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Fracture resistance of tooth fragment reattachment: effects of different preparation techniques and adhesive materials

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Abstract – The purpose of this study was to evaluate and compare the bond strengths of experimentally fractured human tooth fragments reattached with different adhesive materials and retentive techniques *in vitro*. Uncomplicated crown fractures were obtained on intact human mandibular permanent incisors by applying perpendicular load to the buccal aspect of tooth crowns. Fractured teeth were randomly assigned into one of three reattachment protocols: (i) Simple reattachment, (ii) Overcontour preparation, and (iii) Internal dentin groove. The first and second groups were divided into 10 subgroups, and the third group into five subgroups ($n = 10$ per group) with respect to five different adhesive systems (Prime&Bond NT, Adper Single Bond II, Adper Prompt L-Pop, Clearfil S^3 Bond, G Bond) used with or without a hybrid resin composite (Z250). Restored teeth were subjected to thermal cycling, and subsequently to the same loading protocol used for fracturing intact teeth. Fracture strength after reattachment procedures was recorded as a percentage of the original fracture strength. Both type of adhesive material and placement of an intermediate layer of resin composite affected the fracture resistance ($P < 0.05$). The highest fracture strength recovery was obtained using the internal dentin groove technique (54 ± 0.58%, $P < 0.05$), followed by the overcontour and simple reattachment protocols (49 ± 0.58% and 32 ± 0.82%, respectively, $P < 0.05$). Ultramorphological evaluation of bonded specimens revealed voids and microcracks along the adhesive interface, which might contribute to postadhesive failure.

Coronal fractures of anterior teeth are the most frequent form of acute dental injury that mainly affects children and adolescents (1, 2). Today, restoration of such traumatized incisors by reattachment of the original tooth fragment appears to be the most conservative treatment approach, even when a coronal fragment is not completely recovered intact (3). Compared with other restorative techniques (composite restorations, laminate veneers, post and core, etc.), reattachment of fractured fragments can offer several advantages comprising improved esthetics and function (4–6), and restoration of the surface anatomy with increased wear resistance (7). As such, the reattachment technique should especially be considered in children, as it helps to preserve dental tissues during tooth development (8).

The primary cause of failure of the reattached tooth fragment is new trauma or the use of the restored tooth with excessive masticatory forces (4), which justifies many previous attempts that have been directed toward improving the fracture strength of the rebonded fragment. Accordingly, clinicians have tested a variety of retentive preparation designs, as well as different resin-based composites and adhesive materials for the reattachment of tooth fragments. With improvements in hydrophilic adhesives that offer high bond strength values, some investigators have attempted to reattach fragments using these materials without an additional retentive preparation (9, 10). However, Reis et al. (11) have reported that a simple reattachment with no further preparation of the fragment or tooth may not be able to restore even half of the fracture strength of intact teeth. Consequently, many authors have advocated the necessity of using additional preparations to augment the retention of the reattached fragment (11–16). Such preparation methods include enamel beveling of the fragment and remaining crown (12, 13), internal dentin groove (11, 14), external chamfer (11, 15), and the overcontour technique (11, 16); all of which have their own advantages and disadvantages.

In light of many published studies that verified the efficacy of the fragment reattachment techniques, it has become apparent that both the preparation technique and the kind of material used to bond fractured fragments may have significant effects on the fracture strength of such restored teeth (11, 17). To date, only one *in vitro* study (11) has verified the effects of these two major sources of variation together by testing simple reattachment and buccal chamfer techniques and varying the type of resin composite placed subsequent to a single-bottle, etch-and-rinse adhesive. Overall, these observations highlight the need for further investigation into the effects of new adhesive materials that are being continuously developed and introduced for clinical use, and their interactions with retentive preparation techniques under standardized conditions.

The aim of this study was evaluate and compare the bond strengths of experimentally fractured human tooth fragments reattached with different preparation techniques and adhesive resin materials. Additionally, the integrity of the resin–dentin interface of restored teeth was investigated ultramorphologically under the scanning electron microscope. The null hypothesis tested was twofold: (i) The fracture resistance of reattached tooth fragments is affected by both the type of adhesive material and the presence of an intermediate layer of resin composite between fragments, and (ii) The fracture resistance of reattached tooth fragments is affected by the type of retentive preparation technique.

Fig. 1. Specimen mounted on the test jig to perform fracturing load. Inset: Point for application of perpendicular fracture loading.

