Dental Traumatology

Dental Traumatology 2010; **26**: 315–322; doi: 10.1111/j.1600-9657.2010.00906.x

Reattachment of anterior fractured teeth: effect of materials and techniques on impact strength

Renata Camila Bruschi-Alonso[1], Roberta Caroline Bruschi Alonso[2], Gisele Maria Correr[3], Marcelo Corrêa Alves[4], Hugo Roberto Lewgoy[2], Mário Alexandre Coelho Sinhoreti[1], Regina Maria Puppin-Rontani[5], Lourenço Correr-Sobrinho[1]

[1]Department of Restorative Dentistry, Dental Materials Area, Piracicaba Dental School – UNICAMP, Piracicaba-SP; [2]School of Dentistry – Bandeirante University of São Paulo – UNIBAN BRASIL, São Paulo-SP; [3]Dentistry Graduate Program, Positivo University, Curitiba-PR; [4]Department of Morphology, Piracicaba Dental School – UNICAMP, Piracicaba-SP; [5]Department of Pediatric Dentistry, Pediatric Dentistry Area, Piracicaba Dental School – UNICAMP, Piracicaba, São Paulo, Brazil

Correspondence to: Roberta Caroline Bruschi Alonso, Bandeirante University of São Paulo – UNIBAN Brasil, School of Dentistry – Biomaterials, Rua Maria Candida, 1813 – Bloco G – 6º Andar, São Paulo – SP 02071-013, Brazil
Tel.: 55 11 2967 9058
Fax: 55 11 2972 9028
e-mail: robalonso@yahoo.com

Accepted 26 March, 2010

Abstract – *Background/Aim*: The reattachment of dental fragments, as a conservative treatment, should be the first choice to restore fractured teeth. Therefore, the aim of this study was to evaluate the effect of different materials and reattachment techniques on impact strength of bovine incisors. *Material and Methods*: Standardized fragments were obtained when 80 crowns were sectioned 12 mm from the incisal edge. Teeth were mounted in PVC rings, embedded in acrylic resin and polyether to simulate bone support and periodontal ligament. Specimens were distributed in nine groups ($n = 10$), according to the reattachment technique (Direct bonding or Circumferential chamfer); the adhesive system (Single Bond or Clearfil SE Bond); and the intermediated material (Filtek Z350 Flow or Rely X CRA). Sound teeth composed the control group. Circumferential chamfer was prepared after the bonding of the fragment by means of a spherical point and filled with the composite Filtek Z250. The impact strength was evaluated in a universal testing machine Instron. A compressive load was applied at a crosshead speed of 500 mm min^{-1} on the buccal surface, 2 mm from the incisal edge. Data were submitted to ANOVA and Ryan–Einot–Gabriel–Welsch Multiple Range test (5%). *Results*: Mean value of impact strength for control group was 64.8 Kgf. The fragment reattachment using Circumferential chamfer was significantly superior to Direct Bonding. The use of Single Bond significantly increased the impact strength when compared to the use of Clearfil SE. There was no significant difference among Rely X and Filtek X350 Flow. *Conclusion*: No technique or material, when individually considered, was capable of achieving the mechanical strength of the sound teeth; however, the association of reattachment technique Circumferential chamfer with bonding system Single Bond could approximate the immediate impact strength of the restored teeth to that observed in the sound teeth.

Fracture of the anterior teeth by trauma is the most frequent type of injury in the permanent dentition, especially among children from 9 to 11 years old (1, 2). The most affected teeth are maxillary incisors due to their anterior position and protrusion caused by the eruptive process (2, 3).

Several alternatives have been developed to restore the fractured crown, as: resin crowns, stainless steel crowns, orthodontic bands, pin-retained resin, porcelain jacket crowns, porcelain bonded crowns and resin composite restorations (4–7). All these alternatives are reliable and may recover the mechanical strength of the fractured teeth (4–6). However, these techniques are not conservative, require wear of sound dental structure, and have some technical difficulties to obtain perfect tooth contour, color and translucence to match it to the remaining crown portion. Besides, they are time-consuming and high priced.

Considering the disadvantages presented by the conventional restorative techniques, Chosack & Eidelman (8), in 1964, have proposed the restoration of fractured crowns using the dental fragment. However, adequate retention of the fragments could only be achieved with the advent of adhesive dentistry. At present, reattachment of fractured tooth fragments should be the first choice to restore fractured teeth (9–12). This technique offers several advantages over other techniques. It is a conservative procedure. It provides total aesthetical recovery, because the tooth contour, color, translucence, and surface texture are the same of the natural tooth (13–15). It also provides color stability over time and wear at similar rate as the other teeth (13, 14). The clinical procedure is safe and simple, therefore less time in chair is required, which might reduce the cost of the treatment (13–15).

Several techniques have been proposed for reattaching the fragment to the remaining tooth: simple reattachment using only adhesive systems without additional preparation (10, 12, 16–19); simple reattachment using an adhesive system associated with an intermediated material (9, 11, 12, 18–20); enamel beveling before the reattachment (19, 21–23); external chamfer (circumferential or partial) in the fracture line after the reattachment (9, 10, 18, 24); V-shaped internal enamel groove (25); internal dentin groove (9, 18, 22, 23); complete remove of dentin from the fragment before reattachment (26); and overcontour with a thin composite layer (3, 9, 18).

