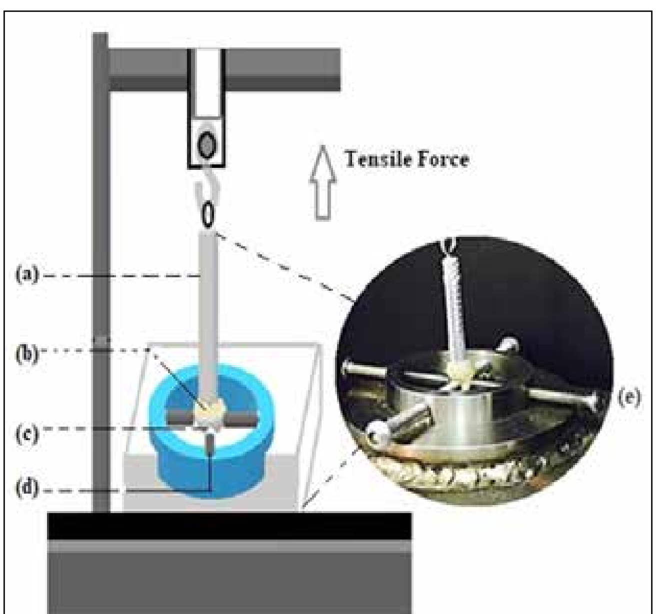


Figure 3. PPZCs dislodgment after applying tensile force parallel to the long axis of composite tooth replica.

IBM Statistical Package for Social Sciences (SPSS) Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp. was used for statistical analysis. A two-way analysis of variance was done (ANOVA) to investigate the possible association between crown type and cement used in the retentive force for crown dislodgment. A Tukey honestly significant difference (HSD) test was performed under the significant result of ANOVA ($P<0.05$).

RESULTS

The summary of dislodging forces for three types of GI luting cements corresponding to different manufacturers of PPZC's has been mentioned in Table 1. The mean retention force was higher for BioCem M = 117, 95% CI [115,119] and FujiCEM® 2 M = 115, 95% CI [113,117] compared to Ketac Cem M = 31, 95% CI [29, 33]. A two-way ANOVA yielded a main effect for the type of cement used, $F(2, 84) = 161.76$, $p = 0.002$. However, the main effect of zirconium crown type used was non-significant, $F(3, 84) = 1.35$, $p = 0.002$. Furthermore, the interaction effect was also non-significant, $F(6, 84) = 1.57$, $p = 0.002$, which suggested that neither the cement type nor crown brand interaction had any significant effect on the retentive force.

The Tukey HSD test was carried out under the significant result of ANOVA (Table 2). Multiple comparison results presented statistical differences between BioCem/ Ketac Cem, and FujiCEM® 2/Ketac Cem but not between groups of BioCem/FujiCEM® 2. However, the mean retentive force was higher for BioCem compared to FujiCEM® 2, but not statistically significant.

TABLE 1. Means and standard deviations (SD) of forces in Newton's required to dislodge PPZCs using three types of GICs

	Type of Crowns			
Type of GICs (Mean± SD)	**Cheng Crowns n=24 N (SD)**	**Sprig EZ n=24 N (SD)**	**NuSmile® ZR n=24 N (SD)**	**Kinder Krowns n=24 N (SD)**
*BioCem (117 ± 09)	110 (15)	130 (23)	112 (17)	117 (22)
*FujiCEM® 2 (115 ± 10)	129 (25)	111 (17)	106 (14)	114 (21)
Ketac Cem Maxicap (31 ± 10)	31 (10)	27 (12)	44 (10)	20 (09)

*BioCem and FujiCEM® 2 has a higher retentive force value compared to Ketac Cem Maxicap.

TABLE 2. Multiple comparisons of the means of retentive force for three GICs by post-hoc Tukey test. P-value was significant at $p < 0.05$

Comparisons	Absolute Difference	Critical Range	Results
BioCem and Ketac Cem Maxicap	*86.35	14.836	Significantly different
BioCem and FujiCEM® 2	1.92	14.836	Not significantly different
FujiCEM® 2 and Ketac Cem Maxicap	*84.21	14.836	Significantly different

*The absolute differences were higher than the critical range indicating the means are significantly different.

TABLE 3. Failure mode categories for three GICs.