Materials and methods

Three hundred and twenty freshly extracted, periodontally involved, sound human mandibular incisor teeth were used in this study. Soft tissue remnants and calculus were removed, later teeth were examined under 4 x optical magnification to discard those with any visible structural defects, cracks, or incipient lesions. Selected teeth were stored in sterile saline at 4°C before use (a maximum of 1 month).

Sound teeth were subjected to a fracturing protocol previously described by Reis et al. (11). Accordingly, the teeth were embedded in self-cure acrylic resin, leaving the anatomical crowns exposed. The buccal surface of each tooth was divided into transversal and longitudinal thirds, and the point for application of the perpendicular loading was placed between the superior and proximal (mesial or distal) thirds (Fig. 1). The specimens were mounted on a custom jig that enabled precise localization of the fracturing force in each tooth crown (Fig. 1). The load was applied to each tooth in a buccal to lingual direction by means of a reinforced stainless-steel rod with a 2 mm^2 ball tip at a cross-head speed of 10 mm min^{-1}. The force required to fracture the tooth was recorded in kilogram force. Fractured teeth and fragments were investigated under 4 x magnification to ensure selection of specimens ($n = 250$) with a perfect fragment fit. All selected teeth had uncomplicated (enamel + dentin) crown fractures (2) that exhibited an oblique fashion from the labial to lingual aspects. The specimens were stored in 0.9% saline solution until the restoration procedures were performed (18).

Reattachment procedures

The chemical compositions of the tested adhesive systems and resin composite material are presented in Table 1. All materials were applied in strict accordance with the manufacturers' instructions. Fractured coronal fragments were restored using three different reattachment techniques:

Table 1. Chemical compositions of the test materials

Material	Manufacturer	Composition
Prime&Bond NT	DENTSPLY/DeTrey Konstanz, Germany	Di- and trimethacrylate resins, PENTA, Nanofillers – Amorphous silicon dioxide, Photoinitiators, Stabilizers, Cetylamine hydrofluoride, acetone
Adper Single Bond 2	3M ESPE, St. Paul, USA	Bis-GMA, HEMA, Silanized silica, Glycerol 1,3 dimethacrylate, diurethane dimethacrylate, water, ethanol, polyalkenoic acid copolymer, photoinitiator
Adper Prompt L-Pop	3M ESPE, St. Paul, USA	Liquid 1: Methacrylated phosphoric esters, bis-GMA, initiators based on camphorquinone, stabilizers Liquid 2: water, HEMA, polyalkenoic acid, Stabilizers
G-Bond	GC, Tokyo, Japan	UDMA, 4-MET, phosphoric ester monomer, TEGDMA, acetone, distilled water, silica fine powder, Initiators
Clearfil S^3 Bond	Kuraray, Okayama, Japan	HEMA, Ethanol, Bis-GMA, MDP, silanated colloidal silica, hydrophobic dimethacrylate, photoinitiators, water
Z250 Resin composite	3M ESPE, St. Paul, MN, USA	bis-GMA, UDMA, Bis-EMA

PENTA, dipentaerythritol penta acrylate monophosphate; bis-GMA, bisphenol A dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; UDMA, urethane dimethacrylate; 4-MET, 4-methacryloxyethyl trimellitic acid; TEGDMA, Triethylene glycol dimethacrylate; MDP, 10-methacryloyloxydecyl dihydrogen phosphate; Bis-EMA, Ethoxylated bisphenol A dimethacrylate.

1. Simple reattachment ($n = 100$): Fragments were restored without an additional preparation. Fractured teeth were randomly assigned into 10 subgroups ($n = 10$ per group). In the first five subgroups, the fragments were reattached using bonding agents only. The adhesives were applied to both fracture surfaces without light curing to avoid any interference with the fit between the bonded parts. The fragment was, then, carefully positioned under magnifying loupes and the buccal and lingual surfaces were light-cured for 60 s each, while pressing the coronal fragment against the matching tooth part. In the remaining five subgroups, the same adhesives were applied in conjunction with a thin layer of uncured hybrid resin composite (Z250, Shade B1, 3M/ESPE, St. Paul, MN, USA). Following adaptation of the fragment, the composite excess was carefully removed, and the adhesive and composite resins were light-cured together as with the first five subgroups.
2. Overcontour ($n = 100$): This technique comprised reattachment of the fragment, followed by superficial preparation and subsequent restoration of the buccal enamel, which creates a slightly over contoured tooth surface (19). Accordingly, the teeth were first subgrouped (bonding agent only per five subgroups; bonding agent + Z250 composite per five subgroups) and restored as with the simple reattachment protocol. Thereafter, a 0.3-mm-deep preparation was made on the buccal surface using water-cooled, high-speed cylindrical diamond burs (19). The preparation extended 2.5-mm coronally and apically to the fracture line (19). In each subgroup, the same adhesive used for fragment reattachment was applied on the buccal cavity and light-cured. Shade B1 Z250 resin composite was used to restore the buccal preparation. Following light curing of the composite, finishing and polishing procedures were made with Soflex® discs (3M ESPE, St. Paul, MN, USA).
3. Internal groove ($n = 50$): Before reattachment, an internal groove (1-mm deep and 1-mm wide) was prepared within the fragment and the remaining tooth by means of a water-cooled, high-speed carbide bur (19). Bonding agents were applied to both surfaces, followed by placement of the Shade B1 Z250 resin composite within the grooves. The fragment was carefully reattached under pressure, the excess composite was removed, and each tooth surface was light-cured for 60 s.