The simple reattachment using adhesive systems associated or not with intermediate materials without additional preparation is the less invasive technique and offers the advantage of better esthetic. However, many studies showed that with this technique, the restored teeth does not recover the original mechanical strength (9–11, 19), in fact, the possibility of debonding of the fragment is higher if teeth is submitted to any impact.

The beveling of the enamel margins of tooth and fragment before reattachment of the fragment can improve the retention and mask the finishing line with a resin composite (21, 22). However, this technique requires additional enamel preparation, and in certain cases, the precise fit between the segments is lost, which makes the correct positioning of the fragment more difficult. For this reason, the chamfer technique was developed. In this technique, a chamfer is created in fracture line after performing the bonding procedure, solving the adaptation problems. Both techniques described above require the placement of a resin composite on the buccal surface of the tooth, which may compromise long-term esthetics, due to the abrasion and discoloration process that may occur in composite when exposed over time to the oral environment.

Besides the innumerous techniques to reattach fragments in fractured teeth, several materials (including adhesive systems and intermediated materials) have also been used. Badami et al. (27) and Farik et al. (28) showed that the fracture strength of teeth submitted to reattachment depends on the adhesive system employed. Pagliarini et al. (17) have observed that fractured teeth submitted to reattachment show higher fracture strength when conventional total-etch adhesive system is employed instead of self-etching systems. Conversely, according to Sengun et al. (29), self-etch and total-etch adhesive systems are appropriated to fragment reattachment in fractured teeth; there is no significant difference among them considering shear bond strength. For now, the studies have pointed out the use of conventional total-etch adhesive systems on fragment reattachment in fractured teeth (9, 11, 17, 20). Few studies employing self-etch adhesives systems were found (17, 29), and there was contradiction on the results.

As intermediated materials, light- dual- or self-cured luting cements, as well as conventional or flowable composites, were proposed (11, 30). Reis et al. (11) claimed that the use of an intermediated material additionally to adhesive system can improve the mechanical properties of the interface, with some influence on the impact strength of the restored teeth (3).

Another aspect of the reattachment procedure in fractured teeth is the longevity. According to Andreasen et al. (24), around 50% of reattached fragments were debonded in 2.5 years. In most cases, the failure was due to new traumas and unphysiologic use of the restored teeth. Thus, the relative low longevity of the restoration of fractured teeth with reattachment techniques justifies the search for new materials and techniques that could improve durability of this kind of restoration. The aim of this study was to evaluate the effect of different materials and reattachment techniques on impact strength of bovine incisors.

Materials and methods

Ninety mandibular bovine incisors were obtained from animals of similar age (approximately 30 months). The teeth were selected according to the dimensions of the crown (25 ± 1 mm length inciso-cervical e 15 ± 1 mm width mesio-distal). Dissected teeth were visually examined for damage using 4× magnification. The extracted teeth were frozen and stored in a 0.5% Chloramine T solution for not more than a week.

To obtain standardized fragments, the crows of 80 teeth were sectioned using a diamond saw under refrigeration in a cutting machine Isomet 1000 (Buehler, Lake Bluff, IL, USA). The section was perpendicular to the long axis of the teeth and parallel to the incisal edge. Each fragment has 12 mm of length.

Then, dental remnants and incisal fragments were submitted to ultrasonic bath for 2 h to remove smear layer and turn the dental surfaces more close to those obtained when the fragment is fractured. The complete removal of smear layer after 2 h in ultrasonic bath was observed in a pilot study using Scanning Electron Microscopy analysis.

For impact strength evaluation, the teeth were individually mounted on plastic cylinders to simulate bone support and periodontal ligament (31). Ten sound teeth were also mounted and used for the control group.

Root surfaces were dipped into melted wax (Probem Lab. de Prod. Farmacêuticos e Odontológicos Ltda., Catanduva, SP, Brazil) up to 2.0 mm below the cemento-enamel junction (CEJ), resulting in a 0.2–0.3 mm thick wax layer. An X-ray film (Kodak, New York, NY, USA) with a centralized circular hole with 5 mm in diameter was used to stabilize the teeth for the embedment procedure, 2.0 mm from the CEJ. This set was positioned downward over a perforated wood plate, and a PVC cylinder (Tigre S. A. Tubos e Conexões, Joinvile, SC, Brazil) with 15.0 mm in diameter and 20.0 mm in height was positioned and fixed with wax. Self-cured acrylic resin (Vipi Flash; Vipi Ind. Com., Pirassununga, SP, Brazil) was manipulated according to the manufacturers' instructions and inserted into the cylinder. After resin polymerization, the teeth were removed from the cylinder, and the wax was removed from the root surface and resin cylinder 'alveolus.' After a polyether impression material (Impregum F; 3M/ESPE, St Paul, MN, USA) was placed in the resin cylinders, the tooth was re-inserted into the cylinder and the material excess was removed with a scalpel blade (Xishan Medical

Table 1. Group distribution according to reattachment technique and materials ($n = 10$)

Materials	Direct bonding		Circumferential chamfer	
	Filtek Flow	Rely X	Filtek Flow	Rely X
Single bond	G1	G3	G5	G7
Clearfil SE bond	G2	G4	G6	G8
	GC – control group – sound teeth			

Instrument factory, Xishan, China). The roots were embedded in resin up to 2 mm below the CEJ.

After periodontal ligament simulation, the sectioned teeth were distributed in eight groups ($n = 10$) according to employed materials (adhesive system and luting agent) and reattachment technique (Table 1). Restorative materials selected for this study are described in Table 2.

