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Fracture resistance of re-attached coronal fragments – influence of different adhesive materials and bevel preparation

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Abstract – The purpose of this study was to investigate the fracture resistance of re-attached coronal fragments of teeth using different materials and tooth preparations. Seventy-two recently extracted bovine incisors were selected. Eight incisors were maintained without any preparation as a control group. The incisal third of the other teeth was sectioned using a diamond saw. In one group ($n = 32$), a 2-mm bevel was prepared, whereas in the second group no preparation was made ($n = 32$). The specimens (beveled and non-beveled) were divided in four groups ($n = 8$) and re-attached with the following materials: a dual-cured resin cement RelyX ARC (RX); a chemically cured composite Bisfil 2B (B2); a light-cured composite Z250 (Z2); and a one-bottle adhesive Single Bond (SB). The bevel region was restored with adhesive and composite. All materials were used according to manufacturer's directions. A light-curing unit was used to polymerize the materials. Specimens were stored in saline solution for 72 h. De-bonding procedures were performed in a testing machine with cross-head speed of 0.6 mm min^{-1}. The load was applied in the incisal third. The resistance to fracture for control group was 70 (7) kg. The fracture resistance for non-beveled and beveled specimens were: SB, 3.3 (2.4) and 17.0 (4.1); RX, 11.5 (3.0) and 16.3 (3.1); Z2, 14.4 (4.2) and 20.5 (1.7); and B2, 19.5 (3.5) and 32.5 (7.4) kg. Analysis of variance (ANOVA) and Fisher's protected least significant difference (PLSD) test disclosed significant influence for materials and cavity designs ($P = 0.001$). The highest failure loads were obtained with the B2 group and then with the Z2 with either bevel or non-bevel. RX produced lower failure loads than the restorative composites. The lowest failure load was obtained with SB in the non-beveled group. No technique studied was able to attain the fracture resistance of the control group and both materials and tooth preparation influenced the fracture resistance.

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Injury to anterior teeth is a relatively common event. Coronal fracture is the most frequent form of acute dental injury. Twenty-five per cent of the American population between 6 and 50 years has suffered some injury in the upper and lower incisors (1). It has been suggested that incidence of dental trauma in the near future will overcome the incidence of caries and periodontal disease in children and teenagers (2). Common restorative treatments such as laminate veneers or full-coverage restorations tend to sacrifice healthy tooth structure and challenge clinicians to match the adjacent unrestored teeth. With composite restorations, there will be difficulties to match the color and they will present higher wear than the enamel structure (3).

The development of adhesive materials has provided new perspective in the treatment of fractured teeth (4–10). The re-attachment of the displaced fragment is a simple and low-cost method, which has the potential to maintain the incisal function in dental structure, providing better and long-lasting esthetic results, increased wear resistance, and thus improved function (11, 12). However, re-attachment is only possible when the fragment is recovered after the trauma, and the fragment is intact with a good adaptation to the remaining tooth. In a long-term survival of fragment bonding in a multicenter clinical study, Andreasen et al. (13) concluded that the good fragment retention, acceptable esthetics, and pulp vitality observed indicated that re-attachment of the coronal fragment was a realistic alternative to the placement of conventional resin-composite restorations.

Generally, the resistance to fracture of the re-attached teeth will not be the same as the intact teeth (9, 15). However, depending on the restorative technique and the material used, the resistance to fracture could be similar to non-fractured teeth (16). There is no agreement in the literature about the best technique to re-attach the fragments and mostly the choice is empirical. Tan & Tjan (17) disclosed a significant influence of the margin design in the resistance to fracture of composite restorations in Class IV fractured teeth. A 2-mm bevel or chamfer provided the highest resistance when compared to a butt joint or a 1-mm bevel or chamfer. Better resistance to fracture of re-attached teeth was found with a circumferential bevel or chamfer than in teeth with no preparation (6, 18). Evaluating different margin designs for tooth re-attachment, Reis et al. (16) verified that overcontour, an internal groove and composite buildup technique were able to restore the fracture resistance of human incisors to values similar to those from non-fractured incisors. Conversely, the re-attachment of the fragments only with dentin-bonding agent provided less than 40% of the control resistance, while in the chamfer group the resistance reached 60%. The resistance to fracture could be directly related to the surface area of adhesion.

