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The Influence of Different Convergence Angles and Resin Cements on the Retention of Zirconia Copings

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Abstract

Purpose: This in vitro study aimed to determine the ability of three resin cements to retain zirconia copings under two clinically simulated conditions.
Materials and Methods: Extracted human molars (72) were collected, cleaned, and divided into two groups. All teeth were prepared with a 15° total convergence angle for group 1 and a 30° total convergence angle for group 2, a flat occlusal surface, and approximately 4-mm axial length. Each group was divided by surface area into three subgroups (n = 12). All zirconia copings were abraded with 50-μm Al_2O_3, then cemented using Panavia F 2.0 (PAN-1) (PAN-2) Rely X Unicem (RXU-1) (RXU-2), and Clearfil SA (CSA-1) (CSA-2). After cementation, the copings were thermocycled for 5000 cycles between 5°C and 55°C with a 15-second dwell time. Then the copings were subjected to dislodgment force in a universal testing machine at 0.5 mm/min. The force of removal was recorded, and the dislodgement stress was calculated. A Kruskal-Wallis test (nonparametric ANOVA) was used to analyze the data ($\alpha = 0.05$), and the nature of failure was also recorded.
Results: The mean (SD) coping removal stresses (MPa) were as follows: PAN-1: 6.0 (1.3), CSA-1: 4.8 (1.4), RXU-1: 5.5 (2.3), PAN-2: 2.8 (1.1), CSA-2: 3.0 (1.25), and RXU-2: 2.6 (1.2). The Kruskal-Wallis test was significant. Mann-Whitney pairwise comparisons of the subgroups were significant ($p < 0.05$) for the comparisons between subgroups of group 1 and group 2. Mode of failure was mixed, with cement remaining principally on the tooth for PAN. For CSA and RXU, mode of failure was mixed with cement remaining principally on the zirconia copings.
Conclusions: Retention values of zirconia copings with three different resin cements were not significantly different. Retention of zirconia copings cemented on the teeth with adequate resistance and retention form was higher than that cemented on teeth lacking these forms. The cement remained mostly on the tooth with the adhesive resin cement with a dentin bonding system. The cement remained mostly on the coping with the self-adhesive resin cement.

Concerned about the esthetics and biocompatibility of final restorations, dentists have begun demanding metal-free dental restorations. Primarily, because of their reduced physical properties, all-ceramic restorations have been limited to crowns in anterior teeth.[1] To overcome this problem, high-strength ceramics such as alumina were developed. This ceramic material was strong enough for fabrication of single posterior all-ceramic crowns, providing adequate survival rates; however, the physical properties of this material were not adequate for fabrication of fixed partial dentures.[2] Consequently, zirconia, a high-strength ceramic, was introduced for dental applications. This ceramic has several properties making it the material of choice where esthetic and high functional demands are concerned.[3] Because of its high fracture strength, its biocompatibility, and its hard and dense surface, zirconia was recommended for use in posterior restorations.[3] However, restoring posterior teeth with zirconium oxide ceramics is a very challenging subject, as two problems are associated with these restorations. The first is related to the abutment teeth, because results of clinical and lab studies indicated that molars were occasionally over-tapered during tooth preparation, resulting in lack of resistance and retention form.[4-6] The second is related to zirconia restorations: zirconia was not found to be bonded to an abutment tooth because it cannot be etched, and it does not contain silica in its structures to bond to a silane coupling agent like other all-ceramic systems.[7] Moreover, the internal adaptations of zirconia frameworks are not as good as metal frameworks, and thus result in a large cement space.[8,9] These problems would reduce the retention stress of the zirconia restoration and make the retention of the restoration depend mostly on the cementing media.

The shear bond strength of different cements on a zirconium oxide surface after different pretreatments has been examined and measured; the results of these studies presented varying and controversial results.[10-20] The results of a shear bond strength study by Blatz et al[10] showed that resin cement containing an adhesive phosphate monomer 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) provided the highest shear bond strength values. On the other hand, a shear bond strength study by Piwowarczyk et al[11] found that after airborne-particle abrasion, RelyX Unicem resin cement provided the highest shear bond strength mean value. To test the retention of zirconia crowns in a clinically simulated condition, the crowns should be cemented to extracted natural teeth using different luting cements and then subjected to axial dislodgment forces.[21-23] At this time, only Ernst et al[22] and Palacios et al[23] have evaluated the retentive strength of zirconium oxide-based crowns with several luting agents and different ceramic pretreatments.