Thermal cycling and debonding procedures

All restored specimens were kept in distilled water at 37°C for 24 h, and subsequently subjected to thermal cycling (1000 ×; 5–55 ± 2°C; dwell time = 15 s; transfer time = 10 s) (20, 21). The specimens were, then, loaded at 10 mm min^{-1} in the same point used for fracturing their intact versions. The force required to fracture the reattached fragment was recorded in kilogram force. For each tooth, the fracture strength was expressed as a percentage of the load required to fracture the sound tooth (strength recovery) (11, 19).

Statistical analysis

Two-way ANOVA was used to investigate the two factors, 'reattachment technique' and 'adhesive material'; and their interaction ($P = 0.05$). LSD *post hoc* test was run to clarify the possible differences among means ($P = 0.05$).

Scanning electron microscopic (SEM) evaluation

For each subgroup, three additional restored (but not refractured) teeth were prepared and sectioned longitudinally to evaluate the tooth–adhesive interface under SEM. The sections were first exposed to 6 N HCl for 15 s followed by 1% NaOCl for 10 min, and dehydrated in ascending grades of ethanol (30%, 50%, 95% for 30 min each, and 100% for 60 min). After the final ethanol bath, the specimens were dried by immersion in hexamethyldisilazane (HMDS, Electron Microscopy Sciences, Hatfield, PA, USA) for 30 min followed by placement on a filter paper inside a covered glass vial for 24 h. Subsequently, the specimens were sputter coated with 20 Å gold–palladium for ultramorphological observation by an SEM (JSM-6400 V, JEOL, Tokyo, Japan) at 15 kV accelerating voltage.

Results

Fracture strength evaluation

The fracture strength values of sound and restored teeth, and the fracture strength recovery values of the test groups are presented in Table 2 as mean and SD. Both the reattachment techniques and the adhesive systems significantly affected the extent of fracture strength recovery (two-way ANOVA, $P = 0.00$). The interaction of these two factors was also significant (two-way ANOVA, $P = 0.00$). Irrespective of the adhesive/restorative system employed, the highest fracture strength recovery was obtained when the fragments were reattached with the internal dentin groove technique (54 ± 0.58%, $P < 0.05$), followed by the overcontour and simple reattachment techniques (49 ± 0.58% and 32 ± 0.82%, respectively, $P < 0.05$).

In the simple reattachment groups, the use of resin composite in the adhesive interface significantly increased the fracture strength recovery values, compared with those reattached with the bonding agents only ($P < 0.05$). When the adhesives were used alone, Clearfil S^3 Bond and Adper Single Bond 2 displayed significantly higher fracture strength recovery values than the other test groups ($P < 0.05$), but the difference between the two materials was not significant ($P = 0.66$). Used together with the resin composite, Clearfil S^3 Bond and G-Bond displayed the highest and lowest fracture strength recovery values, respectively (both $P < 0.05$); and differences between Prime&Bond NT, Adper Prompt L-Pop and Single Bond 2 ($P > 0.05$) were not significant.

