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Debonding force and deformation of two multi-stranded lingual retainer wires bonded to incisor enamel: an *in vitro* study

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SUMMARY The aim of the study was to examine, *in vitro*, the effect of a vertical force on the debond force and deformation of two multi-stranded wires bonded to the lingual enamel of lower incisor teeth.

Two different stainless steel wires were used, 0.016 × 0.022 inch (Bond-A-Braid® Reliance Orthodontic Products) and a three-stranded 0.0175 inch wire (Ortho Technology). An *in vitro* model was used to simulate a vertical force at the interdental wire. Twenty-six pairs of incisors were placed in two groups. A 15 mm length of wire was bonded to the lingual surfaces of each pair of incisors using a common bonding technique. A vertical force was applied to the midpoint of the interdental wire, using an Instron universal testing machine. The failure characteristics examined included the maximum force for debond, the degree of wire deformation, and the site of failure.

Significance was predetermined at $P < 0.05$ and multiple comparisons indicated no significant differences ($P = 0.147$) in the initial mean bond strength between the 0.0175 inch (41.44 N) and 0.016 × 0.022 inch (37.70 N) wires. The main failure type for both the initial and second debond events was fracture of composite bond at the wire–composite interface, cohesive failure. Both wires exhibited similar mean degrees of deflection of 1.30 and 1.51 mm for the 0.0175 inch and 0.016 × 0.022 inch wires, respectively. Rebonding to enamel resulted in significantly lower ($P = 0.001$) mean bond strength for both wires, 0.0175 inch (13.86 N) and 0.016 × 0.022 inch (14.17 N) in comparison with the initial bond strength. Rebonding to previously bonded enamel may be unpredictable and may lead to higher failure rates of bonded lingual retainers.

Introduction

The phenomenon of relapse is well recognized and documented in the orthodontic literature (Riedel, 1960; Nanda and Nanda, 1992). After active treatment is complete, long-term preservation of the corrected tooth positions is desirable, both for the clinician and for the patient. Unwanted post-treatment tooth movements have been attributed to a number of factors including periodontal fibre reorganization (Southard *et al.*, 1992), growth changes after treatment (Richardson, 1994), and type of treatment undertaken (Sadowsky *et al.*, 1994). To counter such relapse, the employment of bonded retainers to the mandibular (Störmann and Ehmer, 2002) or maxillary (Naraghi *et al.*, 2006) incisors has become an established part of orthodontic practice.

The lingual aspect of the lower incisors is the most common site for a bonded retainer. As an indefinite retainer, this has the advantage of good aesthetics with patient preference over removable retainer types (Axelsson and Zachrisson, 1992). Zachrisson (1982) initially presented the use of multi-stranded wire for a lower labial segment retainer bonded only to the canines and adapted to the lingual of the incisors. The reported frequency of failure rate varying from 5.9 to 20.9 per cent, for three different lower multi-stranded stainless steel bonded retainers (Dahl and Zachrisson, 1991) to 53 per cent (Störmann and Ehmer, 2002). Recently, the clinical survival rate over a 41.7 month period in a retrospective study has been reported to be 68.4 per cent for flexible, braided lingual retainers in the mandible (Lie Sam Foek *et al.*, 2008). Alternatively, the use of a nickel–titanium mandibular lingual bonded retainer has been advocated for active re-treatment of the six mandibular anterior teeth followed by passive maintenance of alignment with the same wire (Liou *et al.*, 2001). In addition, the use of more aesthetic material such as reinforced polyethylene ribbon (resin bonded) has become popular (Rose *et al.*, 2002). However, there appears to be no consensus on the most clinically effective diameter of multi-stranded wires used for bonded retainers. Årtun *et al.* (1997) favoured the use of a 0.0205 inch diameter while Rose *et al.* (2002) used a 0.0175 inch multi-stranded wire.

The sites of failure of the bonded retainers are variable and have been reported to be: at the enamel–composite interface (adhesive failure); at the wire–composite interface (cohesive failure); combination of both (compound failure), and stress fracture of the wire (Dahl and Zachrisson, 1991; Årtun et al., 1997).