The purpose of this in vitro study was to determine the ability of three types of resin cements to retain a representative zirconium oxide ceramic crown under two clinically simulated conditions.

Materials and methods

Seventy-two freshly extracted intact human molar teeth were collected in plastic jars containing 0.5% sodium hypochlorite from the oral surgery department at Tufts University School of Dental Medicine, Boston, MA. The collected teeth were kept in the liquid sterilant (0.5% sodium hypochlorite) for 6 hours to disinfect them.[24] Molar teeth were chosen, given their relatively large surface area to resist fracture when stressed and given their diverging roots to resist removal from the imbedding acrylic resin during testing. The teeth were cleaned of surface debris and stains with ultrasonic scaler (Cavitron GEN-119, Sps™, Dentsply, York, PA), and then stored in tap water at room temperature for 1 month before the specimens were prepared. The specimens were kept in tap water throughout the course of the study to prevent them from drying and becoming brittle.

The roots of the selected teeth were notched for retention and embedded along their vertical alignment, with the cementoenamel junction (CEJ) positioned 1 mm above the top of the mounting template (Ultradent, South Jordan, UT). The templates were filled with autopolymerizing acrylic resin (Coldpac, Motloid Company/Yates & Bird, Chicago, IL) to secure the extracted teeth. After mounting the teeth in the acrylic, a slow-speed thin sectioning saw (11–4254-blade, Isomet; Buhler Ltd, Evanston, IL) was used to cut the occlusal surface of each mounted tooth 4 mm above the CEJ. After mounting the specimens in acrylic resin, the specimens were divided randomly into two groups, group 1 and group 2 (Fig 1).

A high-speed handpiece (Midwest Dentsply, Des Plaines, IL) was secured in a surveyor (Degussa F1; DeguDent, Hanau, Germany), and a coarse diamond-tapered rotary cutting instrument (450K Max; Brasseler, Savannah, GA) was oriented at a 7.5° angle from the long axis of the mounted tooth to create a 15° total angle of convergence for group 1. For group 2, the handpiece was oriented at a 15° angle from the long axis of the abutment tooth to create a 30° total convergence angle.

The mounted teeth were secured vertically in a custom jig made of type three dental stone (Microstone, Whip Mix, Louisville, KY) and were held firmly in a surveyor base. Axial reduction was accomplished by rotating the mounted tooth against the rotating bur. Using water spray, the axial surface was reduced to a depth of 1 to 1.5 mm and an axial length of approximately 4 mm, using a new diamond rotary cutting instrument for each tooth specimen. Then the coarse diamond bur was replaced with a fine bur (KD7W6; Brasseler) fitted in the handpiece to make the surface of the preparation smooth.

Impressions of the prepared teeth were made using plastic medicine caps of standard dimensions and polyether impression material (Impregum Penta Soft Quick Step; 3M ESPE, Seefeld, Germany). The polyether tray adhesive (3M ESPE, St. Paul, MN) was previously applied to the internal surface of the cups. The impressions were poured with CAD stone (Garreco, Herb Spring, AR) as recommended by the manufacturer of the zirconium oxide copings (Lava, 3M ESPE, St. Paul, MN) for better scanning. The master die was then scanned at the student technology center at the Postgraduate Prosthodontics Department, Tufts University School of Dental Medicine by one operator using an optical scanner (Lava).

The finish line was set and adjusted as necessary using 3D imaging software (CAD Design; Lava). The copings were designed to be 0.5 mm thick with a 50-μm cement space starting 1 mm above the margin. The coping was designed to have a thicker than normal occlusal section to withstand the force of the dislodgments, and a bar was digitally added to the design using the wax knife tool 3D imaging software (CAD Design; Lava). The bar was then milled and sintered with the zirconia coping to provide a tool for removal of the coping during retention testing (Fig 2).

Three luting agents were evaluated (Table 1): a self-adhesive resin cement (Clearfil SA; CSA), a second self-adhesive resin cement (Rely X Unicem Clicker; RXU), and an adhesive composite resin cement (Panavia F 2.0; PAN). The first two cements did not require any special treatment of dentin, whereas for PAN specimens, a dentin-bonding agent (ED Primer A&B; Kuraray America Co., New York, NY) was applied following manufacturer's recommendations.