The detailed procedures of fragment reattachment for each group are described below:

G1 – Single bond adhesive system (3M/ESPE) was applied according to manufacturer's directions on fractured surfaces of fragment and dental remnants. Phosphoric acid (H_3PO_4) (Scotchbond Etchant; 3M/ESPE) was applied to enamel and dentin for 15 s and rinsed for 10 s. The excess water was blotted leaving tooth surface moist (wet technique). An absorbent paper was used for blotting. Single Bond Adhesive was applied in two consecutive coats during 15 s. Then, the surfaces were dried for 5 s using an air syringe to allow solvent evaporation. The adhesive was light cured for 20 s in each surface (10 s in mesial half and 10 s in distal half) using XL 2500 (3M/ESPE), with irradiance 700 mW cm^{-2}. The flowable composite Filtek Z350 Flow (3M/ESPE) was applied in the fractured surface of the dental remnant, and the fragment was positioned (direct bonding). After fragment positioning, the light curing was proceeded in four stages: 20 s mesial buccal half, 20 s distal buccal half, 20 s mesial lingual half and 20 s distal lingual half.

G2 – Self-etch adhesive system Clearfil SE Bond (Kuraray Co., Tokyo, Japan) was applied according to manufacturer's direction of fracture surface of the fragment and dental remnant. The substrates were dried using an air syringe for 5 s, and the self-etching primer was actively applied during 20 s. A mild air flow was accomplished to remove solvent excess, and at this time, the surface became shiny. Then, Bond was applied using a microbrush and air flowed gently. The adhesive was light cured for 20 s in each surface (10 s in mesial half and 10 s in distal half) using XL 2500, with irradiance 700 mW cm^{-2}. Then, the fragment was directly bonded using the flowable composite Filtek Z350 Flow, as described for G1.

G3 – Single Bond adhesive system was applied as described for G1. Then, the dual resin cement Rely X ARC (3M/ESPE) was handled according to the manufacturer's directions and used for direct bond fragment in the dental remnant. Light curing procedures was performed in the same way performed for Filtek Z350 Flow (described in G1).

G4 – Self-etch adhesive system Clearfil SE Bond was applied as described in G2. Then, the dual resin cement Rely X ARC was applied as described in G3.

G5 – Single Bond adhesive system and the flowable composite Filtek Z350 Flow were applied as described for G1. After reattachment, a 2 mm-depth circumferential chamfer was placed in the fracture line using a diamond round bur (ref # 1016; KG Sorensen, São Paulo, SP, Brazil). The chamfer was restored using the Single Bond adhesive system, according to manufacturer's directions and Filtek Z250 (shade A3; 3M/ESPE).

G6 – Clearfil SE Bond adhesive system was applied as described for G2. The flowable composite Filtek Z350 Flow was applied as described for G1. After reattachment, a 2 mm-depth circumferential chamfer was placed in the fracture line using a diamond round bur (ref # 1016; KG Sorensen). The chamfer was restored using the Clearfil SE Bond adhesive system, according to manufacturer's directions and Filtek Z250.

G7 – Single Bond adhesive system was applied as described for G1. The dual resin cement Rely X ARC was applied as described for G3. After reattachment, a circumferential chamfer was placed in the fracture line and restored as described for G5.

G8 – Clearfil SE Bond adhesive system was applied as described for G2. The dual resin cement Rely X ARC was applied as described for G3. After reattachment, a circumferential chamfer was placed in the fracture line and restored as described for G6.

GC – control group – sound teeth.

The teeth were stored for 24 h at 37°C in 100% humidity, and then submitted finishing and polishing

Table 2. Description of the materials selected for this study

Material/Manufacturer	Type	Composition
Single bond 3M/ESPE, St Paul, MN, USA	Total-etch adhesive system	BisGMA, HEMA, dimethacrylates, ethanol, water, photoinitiator system; methacrylate functional copolymer of polyacrylic and polyitaconic acids
Clearfil SE bond Kuraray Co., Tokyo, Japan	Self-etch adhesive system	*Primer:* MDP; HEMA; Dimethacrylate monomer; Water; Photoinitiator *Bond:* MDP; HEMA; Dimethacrylate monomer; Microfiller; Photoinitiator
Filtek Z350 flow 3M/ESPE	Flowable composite	Bis-EMA; Bis-GMA; TEGDMA, nanofillers and nanoclusters of zirconia/silica, camphorquinone
Rely X ARC 3M/ESPE	Dual resin cement	*Paste A:* Bis-GMA; TEGDMA; inorganic filler zirconia/silica. (68%w); dimethacrylate polymer; amine; photoinitiator system; pigments *Paste B:* Bis-GMA; TEGDMA; inorganic filler zirconia/silica. (67%w).; dimethacrylate polymer; Benzoyl peroxide
Filtek Z-250 3M/ESPE	Hybrid restorative composite	Bis-GMA; Bis-EMA; UDMA; inorganic filler zirconia/silica (60%v)

using diamond burs (ref # 3195F and # 3195FF; KG Sorensen) and Sof-Lex system (3M/ESPE).