In a review of bonded retainers, Bearn (1995) reported that the most common site of failure was the wire–composite interface-cohesive failure. In addition, an *in vitro* study (Bearn *et al.*, 1997) suggested that a composite thickness of greater than 1 mm may offer little clinical advantage. Lumsden *et al.* (1999) reported, in a retrospective study, on the survival of 200 bonded retainers in relation to three defined follow-up periods. The authors found that a greater overall proportion of failures occurred at the adhesive pad than at the wire-adhesive interface. However, early failure was more likely to occur at the adhesive bond while wire breakage was related to the age of the retainer. It is noteworthy that the multi-stranded wires used were 'heat treated' and also contoured to the lingual surfaces of the teeth on models prior to fitting. In the 3 year follow-up study carried out by Årtun *et al.* (1997), the wires were bent indirectly on models prior to debond of the fixed appliances. However, there is no mention of heat treatment of the wires. Lie Sam Foek *et al.* (2008) reported that the majority of failures occurred in the first 6 months after placement and that gender, age of the patient, and operator experience appeared to have no impact on the failure rate.

In a prospective randomized study of three different lower anterior bonded retainers in 103 subjects, Störmann and Ehmer (2002) reported no breakage of the wire. However, bond failure occurred in 34 subjects. This accounted for a distribution of detachment as follows: 53 per cent for the 0.0215 inch and 29 per cent for the 0.0195 inch multi-stranded wires bonded to the six mandibular anterior teeth and 18 per cent for the prefabricated retainer bonded only to the canines. Detachment of the bond was mainly a one-point failure. Of note is that whilst the failure rate of the more rigid wire, bonded only to the canines, was lower than the alternatives, incisor alignment had the greatest rate of relapse with this retainer type (80 per cent).

In a randomized controlled study to compare the survival of resin-reinforced polyethylene woven ribbon and multi-stranded stainless steel wire, Rose *et al.* (2002) reported a statistically significant difference between the failure rate of the two interventions during a 2 year period. The mean survival time was 11.5 months for the resin-reinforced ribbon in comparison with 15.8 months for the multi-stranded wire. The most common site of failure for the resin ribbon was at the reinforced polyethylene–composite interface, cohesive failure, which occurred secondary to crack propagation in the composite parallel to the retainer. The authors did not specify the site of failure of the multi-stranded retainer. However, a recent Cochrane review that included the latter study looked at the survival rate of the resin-reinforced ribbon (50 per cent) versus the multi-stranded wire (90 per cent) and found no significant difference between the two groups (Littlewood *et al.*, 2006).

No study appears to have investigated the force magnitude associated with force application to the interdental wire segment of a bonded retainer. The aims of this *in vitro* study were to evaluate the debonding force, wire deformation, and bond failure location, of the selected bonded wires when a vertical load is applied to the interdental segment of wire. In addition, the effect on the debond force of rebonding to enamel was examined.

Materials and methods

An *in vitro* model was used to simulate a vertical force at the interdental wire between two mandibular incisors. Fifty-two human mandibular incisors were obtained from patients (age range 15–68 years) who were undergoing dental or orthodontic treatment. All the collected teeth were caries free with intact lingual enamel. Ethical approval (04/Q0704/57) was granted to undertake the research. Consent was obtained from each patient who donated teeth for use in this study. The following cross-infection guidelines and storage methods were employed: the teeth were cleaned of debris and stored initially in 0.5 per cent chloramine for 1 week followed by storage in distilled water in a fridge. The teeth were removed from the fridge and stored at room temperature in distilled water for 48 hours prior to bonding.

One operator (MEC) carried all the procedures. Vacuum-formed moulds were constructed using a plaster block with dimensions of 15 × 15 × 10 mm. To simulate the periodontal structure, the roots of the teeth painted were with a thin layer of self-curing silicone to the cemento-enamel junction (Heyedcke *et al.*, 2001). In preparation for the testing, two incisors were placed adjacent to each other to simulate a contact point. The area below the contact point of each specimen was termed the 'pseudo papilla'. The labial aspect of the teeth were supported by a rigid plastic template whilst cold cure resin was poured around the roots of each pair of teeth to the cemento-enamel junction with the crowns left exposed above the level of the acrylic resin. The pseudo papilla was above the level of the cold cure acrylic resin. The specimen block dimensions allowed it to be held in the clamp of an Instron machine (Model 1198, Universal Testing Machine; Instron Limited, High Wycombe, Bucks, UK). In total, 26 specimen blocks were constructed using 52 lower incisor teeth.