Before cementation, the surface areas of the axial surfaces of each prepared abutment tooth were calculated. Then the specimens in each group were distributed into three cementation subgroups using the block randomization method, so each group had similar mean surface areas.

To simulate clinical conditions, provisional cementation was performed by seating the polyether impression material (Impregum Penta Soft Quick Step; 3M ESPE, Seefeld, Germany), lined with a mix of provisional cement without eugenol (Temp Bond NE; Kerr, Orange, CA), on the respective teeth for 10 days while the copings were being fabricated. On receiving of the zirconia copings, the impressions with the provisional cement were removed. The prepared teeth were cleaned with a prophy brush containing water and pumice, and then the abutment teeth were rinsed and kept moist. Each coping was placed

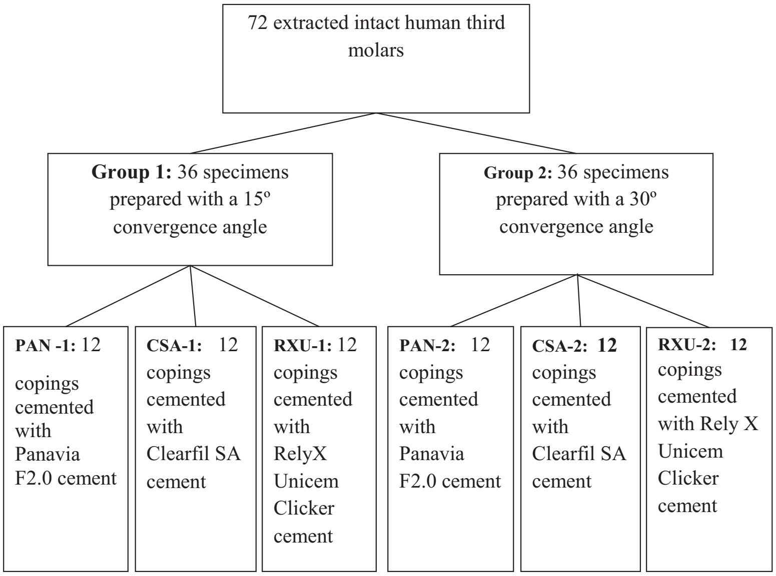

Figure 1 Distribution of groups and subgroups.

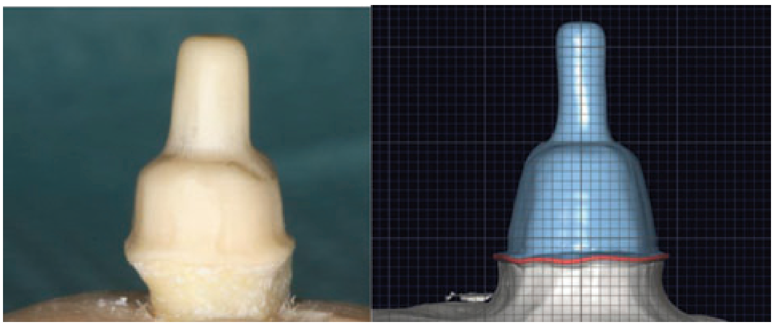

Figure 2 The bar digitally added to the copings.

on its respective tooth, and marginal adaptation was evaluated by a single examiner. After marginal evaluation, the internal surface of each coping was airborne-particle abraded with 50-μm aluminum oxide for a maximum of 15 seconds under 4- to 5-bar pressure (KaVo EWL Type 5423; KaVo Dental GmbH, Biberach, Germany) and a distance of 10 mm. The copings were then cleaned in an ultrasonic bath containing 10% isopropyl alcohol for 5 minutes.

The catalyst and base paste of PAN cement and RXU cement were dispensed and mixed on a mixing pad with a spatula according to the manufacturers' instructions. The CSA was dispensed directly onto the coping according to the manufacturer's instructions. Subsequently, each coping was lined with cement and initially seated with strong finger pressure. The abutment teeth and their respective zirconia copings were then placed in a loading device (Model 5566; Instron Corp, Canton, MA), and each was subjected to a total axial seating force of 75 N per specimen for the specified setting time to allow for room temperature polymerization. Excess cement was cleaned from the margins by small scaler (SM13/14, Hu-Friedy Co., Chicago, IL), and the specimens were stored in water at room temperature for 7 days before thermocycling. After this storage period, the cemented copings were thermocycled for 5000 cycles at a temperature between 5°C and 55°C with a 15-second dwell time. After thermocycling, the copings were subjected to dislodgment forces along the long axis of the abutment tooth until failure using a universal testing machine (Model 5566) at a 0.5 mm/min crosshead speed.