Similar with the simple reattachment groups, the use of resin composite in the adhesive interface significantly increased the fracture strength recovery values in the overcontour technique. Accordingly, Clearfil S^3 Bond

Table 2. The fracture strength (kgf) and fracture strength recovery (FSR, %) values of the test groups

			Sound tooth (kgf)		Restored tooth (kgf)		FSR (%)	
Reattachment technique	Restorative material	*n*	Mean	SD	Mean	SD	Mean	SD
Simple reattachment	1. Prime&Bond NT	10	27.12	2.71	4.20	0.29	15.58	1.52
	2. Prime&Bond NT + RC	10	28.88	4.86	11.93	1.25	41.77	3.08
	3. Adper Single Bond 2	10	29.01	3.98	8.29	0.68	28.96	3.89
	4. Adper Single Bond 2 + RC	10	30.23	6.97	11.52	0.90	40.08	10.22
	5. Adper Prompt L-Pop	10	24.54	1.14	5.56	0.29	22.72	2.10
	6. Adper Prompt L-Pop + RC	10	25.08	5.37	10.03	1.53	40.72	5.12
	7. G-Bond	10	27.25	0.28	5.28	0.84	19.38	3.07
	8. G-Bond + RC	10	26.17	3.02	7.86	1.16	30.26	4.88
	9. Clearfil S^3 Bond	10	27.52	4.60	8.13	0.79	30.10	4.60
	10. Clearfil S^3 Bond + RC	10	24.27	4.77	11.52	2.39	47.42	1.57
Overcontour	1. Prime&Bond NT	10	29.56	1.25	13.96	1.67	47.39	6.71
	2. Prime&Bond NT + RC	10	24.13	1.84	13.69	1.94	56.65	6.25
	3. Adper Single Bond 2	10	33.35	3.43	12.21	1.11	36.67	1.70
	4. Adper Single Bond 2 + RC	10	28.27	5.60	13.83	2.10	49.00	3.55
	5. Adper Prompt L-Pop	10	22.23	3.14	10.30	1.05	47.15	7.75
	6. Adper Prompt L-Pop + RC	10	23.73	4.91	8.54	2.66	35.34	3.54
	7. G-Bond	10	26.84	0.86	11.79	1.33	44.02	5.71
	8. G-Bond + RC	10	30.37	7.16	14.37	1.59	48.84	8.59
	9. Clearfil S^3 Bond	10	28.88	2.37	19.79	2.09	68.42	1.89
	10. Clearfil S^3 Bond + RC	10	31.05	3.87	15.73	2.80	50.95	7.99
Internal dentinal groove	1. Prime&Bond NT + RC	10	31.05	2.69	18.57	1.84	60.16	7.43
	2. Adper Single Bond 2 + RC	10	32.41	3.66	14.50	2.19	44.73	4.34
	3. Adper Prompt L-Pop + RC	10	30.78	4.92	15.32	0.57	50.90	8.16
	4. G-Bond + RC	10	29.01	4.00	16.68	0.57	58.77	10.46
	5. Clearfil S^3 Bond + RC	10	33.62	4.10	19.12	4.00	56.38	4.65

RC, resin composite (Z250); SD, standard deviation.

yielded the highest fracture strength recovery value when used alone ($P < 0.05$). Used in conjunction with the resin composite, Prime&Bond NT displayed the highest fracture strength recovery ($P < 0.05$). In the internal dentin groove technique, the highest fracture strength recovery values were obtained with Prime&Bond NT, G-Bond and Clearfil S^3 Bond ($P < 0.05$), but the differences between the three groups was not significant ($P = 0.66$).

Scanning electron microscopic evaluation

Regardless of the reattachment technique/adhesive system used, local bonding defects were observed in all specimens. In general, these defects manifested as lateral microcracks that were either unfilled or insufficiently filled by the adhesive and/or composite resin (Fig. 2). Similar defects were also observed along the main fracture line and were contained entrapped air (Fig. 2). Representative micrographs of the resin–dentin interfaces of the test groups are presented in Fig. 3. None of the groups displayed a homogenous hybrid layer. In the simple reattachment groups, specimens restored with Adper Prompt L-Pop displayed relatively thicker hybrid layers that varied between 30 and 50 μm (Fig. 3a).

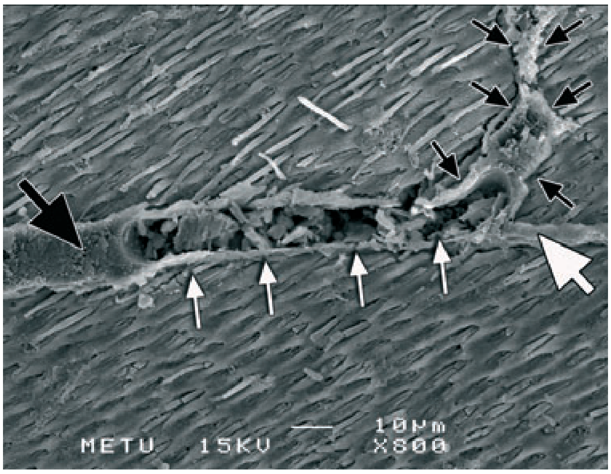

Fig. 2. A typical example of interfacial bonding defects. Small white arrows: air entrapment and insufficient penetration of adhesive resin, resulting in hiatus formation; Small black arrows: a lateral microcrack, filled unevenly by adhesive resin; Big black and white arrows: Non-uniform thickness of hybrid layer (G-Bond, Simple reattachment group, 800 x).