To evaluate the resistance to impact, specimens were positioned in a universal testing machine (Instron 4411, Canton, MA, USA) using a stainless steel device with 70 mm height, and a square base of 70 × 70 mm and a 45 degrees inclined plan with a central hole (21 mm in diameter and 20 mm of depth). The teeth were then submitted to a tangential load at 500 mm min^{-1} cross-head speed (16). The load cell used was 500 kg (5000 N). The antagonistic metallic device was fixed to the universal testing machine and positioned 2 mm from the incisal edge of the buccal surfaces of the teeth. The load required to fracture the specimens was recorded (kgf) and data were submitted to ANOVA One Way and Ryan–Einot–Gabriel–Welsch Multiple Range test at 5% significance. The fracture modes were analyzed using a stereomicroscope (Leica MZ6; Leica Microsystems Ltd., Heebrugg, Switzerland) at 16× magnificence. Fracture modes were classified in: cervical, cohesive in dentin, adhesive or mixed. Descriptive statistics (percentage) was used to analyze the fracture mode.

Results

Table 3 describes ANOVA for the impact strength test. Means, Standard Deviation and the Ryan–Einot–Gabriel–Welsch test at 5% of significance results are described in Table 4.

According to ANOVA, when control group is compared to both reattachment techniques, there is a significant difference (Table 3 – $P < 0.05$). There also is a significant difference among Direct Bond and Circumferential Chamfer (Table 3 – $P < 0.05$). Circumferential Chamfer technique provided higher impact strength mean than Direct Bond technique. However, both techniques showed lower impact strength than control group (Table 4).

Regarding the adhesive system, when control group is compared to both adhesive systems, there was a significant difference (Table 3 – $P < 0.05$). There also was a significant difference among Single Bond and Clearfil SE Bond (Table 3 – $P < 0.05$). Single Bond provided higher means than Clearfil SE Bond. However, both adhesive systems showed lower impact strength than control group (Table 4).

Regarding the intermediated materials, ANOVA revealed that when control group is compared to both intermediated materials, there was a significant difference (TABLE 3 – $P < 0.05$). However, there was no significant difference among Filtek Z350 Flow and Rely X ARC (Table 3 – $P > 0.05$).

According to Table 4, Control group (sound teeth) showed the highest impact strength, but it was not statistically different from G5 and G7 ($P > 0.05$). G2 showed the lowest impact strength, and it was not statistically different from G1, G3 and G4 ($P > 0.05$). G6 and G8 showed intermediated values, which were statistically different from Control group and G2 ($P < 0.05$).

Fracture mode distribution is showed in Fig. 1. Fracture mode of sound teeth (control group) was completely different from the fracture mode of fractured teeth submitted to fragment reattachment (G1–G8). All specimens of Control group showed cervical fracture and the specimens of the experimental groups showed adhesive, cohesive and mixed fractures, always located in the bond line, between fragment and dental remnants. It was observed that fracture mode is highly influenced by the reattachment technique, once direct bond groups (G5–G8) showed mainly adhesive failure and circumferential chamfer groups (G1–G4) showed mainly cohesive or mixed failure. Figure 2 shows representative images of the fracture modes.

Table 3. ANOVA for impact strength test

Sources of variance	DF	SS	MS	F	*P*-value
Group	8	22.4815	2.8101	10.29	<0.0001*
Single bond × Clearfil SE bond	1	2.5382	2.5382	9.30	0.0030*
Control × Clearfil SE bond	1	13.0982	13.0982	47.97	<0.0001*
Control × single Bond	1	6.5924	6.5924	24.14	<0.0001*
Filtek flow × Rely X	1	0.0034	0.0034	0.01	0.9107 ns
Direct bonding × chamfer	1	8.3852	8.3852	30.71	<0.0001*
Control × direct bonding	1	16.2591	16.2591	59.54	<0.0001*
Control × chamfer	1	4.5979	4.5979	16.84	<0.0001*
Error	88	24.0290	0.2730		
Total	96	46.5106			

Mean: 3.26 *statistically significant ($P < 0.05$).
Coefficient of variation = 15.99% ns: not statistically significant ($P > 0.05$).

Table 4. Mean values and standard deviation (SD) of impact strength of control and experimental groups tested

Group[1]	Description[2]	Impact strength (Kgf)	SD	Ryan–Einot–Gabriel–Welsch test[3]
G Control	Sound	64.80	18.35	A
G7	CC + SB + RX	43.36	20.90	AB
G5	CC + SB + FF	37.82	25.68	ABC
G6	CC + CSE + FF	37.44	29.56	BCD
G8	CC + CSE + RX	26.68	11.30	BCD
G1	DB + SB + FF	26.48	16.32	BCDE
G3	DB + SB + RX	23.59	21.64	CDE
G4	DB + CSE + RX	17.55	8.31	DE
G2	DB + CSE + FF	12.42	4.66	E

[1]In order to turn the view of the groups ranking easy, the color of the cell filling represents the reattachment technique: bright gray for circumferential chamfer and dark gray for direct bonding. The color of the letters represents the adhesive system employed: black for Single Bond and white for Clearfil SE Bond.
[2]For group description, the following abbreviations were used: DB, Direct Bonding; CC, Circumferential Chamfer; SB, Single Bond; CSE, Clearfil SE Bond; RX, Rely X ARC; FF, Filtek Z350 Flow.
[3]Mean values followed by different letters are statistically different according to Ryan–Einot–Gabriel–Welsch test at 5% of significance.