The dislodgment force of each zirconia coping was recorded, and the removal stress was calculated using the surface area of the prepared tooth. Additionally, following coping dislodgment, the predominant nature of failure was recorded by a single operator who examined the coping and the tooth under stereomicroscope (Olympus SZ-PT, Tokyo, Japan) based on the following criteria: type 1 when the cement remains mostly on the tooth, type 2 when the cement remains mostly on the coping, and type 3 when a fracture in the coping or the tooth occurs.

The data for force (N) and stress of dislodgment (MPa) were analyzed using a two-way ANOVA and the least significant difference multiple comparison test. The critical level of alpha was set at 0.05. All hypothesis testing was conducted at a 95% confidence level. The data for characterization of the type of failure were given as descriptive information.

Table 1 Materials used

Product	Composition	Manufacturer
Clearfil SA cement	Paste A: Bis phenol A diglycidylmethacrylate (Bis-GMA), Triethyleneglycol dimethacrylate (TEGDMA), 10-Methacryloyloxydecyl dihydrogen phosphate (MDP), Hydrophobic aromatic dimethacrylate, Silanated barium glass filler, Silanated colloidal silica, dl-Camphorquinone, Benzoyl peroxide, Initiator Paste B: Bis-GMA, Hydrophobic aromatic dimethacrylate, Hydrophobic aliphatic dimethacrylate, Silanated barium glass filler, Silanated colloidal silica, Surface treated sodium fluoride, Accelerators, Pigments	Kuraray America Co, New York, NY
Panavia F2.0 cement	Catalyst paste: MDP, Hydrophobic aromatic dimethacrylate, Hydrophobic aliphatic dimethacrylate, Silanated silica filler, Colloidal silica, Catalysts, Others ED primer liquid B: N-Methacryloyl-5-aminosalicylic acid, Water, Catalysts, Accelerators ED primer liquid A: 2-hydroxyethyl methacrylate, MDP, N-Methacryloyl-5-aminosalicylic acid, Water, Accelerators Universal paste: Hydrophobic aromatic Dimethacrylate, Hydrophobic aliphatic dimethacrylate, Hydrophilic aliphatic dimethacrylate, Silanated titanium oxide, Silanated barium glass filler, Catalysts, Accelerators, Pigments, Others Oxyguard II: Glycerol, Polyethyleneglycol, Catalysts, Accelerators, Dyes, Others Etching agent V: Phosphoric acid, Polyvinylpyrolidone, Colloidal silica, Water, Dyes	Kuraray America Co, New York, NY
Rely X Unicem Clicker	Paste A: Fluoroaluminosilicate (FAS) glass, Proprietary reducing agent, HEMA, Water, Opacifying agent Paste B: Methacrylated polycarboxylic acid, BisGMA, HEMA, Water, Potassium persulfate, Zirconia silica filler	RelyX Luting Plus Cement, 3M ESPE, St. Paul, MN
Self-Cure Cross-Linked Acrylic resin	Liquid: Methylmethacrylate, Polymerization inhibitor: hydroquinone, Tertiary amines, Color stable agent, Ultraviolet light absorber (Aromatic Ketone), Cross-linking agent (Polyfunctional acrylic monomer) Powder: Polymethylmethacrylate	Coldpac, Motloid Company/Yates & Bird, Chicago, IL
Coarse Round-End Taper		450K Max; Brasseler, Savannah, GA
Polyether	Base: Polyether macromonomer, Fillers, Plasticizer (high and low viscosity), Pigments, Peppermint Flavorings, Triglycerides, Accelerators Catalyst: Initiator (cationic polymerization initiator), Fillers, Plasticizer, Pigments	Impregum Penta Soft Quick Step; 3M ESPE, Seefeld, Germany
Type V dental stone	Plaster of Paris, Crystalline Silica, Titanium dioxide	Resin Rock, Whip Mix; Louisville, KY
Partially sintered zirconia ceramic copings	Coprecipitated (most powders), Mixed oxide process, Grain size (0.07-0.3 μm), Spray drying, Organic additives	3M ESPE Lava, St. Paul, MN