The enamel surface of each tooth was cleaned with oil free pumice, washed with distilled water, and dried with air. The enamel surfaces were etched with 35 per cent orthophosphoric acid gel (Transbond XT etching gel system; 3M Unitek, Monrovia, California, USA) for 30 seconds, followed by thorough washing, and drying. Following application of the primer (Transbond XT system; 3M Unitek), a passive 15 mm wire length was bonded with light cure adhesive (Transbond XT adhesive; 3M Unitek) between the pairs of teeth in each specimen block. Two different dimension stainless steel wires were used:

1. 016 × 0.022 inch (Bond-A-Braid®, Reliance Orthodontic Products, Itasica, Illinois, USA. Batch No.:302110).
2. Three-stranded 0.0175 inch (Ortho Technology, Tampa, Florida, USA. Batch No.:705-107).

The 26 specimen blocks were divided into two groups for testing, 13 with the 0.016 × 0.022 inch wire and 13 with the 0.0175 inch wire.

While no bends were placed in the wire lengths, a gentle curve was placed in each for a passive fit to the lingual surfaces of the teeth. The midpoint of the wire length was marked with a white pencil and located onto the primed enamel so that it was parallel to the base of the specimen block and was halfway between the pseudo papilla and the simulated contact point of each pair of teeth. A commercially available dome shaped mould wire bonder (Mini-Mold™; Ortho-Care Ltd, Bradford, West Yorkshire, UK) was used to standardize the amount of composite used for each bond. The mould had a groove that allowed the operator to locate the composite so that the wire was in the middle of the composite bond (Figure 1). The dimension of each composite bond was 4 mm in diameter with a maximum depth of composite of 1.5 mm. This gave a 12.6 mm^2 bond area for each bond and a total bond area of 25.2 mm^2 for each specimen. Excess composite was removed from the margins of the mould before light-induced polymerization (Ortholux™ XT Visible light; 3M Unitek). The specimens were stored for 24 hours in distilled water at 37°C prior to testing to failure with a testing machine.

Each specimen was placed and secured in the testing machine so that the chisel edge used to apply the force would not contact any part of the specimen. The vertical force was applied with the chisel edge to the marked midpoint of the interdental wire segment at a crosshead speed of 2 mm per minute (Bryan and Sherriff, 1995). For each specimen, the maximum force, in Newtons (N), required to cause failure was recorded i.e. wire removal from the composite pad on at least one of the incisor pair in a specimen.

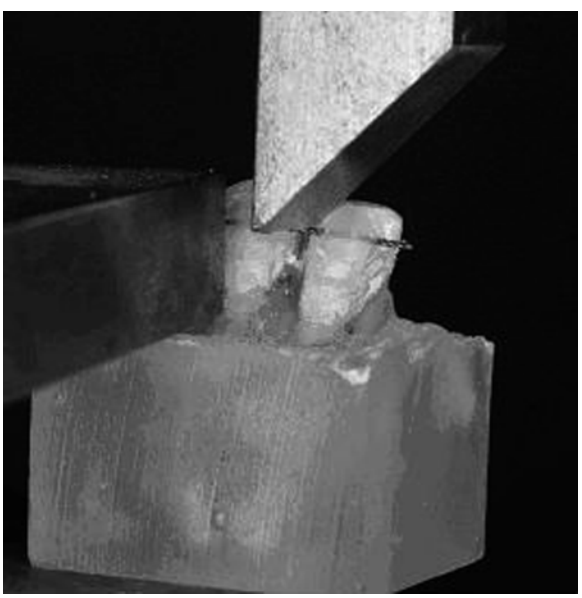

Figure 1 A test specimen in the clamp of the Instron machine, showing an incisor pair with a 15 mm length of wire bonded to the lingual surfaces of the teeth.

