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Rebond strength of bonded lingual wire retainers

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SUMMARY There is no consensus in the literature concerning the rebonding procedure for orthodontic retainers. The aim of this *in vitro* study was to evaluate the bond and rebond strength of retainers bonded to enamel surfaces with and without composite remnants. The retainers were bonded with Excite and Tetric Flow on three different surfaces: clean enamel, enamel where the composite had been removed by a tungsten carbide bur, and with cured composite remnants roughened by a tungsten carbide bur. The bond strength was determined by means of a cantilever–tensile bond strength test using a repeated crossover design. Each tooth was rebonded twice and tested three times ($N = 114$). The surface was examined by scanning electron microscopy (SEM), electron backscatter diffraction and micro X-ray fluorescence (EDAX), and scored using the adhesive remnant index (ARI).

Two-way analysis of variance of the mean bond strengths did not show significant differences between the three different enamel surface treatments. However, the specimens with cured composite remnants showed a higher standard deviation. This was confirmed by Weibull analyses. The ARI score showed that 96.5 per cent of bond fractures occurred at the retainer–resin interface. In contrast to the ARI score obtained in this study, the clinical ARI scores also showed failures at the resin–enamel interface. Based on these results, it is recommended that for rebonding the bond site is controlled, and the enamel surfaces are free of old composites remnants.

Introduction

Retention is the phase of orthodontic treatment aimed at maintaining the teeth in the corrected positions. Without the retention phase, there is a tendency for the teeth to return to their initial position (Al Yami *et al.*, 1999). The true causes of this relapse are not fully understood but might be related to recoil of the fibres holding the teeth in the alveolar bone; pressure from the lips, cheeks, and tongue; ongoing growth; and occlusal contacts (Melrose and Millett, 1998). To minimize relapse or other changes after treatment, almost every patient will require some type of retention. Attitudes to retention have changed over the years, but there is little evidence on which clinical decisions can be based (Melrose and Millett, 1998; Littlewood *et al.*, 2006). There is for example no consensus about the duration of retention. It has been shown that approximately 7 months after orthodontic tooth movement, the fibres around the teeth remodel to the new position (Reitan, 1967). However, even if the teeth are held in the new position for a longer period than the suggested 7 months, it has been shown that in the long-term, teeth can still show some relapse (Little *et al.*, 1981, 1988). Some clinicians, therefore, prefer to retain for longer periods, sometimes indefinitely.

Eighty-four per cent of Dutch orthodontists, who responded to a recent survey preferred bonded retainers as permanent retention (Renkema *et al.*, 2009). One of the problems with bonded lingual wire retainers is debonding from enamel or cohesive failure within the composite. It is not known precisely whether it is necessary to remove the composite remnants completely before rebonding retainer wire after failure.

The clinical procedure of bonding composite to enamel, dentine, metal, and porcelain surfaces is well known. There is no optimal procedure for rebonding a lingual wire retainer to the teeth. In general, cured composites have fewer reactive acrylate groups on the external surface (Vankerckhoven *et al.*, 1982; Padipatvuthikul and Mair, 2007), and rebonding to aged composites might, therefore, at least theoretically, reduce the bond strength between the aged and the newly applied composite. It has been shown, for instance, that there is no significant difference between rebonding strength of 1-day- and 6-month-old cured composites (Rathke *et al.*, 2009). The lack of reactive acrylate groups can partially be compensated by micromechanical retention. For that reason, optimal bonding and rebonding requires roughening of the surface, followed by standard bonding procedures.

The aim of this *in vitro* study was to determine whether or not the composite needs to be removed completely before retainers can be successfully rebonded. Therefore, the initial bond strength and rebond strength of lingual wire retainers using a flowable composite were determined. The hypothesis formulated was that bond strength differs between bonded and rebonded retainers.

Materials and methods

The bond strength of retainers was determined on three different surfaces: clean enamel, enamel from which all composite had been removed by a tungsten carbide bur, and cured composite roughened by a tungsten carbide bur. The bond strength of the retainer was determined by means of a cantilever tensile bond strength test (TBS).

Enamel from 38 freshly extracted bovine teeth (Nakamichi *et al.*, 1983; Oesterle *et al.*, 1998), randomly collected from 2-year-old cattle, was used as the substrate. The crowns were sectioned from the roots and embedded in cylindrical polymethyl methacrylate moulds. The vestibular enamel surface was ground on wet silicon carbide paper up to grit 1200 to create a flat standard bonding surface.