Results

For the 72 specimens, the mean (SD) surface area was 74.4 (8.0) mm^2. The mean (SD) axial surface area for group 1 was 76.4 (7.8) mm^2. The mean (SD) for the subgroups was 70.7 (8.5) mm^2 for PAN-1, 73.2 (8.25) mm^2 for CSA-1, and 73.0 (12.4) mm^2 for RXU-1. For group 2, the mean (SD) axial surface area was 72.4 (9.7) mm^2. The mean (SD) axial surface areas for the subgroups were as follows: PAN-2 75.8 (8.0) mm^2, CSA-2 76.5 (6.0) mm^2, and RXU-2 77.0 (9.5) mm^2.

The coping removal stresses are illustrated in Figure 3. When a zirconia coping fractured, an abutment tooth fractured, or a root dislodged before the test was completed, the force recorded was the maximum before the occurrence of one of the previous events; however, the actual force would exceed the presented value.

The mean (SD) coping removal stresses for group 1 subgroups (MPa) were (PAN-1) 6.0 (1.3), (CSA-1) 4.8 (1.4), and (RXU-1) 5.5 (2.3). PAN-1 showed the highest mean crown removal stress; however, because one coping fractured during the test, and two teeth were dislodged from the acrylic base before the test completed, the maximum removal stress would be more than 6.0 MPa. For RXU-1, three zironia copings fractured. Thus, the removal stress for this group would also be more than the actual recorded value. For the CSA-1 group, one zirconia coping fractured, two teeth dislodged before the test was completed, and one tooth had root fracture before the test was completed. Therefore, removal stress of this group would also be more than 4.8 MPa. For all above-mentioned groups, the mean dislodgment stress was influenced by the cohesive strength of the tooth and the cohesive stress of the zirconia coping.

The mean (SD) coping removal stresses (MPa) for group 2 PAN-2, CSA-2, and RXU-2 were 2.8 (1.1), 3.0 (1.25), and 2.6 (1.2), respectively (Fig 3). In the subgroups PAN-2, CSA-2, and RXU-2 no specimens were lost because of root fracture or tooth dislodgment from the acrylic and coping fracture. CSA-2 exhibited the highest mean crown removal stress followed by PAN-2 and RXU-2. Because it is often easier to understand magnitudes for force, the results were also converted to Newtons. The mean (SD) removal force for subgroups PAN-1, CSA-1, and RXU-1 were 427 (94) N, 350 (104) N, and 402 (166) N, respectively. The mean (SD) removal force for subgroups PAN-2, CSA-2, and RXU-2 were 200 (82) N, 253 (103) N, and 201 (89) N, respectively.

Two-way ANOVA was first applied to these data, because two categorical factors (convergence angle and cement type) are associated with a continuous outcome (coping removal stress), the outcomes are not related to each other, and the shape of the histogram was not statistically significantly different from the normal curve; however, the assumption of equal variance was violated because the Levene's test for equal variances was significant for MPa (0.010) and for N (0.014). Therefore, these data do not meet the requirement of the two-way ANOVA model.

Two separate Kruskal-Wallis tests were also done on the two major groups to evaluate if the difference was significant among the subgroups of the same group. The p-values were insignificant among the subgroups of group 1 (PAN-1, CSA-1, RXU-1) MPa ($p = 0.232$) and N ($p = 0.312$), and among the subgroups of group 2 (PAN-2, CSA-2, RXU-2) MPa ($p = 0.508$), and N ($p = 0.378$) as well. Based on these results, Mann-Whitney pairwise comparisons of the all subgroups were done. Nevertheless, the Mann-Whitney pairwise comparisons revealed statistically significant differences in crown removal stress between subgroups of group 1 to subgroups of group 2.

The results for characterization of failure type are presented in Figure 4. Overall, the predominant mode of failure for group 1 was type 2 (42.42%), where the cement was found principally on the copings. This was followed by type 3 (30.3%), where the copings, tooth, or root fractured, and type 1 (27.27%), where the cement was found principally on the tooth. For the cement group PAN-1, 27.27% of the specimens had cement in the copings followed by 45.45% of the specimens with cement principally on the tooth, and 27.27% where copings, tooth, or root fractured. In contrast, failure modes for CSA-1 were 54.54% for cement principally on the coping, 36.36% with coping fracture, and 9% with cement principally on the tooth. The group of copings cemented with RXU-1 had 36.36% of the specimens with cement in the coping, 36.36% on the tooth, and 27.27% with coping fracture. The predominant mode of failure for group 2 was type 1 (60%), where the cement was found principally on the tooth. This was followed by type 2 (40%), where the cement was found principally on the copings. For the cement subgroup PAN-2, 72% of the specimens had cement on the tooth and 28% on the copings. For CSA-2 mode of failure was 66.66% on the coping and 33.33% within the tooth. The subgroup of copings cemented with RXU-2 had 25% of the specimens with cement on the tooth and 75% with the cement on the coping.

