Effect of Resin Cements and Aging on Cuspal Deflection and Fracture Resistance of Teeth Restored with Composite Resin Inlays

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Purpose: To evaluate the influence of resin cements and aging on cuspal deflection, fracture resistance, and mode of failure of endodontically treated teeth restored with composite resin inlays.

Materials and Methods: Seventy-two maxillary premolars were divided into 6 groups: 1: sound teeth as control (C); 2: preparations without restoration (WR); 3: inlays luted with RelyX ARC (ARC); 4: inlays luted with RelyX Unicem (RLXU); 5: inlays luted with Maxcem Elite (MCE); 6: inlays luted with SeT (ST). Groups 2 to 6 received mesio-occlusal-distal preparations and endodontic treatment. Stone casts were made for groups 3 to 6. Composite resin inlays were built over each cast and luted with the resin cements. A 200-N load was applied on the occlusal aspect and the cuspal deflection was measured using a micrometer before and after 500,000 cycles of fatigue loading (200 N; 500,000 cycles). The specimens were then submitted to an axial load until failure.

Results: The median cuspal deflection (µm) and median fracture resistance (N) were calculated and statistically analyzed using Kruskal-Wallis and Mann-Whitney tests ($p < 0.01$). Values followed by the same letter represent no statistically significant difference. Cuspal deflection before cyclic loading: C = 3 µm[a]; ARC = 4 µm[ab]; RLXU = 5 µm[ab]; MCE = 21 µm[b]; ST = 51 µm[bc]; WR = 69 µm[c]. Cuspal deflection after cyclic loading: ARC = 6 µm[a]; RLXU = 19 µm[ab]; MCE = 33 µm[b]; ST = 62 µm[b]. Fracture resistance in N: C = 1902[a]; ARC = 980[b]; RLXU = 670[c]; MCE = 533[c]; ST = 601[c]; WR = 526[c]. According to the Wilcoxon test, there was no statistical difference between the cuspal deflection before and after cyclic loading only for ARC ($p = 0.015$). There was a predominance of recovery fractures for the restored groups.

Conclusion: Composite resin inlays luted with RelyX ARC maintained cuspal deflection stability and showed higher fracture resistance of the teeth than did inlays luted with the other cements tested.

Keywords: resin cements, cuspal deflection, fracture resistance.

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Posterior teeth naturally suffer cuspal deflection under application of a load as a result of their structural design. When mesio-occlusal-distal (MOD) preparation and endodontic treatment are performed, this trend towards cuspal deflection under masticatory loads is increased due to the decrease in the stiffness of the tooth.[15,21,33] Therefore, a coronal restoration must be capable of restoring the stiffness of the original tooth to a certain degree to decrease mechanical fatigue of the cusps.[7]

Numerous techniques and restorative materials have been indicated to recover the stiffness of endodontically treated teeth.[27,39] Teeth with wide MOD cavities and restored with amalgam present less fracture resistance due to the inability of the amalgam to bond to the dental substrate and reinforce the weakened tooth.[6,7] In view

Table 1 Resin cements used in the study

Material	Batch no.	Composition	Manufacturer
RelyX ARC (conventional)	GW9JJ	Bis-GMA, tri-ethyleneglycol dimethacrylate, zircon/silica filler, photoinitiators, amine, benzoic peroxide, pigments	3M ESPE; St Paul, MN, USA
RelyX Unicem Clicker (self-adhesive)	395667	Methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, initiator components, stabilizers	3M ESPE
Maxcem Elite (self-adhesive)	3200650	GPDM, monomers, non-hazardous inert mineral fillers, ytterbium fluoride, activators, stabilizers, and colorants	Kerr; Orange, CA, USA
SeT (self-adhesive)	S0907083	Acidic monomers, camphorquinone, fluoroaluminosilicate glass, urethane dimethacrylate	SDI; Bayswater, VIC, AS

Bis-GMA: bisphenol-A-glycidyl methacrylate; HEMA: 2-hydroxyethylmethacrylate; GPDM: glycerol phosphate dimethacrylate.

of esthetic demands, the most commonly used materials are ceramics and composite resins. In the case of composite resin restorations, the indirect technique is considered the best treatment option to restore teeth with wide cavities and to overcome polymerization shrinkage.[34] These indirect restorations are luted with adhesive materials, such as adhesive systems associated with resin cements, which favor reinforcement of the weakened tooth.[6,8,29,35]

Compared with conventional cements, resin cements are widely used because of their favorable mechanical properties (compression strength, low solubility, and greater wear resistance), esthetics, and the ability to bond to restorative materials when properly pretreated.[5] A new category of resin cements, self-adhesive resin cements, has gained popularity with clinicians because they are easy to use and the luting procedure takes less time compared with resin cements that require the application of an adhesive system. Without the adhesive system, part of the sensitivity of the technique is eliminated.[1,5] Despite being easier to apply, the ability of these self-adhesive materials to bond adequately to both the dental structures and the restorative material to strengthen the tooth should still be a priority.