The material to be used for bonding the fractured fragment is also controversial. Andreasen et al. (15) concluded that materials with relatively high-mechanical properties, such as resin, should be used in conjunction with adhesive instead of the application of adhesive only in order to resist the functional stresses. In a recent study, Farik et al. (19) verified that most of fifth-generation bonding agents increased the fracture resistance of re-attached coronal fragments when used in conjunction with an unfilled resin. Because, sometimes the fracture was extensive involving a large area of dentine, it could be difficult to completely polymerize the resin with light-curing units through dental tissues (20). Then, a chemically cured or a dual-cured material might be necessary to overcome this problem. However, Dean et al. (6) found no significant differences between light- or chemically cured composites to re-attach fractured teeth. Investigating different materials (dual- and light-cured), Reis et al. (21) did not find any significant influence of the material in the re-attachment fracture resistance.

The purpose of this study was to investigate the resistance to fracture of bovine incisors re-attached with no preparation or with a bevel using five adhesive materials. The hypotheses to be tested were that bevel preparation and different adhesive materials did not influence the resistance to fracture of re-attached coronal fragments.

Materials and methods

Tooth preparation

Seventy-two recently extracted bovine incisors with similar dimensions were selected from bovines killed at 30 months. The teeth were scaled to remove soft tissue and then they were stored in sodium azide solution until testing.

Eight incisors were tested intact, as a control group. In the remaining teeth, standardized fragments were obtained by cutting the incisal edge with a diamond saw, perpendicular to the long axis of the tooth (18). The fragments measured 4 mm from the incisal edge (inciso-gingivally). In half of the specimens ($n = 32$), a 2-mm circumferential bevel was prepared in the fractured tooth and in the fragment. Bevel preparation was made at 45°, using a diamond bur in high speed, under air–water cooling. This procedure was made with the aim to increase the amount of adhesive materials in the re-attachment site. No preparations were made in the remaining 32 teeth.

Restoration of the fractured teeth

Manufacturers and batch numbers of the tested materials are presented in Table 1. Prior to the re-attachment, all specimens were submitted to prophylaxis with pumice. The two groups (beveled or non-beveled) were divided in four subgroups ($n = 8$) and the fragments were re-attached using one of the following materials:

RelyX ARC (RX) group

Dual-cured adhesive resin cement RX (3M ESPE, St Paul, MN, USA) was used. Both tooth and fragment were etched with 37% phosphoric acid for 20 s. After

Table 1. Commercial materials used in the experiment

Brand name	Abbreviation	Manufacturer	Batch no.
One-Step Plus	OS	Bisco Inc, Schaumburg, IL, USA	0200000711
Single Bond	SB	3M ESPE, St Paul, MN, USA	1GA
Filtek Z250	Z2	3M ESPE, St Paul, MN, USA	9AM
RelyX ARC	RX	3M ESPE, St Paul, MN, USA	CCCC
Bisfil 2B	B2	Bisco Inc, Schaumburg, IL, USA	0200000722

washing and gently drying, maintaining the dentine moist, a one-bottle dental adhesive (Single Bond (SB), 3M ESPE) was applied, followed by the placement of a thin layer of mixed catalyst and base pastes of the cement. To facilitate the adaptation of the fragment, the bonding agent was not light cured. The coronal fragment was adapted to the remaining dental structure and re-attached using hand pressure. The excess material was removed before polymerization. The resin cement was polymerized for 40 s in each surface, buccal and lingual, with an XL 3000 light-curing unit (3M ESPE).

Bisfil 2B (B2) group

Chemically cured resin composite B2 (Bisco Co, Schaumburg, IL, USA) was used for the re-attachment. Dental structure and fragments were conditioned with 37% phosphoric acid for 20 s. A one-bottle dental-bonding agent (One-Step Plus, Bisco) was applied over the conditioned and moist surfaces. Catalyst and base pastes were mixed and placed over the treated surfaces in a thin layer. After excess removal, the fragment was maintained in position with hand pressure for 5 min to allow the polymerization of the material.