A crossover experimental study design with repeated tests (Figure 1) was used. This means that each tooth was rebonded twice and tested three times. The teeth were randomly assigned to one of the two groups and numbered. After initial bond strength was determined (T1A), the composite remnants were removed for the second test (T2A) and then rebonded without composite removal for the third test (T3A). The second group had no removal of composite remnants for the second test (T2B) and all the composite removed for the third test (T3B). Thus, each tooth was its own control.

Bonding of the wire to the teeth was standardized according to the following protocol: the enamel surface was etched with 37 per cent phosphoric acid for 30 seconds and sprayed using an abundant supply of water for 30 seconds. Thereafter, the teeth were dried in a stream of oil-free air. Prior to the application of Tetric Flow (Ivoclar Vivadent, Schaan, Liechtenstein), the enamel surface and wire were covered with Excite bonding adhesive (Ivoclar Vivadent). Firstly, a thin layer of bonding agent was applied for 10 seconds, after which the excess material on the teeth was dispersed by applying a stream of oil-free air. Subsequently, a 15 mm long 0.0215 inch (1 mm) round Pentaflex wire (American Orthodontics, Sheboygan, Wisconsin, USA; stainless steel, CO-AX spool) covered in uncured Excite bonding was placed. The wire placement was tension free and was kept in place due to the cohesive force of the bonding agent. Correction of the wire was possible until the composite was cured for 20 seconds with a small light-emitting diode light (Acteon Group, Bordeaux, France).

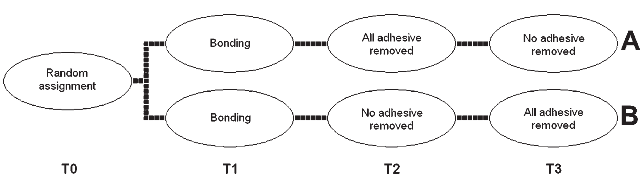

Figure 1 Schematic representation of the study design.

The bonding area was standardized by applying a metal mould with a diameter of 4 mm and a height of 2 mm. The mould had, at the site facing the tooth, two grooves that enabled the wire to run tension free through the mould. Each wire was covered by a 1 mm layer of composite. Curing took place for 20 seconds both on the bonding layer and on the composite at a distance of 10 mm between the lamp tip and the tooth, perpendicular to the buccal surface. After preparation, the specimens were stored in distilled water at a temperature of 37°C for 2 weeks.

Bond strength testing

The bond strength of the retainer was determined by means of a cantilever–TBS test (Figure 2). The tensile load was applied to the wire 2 mm from the bond site. This resulted in a vertical moment and tensile force acting on the wire–composite–tooth system. The specimens were mounted in a universal testing machine (Hounsfield Ltd., Redhill, Surrey, UK). The crosshead speed during testing was 0.5 mm/minute. The loads at fracture were recorded in Newtons. After testing, the type of fracture was scored using the adhesive remnant index (ARI; Årtun and Bergland, 1984) to identify the weakest point in the wire–composite–tooth system. A score of 0 indicated that no adhesive was left on the enamel, 1 less than half of the adhesive remained, 2 more than half of the adhesive remained, and 3 all adhesive remained on the enamel surface. The scores were determined using a stereomicroscope (Olympus, Tokyo, Japan) at ×25 magnification by the same investigator (KvW).

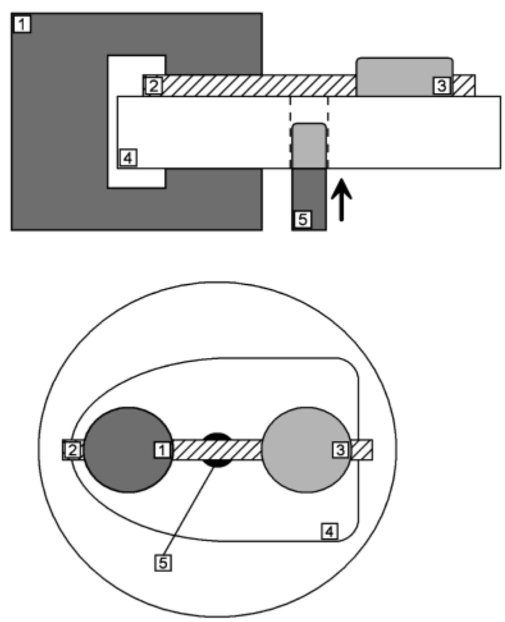

Figure 2 Schematic representation of the test setup. 1. clamp, 2. wire, 3. composite, 4. teeth embedded in a cylindrical polymethyl methacrylate mould, and 5. pushing rod of the universal testing machine. The wire is fixed at both sites, one end by the composite and the other end by the clamp.