Most studies have evaluated the bond strength of self-adhesive resin cements to enamel and dentin[1,11,26] and to restorative materials,[45] as well as their mechanical properties.[24,31] However, there are no studies showing the influence of these cements on cuspal deflection and resistance of endodontically treated teeth restored with composite resin inlays.

The aim of this study was thus to evaluate the influence of four resin cements, one conventional and three self-adhesive, on the following variables: (1) cuspal deflection before and after cyclic mechanical loading, (2) fracture resistance, and (3) fracture mode of endodontically treated maxillary premolars restored with composite resin inlays. The null hypothesis was that the use of different resin cements to lute composite inlays do not influence cuspal deflection, fracture resistance, or fracture mode of the teeth.

MATERIALS AND METHODS

MOD Preparation

Seventy-two sound maxillary first premolars, extracted for therapeutic reasons, were obtained from the Tooth Bank after the approval of the Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul. The teeth were cleaned and disinfected in 10% thymol for 24 h, and then stored in distilled water at 4°C. The water was changed every week, and the teeth were used within 6 months. The buccal-palatal and mesiodistal dimensions of each tooth were measured with a digital caliper (Mitutoyo; Suzano, SP, Brazil). A variation of 0.5 mm was allowed for each measurement to standardize the dimensions of the teeth.

Each tooth was mounted vertically in a plastic cylinder with self-curing acrylic resin (Jet Classico; São Paulo, SP, Brazil) up to 2 mm below the cementoenamel junction (CEJ). The teeth were randomly divided into 6 groups (n = 12): group 1, sound teeth (control); groups 2 to 6, teeth with MOD preparation and endodontic treatment. Group 2 was not restored, and the other groups were restored with composite resin inlays, which were luted with RelyX ARC (group 3), RelyX Unicem (group 4), Maxcem Elite (group 5) and SeT (group 6). Table 1 shows the composition and manufacturers' details of the materials used.

A single operator performed the MOD preparations using a standardized preparation machine. This device consisted of a high-speed handpiece (Kavo; Joinville, SC, Brazil) coupled to a mobile base. The mobile base moves vertically and horizontally in increments of 3 µm with the aid of a micrometer (Mitutoyo; Tokyo, Japan). The long axis of the tooth was positioned vertically on the preparation machine, and the tooth was cut using a no. 4159 diamond bur (KG Sorensen; Barueri, SP, Brazil) attached to the high-speed handpiece under constant water and air cooling. The preparations presented rounded internal angles, divergent walls, and an occlusal box width of two-thirds of the intercuspal distance, yielding a bucco-palatal distance of 4 mm, with a maximum variation of 0.5 mm. The bottom of the proximal boxes was located 1 mm above the CEJ, with a depth of 5 mm at the isthmus and a maximum variation of 0.5 mm. The preparations had only buccal and palatal walls, and a common floor from mesial to distal, so that the pulp floor of the occlusal box and the gingival floor of the proximal boxes were unified on the same level (Fig 1). The diamond bur was replaced after every five preparations.

After the preparations were completed, endodontic access was prepared with a no. 8 spherical carbide bur (SS White; Lakewood, NJ, USA). The preparation of the chamber was round, with divergent walls. Flexo-File files (Kerr; Orange, CA, USA) numbers 15 to 40 were manually placed in the root canals to standardize the preparation. A 2.5% sodium hypochlorite solution was used to irrigate and clean the root canal. After the root canal preparation, all teeth were filled with gutta-percha cones (Dentsply Maillefer; Ballaigues, Switzerland) and N-Rickert endodontic sealer (Inodon; Porto Alegre, RS, Brazil) using the lateral condensation technique. The sealer excess was removed from the cavity using a cotton pellet embedded with 70% ethanol. The access to root canals was covered with gutta-percha. The teeth were stored in distilled water at room temperature.

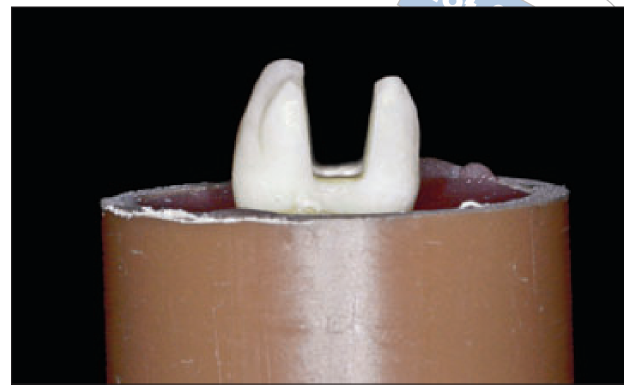

Fig 1 MOD cavity. The preparations presented rounded internal angles, divergent walls, and an occlusal box width of two-thirds of the intercuspal distance. The bottom of the proximal boxes was located 1 mm above the CEJ. The preparations had only buccal and palatal walls, and a common floor from mesial to distal.