Filtek Z250 (Z2) group

Light-cured resin composite Z2 (3M ESPE) was employed as the intermediate material. Both fragment and remaining tooth structure were conditioned with 37% phosphoric acid for 20 s. Following washing and gently drying, keeping the dentine moist, a one-bottle dental-bonding agent (SB, 3M ESPE) was applied. A thin layer of Z2 was placed over the conditioned surfaces and the fragment was adapted. After excess removal, the interface was light cured for 40 s in buccal and lingual directions.

SB group

A one-bottle dental-bonding agent SB (3M ESPE) was used. After 37% phosphoric acid etching, the adhesive system was applied on moist dental surfaces and the fragment was adapted. The polymerization took place for 40 s in each surface.

The XL 3000 light-curing unit was used with an energy output higher than 450 mW cm^{-2} as measured by the radiometer.

In those beveled groups after re-attachment procedures, the bevel region was acid etched and then treated with the adhesive system (SB) and incrementally filled with light cured composite resin (Z2). To polymerize materials in the bevel region, the photo activation was made in both buccal and lingual surfaces for 40 s in each direction. The re-attached teeth were stored in 0.9% saline solution for 72 h.

De-bonding procedures

Using acrylic resin, the specimens were embedded in a PVC matrix just next to the bond line. Then, the specimens were confined in a holder and adapted in a universal testing machine (Instron Corp., Canton, MA, USA).

The perpendicular load was applied at the incisal third in a buccal-to-lingual direction by means of a small stainless steel blade placed at the end of a jig held in the cross-head of the universal testing machine. The cross-head speed was set at 0.6 mm min^{-1} (16). A small notch was made in the incisal third, near the bond line, with a diamond saw to facilitate the accommodation of the blade and to ensure the application of the load in the same point in all specimens. The force (kg) required to fracture the tooth was recorded and resistance to fracture was calculated.

Statistical analysis

A two-way ANOVA (StatView, SAS Institute, Cary, NC, USA) was used to investigate the two factors, cavity design and adhesive materials, and their interaction. A Fisher's PLSD *post hoc* test was run to clarify the possible differences among means at a 0.05 level of significance.

Results

Table 2 lists the data for failure loads for the four bonding conditions for each preparation technique (non-bevel versus bevel). The ANOVA of the data is summarized in Table 3. Both factors of bonding condition and preparation technique were significant ($P=$ 0.001) with a power of 1.00. The interaction was also significant ($P=0.0029$) with a power of 0.92.

Table 2. Mean loads (kg) at failure for bonding conditions for unprepared teeth and teeth prepared with a bevel

Bonding condition	No preparation	Bevel
Single Bond	3.3 (2.4)	17.0 (4.1)
RelyX ARC	11.5 (3.0)	16.3 (3.1)
Filtek Z250	14.4 (4.2)	20.5 (1.7)
Bisfil 2B	19.5 (3.5)	32.5 (7.4)

Mean resistance of fracture for intact bovine teeth was 70 (7) kg.
Mean with standard deviations in parentheses ($n = 8$). Fisher's PLSD intervals for comparisons of means among four bonding conditions and between prepared and unprepared teeth were 2.8 and 2.0 kg, respectively, at the 0.05 level of significance.

For the bonding conditions tested, preparations with bevels were more resistant to fracture ($P=$ 0.001). The highest failure loads were obtained for the chemically cured resin composite (B2) and followed by the light-cured composite (Z2) with either bevel preparation or no preparation. The dual-cured resin cement (RX) produced lower failure loads than the resin composites. The lowest failure load was observed when the bonding agent (SB) was used alone, this load being approximately 10% of the failure load provided by the beveled group with the chemically cured composite. However, when the bonding agent alone was used in conjunction with a bevel preparation, the failure load increased almost five times (Fig. 1).

The mean fracture resistance obtained for the non-prepared bovine incisors was 70 (7) kg. When comparing this resistance with the mean resistances to fracture provided for the different combinations of adhesive materials and technique employed in this study, it was found that none of them achieved at least 50% of the fracture resistance exhibited for the control group (Fig. 1).