Discussion

In this study, zirconia copings were cemented onto teeth having the retention and resistance forms recommended in the literature, and on teeth lacking these forms; however, the retention values for the groups cemented onto teeth with suitable retention and resistance forms were compared to results of previous studies that used similar procedures, which evaluated gold casting and zirconia coping retention for various cements. The mean coping removal stresses for the axial surface of the three cementation groups were 6.0 MPa (PAN-1), 4.8 MPa (CSA-1), and 5.5 MPa (RXU-1), respectively. This is greater than the range of removal stress shown for gold castings when using zinc phosphate cement (3.7 MPa) and glass ionomer cement (4.2 MPa).[12] Thus, the retention values obtained in this study are adequate to retain zirconium oxide ceramic crowns. The findings of this study are in accordance with the study by Palacios et al,[23] in which no statistically significant difference between three different resin types was found; however, in that study, the retention values for PAN (6.9 MPa) and RXU (6.7 MPa) were higher than the retention values recorded in this study, especially considering that Palacios et al tested the cements at 20° of convergence, which is higher than the angle used in this study. The possible explanation could be that the zirconia copings (Procera AllZirkon; Nobel Biocare, Yorba Linda, CA) tested in that study were different in

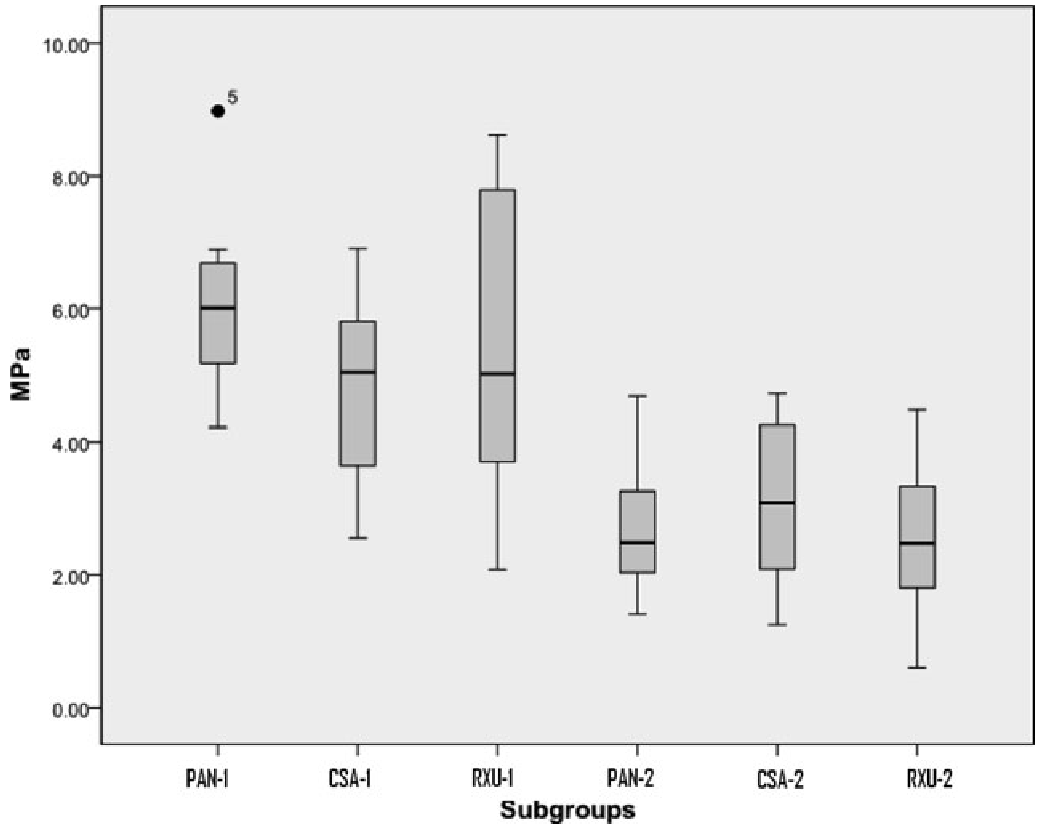

Figure 3 Distribution of coping removal stress.