Type of GICs	Failure modes		
	Type A	**Type B**	**Type C**
BioCem (n=32)	21 (63%)	5 (17%)	6 (20%)
FujiCEM® 2 (n=32)	23 (70%)	4 (12%)	5 (18%)
Ketac Cem Maxicap (n=32)	16 (50%)	2 (8%)	14 (42%)

*Ketac Cem presenting lower percentage of type A failure mode. RMGICs having higher number of type B failure compared to Ketac Cem. Ketac Cem with higher percentage of type C failure mode

Three different types of failure modes were identified (Table 3): Type A- Adhesive failure with remaining cement predominantly on zirconium crown, Type B- Adhesive failure with remaining cement predominantly on composite tooth replica, Type C- Cohesive failure with the cement remaining equally on both surfaces (crown and composite tooth model). The predominant mode of failure was Type A in all cement groups. Ketac Cem group had relatively lower samples exhibiting Type A and Type B failures in comparison with BioCem and Fuji CEM® 2. Type C failure mode was highest for Ketac Cem group.

DISCUSSION

Retention and stability of PPZCs depend upon (i) type of luting cements used, (ii) their inner surface anatomy (iii) remaining OCH after abutment tooth preparation and (iv) gingival moisture contamination. [6,9,10,19,21] The present study compared the retentive force of commonly used glass ionomer luting cements for PPZC's fabricated with contrasting techniques that affect their internal surfaces. The other affecting factors such as moisture contamination, OCH, total occlusal convergence angle was controlled and kept uniform for all tested samples.

The GI cements were selected primarily based on manufacturer recommendations and their extensive use with PPZCs in previous studies. [6,9,10,19] Resin cements were excluded from the current study as they are not-moisture tolerant [22] and tooth preparation for PPZC is sub-gingival that often induce gingival hemorrhage.[5] Resin modified GICs like BioCem and FujiCEM® 2 have low solubility and are less susceptible to early erosion with higher compressive and tensile strength than conventional glass-ionomer luting cement. [12] FujiCEM® 2 has F2 flex fuse technology that provides improved strength, low film thickness, and excellent marginal integrity. [23] BioCem is a bioactive cement having hydrophilic composition that shows extremely low water sorption and solubility.[24] Bioactivity refers to the property of a cement to form hydroxyapatite (HA) when immersed in-vitro in a physiological phosphate-buffered saline solution.[25] This property permits the cement to form hydroxyapatite tags along the margin of tooth and cement preventing micro-leakage and cement washout. [6,24]

In the present study, both BioCem and FujiCEM® 2 exhibited higher retentive force compared to Ketac Cem. These results were consistent with the previous studies done on zirconia ceramics.[26-28] Ketac Cem has been used successfully with SSCs as they can be crimped at the cervical margin to lock in the cement, which is not possible with PPZCs as they require passive fit. [5] Clinically preparation of an abutment tooth to fit a preformed zirconia crown will more likely lead to a bit of an open margin. A greater micro-leakage at the Ketac Cem/zirconia interface might have resulted in a lower retentive force. These results were similar to the in-vitro study done by Stepp et al. [6] 2018 with natural teeth on micro leakage of cements in prefabricated zirconia crowns. A greater microleakage at crown margins and throughout cement was observed in their study when Ketac Cem was used to cement PPZCs to natural teeth. Additionally, BioCem had reduced microleakage due to the formation of hydroxyapatite tags (HA), creating an additional barrier.[6] Besides, lower retentive force for Ketac Cem, the current study also indicated that retentive force between BioCem and FujiCEM® 2 had no statistical difference. The use of composite tooth-replica could have minimized the bioactive properties of BioCem due to non-formation of HA tags resulting in similar retentive force for BioCem and FujiCEM® 2.

Composite core build-up material was used instead of natural tooth due its similar hardness and fracture toughness to the tooth structure.[29] The compressive strength and flexural strength of dual-cure core buildup flowable composite are recorded to be 280 MPa and 119 MPa respectively.[30] In comparison, the ultimate compressive strength for the natural dentine is recorded to be 250–350 MPa [31] while the flexural strength is 212.9±41.9 MPa.[32] Therefore this core build-up material acted as suitable replacement for natural dentine in the present study. However, the mechanism of bonding with glass ionomer based luting materials differs, when natural dentine is used in place of composite tooth replica. In conventional/resin modified glass ionomer cement bonding to tooth structure takes place through chemical bonding,[33] whereas in case of composite tooth replica the chemical bonding is formed with RMGIC [34] and micromechanical retention takes place with conventional GIC.[35] This difference in bonding mechanism is not bound to influence the retentive force values in the current study. The use of natural teeth in an in-vitro study conducted to determine the clinical performance of four cements for luting zirconium oxide ceramic lava crowns showed comparable results to the present study. Conventional GIC luting cements had a lower retentive strength in comparison to RMGI cements.[36]