Restorative Procedures

Impressions of the preparations were taken with Express XT polyvinyl siloxane (3M ESPE; St Paul, MN, USA) using individual trays made from self-curing acrylic resin (Jet Classico, São Paulo, SP, Brazil) with the putty/wash one-step technique. The impression material was allowed to set for 10 min before it was removed from the preparation. After 1 h, the impressions were poured using Durone Type IV stone (Dentsply; York, PA, USA). After 1 h, the casts were removed from the impression, numbered according to their group, and placed in dry storage.

Cavity surfaces were lined with two coats of die spacer, which corresponds to a thickness of approximately 30 μm,[20] maintaining a distance of 1.0 mm to the marginal areas. Four horizontal layers of Filtek Z350XT nanofilled composite resin (3M ESPE) were inserted in the casts using Thompson spatulas no. 2 and 12, which resulted in a 90-degree inclination between the internal slopes and cusps. Each resin layer was light cured for 40 s. Restorations were then light cured for 60 s on each free surface, followed by finishing with flexible disks (TDV; Pomerode, SC, Brazil) and 8093F and 8093 FF silicone tips (KG Sorensen). During all the experiment, a quartz-tungsten-halogen curing unit (Optilux Plus; Ribeirão Preto, SP, Brazil) was used for photopolymerization. A light intensity between 450 and 500 mW/cm^2 was controlled with a radiometer (model 100, Demetron/Kerr; Danbury, CT, USA).

Luting Procedures

The internal surfaces of the inlays were sandblasted with 50-μm aluminum oxide for 5 s, followed by silane application (Ceramic Primer, 3M ESPE) and a layer of bond (Scotchbond Multi-Purpose bond, 3M ESPE), followed by light curing for 20 s.

In group 3, Scotchbond Multi-Purpose adhesive system (3M ESPE) was applied. The tooth preparations were etched with 37% phosphoric acid for 15 s, followed by rinsing with air and water spray for 15 s. The excess water was removed with cotton buds. A layer of primer was applied, followed by gentle air drying for 5 s. Then, the bond was applied with a microbrush and light cured for 10 s. Equal lengths of base and catalyst pastes of RelyX ARC resin cement were mixed for 15 s and put on the inlay and preparation.

For RelyX Unicem, Maxcem Elite, and SeT, the tooth structure was simply cleaned with an air-water syringe and the excess water was removed with cotton buds. Subsequently the self-adhesive resin cements were applied. In group 4, equal quantities of base and catalyst pastes of RelyX Unicem Clicker were mixed and applied on the inlay and preparation. In group 5, the Maxcem Elite was placed directly on the inlay and preparation with the aid of a self-mixing tip. In group 6, the internal content of a capsule of SeT was activated for 10 s and applied on the inlay and preparation. In groups 3 to 6, the inlay was placed on the preparation and a load of 1 kg was applied by means of a metal tool. After 2 min, the excess of cement was removed with a microbrush, followed by light curing for 60 s on each free surface. The specimens were stored in distilled water at 37°C for 72 h and then submitted to the cuspal deflection test.

Cuspal Deflection Test

Resin spheres (approximately 1.5 mm in diameter) were fixed with adhesive on both cusps. Following the methodology described by Gonzáles-López et al,[15] the spheres were positioned on the cuspal vertices and served as reference points for measuring the intercuspal distance using a precision micrometer (Mitutoyo) with a measurement sensitivity of 1 μm. A fixation device was used to fix the micrometer in the same position. Each specimen was attached to the lower platen of a universal testing machine (Emic DL-2000, EMIC; São José dos Campos, PR, Brazil), and a steel sphere with an 8-mm diameter was used to apply a 200-N oc-

Fig 2 Cuspal deflection test: the resin spheres are positioned on the cuspal vertices and served as reference points for measuring the intercuspal distance using a micrometer. A steel sphere with 8-mm diameter contacts the buccal and palatal cuspal inclines.

clusal load at a crosshead speed of 0.5 mm/min. The load was applied parallel to the long axis of the tooth, simultaneously contacting the buccal and palatal cuspal inclines (Fig 2). When the 200-N load was achieved, the machine was locked and three consecutive measurements of the cuspal deflection were made. The mean distance of the composite resin spheres prior to application of the load was subtracted from the mean distance of the spheres after application of the load, yielding the cuspal deflection value. The specimens were then submitted to cyclic fatigue loading (Erios ER-11000, Erios; São Paulo, SP, Brazil) at 200 N for 500,000 cycles at 1 Hz in distilled water. After cyclic fatigue loading, the cuspal deflection was measured again as before. The teeth with nonrestored prepared cavities were not submitted to cyclic fatigue loading.

Fracture Resistance Testing

The specimens were subjected to compression in a universal testing machine (EMIC). A steel sphere with an 8-mm diameter was used to apply an occlusal load parallel to the long axis of the tooth at a crosshead speed of 0.5 mm/min, simultaneously contacting the buccal and palatal cuspal inclines. The load was applied until fracture occurred. The maximum load was recorded in Newtons.