Discussion

In this study, sound and restored teeth were subjected to a fracturing load in accordance with the experimental protocol described by Reis et al. (11). This technique allows for measuring the fracture strength of each tooth before the reattachment procedure (10, 23), which enables each fragment-bonded tooth to have its own control (11). Compared with the sectioning technique, the fracturing method generally maintains a precise fit

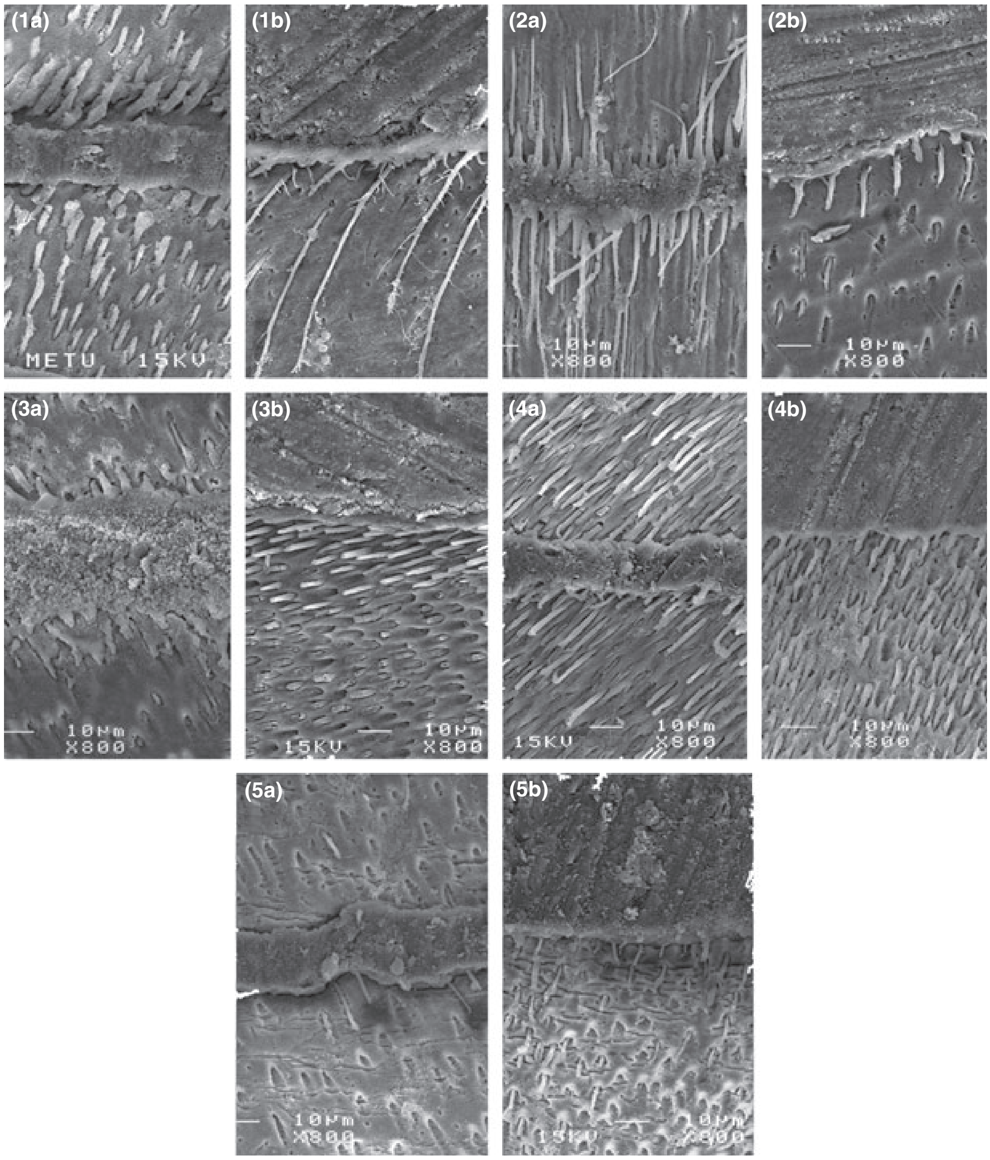

Fig. 3. Representative scanning electron micrographs of the adhesive interfaces. 1: Prime&Bond NT; 2: Single Bond 2; 3: Adper Prompt L-Pop; 4: G-Bond; 5: Clearfil S^{3}Bond. In each group, 'a' and 'b' demonstrate the tooth-bonded fragment interface and composite–tooth interface, respectively.