Better performance of RMGICs can be attributed to their dual mechanism of enhanced mechanical properties and less microleakage. However, this finding was in contrast to the results obtained by Rosato *et al* [10] 2018 where Ketac Cem had the highest retentive force followed by BioCem and FujiCEM® 2 luting cements. They had cemented EZ-Pedo PPZC on extracted human permanent teeth instead of composite tooth replica used in the current study. The Ketac Cem bonding to the dentinal surface of the tooth is chemical, [33] which was not possible with composite tooth model. On the contrary, chemical bonds could be formed at RMGIC/composite tooth replica due to attachment of resin tags present in the replica and hydroxyl-ethyl-methacrylate incorporated in RMGI based luting cements. [34]

In vitro studies that can simulate the intraoral environment can be used as a predictor of the possible clinical performance of a material. The thermocycling process was therefore undertaken to mimic the oral conditions. The performance of the cement bond strength after thermocycling is important than the initial bond strength, as they contribute to the degradation of cement-ceramic bonds over a period of time. [37] Initiation of the thermocycling process after crown cementation and salivary aging might have resulted in a low retentive force for Ketac Cem. Lüthy *et al* 2006 [26] also stated that the bond strength of conventional GIC's is lowered after aging by thermocycling due to their high moisture sensitivity in comparison to RMGICs as the mechanical property of former cement decreases due to water sorption.

Commercial variants of PPZC differ in their internal surface design and to the best knowledge of investigators, no study has been conducted that compared all four available brands. It was planned to analyze whether the geometry of the internal surface would influence the retentive force. The Sprig EZ crowns have patented mechanical undercuts Zir-Lock system, aluminum oxide blasted on the internal surface to double the surface area to increase cement retention and margin lock feature to prevent cement washout. [10,16] With NuSmile® ZR Try-in system, the crown to be cemented remains pristine with an uncontaminated intaglio surface. This gives an added advantage to NuSmile® ZR crowns to avoid moisture contamination from salivary and gingival bleeding which can adversely affects the bond strength of cement to zirconia. NuSmile® ZR try in crowns ensures optimal cement retention to zirconia by providing a clean zirconium oxide surface and phosphate bonds for reaction between the NuSmile® ZR crown and luting cement.[6, 15] Cheng Crowns have treated intaglio surface and features a simulated knife-edge crimped margins to allow for better retention while Kinder Krowns have internal retention threads that offer mechanical retention of restoration.[17, 18]

These manufacturing differences and varied internal surface designs of PPZCs resulted in contrasting interactions with luting cements. Internal retention feature seen in Kinder Krowns, Cheng Crowns and Sprig EZ crowns produced a mechanical bond with luting materials whereas attachment between NuSmile® ZR crowns and cement relied on chemical bonding. [6, 15-18] The present study, however showed that statistically, the interaction effect between cement type and crown brand had no significant effect on the retentive force despite the differences on the internal surface for each crown form.

Greater number of samples in all three groups exhibited adhesive failures during the analysis of failure modes which were consistent with the observations made by Rosato *et al* and Jing *et al*. [10, 19] This finding indicated that there was a weak micro-mechanical bonding and no chemical bonding of GI luting cements with zirconia. [37] Four important observations were seen during failure mode evaluation. In the majority of samples tested, cement was retained predominantly on the internal surface of primary zirconium crowns. This phenomenon might have taken place due to the inherent mechanical grooves/threads (seen in Sprig EZ Crowns and Kinder Krowns) and intaglio surface pattern (seen in NuSmile® ZR and Cheng Crown) of PPZCs placed by the manufactures to enhance cement retention. [15-18] Secondly, Ketac Cem group had a lesser percentage of samples exhibiting Type A modes of failure and resulted due to their lower bond strength with PPZCs. [24] Thirdly, a higher percentage of RMGIC group exhibited type B failures compared to the conventional GIC. This is the result of chemical bonding between RMGI luting cements and composite resins used in the fabrication of abutment tooth replicas through co-polymerization of un-reacted monomer. [34] Finally, cohesive failures were predominant in Ketac Cem group as an outcome of their reduced mechanical properties resulted from water sorption at open cervical margins of PPZCs. [38]

The limitations of the current study included the use of composite tooth models replicas in place of human enamel. This was done to standardize the specimens whereas the same would have been difficult with extracted primary teeth. The design and geometry of the universal testing system might not mirror the clinical scenario and finally the use of a relatively small number of samples per cement. However, the data from the present study may help in the correct selection of luting materials for PPZCs cementation. These results need to be supplemented by prospective long-term randomized controlled clinical trials.

CONCLUSIONS

The amount of retentive force required to dislodge the posterior primary zirconium crowns depends on the type of glass ionomer luting cements and is not influenced by their inner surface anatomy. Within the limitations of this study, the results also suggest that resin modified glass-ionomer cements offered better retention of PPZCs compared to conventional glass-ionomer cements.

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None

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