Fracture Mode Analysis

After visual examination, the fractures were classified as follows: type I, cusp fracture at the CEJ; type II, cusp fracture below the CEJ; type III, cusp fracture at the CEJ with part of the inlay attached; type IV, cusp fracture below the CEJ with part of the inlay attached; and type V, longitudinal fracture dividing the tooth along the axis.

Statistical Analysis

Cuspal deflection and fracture load data were submitted to the Kolmogorov-Smirnov normality test. As there was no normality, both variables were analyzed by Kruskal-Wallis and Mann-Whitney non-parametric tests. The Wilcoxon non-parametric test was used to compare the cuspal deflection data before and after cyclic loading ($\alpha < 0.01$).

RESULTS

According to the Kruskal-Wallis test, there was a significant difference between the groups for cuspal deflection ($p < 0.0001$). Before cyclic loading, the highest cuspal deflection was obtained in group 2 (nonrestored cavity; 69 μm); this did not differ statistically significanlty only from the SeT group (51 μm). The lowest cuspal deflections were obtained in group 1 (sound teeth; 3 μm), group 3 (RelyX ARC; 4 μm), and group 4 (RelyX Unicem; 5 μm); these did not differ statistically between each other ($p < 0.01$). An intermediate value

Table 2 Median cuspal deflection (μm) of the groups before and after cyclic loading

Groups	n	Cuspal deflection before cyclic loading (25th and 75th percentile values)	Cuspal deflection after cyclic loading (25th and 75th percentile values)
1. Sound teeth	12	3^{a} (3-4)	n.a.
2. Cavity	12	69^{c} (56-83)	n.a.
3. RelyX ARC	12	4^{abA} (2-8)	6^{aA} (4-9)
4. RelyX Unicem	12	5^{abA} (4-30)	19^{abB} (7-49)
5. Maxcem Elite	12	21^{bA} (6-36)	33^{bB} (7-57)
6. SeT	12	51^{bcA} (25-75)	62^{bB} (43-91)

Medians in the columns followed by the same superscript small letter did not differ statistically according to the Mann-Whitney test at a significance level of 1%. Medians in the rows followed by the same superscript capital letter did not differ statistically according to the Wilcoxon test at a significance level of 1%. n.a.: not applicable.

was obtained in group 5 (Maxcem Elite; 21 µm), which did not differ statistically from the RelyX ARC, RelyX Unicem, and SeT groups. After cyclic loading, the highest cuspal deflection was obtained for group 6 (SeT group; 62 µm), which did not differ statistically from group 5 (Maxcem Elite; 33 µm) or group 4 (RelyX Unicem; 19 µm). Group 3 (RelyX ARC; 6 µm) had the lowest cuspal deflection, which did not differ statistically from the RelyX Unicem group (Table 2).

According to the Wilcoxon test, there was a statistically significant difference between the cuspal deflection before and after cyclic loading for the RelyX Unicem ($p = 0.001$), Maxcem Elite ($p = 0.004$), and SeT groups ($p = 0.0001$). There was no statistically significant difference only for the RelyX ARC group ($p = 0.015$) (Table 2).

According to the Kruskal-Wallis test, there was a statistically significant difference for fracture resistance between the groups ($p < 0.0001$). The highest fracture resistance was obtained for group 1 (sound teeth; 1902 N), which differed statistically significantly from the other groups ($p < 0.01$). The second highest value was obtained for group 3 (RelyX ARC; 980.8 N), which was statistically significantly different from the other groups. Groups 4 (RelyX Unicem; 670.6 N), 5 (Maxcem Elite; 533.5 N), 6 (SeT; 601.3 N), and 2 (nonrestored cavity; 526.6 N) were not statistically significantly different from each other ($p > 0.01$) (Table 3).

Table 3 Median fracture resistance (N) of the experimental groups

Groups	n	Median of fracture resistance (N) (25th and 75th percentile values)
1. Sound teeth	12	1902^{a} (1434.5-2421.5)
2. Cavity	12	526.6^{c} (408.5-652.3)
3. RelyX ARC	12	980.8^{b} (761.4-1450)
4. RelyX Unicem	12	670.6^{c} (523.6-728.6)
5. Maxcem Elite	12	533.5^{c} (413.4-675.5)
6. SeT	12	601.3^{c} (523.8-761.5)

Medians followed by the same superscript letter did not differ statistically significantly according to the Mann-Whitney test at a significance level of 1%.

All the sound teeth presented type I fractures (100%). Type II fractures occurred in all samples of the nonrestored cavity group and the Maxcem Elite group. Five type I fractures (Fig 3A), six type II fractures (Fig 3B), and one type IV fracture (Fig 3C) occurred in the RelyX ARC group. There was a predominance of type II fractures in the RelyX Unicem and SeT groups. There was no occurrence of type III or V fractures (Table 4).

Fig 3 Fracture modes observed in the study: a – type I fracture occuring in the RelyX ARC group: cusp fracture at the CEJ; the fracture was in the tooth/inlay interface, preserving the restoration; b – type II fracture occuring in the RelyX Unicem group: cusp fracture below the CEJ; the fracture was in the tooth/inlay interface, preserving the restoration; c – type IV fracture occuring in the RelyX ARC group: cusp fracture below the CEJ; the fracture was in the composite resin inlay first, preserving the tooth/inlay interface and leaving part of the restoration attached to the cusp.