between the remnant and the fragment that most uncomplicated crown fractures have (17). Furthermore, the surface anatomy produced by sectioning differs from that obtained by fracturing, as a fractured surface runs parallel to the main direction of enamel prisms, whereas the orientation of a sectioned surface is dictated by the alignment of the diamond saw used to section the incisal edge (22, 23). Finally, the fracturing protocol provides a better simulation of the clinical condition as it generates smear-free fractured surfaces, whereas the sectioning technique produces a cut surface of coronal dentin that incorporates a smear layer. As known, the bond strength to uncut (smear-free) dentin is reportedly lower than that obtained with smear-covered, sectioned coronal dentin (24); which might be responsible for the low fracture strength recovery values obtained with reattachment techniques. In terms of retention, the clinical outcome of restorations utilizing tooth fragments is still primarily dependent on strong and durable enamel bonding (25). In spite of the ever-increasing popularity of self-etching bonding agents, adhesive systems that utilize phosphoric acid as a separate conditioner still represent the gold standard of reliable and strong enamel bonding (10, 26, 27). Self-etching adhesives can provide dentin bond strengths that are equal to or greater than those achieved with etch-and rinse adhesives (27), whereas many *in vitro* studies have discouraged the use of these materials on intact enamel because of significantly lower bond strengths, greater microleakage, and shallow etching patterns that prevent good penetration of the bonding resin (26, 28). To overcome these problems, many manufacturers recommend an additional preceding etching step of enamel with phosphoric acid, especially in the case of non-instrumented enamel (29). Indeed, several *in vitro* studies have clearly indicated that phosphoric acid etching increases the bond strength of self-etching adhesives to enamel (29–32). In light of these observations, the tested self-etching adhesives were applied to the fractured surfaces following selective phosphoric acid etching of the enamel surfaces. The results showed that this procedure had differential effects on the fracture strength recovery values obtained with the tested self-etch adhesives. For instance, when the adhesives were used alone for simple reattachment of fragments, the self-etch adhesive Clearfil S^3 Bond yielded the highest fracture strength recovery value, which was similar to that of the etch-and-rinse adhesive, Adper Single Bond. Again, when the adhesives were used together with the resin composite for simple reattachment, Clearfil S^3 Bond displayed the highest fracture strength; whereas the relatively inferior fracture strength recovery value of Adper Prompt L-Pop was comparable with those obtained both etch-and-rinse test materials. Similar outcomes were observed in the overcontour technique, with Clearfil S^3 Bond showing the highest fracture strength when used alone; and Clearfil S^3 Bond yielding the second highest fracture strength recovery value after the etch-and-rinse adhesive, Prime&Bond NT. Finally, in the internal dentin groove technique, two of the highest three fracture strength recovery values were obtained with self-etching adhesives (G-Bond and Clearfil S^3 Bond). Overall, our findings indicate that selective phosphoric acid-etching of enamel can increase the bond strengths of some single-step self-etching adhesive resins (33) to levels that are comparable with or greater than those of etch-and-rinse adhesive systems (34). These results necessitate acceptance of the first null hypothesis, as the type of adhesive material and presence of an intermediate composite layer between fragments had significant effects on the fracture resistance of rebonded teeth.