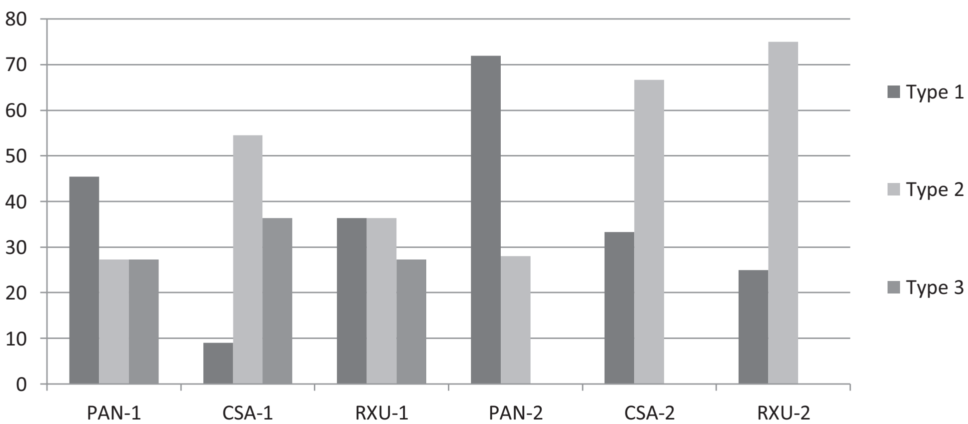

Figure 4 Modes of failure for the subgroups.

design than the type of copings tested in our study. The composition of zirconia and the way of manufacturing is specific for each system; therefore, conclusions drawn for one zirconia system may not be valid to others. In the Palacios et al study, a SEM image of the coping before sandblasting revealed rough surface texture, which could enhance the retention of the copings. On the other hand, Ernst et al[22] used the same methodology and the same type of zirconia copings (Lava) used in this study, but different resin cements. They prepared the teeth with ten degree angle of convergence and found no statistically significant difference between the resin cement types. The retention values for PAN (4.0 MPa) and RXU (4.8 MPa) in the Ernst et al study were lower than the values recorded in this study, considering that the degree of convergence was smaller, although they reported high SD values.

Comparing the results of these two studies and the current study, it seems noticeable that the retention value of the zirconia copings increased as the convergence angle of the tooth abutments increased. The possible explanation for this fact is that the internal and marginal adaptation of the coping could decrease as the convergence angle increases. This is supported by the findings of a study by Iwai et al,[9] in which marginal and internal adaptation significantly decreased as convergence increased from 6° to 20°. They explained this improvement, pointing out that the scanning power of the CAD scanner could be enhanced with a convergence angle of 20°. Moreover, the increase in cement thickness can lead to higher amounts of water absorption.[8,9] Water absorption leads to degradation of resin cement, changing its chemical and physical properties.[8,9] Aging using water storage drastically reduced the reliability of ceramics when a thick layer of resin cement was used.[8] However, this proportional relationship ceases to exist when the tooth does not have enough resistance and retention form. Shillingburg et al[25] suggested that the convergence angle of abutment preparation should be between 10° and 22° to provide adequate resistance to the dislodgement of the final restoration. Also, Goodacre et al[5] recommended that the convergence angle ideally should range between 10° and 20° to guarantee complete seating of the restoration.[4-6] In this study, specimens from group 2 were prepared with a total convergence angle intentionally above these limits. In this way, the role of the cement to retention of the crowns is better evaluated. The retention values for these groups were less and statistically significant different (PAN-2: 2.8 MPa, CSA-2: 3.0 MPa, RXU-2: 2.6 MPa) compared with results of group 1 and previous studies.

Another factor that may play a role in the retention of the zirconia copings tested in this study was the relative adaptation of the zirconia coping to the prepared abutment tooth. The internal adaptation for several copings fabricated for this study was exceedingly passive, and the internal adaptation was not as good as that obtained for cast restorations. According to Wettstein et al,[8] the fit of zirconia restorations was not as good as the fit of metal ceramic restorations.