After testing, the specimens were prepared for rebonding. The residual adhesive on the teeth was carefully removed from the enamel with a fluted tungsten carbide bur in a high-speed dental handpiece under dry conditions (3000 rpm; Zachrisson and Årtun, 1979). Removal of the resin was considered complete when no resin was apparent on visual inspection using an operational lamp. After removal of the adhesive resin with the bur, the enamel surfaces were not further polished before etching. For each specimen, a new wire was used.

Scanning electron microscopy and electron backscatter diffraction and micro X-ray fluorescence

Randomly selected specimens of a number of teeth were gold sputtered (Edwards Sputter Coater S150B; Edwards High Vacuum, Crawley, West Sussex, England) and examined by means of scanning electron microscopy (SEM; Philips SEM XL 20, Eindhoven, Netherlands). Bulk method quantification of the tooth and composite surfaces was carried out using electron backscatter diffraction and micro X-ray fluorescence (EDAX; Edax, Inc., Mahwah, New Jersey, USA).

Statistical analysis

Descriptive statistics were used to calculate the mean value, the standard deviation, the mean error, and the coefficient of variation of the measured data. Two-way analysis of variance was employed to test the effect within the two main groups. A level of $P < 0.05$ was considered significant. A Tukey *post hoc* test was performed to test individual differences. The software used was SigmaStat Version 3.0 (SPSS Inc., Chicago, Illinois, USA). To estimate bonding performance, the data were also analysed using Weibull statistics. The results of this analysis are presented as η and β, in which η is the characteristic life and β is the slope of the Weibull distribution curve, which is related to reliability. Furthermore, L_1 can be determined which refers to the value at which 1 per cent of the specimens will fail at that given bond strength. The Weibull analysis was carried out using WinSMITH (Barringer and Associates, Humble, Texas, USA).

Results

The mean initial bond strength and rebond strength of the lingual wire retainers and their standard deviations are presented in Table 1. Analysis showed no statistically significant differences between the two groups ($F = 0.005$; $P = 0.94$) and the rebonding procedures ($F = 0.360$; $P = 0.70$). Although comparison of the mean value of the test series did not show significant differences for rebonding, the specimens of the cured composite group showed a higher standard deviation (Figure 3). As the standard deviation is related to reliability of the bonding procedure and might possibly predict clinical performance,

Table 1 The mean bond strength (in Newton) and standard deviation in parentheses and the adhesive remnant index (ARI) score for the different enamel surfaces.

	Bond strength	ARI
T1A initial bond strength	76.6 (11.4)	2.9 (0.2)
T2A cleaned rebonded	76.6 (11.9)	2.9 (0.2)
T3A roughened rebonded	77.5 (15.3)	3.0 (0.0)
T1B initial bond strength	74.5 (9.0)	3.0 (0.0)
T2B roughened rebonded	78.6 (16.2)	2.9 (0.2)
T3B cleaned rebonded	78.2 (11.9)	2.9 (0.2)

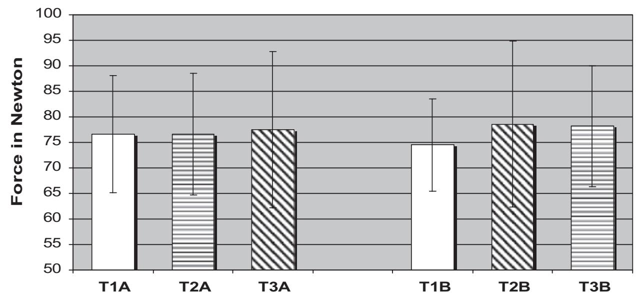

Figure 3 Mean bond strength (in Newton) and standard deviations of both test series, the open bar indicates the initial bond strength (T1A and T1B). The horizontal striped bar the rebond strength on cleaned enamel (T2A and T3B), and the diagonal striped bar the rebond strength on roughened cured composite (T3A and T2B).

Table 2 The mean characteristic strength (η) (in Newton) and Weibull modulus (β) of the different enamel surfaces and their calculated L_1.

	η (N)	β	L_1 (N)
T1A initial bond strength	81.1	8.18	46.2
T2A cleaned rebonded	81.2	7.70	44.7
T3A roughened rebonded	82.7	6.57	41.1
T1B initial bond strength	78.2	9.72	48.7
T2B roughened rebonded	84.1	6.26	40.3
T3B cleaned rebonded	82.6	8.30	47.5

the data were also analysed using Weibull statistics. The results of this analysis are presented in Table 2. The parameter L_1 for the groups with rebonding on the composite remnants was 40.3–41.1 N, and for the other groups 44.7–48.7 N (Figure 4).