In this study, the highest fracture strength recovery was obtained using the internal dentin groove technique, followed by the overcontour and simple reattachment protocols. The fracture strength recovery values obtained with the simple reattachment technique fall within a similar range (~30–40%) with those previously reported using the same fracturing protocol (11, 19). However, the fracture strength recovery values of the internal groove and overcontour groups were at least 40% lower than those reported in the latter two studies (11, 19). This stark difference can be explained by two factors. First, those studies tested the initial bonding effectiveness of fragment reattachment, whereas the specimens herein were subjected to thermal cycling before applying the fracture load. Previous studies have clearly shown that the fracture strength of etch-and-rinse and self-etching adhesives to both enamel and dentin decrease when specimens are subjected to thermal cycling (35–38). Second, fracture strength of a rebonded fragment drops drastically with an increase in loading speed (9, 39), and the cross-head speed used herein was 10 x faster than that used in those two studies (11, 19). The rationale behind increasing the testing speed 10 times was to observe the outcome of bonding efficiency in a 'non-physiological use' scenario (4, 9, 19), which is a major cause of postadhesive failure (4). Based on the present results, the internal dentin groove technique generated the highest bond strength recovery, but this value did not exceed 60% of an intact tooth's fracture strength. Unfortunately, the amount of strength recovery needed to keep the fragment in position long-term still remains unknown. Perhaps fracture strengths as low as 50–60% may be sufficient if these values are confirmed by clinical studies (17).

Previous studies have limited their attention on techniques and materials that could increase the bonding effectiveness of restored fractured tooth segments. The present ultramorphological findings extend their results by demonstrating the existence of voids and microcracks along the fragment–tooth adhesive interface, which could limit the efficiency of such clinical procedures. Especially, the microcracks could act as notches that induce further crack propagation under intermittent mechanical loading *in vivo*; and possibly lead to the failure of rebonded fragments because of subcritical cracking (39, 40). It should be emphasized that existence of voids may also weaken the integrity of the tooth–adhesive interface. If these initial findings are confirmed by further studies, then the etiology of failure of reattached tooth fragments may involve such local bonding defects.

Conclusions

In light of the results obtained and within the limitations of this *in vitro* study, the following conclusions were drawn:

1. Both the type of adhesive material and the preparation technique affected the fracture strength recovery of reattached tooth fragments, leading to acceptance of the null hypothesis.
2. Regardless of the adhesive technique employed, reattachment of fragments with an intermediate resin composite layer significantly increased the fracture strength recovery.
3. Based on ultrastructural findings, establishment of an ideal adhesive interface between tooth fragments does not appear to be possible. Local defects such as voids or microcracks might act as the achilles heel of the adhesive interface, eventually leading to the failure of reattached fractured tooth segments under *in vivo* loading conditions. Further studies are required to elucidate the effect of these defects on fracture resistance.

References

1. Andreasen JO, Ravn JJ. Epidemiology of traumatic dental injuries to primary and permanent teeth in a Danish population sample. Int J Oral Surg 1972;1:235–9.
2. Andreasen FM, Andreasen JO. Crown fractures. In: Andreasen FM, Andreasen JO, editors. Textbook and color atlas of traumatic injuries to the teeth. Copenhagen, Denmark: Mosby; 1994. p. 219–56.
3. Munksgaard EC, Højtved L, Jørgensen EH, Andreasen JO, Andreasen FM. Enamel-dentin crown fractures bonded with various bonding agents. Endod Dent Traumatol 1991;7:73–7.