In this study, the three tested resin cements were two-paste materials, and the differences between the retention strength provided by these systems were not statistically significant, PAN and CSA resin cements containing MDP. In addition to the MDP group, PAN uses dentin-bonding agent ED Primer to enhance dentin bonding. Different shear bond studies recommended using resin cements containing MDP adhesive monomer, which makes chemical bonds to metal oxides in zirconia surfaces and, therefore, long-term durable resin bonds to zirconium oxide coping surfaces.[12-16] Blatz et al,[16] Ozcan and Vallittu,[17] and Wolfart et al[18] found that the highest shear bond strength was provided by airborne particle abrasion of the zirconia surface followed by application of MDP-containing resin luting agent. In another study, Kern and Wegner[19] airborne-particle abraded the zirconia ceramic surface with 110-mm aluminum oxide, applied different luting agents, and found that the phosphate resin cement (PAN and PAN 21) provided the highest bond strength values. This is in partial agreement with the results of this study: in group 1 the retention value of PAN cement was the highest among the other groups. However, the difference was not statistically significant. Blatz et al[10] compared the bond strength of several self-adhesive resin cements before and after artificial aging. Similar to this study, application of self-adhesive resin cement (CSA) resulted in higher bond strengths compared to RXU.

RXU clicker is a dual-cure, two-paste, automix resin material containing methacrylate monomers with phosphoric acid groups. This cement is able to make a hydrogen bond with the zirconia surface because the phosphoric acid groups in its composition promote this surface bonding. Piwowarczyk et al[11] concluded that the highest shear bond strength was obtained by airborne particle-abrading the ceramic surface and using resin cements containing methacrylates with phosphoric acid (RXU). Another study by Piwowarczyk et al[20] evaluated shear bond strengths of several cements and found that after airborne particle abrasion, the highest bond strength values were obtained with RXU.

The above-mentioned studies were shear bond strength studies, which do not replicate clinical circumstances and the cementation process. Therefore, this testing design does not reflect the factors that may affect the performance of the cement. Moreover, the testing methods and conditions used in these studies were different, making it difficult to compare the results.

Close evaluation of the failure modes of adhesive resin cement groups (PAN-1, PAN-2) revealed mostly type one failure, when the cement was mostly on the abutment tooth; whereas for the self-adhesive resin cement groups (CSA-1, CSA-2 and RXU-1, RXU-2), the mode of failure was mostly type two, where the cement was mostly on the copings. The possible explanation for these findings is that the dentin bonding system used with adhesive resin cements provided a stronger bond to the abutment tooth than the mechanical retention provided by sandblasting of the intaglio surface of the copings. With the use of the self-adhesive resin cement, the mechanical interlocks provided by sandblasting were stronger than the mechanical interlock provided by the surface etching of the tooth; however, this is caused by the setting of the self-adhesive resin cements. Type three failure modes occurred only in group 1. This was because of a high stress removal, which resulted in fractures of the coping, tooth, and root, before the crown was dislodged. This was unlike group 2, where the stress was lower than the crown stress removals for group 1. This problem can be avoided in future studies by increasing the thickness of the copings to 1 mm, and by using specimens with strong divergent roots, and stronger acrylic resin material than the one that used in this study.

This was an in vitro study, which may not completely replicate in vivo performance of the tested materials. More research is required to examine different zirconium oxide brands, different surface pretreatments, thermomechanical cycling loading, and different cementing media. Additionally, randomized clinical trials and long-term perspectives are needed to assess the benefits of certain clinical procedures.

Conclusions

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

(1) The differences between the three resin cements used in the study were not statistically significant in group 1, where the zirconia copings cemented on teeth had adequate retention and resistance form.

(2) The differences between the three resin cements used in the study were not statistically significant in group 2, where the zirconia copings cemented on teeth did not have adequate retention and resistance form.
(3) Retention of zirconia copings cemented on the teeth that had adequate resistance and retention form was higher than that cemented on teeth lacking these forms.
(4) The use of composite resin cement with a dentin bonding system did not yield greater retention.
(5) Type of failure of adhesive resin cement with a dentin bonding system (PAN F 2.0) was predominantly type one, where the cement mostly remained on the tooth.
(6) The type of failure of self-adhesive resin cement (CSA, and RXU) was predominantly type two, where the cement mostly remained on the coping.

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