After each specimen had been evaluated, all visible composite adhesive was removed with a tungsten carbide bur until the enamel appeared shiny. The wire was rebonded and testing was repeated on the same day. The protocol for rebonding was similar to that used by Bishara *et al.* (2000) for examination of repeated bonding of orthodontic brackets. This approach was adopted to try to simulate the clinical situation of rebonding a retainer wire.

Evaluation of adhesive failure

The adhesive remnant index (ARI) was used to assess the amount of adhesive resin retained on the enamel surfaces of each tooth in a specimen pair where failure of the bond had occurred (Årtun and Bergland, 1984). The evaluation of the composite and enamel surfaces in this study was undertaken using a steromicroscope (Stemi-2000-C; Zeiss, Jena, Germany) at ×20 magnification. As there were two bond sites per specimen, the ARI score of both sites was recorded and then the data of the bond that failed first were analysed. Where failure of both bonds appeared to occur simultaneously, the lower score was recorded.

The ARI has a scale range between 0 and 3:

0 = no adhesive retained on the enamel (adhesive failure at composite–enamel interface).

1 = less than 50 per cent of adhesive retained on the enamel (adhesive failure predominantly at composite–enamel interface).

2 = more than 50 per cent but less than 100 per cent of adhesive retained on enamel (cohesive failure predominantly at the wire–composite interface).

3 = all adhesive retained on the enamel with an impression of the wire (cohesive failure at the wire–composite interface).

Evaluation of wire deflection

The amount of wire deflection after failure was assessed using the objective lens of the stereomicroscope (×20 magnification) and was measured in millimetres (mm).

Results

Data were analysed using Stata Release 9.2 (Stata Statistical Software, College Station, Texas, USA). Significance was predetermined at $P < 0.05$.

Bond strengths

The summary data for the bond and rebond tests is reported in Table 1 and Figure 2. The effect of the wire and bonding sequence was evaluated using analysis of variance. There was no significant difference between the debond strength of the two wires for the first (P = 0.147) or second (P =

Table 1 Summary data for debond force.

Wire dimension (inches)	Observation (*n*)	Experiment	Mean (N)	Standard deviation (N)	Standard error of mean	95% Confidence interval
0.016 × 0.022	13	Bond	37.70	5.54	1.54	3.02 (34.68–40.72)
0.016 × 0.022	13	Rebond	14.17	1.69	0.33	0.92 (13.25–15.09)
0.0175	13	Bond	41.44	5.89	1.63	3.20 (38.24–44.22)
0.0175	13	Rebond	13.86	1.36	0.37	0.74 (13.12–14.6)

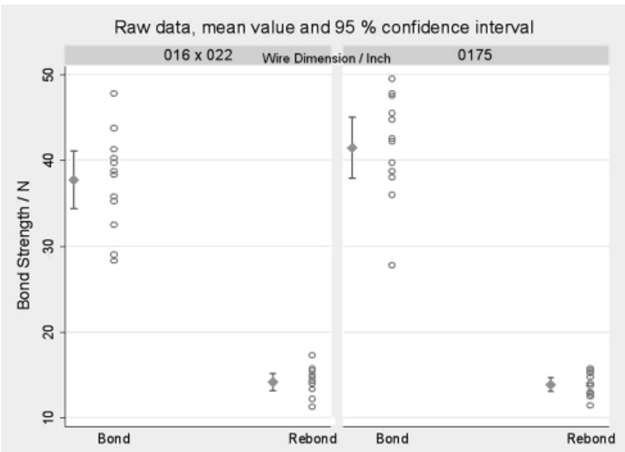

Figure 2 Summary data for debond strength for the 0.016 × 0.022 inch and 0.0175 inch wires.

0.154) debond sequence. In addition, there was no significant wire to bond/rebond sequence interaction term or effect of wire. However, both wires had significantly lower rebond strengths in comparison with the first bond strengths ($P = 0.001$).

Wire deflection

The summary data is presented in Table 2. These data were analysed using Kruskal–Wallis tests. For both the first and the second debond data, there was no significant difference between the two wires ($P > 0.05$).