Types of failure and their distribution

The failure sites were evaluated and ordered in four possible types of failure by ARI score. Of all cantilever–TBS evaluated ($N = 114$), 110 showed an ARI score of 3, and 4 an ARI score of 2, suggesting that 96.5 per cent of the bonding fractures most probably occurred at the retainer–resin interface. The mean ARI scores are summarized in Table 1.

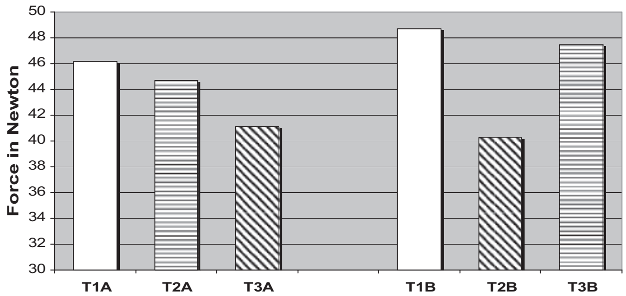

Figure 4 L_1 (in Newton) of the Weibull analysis, which represents the bond strength at which 1 per cent of the specimens will fail. The open bar indicates the initial bond strength (T1A and T1B), the horizontal striped bar the rebond strength on cleaned enamel (T2A and T3B), and the diagonal striped bar the rebond strength on roughened cured composite (T3A and T2B).

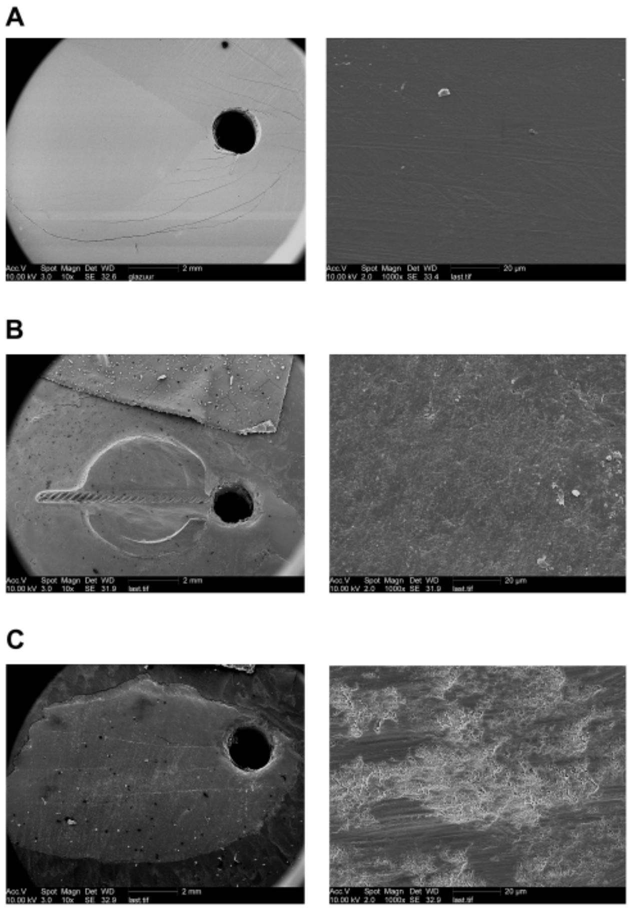

Figure 5 Scanning electron micrographs at a magnification of ×10 and ×1000 showing (A) the surface of clean bovine enamel, (B) the roughened cured composite prior to rebonding and (C) the carefully cleaned enamel prior to rebonding.

SEM and EDAX

Figure 5a shows the enamel prior to initial bonding and Figure 5b and 5c the roughened composite and cleaned enamel prior to rebonding. SEM and EDAX analyses revealed no or very little composite remnants on enamel surfaces after carefully cleaning with a fluted tungsten carbide bur (Figure 5c). Figure 5b shows that the term, roughening of the composite, can be better described as mechanical cleaning as almost no roughening was observed. Figure 6a and 6b show cross-sections of the specimens used. Again, SEM and EDAX analyses revealed no or very little composite remnants, even inside the deeper etched compartments of the enamel after careful cleaning with a fluted tungsten carbide bur.