Table 4 Fracture mode in the groups

Type of fracture	1. Sound teeth	2. Nonrestored cavity	3. RelyX ARC	4. RelyX Unicem	5. Maxcem Elite	6. SeT
I	12		5	1		3
II		12	6	11	12	9
III						
IV			1			
V						

Type I, cusp fracture at the CEJ; type II, cusp fracture below the CEJ; type III, cusp fracture at the CEJ with part of the inlay attached; type IV, cusp fracture below the CEJ with part of the inlay attached; type V, longitudinal fracture dividing the tooth along the axis.

DISCUSSION

The null hypothesis of the present study was rejected, as there was a difference in cuspal deflection and fracture resistance between the groups.

Cuspal deflection is a nondestructive method that verifies the deformation of the cusps when a load is applied in the occlusal region. The clinical importance of cuspal deflection is that an increase in deflection results in a greater degree of deformation, thereby increasing the potential for fatigue failure. This type of failure, characterized by fracture in the presence of stress far below the maximum strength of the restored tooth, occurs in most dental fractures.[3]

In this study, a standard occlusal load of 200 N was applied to perform the cuspal deflection test. The load of 200 N can be applied without the risk of tooth fracture,[21] as it is intermediate between 100 and 300 N, which corresponds to the range of normal biting force for maxillary premolars.[40,42] Cuspal deflection was measured before and after cyclic fatigue loading with the objective of analyzing the stiffness stability of the restored teeth after artificial aging. This evaluation is important, since the restored teeth are submitted to occlusal stresses in the oral environment.

Although the methodology used tried to avoid the influence of confounding variables, the variability of the cuspal deflection values was high, and the non-parametric test had to be applied. There was a statistically difference between group 1 (sound teeth; 3 μm) and group 2 (teeth with a nonrestored prepared cavity; 69 μm). This small cuspal deflection of the sound teeth is due to the very stiff behavior of sound teeth under load.[21] Loss of dental structure, such as enamel and dentin, causes a decrease in tooth stiffness, and consequently there is an increase in cuspal deflection under occlusal loads.[15,21] Therefore, it is necessary to try to recover this stiffness when restoring the tooth.

RelyX Unicem was the only self-adhesive resin cement that did not differ statistically from the sound-tooth group (3 μm) before the fatigue loading. The bond mechanism of RelyX Unicem to tooth structures appears to be chemical rather than micromechanical in nature.[14] This bond is established by the specific multifunctional phosphoric-acid methacrylate, which is ionized at the time of mixing and reacts with the hydroxyapatite of the mineral tissues of the tooth.[14] According to the manufacturer, Maxcem Elite contains glycerol dimethacrylate dihydrogen phosphate monomer (GPDM) and other adhesive monomers to improve wettability. GPDM is purportedly responsible in part for its self-etching and adhesive properties (Technical Bulletin, 2007).

Various factors may influence the adhesion of self-adhesive resin cements to dentin, including chemical composition, viscosity and pH. Maxcem Elite tends to maintain its low pH (2.2), while the pH of RelyX Unicem increases after 48 h (from 2.8 to 7.0).[18] Although a low pH is necessary for adequate tooth etching, it has been speculated that if the pH is maintained for a long time, as in the case of Maxcem Elite, there could be an adverse effect on the bond between this cement and the dental structure.[18] Studies have shown higher bond strength to dental substrate for RelyX Unicem in comparison with Maxcem Elite.[16,26] As the bond strength between the luting agent and the tooth is important to reinforce the weakened tooth,[6] this difference in bond strength could explain the lower cuspal deflection for RelyX Unicem than for Maxcem Elite.

The self-adhesive resin cement SeT contains an acidic monomer that is responsible for etching the tooth surface. However, it is not known exactly what type of acid monomer is used, or whether it has a chemical interaction with the tooth. In a recent study comparing the bonding ability of different self-adhesive resin cements, the adhesion of SeT to dentin did not withstand the cutting methodology used to obtain the test specimens (beams) for evaluation of the microtensile bond strength (personal communication, Dr. Priscila Stona, School of Dentistry of Pontifical Catholic University of Rio Grande do Sul, Brazil). This material probably interacted less with dental substrates than did RelyX Unicem and Maxcem Elite, explaining the highest cuspal deflection.

All self-adhesive resin cements allowed a significant increase in cuspal deflection after cyclic fatigue loading, and the conventional resin cement RelyX ARC was the only material that retained the stiffness of the teeth. The different values in cuspal deflection after fatigue loading may be related to the quality and stability of the adhesion between the resin cements and the tooth structures.