Adhesive remnant index

The ARI of the bond site that failed first in each specimen was analysed. The ARI for the two groups tested are presented in Table 3. There was no event of wire fracture. The ARI was analysed by a Kruskal–Wallis test for single ordered data using exact non-parametric inference to allow for the small sample size. There was no significant difference between the distribution of the ARI score between bond and rebond events ($P = 0.22$).

Discussion

This study was undertaken to examine the force required to debond a segment of a bonded retainer wire when a vertical force was applied to an interdental segment of wire. There are no previous studies that have examined a force applied to an interdental segment of bonded retainer wire.

The limitations of using teeth from a wide age group of donors are acknowledged. Indeed, whilst limiting the tooth type to human mandibular incisors only, the most frequent site for bonded retainers, variations exists in the lingual morphology, age of enamel, and tooth size (Mattick and Hobson, 2000), which would have had effects on the moment of forces created at the bonded interfaces. The use of the polyethylene layer on the roots of the teeth allowed simulation in part of the periodontium and the flexibility that occurs in the dento-periodontal apparatus during application of forces (Heyedcke *et al.*, 2000), whilst placing the wire above the level of the pseudo papilla standardized the position for each specimen. No attempt was made to quantify the individual force vectors or indeed the effect of the pseudo-periodontium on the force applied.

While Reynolds (1975) suggested that 6–8 MPa was sufficient to withstand orthodontic forces for brackets, these data are not applicable to bonded retainer wires. There would appear to be little information in the literature on the minimum clinically accepted bond strength in relation to bonded retainer wires. The results of the present study are expressed in Newton, the unit of force, as opposed to Pascal, the unit of pressure. If one were to express the units in Pascals, it would imply that the force was homogenously distributed across the surface area of the bond, a fact that has been disproved (Katona and Moore, 1994) in a study of bracket loading. Indeed, complex forces arise when a vertical force is applied to a wire bonded at both ends and tension, shear, and torsion forces may occur simultaneously.

Radlanski and Zain (2004) found that force application directly to the adhesive pad of a wire/bond combination yielded a higher mean force for failure of 64.3 N in comparison with 20.8 N when a cantilevered wire, bonded at one end, was placed under shear and tensile forces. On introduction of the horizontal tension force vector to the wire, there was an increase in early failure at the composite–wire interface (cohesive failure). In the present study, the application of a vertical force to the midpoint of the interdental wire will have resulted in complex multivectorial forces across the two bond sites in each specimen leading to some horizontal tensional forces. The mean *in vitro* force

Table 2 Wire deflection data.

Wire dimension (inches)	Observation (*n*)	Experiment	Mean deflection (mm)	Standard deviation	Standard error of mean	95% Confidence interval
0.016 × 0.022	13	Bond	1.51	0.34	0.09	0.18 (1.33–1.69)
0.016 × 0.022	13	Rebond	1.32	0.29	0.08	0.16 (1.16–1.48)
0.0175	13	Bond	1.30	0.28	0.07	0.15 (1.15–1.45)
0.0175	13	Rebond	1.31	0.29	0.08	0.16 (1.15–1.46)

Table 3 Adhesive remnant index (ARI): score frequency

Wire dimension (inches)	Observations (*n*)	Experiment	ARI = 0	ARI = 1	ARI = 2	ARI = 3
0.016 × 0.022	13	Bond	0	0	13	0
0.016 × 0.022	13	Rebond	0	3	10	0
0.0175	13	Bond	0	0	13	0
0.0175	13	Rebond	0	2	11	0

required to debond the 0.016 × 0.022 inch and 0.0175 inch wires and adhesive combinations were 37.7 N and 41.44 N, respectively, force magnitudes between the forces reported by Radlanski and Zain (2004). In addition, failure was largely at the composite–wire interface (cohesive failure) concurring with the aforementioned study. Radlanski and Zain (2004) suggested that the bond strength of the wire/bond/enamel combination is weakened by the presence of 'freely tensioned' wire in the bonded retainer system and that such sections should be kept as short as possible to reduce the impact of tensile forces. In the present study, the length of freely tensioned wire allowed the application of force to the system. However, it would be interesting to reduce the length and to assess the forces required for failure.