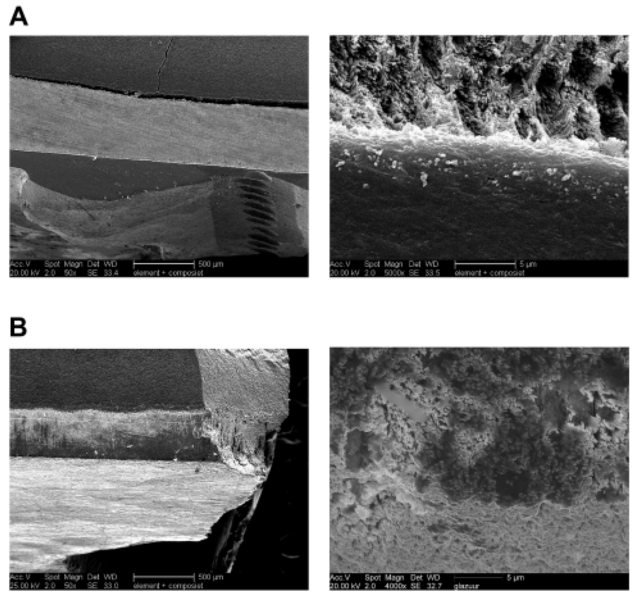

Figure 6 Scanning electron micrographs at a magnification of ×10 and ×5000 showing (A) the cross-section of roughened cured composite prior to rebonding and (B) at a magnification of ×10 and ×4000 showing the cross-section of carefully cleaned enamel prior to rebonding.

Discussion

Clinically, the reliable bonding of lingual wire retainers is important. The bonded wire retainer is a very complex system on which forces are exerted from different directions. For that reason, shear bond strength (SBS), cantilever loads, torque, and tensile strength tests can be performed to evaluate the bond strength of the wire to the enamel. Most tests focus on SBS. In general, the limitation of these SBS tests is that they are less uniform during stress distribution testing, causing unreliable and incomparable results. For this reason, bonding systems are often evaluated by means of (micro)-TBS tests instead of SBS tests. The test used in the present study applied a minimum of cantilever action on the retention wire and failure was, therefore, induced as a result of tensile forces. In this manner, the TBS tests were similar to the study of Radlanski and Zain (2004).

The results of the present research showed no statistically significant difference between initially bonded and rebonded lingual wire retainers. There was also no significant difference between the specimens from which the old composite had been removed prior to rebonding. Based on these results, the hypothesis that the bond strength differs between bonded and rebonded retainers was rejected. The initial bond strength observed in this study was in agreement with the values reported in the literature (Radlanski and Zain, 2004) that Tetric Flow showed the highest bond strength of the investigated materials and failed at a load of 75.7 N.

The standard deviation of the rebonded wires, which were applied to the enamel surface with the composite remnants, was much higher in both groups (T3A and T2B). For that reason, the data were analysed using Weibull statistics. The Weibull statistical fracture theory is widely applied to the fracture of ceramic materials. The characteristic strength (η) is related to mean TBS, and the Weibull modulus (β) characterizes the spread of failure, i.e. the standard deviation of a normal (Gaussian) distribution. Therefore, a higher Weibull modulus will result in more predictable and, possibly, improved clinical performance. From the results, it can be seen that ranging from 6.26 to 6.57, the Weibull modulus (β) for groups T3A and T2B was lower compared with the other groups showing 7.70–9.72. The characteristic strength (η) and the Weibull modulus (β) can be used to calculate L_1, which refers to the bond strength at which 1 per cent of the specimens will fail (Table 2). The parameter L_1 for the groups with rebonding on the composite remnants was lower (40.3–41.1 N) compared with the other groups (44.7–48.7 N; Figure 4), suggesting that leaving composite remnants on enamel surface will lead to less reliable bonding and most probably less effective bonding in the clinical situation.

The ARI scores indicate that 96.5 per cent of bond fractures occurred purely at the retainer–resin interface showing that the composite itself is the weakest link in this type of bonding and not the composite to enamel. The present study was conducted as an *in vitro* investigation under ideal, or at least well-controlled, circumstances. This indicates that the enamel surfaces were clean before bonding, and no saliva, calculus, or plaque contamination occurred during the bonding procedure. The wire–composite–tooth system was also not subjected to fatigue. These considerations support the idea that an ARI score of 0, which is frequently observed in the clinical situation, probably reflects a multifactorial problem rather than resin failure only. This is supported by the literature (Zachrisson, 1977; Årtun and Urbye, 1988; Bearn 1995). If any improvements of bond strength are needed, a closer look should be taken at the composite but, even more importantly, the bonding site should be controlled during retainer placement. Furthermore, based on the results of the Weibull analysis, it is recommended that for rebonding, the enamel surface is completely free of old composite remnants.

Conclusions

A possible explanation for the difference between *in vitro* and *in vivo* results might be the clinical circumstances that influence bonding. In order to obtain ideal bonding conditions for rebonding lingual retainers, it is recommended that the bonding site is clean and dry but also free of old composites remnants.

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