Discussion

Impact strength evaluation of anterior teeth is important due to the high frequency of trauma in this region (1, 2). Moreover, impact strength evaluation of fractured teeth submitted to reattachment is also relevant, as most flaws

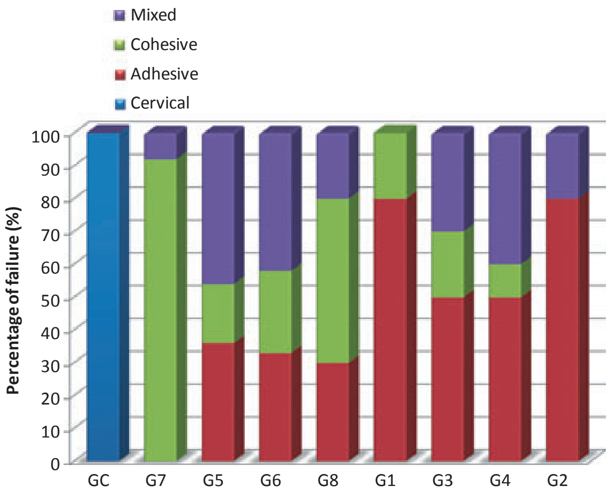

Fig. 1 Fracture mode distribution. Adhesive fractures were the predominant pattern in groups submitted to direct bonding (G1, G2, G3, G4), whereas cohesive and mixed fractures were predominant in groups submitted to circumferential chamfer (G5, G6, G7, G8). Control group (sound teeth) showed cervical failure, which is completely different from failure observed in the reattached experimental groups.

of reattached teeth occur due to new trauma (3, 4). In this way, methods to increase the impact strength of the restored teeth could increase the longevity of the restoration.

In this *in vitro* study, the immediate impact strength of anterior fractured teeth was evaluated. In order to evaluate impact, a very high crosshead speed was selected (500 mm min^{-1}) and the compressive load was applied in the incisal third at 45 degrees to simulate an impact from a fall. Farik & Munksgaard (16) observed a significant reduction on impact strength (about 30%) when specimens were tested at 500 mm min^{-1} in comparison with testing at 0.5 mm min^{-1}. Otherwise, new traumas are a common cause of failure of fragment reattachment (24, 32). In this way, the effects of reattachment technique, type of adhesive system and intermediated material on immediate impact strength were determined. It was observed that reattachment technique is the determinant factor; the type of adhesive system shows a secondary, but significant influence; and, intermediated material has no influence on impact strength of the restored teeth.

The ranking of impact strength mean values of experimental groups (Table 4) shows that the circumferential chamfer technique (G5, G6, G7, G8) is more effective than the direct bonding technique (G1, G2, G3, G4). These results corroborate with those found by De Santis et al. (10), Reis et al. (11) and Demarco et al. (19). Enamel prisms are altered during the chamfer preparation, increasing the bonding area and allowing higher bond strength of the fragment to the dental remnant. Besides, a material with superior mechanical properties is inserted in bonding line when the chamfer is filled with a composite, making the bonding line stronger when compared to the bonding line resulted from the direct bonding (10, 19).

Fracture mode analysis confirmed impact strength results. Fracture mode, likewise impact strength, was severally influenced by the reattachment technique. While specimens submitted to direct bonding technique showed predominantly adhesive fractures, specimens submitted to circumferential chamfer showed predominantly cohesive and mixed fractures, with considerable reduction in adhesive fractures. Additionally, cohesive fractures were related to higher impact strength, as observed for G7, which showed the highest impact strength of the experimental groups and 90% of cohesive fractures. Inversely, the lowest impact strength was observed for G2, and this group showed 80% of adhesive failures.

In opposition to the results of the present study, studies of Reis et al. (9) and Loguercio et al. (18) had observed that chamfer technique was not superior to direct bonding. However, in these studies, the chamfer was prepared only in lingual surface, what could not be sufficient to increase enough the bonding area, the mechanical strength of the bonding line, and, consequently, the fracture strength of the restored teeth. Reis et al. (3, 9, 11) suggested that the insertion of composite in all fracture line increases the chair time and complicates the achieving of adequate esthetic to the restoration. Moreover, the presence of large quantity of composite exposed to the oral environment could reduce the esthetic longevity of the restoration due to the abrasion and discoloration process that might occur with time (3, 9, 11). Conveniently, the selection of a composite with good mechanical properties associated with a maintenance program to periodically polish the restoration could notably reduce these problems.

In other parameter analyzed in this study, statistically significant difference was observed between the adhesive systems (Table 3). Total-etch adhesive system Single Bond provided higher impact strength than the self-etch adhesive system Clearfil SE Bond (Table 4).

Enamel etching with phosphoric acid provides selective dissolution of prisms, increasing porosity and surface energy, allowing better surface wetting by the adhesive and better interlocking between adhesive and substrate (33). Considering self-etching adhesives, the pattern of enamel etching is less favorable to the bonding (33). The differences in enamel etching pattern are determined by the pH difference between the systems. Phosphoric acid pH is 0.5 (according to manufacturer), whereas pH of self-etching primer of Clearfil SE Bond is 2.3, which is not low enough to effectively dissolute the enamel prisms.