One of the problems faced by the clinician is the repair of debonded retainer wires. Ideally, one would like pristine enamel to bond a new wire. In the present study, the force needed to debond during the second loading sequence was significantly lower than in the first sequence. Bishara *et al.* (2000) reported an overall decrease in bond strength during an *in vitro* examination of repeat bonding of new brackets to human tooth enamel. A greater force was required during the first debonding due to the initial etched enamel providing greater mechanical retention with tags of resin of up to 50 μm penetrating into the enamel (Bishara *et al.*, 2000) whilst the debridement procedure may lead to loss of 55.6 μm of enamel (Fitzpatrick and Way, 1997). The present study demonstrated that repeat bonding of wire to non-virgin enamel yielded a significantly lower force for debond in comparison with the initial bond ($P = 0.001$). This highlights the value of a consistent bonding technique by the clinician and reliability of the initial bonding procedure. In the present study for both first and second debond sequences, the main mode of failure was at the wire–composite interface. Perhaps, one could have expected to see more enamel/composite, adhesive failures, during the second sequence given the potential for reduced micromechanical retention of the enamel. However, the sample size was small and may have contributed to the small number of adhesive failures.

Since the extensive review of bonded retainer wires by Bearn (1995) contemporary practice has leaned towards the use of smaller diameter flexible multi-stranded stainless steel wires bonded to the six lower anterior teeth. The premise for using more flexible wire is to allow physiological movement of teeth, in particular those with periodontal considerations. The use of flat braided wires is not as widely reported as circular cross-sectional wires in relation to bonded retainers. The number of smaller wires composing the multi-stranded wires has also been investigated. Årtun *et al.* (1997) favoured use of a 0.0205 inch diameter five stranded twisted wire and postulated that the use of five rather three strands reduced the tendency of stress fracture of the wire, whilst Rose *et al.* (2002) used a 0.0175 inch multi-stranded wire. In the present study, no wire fractures were encountered, probably due to a combination of the 'young' age of the wire in comparison with *in vivo* studies (Lumsden *et al.*, 1999) and the flexural properties of the wires. In addition, the upper aspect of the wire demonstrated compressive loading whilst the lower surface experienced tensile stress during force application. In the present study, both wires exhibited similar small measurable deflections. However, there is little in the literature regarding the flexural loading and unloading of bonded retainer wires.

Indeed, no common consensus on the most clinically effective diameter of multi-stranded wires used for bonded retainers has been reached. The measured deflections in conjunction with the ARI scores may suggest that the force experienced by these flexible interdental wires drags the wire and deforms the interdental segment, leading to propagation of cracks within the composite, most likely along the wire–composite interface, and subsequent bond failure at the wire–composite interface i.e. cohesive failure. Intricate forces occur at the cohesive and adhesive interfaces due to the forces applied directly to the wire and by differential movement between the teeth to which the wire is bonded, a postulate previously contended by Bearn *et al.* (1997). In addition, the positioning of the wire more gingivally may increase the flexibility of the bonded retainer system (Andrén *et al.*, 1998), a factor that is influenced by tooth size and morphology and gingival contour.

It must be remembered that the data analysis from this study is relevant to the *in vitro* application of the specific adhesive, Transbond XT etching gel system, 3M Unitek, and does not account for the many *in vivo* dependent variables e.g. temperature, saliva, cyclic loading from mastication, or microbial effects. It has been suggested that *in vitro* findings can be expected to apply strongly to the *in vivo* experience due to the less favourable working conditions (Lie Sam Foek *et al.*, 2008). However, clinical studies are required to determine the ideal wire dimensions for lingual bonded retainers.

Conclusions

The following conclusions may be drawn from the present study:

1. There would appear to be little difference in *in vitro* bond strength and deformation of 0.016 × 0.022 inch and 0.0175 inch multi-stranded stainless steel wires.
2. Rebonding to previously bonded enamel may be unpredictable and may lead to higher failure rates of bonded lingual retainers.

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