4. Andreasen FM, Norén JG, Andreasen JO, Engelhardtsen S, Lindh-Strömberg U. Long-term survival of fragment bonding in the treatment of fractured crowns: a multicenter clinical study. Quintessence Int 1995;26:669–81.
5. Santos JF, Bianchi J. Biologic esthetic restorations. J Esthet Dent 1992;4:S1–3.
6. Maia EA, Baratieri LN, de Andrada MA, Monteiro S Jr, de Araújo EM Jr. Tooth fragment reattachment: fundamentals of the technique and two case reports. Quintessence Int 2003;34:99–107.
7. Farik B, Munksgaard EC, Kreiborg S, Andreasen JO. Adhesive bonding of fragmented anterior teeth. Endod Dent Traumatol 1998;14:119–23.
8. Macedo GV, Diaz PI, De O Fernandes CA, Ritter AV. Reattachment of anterior teeth fragments: a conservative approach. J Esthet Restor Dent 2008;20:5–18.
9. Andreasen FM, Steinhardt U, Bille M, Munksgaard EC. Bonding of enamel-dentin crown fragments after crown fracture. An experimental study using bonding agents. Endod Dent Traumatol 1993;9:111–4.
10. 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.
11. Reis A, Francci C, Loguercio AD, Carrilho MR, Rodriques Filho LE. Re-attachment of anterior fractured teeth: fracture strength using different techniques. Oper Dent 2001;26:287–94.
12. Simonsen RJ. Traumatic fracture restorations: An alternative use of the acid etch technique. Quintessence Int 1979;10:15–22.
13. Burke FJ. Re-attachment of a fractured central incisors tooth fragment. Br Dent J 1991;170:223–5.
14. Walker M. Fractured-tooth fragment re-attachment. Gen Dent 1996;44:434–6.
15. Davis MJ, Roth J, Levi M. Marginal integrity of adhesive fracture restorations. Quintessence Int 1983;14:1135–46.
16. Fahl N Jr, Denehy GE, Jackson RD. Protocol for predictable restoration of anterior teeth with composite resins. Pract Periodontics Aesthet Dent 1995;7:13–21.
17. 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.
18. Farik B, Munksgaard EC. Fracture strength of intact and fragment-bonded teeth at various velocities of the applied force. Eur J Oral Sci 1999;107:70–73.
19. 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.
20. Mitsui FH, Peris AR, Cavalcanti AN, Marchi GM, Pimenta LA. Influence of thermal and mechanical load cycling on microtensile bond strengths of total and self-etching adhesive systems. Oper Dent 2006;31:240–247.
21. Cehreli SB, Gungor HC, Karabulut E. Er,Cr:YSGG laser pretreatment of primary teeth for bonded fissure sealant application: a quantitative microleakage study. J Adhes Dent 2006;8:381–6.
22. Badami AA, Dunne SM, Scheer B. An *in vitro* investigation into the shear bond strengths of two dentine-bonding agents used in the reattachment of incisal edge fragments. Endod Dent Traumatol 1995;11:129–35.
23. Reis A, Kraul A, Francci C, de Assis TG, Crivelli DD, Oda M et al. Re-attachment of anterior fractured teeth: fracture strength using different materials. Oper Dent 2002;27:621–7.
24. Kijsamanmith K, Timpawat S, Harnirattisai C, Messer HH. Micro-tensile bond strengths of bonding agents to pulpal floor dentine. Int Endod J 2002;35:833–9.
25. Liebenberg W. Commentary. Reattachment of anterior teeth fragments: A conservative approach. J Esthet Restor Dent 2008;20:19–20.
26. Pashley DH, Tay FR. Aggressiveness of contemporary self-etching adhesives. Part II: etching effects on unground enamel. Dent Mater 2001;17:430–44.
27. De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M et al. A critical review of the durability of adhesion to tooth tissue: methods and results. J Dent Res 2005;84:118–32.
28. Kanemura N, Sano H, Tagami J. Tensile bond strength to and SEM evaluation of ground and intact enamel surfaces. J Dent 1999;27:523–30.
29. Van Landuyt KL, Kanumilli P, De Munck J, Peumans M, Lambrechts P, Van Meerbeek B. Bond strength of a mild self-etch adhesive with and without prior acid-etching. J Dent 2006;34:77–85.
30. Walker MP, Wang Y, Swafford J, Evans A, Spencer P. Influence of additional acid etch treatment on resin cement dentin infiltration. J Prosthodont 2000;9:77–81.
31. Torii Y, Itou K, Nishitani Y, Ishikawa K, Suzuki K. Effect of phosphoric acid etching prior to self-etching primer application on adhesion of resin composite to enamel and dentin. Am J Dent 2002;15:305–8.
32. Erhardt MC, Cavalcante LM, Pimenta LA. Influence of phosphoric acid pretreatment on self-etching bond strengths. J Esthet Restor Dent 2004;16:33–40.
33. 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.
34. Watanabe T, Tsubota K, Takamizawa T, Kurokawa H, Rikuta A, Ando S et al. Effect of prior acid etching on bonding durability of single-step adhesives. Oper Dent 2008;33:426–33.
35. 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.
36. Davidson CL, Abdalla AI, De Gee AJ. An investigation into the quality of dentine bonding systems for accomplishing a durable bond. J Oral Rehabil 1993;20:291–300.
37. El-Araby AM, Talic YF. The effect of thermocycling on the adhesion of self-etching adhesives on dental enamel and dentin. J Contemp Dent Pract 2007;8:17–24.
38. Price RB, Derand T, Andreou P, Murphy D. The effect of two configuration factors, time, and thermal cycling on resin to dentin bond strengths. Biomaterials 2003;24:1013–21.
39. Nalla RK, Imbeni V, Kinney JH, Staninec M, Marshall SJ, Ritchie RO. *In vitro* fatigue behavior of human dentin with implications for life prediction. J Biomed Mater Res 2003;66A:10–20.
40. Kruzic JJ, Nalla RK, Kinney JH, Ritchie RO. Mechanistic aspects of *in vitro* fatigue-crack growth in dentin. Biomaterials 2005;26:1195–204.