The primer of Clearfil SE Bond contends acidic monomers as unsaturated methacrylated phosphate monoester, 10-methacryloxydecyl dihydrogen phosphate (MDP), in concentration of 25–30%. Hipólito et al.(33), by means of morphological analysis (SEM) and bond strength test, observed that the enamel etching produced by the SE primer is less aggressive, what can result in superficial interaction with enamel and lower potential for micromechanical interlocking when compared to the phosphoric acid treatment. Rotta et al. (34) showed reduction on bond strength to enamel when self-etching primer is used. In this way, it should be considered that an adequate bonding to enamel is essential for the

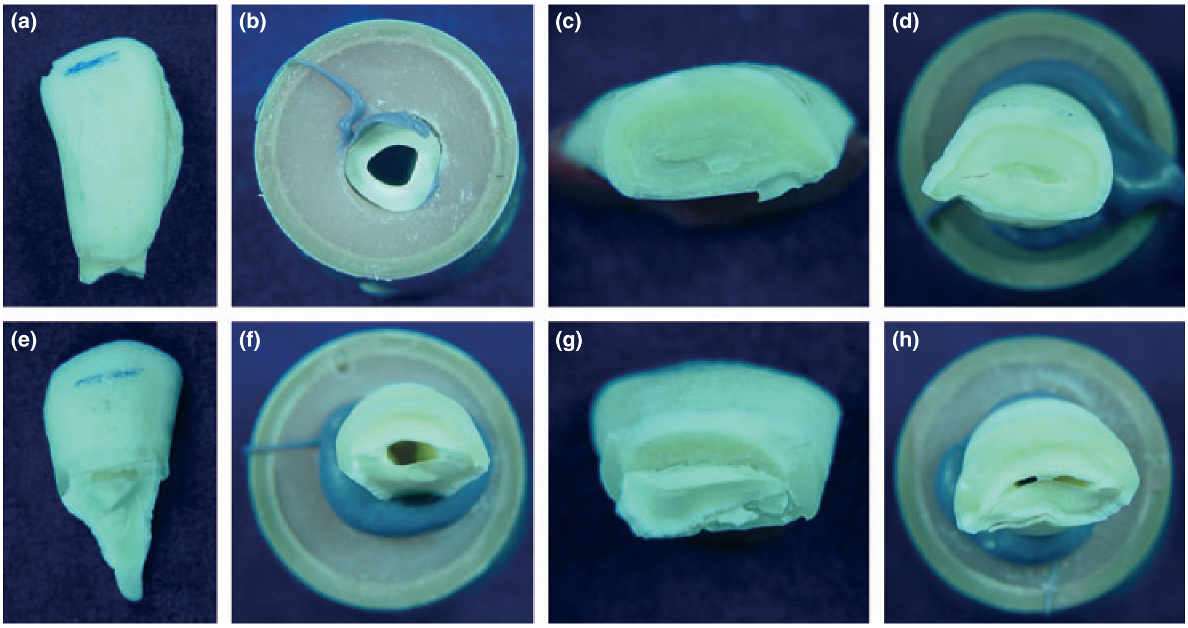

Fig. 2 Representative images of the fracture modes: Cervical fracture: (a) Crow, (b) Root. This fracture mode was observed only in control group (sound teeth). The fracture occurred in cervical region, local of the highest constriction of the teeth; Adhesive fracture: (c) Fragment, (d) Dental remnant. This kind of fracture was associated with lower impact strength values, and it occurred in direct bonding groups. There was complete debonding of the fragment. In most cases, the part of the adhesive applied in the remnant fracture surface and all the intermediated material stay bonded to the fragment after the fracture; Cohesive fracture: (e) Fragment, (f) Dental remnant. The fracture has occurred next to reattachment line, but in the dental remnant. This kind of fracture was associated with higher impact strength values. It was found mainly in the circumferential chamfer groups, especially in G7, which showed the highest impact strength, mean of the experimental groups; Mixed fracture: (g) Fragment, (h) Dental remnant. This kind of fracture showed in part adhesive failure and in part cohesive failure in dental remnant. Mixed failure showed uniform distribution in most experimental groups.

success of any restoration, and, in special, in cases of reattachment of fragments.

In contrast, the bonding to dentin is reported as effective and comparable for self-etch and total-etch adhesive systems (35, 36), because the bonding mechanism to dentin for both systems is based on hybridization. The difference relies on the morphology of the hybrid layer, which is less thick and more uniform when self-etching adhesives are used (35, 37). Besides, the collagen network is not completely deprived from hydroxyapatite, what not only avoid the collagen collapse, but also may serve as a receptor for additional intermolecular interaction with specific carboxyl or phosphate groups of the functional monomers (37). Clinically, self-etch systems not only simplify the bonding procedures by eliminating steps (rinse and dry), but also eliminate some of the technique-sensitivity of total-etch systems.

The risk of over etching of the dentin is evident when phosphoric acid is used. Many studies have evidenced the incomplete penetration of the adhesive in demineralized dentin as the main mechanism of bonding degradation (37–41). The exposed and not resin impregnated collagen is considered the weak zone of the bonding. Thus, despite the higher impact strength provided by the total-etch adhesive, some benefits of the self-etching systems should be pointed out. The risk of over etching does not exist in self-etching adhesives, as demineralization and resin infiltration are concomitant, avoiding the incomplete penetration of the monomers in the demineralized dentin (36). Moreover, in many trauma situations, the dentin exposed in the fractured surface is deep and very close to the pulp. And in this case, the use of self-etching adhesive could be more appropriate due to the reduced risk of postoperatory sensitivity. Some authors have suggested the additional etching of enamel with phosphoric acid as an alternative to solve the bonding problems of self-etching adhesives (33, 41, 42).

Still considering the materials used in reattachment of fragments, it was observed that the luting agent (intermediated material) had no direct influence on impact strength, corroborating with Reis et al. (11) and Farik et al. (30). There was no significant difference between the dual-cured luting cement Rely X ARC and the flowable composite Filtek Z350 Flow. It probably has occurred because both materials have similar mechanical properties.