The highest repair fracture resistance was provided by the B2 with bevel (46% of control). B2 with no

Table 3. Analysis of variance (ANOVA)

Source of variation	Sum of squares	df	Mean square	F	P-value	Power
Among materials	2208	3	736	45.7	0.0001	1.00
Between preparations	1413	1	1414	87.8	0.0001	1.00
Interaction M × P	254	3	84.7	5.26	0.0029	0.92
Residual	902	56	16.1			

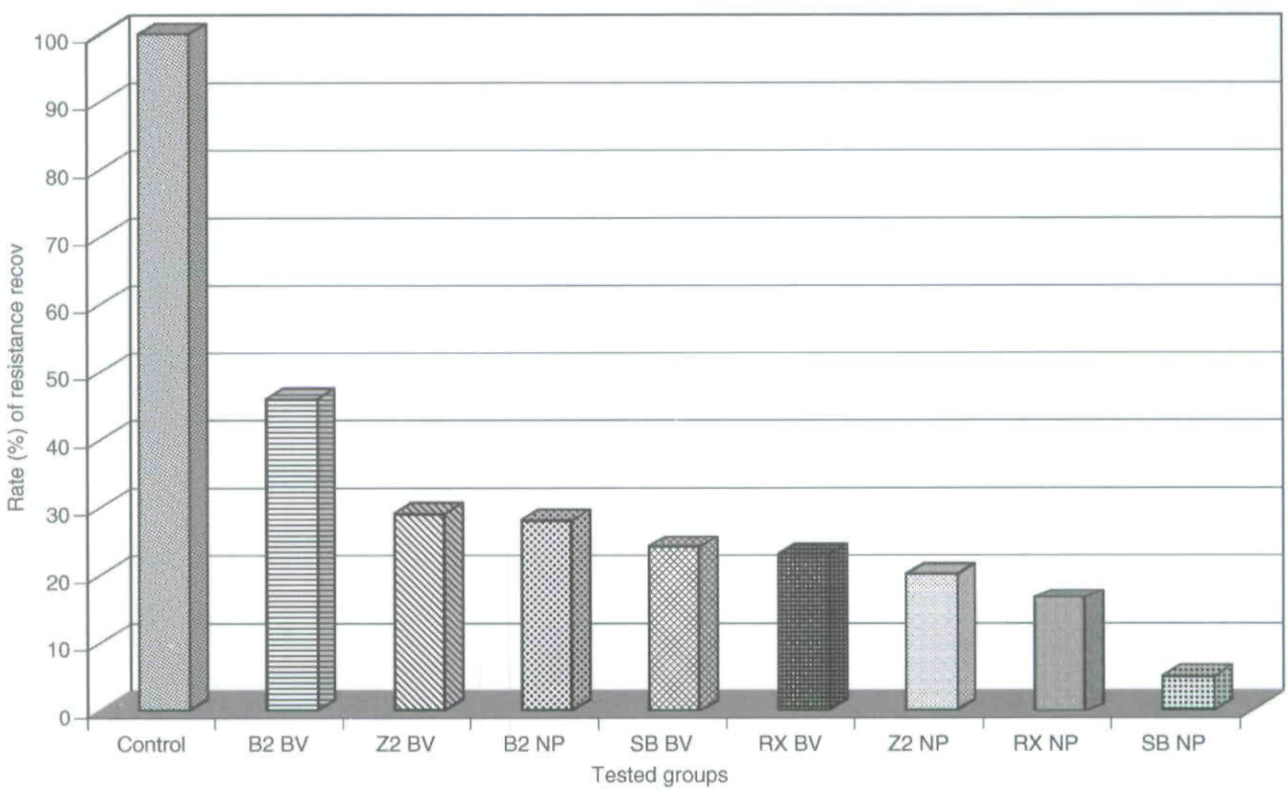

Fig. 1. Recovering rate of fracture resistance in relation to control group for tested materials and conditions.

preparation and Z2 with bevel increased the fracture resistance to about one-third of the control group fracture resistance (28 and 29%, respectively), while Z2 without preparation provided a resistance of 20% of the control group fracture resistance. Fracture resistance about 25% of the control teeth fracture resistance was obtained with the dentine bonding agent and the dual-cured resin cements when they were combined with bevel. The dual-cured resin cement without bevel gave 16% of the control group fracture resistance. However, the worst result was obtained when the dentin-bonding agent was used alone, with a fracture resistance lower than 5% of the fracture resistance of the control group.