Several studies showed that self-adhesive resin cements perform comparably to multistep systems on coronal dentin,[1,2,11,16,19] while others showed significantly lower bond strengths to dentin.[10,26,41] These resin cements did not cause demineralization of the superficial dentin, and formation of a hybrid layer was not observed.[2,11,28,44] On enamel, self-adhesive resin cements have lower bond strength compared with resin cements requiring an adhesive system.[1,16,26] In the present study, all the inlay margins of the prepared teeth were within enamel. It is likely that the micromechanical retention obtained with the hybrid layer formed on enamel[17] and dentin[30] by the 37% phosphoric acid etching and subsequent adhesive polymerization is important for the bond stability after aging, justifying the lower cuspal deflection of RelyX ARC. An alternative for increasing the bond strength of self-adhesive resin cements was to etch the enamel with phosphoric acid;[11,12,19] however, on dentin, this etching harms the effectiveness of the bond. De Munck et al[11] showed that a weak layer of hydroxyapatite-depleted collagen remained between RelyX Unicem and unaffected dentin, and concluded that this poorly infiltrated collagen mesh is the weak link in the whole adhesive complex.

Among the properties required of a luting agent, its potential for adhesion to restorative materials is of greatest importance. According to Zang and Degrange,[45] the adhesion of self-adhesive resin cements to the restorative material depends on the nature of the multifunctional monomer contained in the formulation, and these luting agents have potential for specific adhesion to selected restorative substrates. In the present study, the internal surface treatment of the composite resin inlays was the same for all groups. The surface was sandblasted with 50- µm aluminum oxide, followed by silane and a bond layer application. According to the study by Fuentes et al,[13] self-adhesive resin cements do not require application of an intermediate agent to microretentive Filtek Z250 overlays to improve the bonding capacity of the dentin/ indirect composite restoration complex. However, these authors evaluated the bond to dentin, and not specifically the bond between self-adhesive resin cements and the composite resin surface with and without a bond layer. We chose to apply a bonding agent because it would facilitate the penetration of resin monomers into surface irregularities allowing micromechanical interlocking.[9] Therefore, the different viscosities and the different penetration abilities of the resin cements into the surface irregularities were eliminated, and the adhesion was established between the resin cements and the bonding agent.

The fracture resistance and mode of fracture were also evaluated in this study. The group of sound teeth presented the highest fracture resistance (1902 N), which differed significantly from the experimental groups; these data concur with previously published studies.[8,35,36,39,43] The enamel is supported by the total dentin volume, making it less prone to fracture, which explains the higher value obtained for the fracture resistance.[23] Among the resin cements used, the RelyX ARC group obtained the highest value (980 N). It seems that the application of an adhesive system on the tooth substrate before the resin cement allows better adhesion at the tooth/restoration interface. Studies have shown that indirect restorations fixed with the adhesive technique provided greater strength to the dental structure compared with the conventional luting technique, eg, zinc phosphate cement.[4] Therefore, the use of adhesive restorations has been recommended for reinforcing remaining dental structures,[27,38] even if the recovery of strength is only partial.[35,39] Composite resin inlays luted with RelyX ARC recovered 51% of the strength of sound teeth.

The fracture resistance in groups luted with self-adhesive resin cements did not differ significantly; the values were lower in comparison with the sound-tooth group and the RelyX ARC group. RelyX Unicem recovered 35% of the resistance of sound teeth; Maxcem Elite recovered 28% and SeT 31%. The fracture resistance of the teeth restored with inlays and luted with self-adhesive resin cements did not differ statistically significantly from the teeth with nonrestored cavities. However, the teeth with nonrestored cavities were not submitted to mechanical fatigue, because it was technically impossible to adapt the plunger of the cyclic loading machine when there was no restoration.

In the sound-tooth group, all fractures were type I (CEJ limit), which might be due to the maximum strength inherent in sound teeth. When a sound tooth is submitted to a compressive load, it is presented with a higher stress concentration in the enamel and dentin around the cervical area, which explains the fractures in this region.[23] In the teeth with nonrestored cavities (group 2) and teeth luted with self-adhesive resin cements (groups 4 to 6), there was a predominance of type II fractures (cuspid fracture below the CEJ). This may be explained by the tooth preparation and loss of tooth volume, both depth and thickness, leading to an increase in stress in the region below the CEJ.[23,25] The loss of dental structure associated with the lower adhesion capacity of the self-adhesive resin cements in comparison with resin cements requiring an adhesive system[1,10,16,26,41] probably contributed to the similar fracture mode found for this category of resin cement and the nonrestored cavities group. RelyX ARC was the only experimental group that had similar numbers of type I and II fractures, showing that the conventional adhesive luting technique (adhesive system + resin cement) favors adhesion and higher tooth preservation in the case of fracture, but does not recover the resistance of the sound tooth. Besides that, one specimen had type IV fracture. In this case, the fracture occurred in the composite resin inlay first, preserving the tooth/inlay interface and leaving part of the restoration attached to the cusp. This finding could be related to the higher adhesion capacity of RelyX ARC to the tooth structure. In general, there was a predominance of type I and type II fractures in the experimental groups. These fractures occurred between the tooth substance and the inlay, indicating that this interface represents the weakest part of the restored tooth, independent of the resin cement used. Nevertheless, the fractures that occurred in the experimental groups allowed recovery of the dental structure, probably because the teeth were restored with composite resin inlays, instead of ceramic inlays. Composite resin has a lower elastic modulus than ceramic; thus, higher loads are absorbed within the composite resin than in ceramic.[32] Therefore, because composite resin transmits less of the applied load to the underlying tooth structure,[22] less severe fractures occurred. Dalpino et al[8] and Silva et al[37] also verified a prevalence of recoverable fractures when the teeth were restored with resin materials.