Therefore, when individually considered, none of the factors (reattachment technique, adhesive system and luting agent) was capable to restore the original strength of the teeth, regardless the other factors. However, an appropriate association between reattachment technique and adhesive system can completely rehabilitate the reattached teeth, providing impact strength similar to sound teeth. In this study, the appropriate association was found between circumferential chamfer technique and total-etch adhesive system Single Bond. The best recovery of immediate impact strength was observed for G7 and G5, which showed, respectively, 71.5% and

58.3% of the impact strength observed on G control. In addition, there was no statistical difference among these groups and control group – sound teeth ($P > 0.05$) (Table 4). Failure mode evaluation showed higher frequency of cohesive fractures for these groups, indicating high bond strength between fragment and dental remnant. However, it should be stood out that fracture mode of G control was completely different from that observed for the experimental groups. G control showed cervical fracture, which occurs in the area of most constriction and less volume of the teeth.

The lowest impact strength values were found when the association between direct bonding technique and self-etch adhesive system was used (G2 and G4). G2 and G4 showed significant reduction on impact strength values when compared to G5, G7 and G control. In this way, this inappropriate association leads to fragility of the reattached fragment, with higher risk of debonding. Failure mode evaluation confirmed it, and G2 and G4 showed high frequency of adhesive fractures corroborating with the low impact strength values.

The recover of the impact strength of the restored teeth is the main goal of fragment reattachment. Based on the results of this study, the reattachment technique is the main factor that determines the impact strength. However, the proper selection of the materials, in special, in the bonding system is also important and should be carried out carefully, because flaws during the bonding procedure could reduce the bond strength of the segments. In this way, the results of this study provide information about immediate impact strength of restored teeth, studies evaluating the long-term durability of reattachment, involving thermal and mechanical challenging, and the results are necessary to predict the longevity of this treatment.

Conclusion

Based on the results of this study, it could be concluded:

1 Impact strength of fragment reattached teeth is mainly determined by reattachment technique. Circumferential chamfer technique showed better results than direct bonding technique;

2 Adhesive system selection has secondary, but significant effect on impact strength of fragment reattached teeth. Total-etch adhesive system (Single Bond) showed better results than self-etch system (Clearfil SE Bond);

3 Intermediated material had no influence on impact strength of fragment reattached teeth. Filtek Z350 Flow and Rely X ARC showed similar results;

4 Only the association of reattachment technique using circumferential chamfer with the total-etch adhesive system Single Bond could approximate the impact strength of the fragment reattached teeth of that achieved by sound teeth.

References

1. Tovo MF, dos Santos PR, Kramer PF, Feldens CA, Sari GT. Prevalence of crown fractures in 8–10 years old schoolchildren in Canoas, Brazil. Dent Traumatol 2004;20:251–4.
2. Zuhal K, Semra OE, Huseyin K. Traumatic injuries of the permanent incisors in children in southern Turkey: a retrospective study. Dent Traumatol 2005;21:20–5.
3. Reis A, Loguercio AD, Kraul A, Matson E. Reattachment of fractured teeth: a review of literature regarding techniques and materials. Oper Dent 2004;29:226–33.
4. Andreasen FM, Daugaard-Jensen J, Munksgaard EC. Reinforcement of bonded crown fractured incisors with porcelain veneers. Endod Dent Traumatol 1991;7:78–83.
5. Torbjorner A, Karlsson S, Odman PA. Survival rate and failure characteristics for two post designs. J Prosthet Dent 1995;73:439–44.
6. Fredriksson M, Astback J, Pamenius M, Arvidson K. A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts. J Prosthet Dent 1998; 80:151–7.
7. Gorecka V, Suliborski S, Biskupski T. Direct pulp capping with a dentin adhesive resin system in children's permanent teeth after traumatic injuries: case reports. Quintessence Int 2000;31:241–8.
8. Chosack A, Eidelman E. Rehabilitation of a fractured incisor using the patient's natural crown. Case report. J Dent Child 1964;31:19–21.
9. Reis A, Francci C, Loguercio AD, Carrilho MR, Rodriques Filho LE. Reattachment of anterior fractured teeth: fracture strength using different techniques. Oper Dent 2001;26:287–94.
10. De Santis R, Prisco D, Nazhat SN, Riccitiello F, Ambrosio L, Rengo S et al. Mechanical strength of tooth fragment reattachment. J Biomed Mater Res 2001;55:629–36.
11. Reis A, Kraul A, Francci C, de Assis TG, Crivelli DD, Oda M et al. Reattachment of anterior fractured teeth: fracture strength using different materials. Oper Dent 2001;27:621–7.
12. Farik B, Munksgaard EC, Andreasen JO, Kreiborg S. Fractured teeth bonded with dentin adhesives with and without unfilled resin. Dent Traumatol 2002;18:66–9.
13. Vissichelli VP. Restoration of a fractured maxillary central incisor by using the original tooth fragment. Gen Dent 1996;44:238–40.
14. Kanca J III. Replacement of a fractured incisor fragment over pulpal exposure: a long-term case report. Quintessence Int 1996;27:829–32.
15. Maia EA, Baratieri LN, de Andrada MA, Monteiro S Jr, Araujo EM Jr. Tooth fragment reattachment: fundamentals of the technique and two case reports. Quintessence Int 2003;34:99–107.
16. Farik B, Munksgaard EC. Fracture strength of intact and fragment-bonded teeth at various elocities of the applied force. Eur J Oral Sci 1999;107:70–3.
17. Pagliarini A, Rubini R, Rea M, Campese M. Crown fractures: effectiveness of current enamel-dentin adhesives in reattachment of fractured fragments. Quintessence Int 2000;31:133–6.
18. Loguercio AD, Mengarda J, Amaral R, Kraul A, Reis A. Effect of fractured or sectioned fragments on the fracture strength of different reattachment techniques. Oper Dent 2004;29:295–300.
19. Demarco FF, Fay RM, Pinzon LM, Powers JM. Fracture resistance of re-attached coronal fragments – influence of different adhesive materials and bevel preparation. Dent Traumatol 2004;20:157–63.
20. Farik B, Munksgaard EC, Andreasen JO. Impact strength of teeth restored by fragment-bonding. Endod Dent Traumatol 2000;16:151–3.
21. Simonsen RJ. Traumatic fracture restoration: an alternative use of the acid etch technique. Quintessence Int Dent Dig 1979;10:15–22.
22. Walker M. Fractured-tooth fragment reattachment. Gen Dent 1996;44:434–6.
23. Worthington RB, Murchison DF, Vandewalle KS. Incisal edge reattachment: the effect of preparation utilization and design. Quintessence Int 1999;30:637–43.