Discussion

In the present study bovine teeth were used to perform the tests. Human teeth are preferred for *in vitro* tests. However, preventive approaches in dentistry have reduced the availability of human teeth, and ethical problems have limited their use. Bovine teeth had been reported as an acceptable substitute for human teeth, and the bond strengths obtained for bovine and human teeth were similar in *in vitro* studies (22, 23), except in deep dentine (24). Also, the morphology of the bovine enamel and dentine resembled that of human enamel and dentine (25, 26).

The cross-head speed can effectively influence the bonding of fractured teeth. Lower fracture strength will be produced at $500\ \mathrm{mm\ min^{-1}}$ than at $1\ \mathrm{mm\ min^{-1}}$ (11, 19). In fact, the load used in this study will not simulate the clinical condition, but this cross-head speed is usually employed in similar tests (16, 21).

Re-attachment of coronal fragments is an important technique for restoring fractured teeth and provides advantages over resin-composite restoration, including better esthetic appearance, maintenance of tooth form and color, minimal tooth loss, increased wear resistance, and, thus, improved function (12). The simple and conservative technique, the good fragment retention and the satisfactory esthetics indicate that re-attachment of the coronal fragment is a realistic alternative to placement of conventional resin composite restorations in the management of fractured anterior teeth (14).

The results of this study demonstrated that neither the bevel nor the different materials were able to attain the fracture resistance obtained from intact teeth, which is in accordance with previous findings in literature (8, 9, 15, 27). In such a situation, the patient should be cautioned to limit the function of the fractured teeth. In an interesting study, Reis et al. (16) verified that specimens only bonded or prepared with a chamfer and bonded had a fracture resistance of 37 and 60%, respectively, when compared to intact incisive human teeth. These authors have also verified that other restorative techniques (internal grooves, overcontouring and resin composite restoration) achieved more than 90% of the fracture resistance of the intact teeth. They attributed the increased fracture resistance in such techniques to the higher bonding area obtained after preparation. Conversely, some studies have found similar resistance to fracture between intact teeth and re-attached teeth, even when the fragment was only bonded to the remaining dental structure (10, 19). The best fracture resistance in our study was about 50% of the control group, which is similar to results from one study using bovine incisors (27). The differences among results of different studies could be also related to the various methodologies used to perform the tests.

There was significantly higher fracture strength in the specimens re-attached after bevel preparation that in non-beveled specimens in our study. This result confirms that reported by Reis et al. (16). Also, Reis et al. (21) reinforced that specimens bonded without preparation showed a fracture resistance significantly lower than specimens re-attached with a chamfer. In addition to the higher surface area provided by beveling, the presence of composite resin in the interface, with better mechanical properties, could be highlighted as a reason for enhanced resistance in the beveled group for all materials tested (15, 18). Despite the enhanced strength, the presence of composite in the re-attachment interface may impair the long-term esthetics, as composite may change the color with aging (28).

In relation to the material used for bonding the incisal edge of the bovine incisors, the best fracture resistance was obtained with the chemically cured composite resin, followed by the light-cured composite resin, and then the resin cement. The lowest fracture resistance was found when using only the dentine bonding agent.

As there is a decrease in light intensity with the interposition of dental tissue, the chemical cure of the B2 might have provided a better polymerization than that observed in the other groups. Despite the use of a high-intensity light curing unit with polymerization for buccal and lingual surfaces, these procedures might not be sufficient to produce an adequate degree of conversion, because the bovine teeth presented a larger thickness compared to human teeth. A higher degree of conversion of monomers can lead to higher bond strength of composites to the dental structure (29). Demarco et al. (30) verified that the dual-cured adhesive systems had a tendency to exhibit better bond strengths over time than the light-cured adhesive systems (7 days). However, the dual-cured resin cement (RX) did not produce a fracture resistance similar to that of the chemically cured resin. As B2 is a heavy-filled composite resin, it may have better mechanical properties than the resin cement (21). Theoretically, a resin that is slightly elastic might act as a shock absorber to withstand functional stress (15). However, the low-flexural strength of such material could reduce the resistance to de-bonding. In addition, the materials were used with different fifth-generation dentine bonding agents. While B2 was used with One-Step Plus, RX was applied together with SB. The composition and the mechanism of action from adhesives of the same generation can influence the bonding ability (31). Nevertheless, investigating the performance of different adhesive system in the re-attachment of fractured teeth, Farik et al. (19) did not find any significant difference between One-Step and SB.