Transfer of the results of laboratory studies to the clinical situation must be done with caution, because in vitro studies cannot reproduce the real situation in the oral cavity. According to the results obtained, self-adhesive resin cements were less able to maintain the stiffness of the tooth/restoration complex than was the conventional resin cement RelyX ARC. However, clinical studies are necessary to confirm this observation.

CONCLUSION

Despite the limitations of this in vitro study, the following conclusions can be drawn: 1. The composite resin inlays luted with the conventional resin cement RelyX ARC provided lower cuspal deflection after cyclic fatigue loading, as well as higher fracture resistance compared with the self-adhesive resin cements. 2. None of the composite resin inlays luted with the resin cements was capable of recovering the resistance of a sound tooth. 3. Fractures that occurred in the inlays luted with RelyX ARC were more favorable for recovery of the dental structure in comparison with the inlays luted with self-adhesive resin cements.

REFERENCES

1. Abo-Hamar SE, Hiller KA, Jung H, Federlin M, Friedl KH, Schmalz, G. Bond strength of a new universal self-adhesive resin luting cement to dentin and enamel. Clin Oral Invest 2005;9:161-167.
2. Al-Assaf K, Chakmakchi M, Palaghias G, Karanika-Kouma A, Eliades G. Interfacial characteristics of adhesive luting resins and composites with dentine. Dent Mater 2007;23:829-839.
3. Anusavice KJ. Phillips – Dental Materials, ed 10. Rio de Janeiro: Guanabara, 1998:23-68.
4. Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. J Prosthet Dent 2006;95:117-123.
5. Burke FJT. Trends in indirect dentistry: 3. Luting materials. Dent Update 2005;32:257-260.
6. Camacho GB, Gonçalves M, Nonaka T, Osório AB. Fracture strength of restored premolars. Am J Dent 2007;20:121-124.
7. Cerutti A, Flocchini P, Madini L, Mangani F, Putignano A, Docchio F. Effects of bonded composite vs. amalgam on resistance to cuspal deflection for endodontically-treated premolar teeth. Am J Dent 2004;17:295-300.
8. Dalpino PH, Francischone CE, Ishikiriama A, Franco EB. Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly restored with ceramic materials. Am J Dent 2002;15:389-394.
9. D'Arcangelo C, Vanini L. Effect of three surface treatments on the adhesive properties of indirect composite restorations. J Adhes Dent 2007;9:319-326.
10. De Angelis F, Minnoni A, Vitalone LM, Carluccio F, Vadini M, Paolantonio M, D'Arcangelo C. Bond strength evaluation of three self-adhesive luting systems used for cementing composite and porcelain. Oper Dent 2011;36:626-634.
11. De Munck J, Vargas M, Van Landuyt K, Hikita K, Lambrechts P, Van Meerbeek B. Bonding of auto-adhesive luting material to enamel and dentin. Dent Mater 2004;20:963-971.
12. Duarte S Jr, Botta AC, Meire M, Sadan A. Microtensile bond strengths and scanning electron microscopic evaluation of self-adhesive and self-etch resin cements to intact and etched enamel. J Prosthet Dent 2008; 100:203-210.
13. Fuentes MV, Ceballos L, González-López S. Bond strength of self-adhesive resin cements to different treated indirect composites. Clin Oral Invest 2012;[*Epub ahead of print*] DOI 10.1007/s00784-012-0752-y
14. Gerth HUV, Dammaschke T, Züchner H, Schäfer E. Chemical analyses and bonding reaction of RelyX Unicem and Bifix composites – a comparative study. Dent Mater 2006;22:934-941.
15. González-López S, De Haro-Gasquet F, Vilchez-Díaz MA, Ceballos L, Bravo M. Effect of restorative procedures and occlusal loading on cuspal deflection. Oper Dent 2005;30:33-38.
16. Goracci C, Cury AH, Cantoro A, Papacchini F, Tay FR, Ferrari M. Microtensile bond strength and interfacial properties of self-etching and self-adhesive resin cements used to lute composite onlays under different seating forces. J Adhes Dent 2006;8:327-335.
17. Gwinnett AJ, Matsui A. A study of enamel adhesives. The physical relationship between enamel and adhesives. Arch Oral Biol 1967;12:1615-1619.
18. Han L, Okamoto A, Fukushima M, Okiji T. Evaluation of physical properties and surface degradation of self-adhesive resin cements. Dent Mater J 2007;26:906-914.
19. Hikita K, Van Meerbeek B, De Munck J, Ikeda T, Van Landuyt K, Maida T, Lambrechts P, Peumans M. Bonding effectiveness of adhesive luting agents to enamel and dentin. Dent Mater 2007;23:71-80.