24. Andreasen FM, Noren JG, Andreasen JO, Engelhardtsen S, Lindh-Stromberg U. Long-term survival of fragment bonding in the treatment of fractured crowns: a multicenter clinical study. Quintessence Int 1995;26:669–81.
25. Simonsen RJ. Restoration of a fractured central incisor using original tooth fragment. J Am Dent Assoc 1982;105:646–8.
26. Capp CI, Roda MI, Tamaki R, Castanho GM, Camargo MA, Cara AA. Reattachment of dehydrated dental fragment using two techniques. Dent Traumatol 2009;25:95–9.
27. Pusman E, Cehreli ZC, Altay N, Unver B, Saracbasi O, Ozgun G. Fracture resistance of tooth fragment reattachment: effects of different preparation techniques and adhesive materials. Dent Traumatol 2010;26:9–15.
28. Farik B, Munksgaard EC, Kreiborg S, Andreasen JO. Adhesive bonding of fragmented anterior teeth. Endod Dent Traumatol 1998;14:119–23.
29. Sengun A, Ozer F, Unlu N, Ozturk B. Shear bond strengths of tooth fragments reattached or restored. J Oral Rehabil 2003;30:82–6.
30. Farik B, Munksgaard EC, Suh BI, Andreasen JO, Kreiborg S. Adhesive bonding of fractured anterior teeth: effect of wet technique and rewetting agent. Am J Dent 1998;11:251–3.
31. Soares JC, Pizi ECG, Fonseca RB, Martins LRM. Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. Braz Oral Res 2005;19:11–6.
32. Alonso RCB, Papa AMC, Casteleti MGSC, Sacramento PA, Puppin-Rontani RM. Reattachment of an autogenous tooth fragment – 36-month follow-up: fast and safe rehabilitation of fractured teeth. Perspect Oral Sci 2009;1:37–42.
33. Di Hipolito V, de Goes MF, Carrilho MR, Chan DC, Daronch M, Sinhoreti MA. SEM evaluation of contemporary self-etching primers applied to ground and unground enamel. J Adhes Dent 2005;7:203–11.
34. Rotta M, Bresciani P, Moura SK, Grande RH, Hilgert LA, Baratieri LN et al. Effects of phosphoric acid pretreatment and substitution of bonding resin on bonding effectiveness of self-etching systems to enamel. J Adhes Dent 2007;9:537–45.
35. Correr GM, Puppin-Rontani RM, Correr-Sobrinho L, Sinhoreti MA, Consani S. Effect of sodium hypochlorite on dentin bonding in primary teeth. J Adhes Dent 2004;6:307–12.
36. Hannig M, Reinhardt KJ, Bott B. Self-etching primer vs phosphoric acid: an alternative concept for composite-to-enamel bonding. Oper Dent 1999;24:172–80.
37. Van Meerbeek B, Vargas M, Inoue S, Yoshida Y, Peumans M, Lambrechts P et al. Adhesives and cements to promote preservation dentistry. Oper Dent 2001;26(Suppl. 6):119–44.
38. Nakabayashi N, Pashley DH. Hybridization of dental hard tissues, 1st edn. Tokyo: Quintessence Publishing; 1998.
39. Sano H, Shono T, Takatsu T, Hosoda H. Microporous dentin zone beneath resin-impregnated layer. Oper Dent 1994;19:59–64.
40. Sano H, Takatsu T, Ciucchi B, Horner JA, Matthews WG, Pashley DH. Nanoleakage: leakage within the hybrid layer. Oper Dent 1995;20:18–25.
41. Sano H, Yoshiyama M, Ebisu S, Burrow MF, Takatsu T, Ciucchi B et al. Comparative SEM and TEM observations of nanoleakage within the hybrid layer. Oper Dent 1995;20:160–7.
42. Lührs AK, Guhr S, Schilke R, Borchers L, Geurtsen W, Günay H. Shear bond strength of self-etch adhesives to enamel with additional phosphoric acid etching. Oper Dent 2008;33:155–62.