One problem when using a chemically cured or a dual-cured material is the possibility of color changing because of the presence of amine accelerator (32), impairing the esthetics over time. This shortcoming could be reduced by applying the combination of the chemically cured resin in the re-attachment interface and a light-cured resin composite in the bevel region. Such combination produced the best resistance to fracture in our study and may be a useful technique to be applied in the dental clinic because it combines the esthetics and the resistance. Previously, Dean et al. (6) found similar results after re-attachment using light-cured or chemically cured cements. Reis et al. (21) showed no significant difference in the re-attachment resistance using resin cement in light- or dual-cured version. However, these authors tested their specimens after 24 h. In our study, the specimens were tested after 72 h. Perhaps the polymerization process might continue after 24 h, ensuring better degree of conversion and consequently more stable bond strengths (30).

Some results have indicated that the fracture resistance using some dentine bonding agents alone, without any additional tooth preparation, is the same as that those obtained with intact teeth (10). In the present study, the fracture resistance produced for specimens only bonded with adhesive system (SB) was less than 5% of that produced in intact bovine teeth. In our study, the incisal edge was sectioned using a diamond disk. This is not similar to what happens in a tooth fracture. The disposition of the enamel prisms will not be the same and also the fragment probably will not fit to the remaining tooth structure as precisely as in case of fracture (21). This situation could make it difficult to use an adhesive as the unique re-attachment agent as a thicker layer of material may be necessary to fill the gaps present in the interface. Our results tend to confirm the Farik et al. (19) hypothesis. Total-etch, one-bottle dental bonding agents are a combination of the primer and adhesive in the same bottle, and the amount of resin present in these adhesive systems may not be sufficient to ensure an appropriate bonding when used for re-attachment purpose. Even the application of an unfilled resin in addition to the one-bottle adhesive systems will significantly enhance the re-attachment resistance (19). Pagliarini et al. (33) have advised that for the re-attachment of fractured tooth fragments, multiple-step adhesives may guarantee a bonding force stronger than one-bottle adhesives because of the higher resin content in such adhesive systems. Not only the composition of the adhesive system is important but also the technique for its application, as differences, for example, in the wetting of dental substrate could impair the adhesive properties (34). Thus, it is important to follow the manufacturer's indications, which was performed in this study, using the adhesive systems with moist dentine. When evaluating the results of the present study, the combination of the adhesive system with the resin composite (in bevel group) increased the fracture resistance five times when compared to the application of the adhesive alone. De Santis et al. (18) have also shown that a circumferential double chamfer prepared around the external cut interface and filled with light-cured resin composite improved the static and fatigue bending properties when compared to re-attached bovine incisors using adhesive system alone. In relation to the light-cured composite, it recovered 20 or 30% of the fracture resistance of intact bovine incisors, when applied without preparation or with a bevel, respectively. The filler content of this heavy-filled composite provides better mechanical properties and thus could reinforce the re-attachment interface (15). Nevertheless, because both the light-cured and the chemically cured composites are heavy filled, they may not flow adequately in the re-attachment site (35), making good apposition between the fragment and the tooth difficult, particularly when there is small loss of dental structure after coronal fracture. Despite this fact, improved fracture resistance was not observed using a flowable resin for re-attachment when compared to a hybrid resin composite (21).

There are promising findings in the present study; however, the resistance to fracture found in different techniques were not able to restore the resistance to fracture of the intact bovine teeth. Thus, the investigation of new materials and techniques is necessary to improve the resistance and the longevity of re-attachment of coronal fragments.

The hypotheses tested were rejected as both the presence of a bevel and the type of material employed for re-attachment influenced the fracture resistance of re-attached bovine incisors.

Conclusions

None of the techniques tested provided fracture resistance similar to that found with the intact bovine incisors. The presence of a bevel increased the resistance to fracture in all materials used for re-attachment. The adhesive materials provided different levels of fracture resistance, with the best fracture resistance obtained with the chemically cured composite in the beveled specimens and the worst fracture resistance obtained with the bonded specimens with adhesive system alone.

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