20. Jacob SJ, Hedge C, Prasad KD, Shetty M. An in vitro study to evaluate the effect of storage time and application of subsequent layers on the variation in thickness of three commercially available die spacers. Indian J Dent Res 2010;21:92-97.
21. Jantarat J, Palamara JE, Messer HH. An investigation of cuspal deformation and delayed recovery after occlusal loading. J Dent 2001;29:363-370.
22. Jiang W, Bo h, Yongchun G, LongXing N. Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis. J Prosthet Dent 2010;103:6-12.
23. Khera SC, Goel VK, Chen RC, Gurusami SA. Parameters of MOD cavity preparations: a 3-D FEM study, Part II. Oper Dent 1991;16:43-54.
24. Kumbuloglu O, Lassila LV, User A, Vallittu PK. A study of the physical and chemical properties of four resin composite luting cements. Int J Prosthodont 2004;17:357-363.
25. Lin CL, Chang CH, Ko CC. Multifactorial analysis of an MOD restored human premolar using auto-mesh finite element approach. J Oral Rehabil 2001;28:576-586.
26. Lührs AK, Guhr S, Günay H, Geurtsen W. Shear bond strength of self-adhesive resins compared to resin cements etch and rinse to enamel and dentin in vitro. Clin Oral Invest 2010;14:193-199.
27. Monga P, Sharma V, Kumar S. Comparison of fracture resistance of endodontically treated teeth using different coronal restorative materials: an in vitro study. J Conserv Dent 2009;12:154-159.
28. Monticelli F, Osorio R, Mazzitelli C, Ferrari M, Toledano M. Limited decalcification/diffusion of self-adhesive cements into dentin. J Dent Res 2008;87:974-979.
29. Morin D, Delong R, Douglas WH. Cusp reinforcement by the acid etch technique. J Dent Res 1984;63:1075-1078.
30. Nakabayashi N, Kojima M, Masuhara E. The promotion of adhesion by the infiltration of monomers into tooth substrate. J Biomed Mater Res 1982;16:265-273.
31. Nakamura T, Wakabayashi K, Kinuta S, Nishida H, Miyamae M, Yatani H. Mechanical properties of new self-adhesive resin-based cement. J Prosthodont Res 2010;54:59-64.
32. Peutzfeldt A. Indirect resin and ceramic systems. Oper Dent 2001;6:153-176.
33. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989;15:512-516.
34. Reeves GW, Lentz DL, O'Hara JW, McDaniel MD, Tobert WE. Comparison of marginal adaptation between direct and indirect composites. Oper Dent 1992;17:210-214.
35. Santos MJMC, Bezerra RB. Fracture resistance of maxillary premolars restored with direct and indirect adhesive techniques. J Can Dent Assoc 2005;71:585-585d.
36. Shahrbaf S, Mirzakouchaki B, Oskoui SS, Kahnamoui MA. The effect of marginal ridge thickness on the resistance of endodontically-treated, composite restored maxillary premolars. Oper Dent 2007;32:285-290.
37. Silva SBA, Hilgert LA, Busato A LS. Fracture resistance of resin-based composite and ceramic inlays luted to sound human teeth. Am J Dent 2004;17:404-406.
38. Soares PV, Santos-Filho PC, Queiroz EC, Araújo TC, Campos RE, AraújoCA, Soares CJ. Fracture resistance and stress distribution in endodontically treated maxillary premolars restored with composite resin. J Prosthodont 2007;17:114-119.
39. Steele A, Johnson B. In vitro fracture strength of endodontically treated premolars. J Endod 1999;25:6-8.
40. Tortopidis D, Lyons MF, Baxendale RH, Gilmour WH. The variability of bite force measurement between sessions, in different positions within the dental arch. J Oral Rehabil 1998;25:681-686.
41. Viotti RG, Kasaz A, Pena CE, Alexandre RS, Arrais CA, Reis AF. Microtensile bond strength of new self-adhesive luting agents and conventional multistep systems. J Prosthet Dent 2009;102:306-312.
42. Widmalm SE, Ericsson SG. Maximal bite force with centric and eccentric load. J Oral Rehabil 1982;9:445-450.
43. Yamada Y, Tsubota Y, Fukushima S. Effect of restoration method on fracture resistance of endodontically treated maxillary premolars. Int J Prosthodont 2004;17:94-98.
44. Yang B, Ludwig K, Adelung R, Kern M. Micro-tensile bond strength of three luting resins to human regional dentin. Dent Mater 2006;22: 45-56.
45. Zhang C, Degrange M. Shear bond strengths of self-adhesive luting resins fixing dentine to different restorative materials. J Biomater Sci Polym 2010;21:593-608.

Clinical relevance: Composite resin inlays luted with the conventional resin cement RelyX ARC may more effectively maintain the stiffness of the restored teeth after aging in comparison with self-adhesive resin cements.