An *in vitro* comparison between a bonded retainer system and a directly bonded flexible spiral wire retainer

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SUMMARY Bonded lingual retainers are becoming more popular to stabilize the results of orthodontic treatment. The *in vitro* shear strength of a flexible spiral wire (FSW) retainer (Zachrisson, 1977, 1983) bonded with Prisma Fil® was compared to the 'A'-Company bonded lingual retainer system, bonded with either Concise® or Right-On®, to human enamel. Statistical analysis of the results showed no significant differences between the 'A'-Company system when bonded with Concise or Right On, Concise having a greater mean bond strength, but also a greater range of bond strength values.

All the materials tested gave bond strengths that were adequate for clinical practice and it is concluded that the choice of bonded retainer system can be made upon grounds of clinical convenience or cost.

Introduction

Bonded lingual retainers are used principally for long-term retention of treated orthodontic cases and for the permanent splinting of periodontally involved teeth.

Zachrisson (1977, 1983) introduced the flexible spiral wire (FSW) retainer (Fig. 1), where a multistranded stainless steel wire was bonded to each tooth in the labial segment. This was designed as a simple way to retain teeth in difficult clinical situations, particularly to prevent space reopening and rotational relapse. The undercuts on the multistranded wire provide mechanical retention for the bonding composite. The wire's flexibility allows some degree of physiological movement of the retained teeth, aiding periodontal health. It also reduces stress concentration within the bonding composite thus minimizing its probability of subsequent failure.

Recently, ‘A’-Company has introduced a Bonded Lingual Retainer (‘A’-Company, Inc. P.O. Box 81247, San Diego, CA 92138) in kit form (Fig. 2). This retainer is produced by placing engineered ‘pads’ over a length of six stranded contoured tempered steel wire and bonding them to the lingual surfaces of the labial segments with a conventional adhesive. Retainer placement is claimed to be quick and easy, to reduce chairside time, to be very acceptable to the patient due to the low, smooth profile of the pads, and to be easy to keep clean. The aim of this study was to compare the shear strength of the ‘A’-Company bonded lingual retainer with a directly bonded retainer similar to that described by Zachrisson (1977, 1983).

Review of the literature

Composite considerations

An adhesive is a material that, when applied to substrate surfaces, can join them and resist separation (Kinloch, 1980). In this context, a dental composite can be regarded as an adhesive.

All teeth are subject to regular mechanical loading. Waters (1980) measured the maximum achievable biting force upon a single tooth as 265 N, but noted that regular loading was in the range 3–18 N. This has been confirmed by a number of authors (Bates et al., 1975; Proffit et al., 1983; Lundgren and Laurell, 1984; Lassila et al., 1985). A composite-enamel bond must also resist the stresses induced by polymerization shrinkage and regular differential thermal changes between the composite resin and enamel.

In a clinical environment the theoretical bond strength of a composite material is never
achieved due to the presence of internal stress concentrators (such as air voids, cracks or defects) and external stress raisers (due to the geometry of the occlusal loading). These lead to failure of the adhesive joint (adhesive failure), or to failure within the composite itself (cohesive failure), at forces well below the theoretical maximum (de Groot, 1986). Composite failure is usually a combination of adhesive and cohesive failure (Retief, 1974; Low et al., 1975; Rasmussen, 1978; Alexandre et al., 1981; Jassem et al., 1981; de Groot, 1986). The mechanism of composite failure is not fully understood. It is believed that an internal crack begins to
propagate through the composite, following internal flaws and voids (Jassem et al., 1981). The crack propagates towards and then follows the enamel surface, with the failed bond showing both adhesive and cohesive failures. Gottlieb et al. (1982) measured the bond strength of composite to enamel as being in the range of 10–20 MPa.

Zachrisson (1986) noted that bond failure was most commonly due to either disturbed setting of the composite, moisture contamination of the bonding enamel or inadequate contouring of the adhesive. The adhesive must be contoured so that masticated material is deflected, to minimise the pressure upon the retainer abutments. He advised that the wire retainer should be lightly held in position with composite, before the bulk of material is added.

Flexible spiral wire considerations
Zachrisson (1983) noted that the incidence of wire fracture decreased as the diameter of the wire increased, and that bonding FSW retainers to the lingual surfaces of premolars led to unacceptable levels of failure.

Dahl and Zachrisson (1991) followed up a series of 166 bonded retainers placed during the period 1980–1988. They used the techniques described by Zachrisson (1983, 1985), but used two types of wire of the same diameter, a three-stranded spiral wire (mean retention period, 6 years) and a five-stranded spiral wire (mean retention period, 3 years). They showed an overall bond failure rate of 13.8 per cent and a wire fracture rate of 10.8 per cent. The five-stranded wire showed a significantly lower failure rate than the three-stranded wire, probably due to the improved flexibility of the five-stranded wire.

Periodontal considerations
There have been few investigations of the periodontal implications of the FSW retainer. Becker and Goultschin (1984) noted that a bonded retainer would allow access for both periodic scaling and periodontal surgery. Årtun (1984) stressed the importance of meticulous technique and careful placement of the FSW retainer. There must be no contact between the retainer wire and the interdental papillae, or between the composite bonds and the gingival margin. The composite must be trimmed and polished to avoid areas of plaque retention. Årtun (1984) and Årtun et al. (1987) used periodontal indices to score the accumulation of plaque and calculus, and to assess the periodontal condition next to a series of bonded lingual retainers. After an average of 2.3 years placement they noted only occasional accumulations of plaque and calculus that resulted in no apparent damage to the dental hard or soft tissues. Dahl and Zachrisson (1991) noted that maxillary retainers were generally plaque and calculus free, but mandibular retainers often showed accumulations of calculus interdentally. Occlusal contact upon the retainer is undesirable. Årtun and Urbye (1988) reported bond failure in 12 of 24 patients who had maxillary lingual retainers placed following treatment for advanced loss of periodontal support, in an average retention period of 16 months. However, in these cases the overbite was not reduced and the high failure rate could be explained by the action of occlusal forces and abrasion of the composite by the opposing teeth. Dahl and Zachrisson (1991) found abrasion of the bonding composite or wear facets in the retainer wire and associated this with incompletely reduced overbites. However, they noted this abrasion in cases without tooth contact and speculated that it may be due, in part, to chewing or toothbrushing.

Complications of FSW retainers
The most common side-effects of the FSW retainer is the opening of small spaces (0.5–2 mm) distal to the terminal unit of the intact retainer (Dahl and Zachrisson, 1991). This can occur unilaterally or bilaterally and is usually seen in cases of extraction or bimaxillary proclination. These spaces usually appear in the first 6 months of retention and do not open further during the retention period.

A bond or wire failure within the retainer may result in space opening within the retained segment. Becker and Goultschin (1984) noted that a FSW retainer could be repaired without removal. A single failed bond can be removed and carefully replaced, while a failed section of wire can be excised and a new piece contoured and bonded into place. Zachrisson (1986), and Dahl and Zachrisson (1991) advised closing spacing due to failure of a bond with finger pressure, steel ligatures or elastics and bonding a temporary retainer labially to ensure stability of the teeth while the retainer was repaired.

Dahl and Zachrisson (1991) reported that in
2 of 142 patients, some rotational relapse occurred where the retainer was short (only involving two or three teeth). Gorelick et al. (1982) found no white spot lesions on the lingual surfaces of the lower labial segment following FSW retainer wear for an average of 24 months. Becker and Goultschin (1984) stated that caries was very rare on the tooth surfaces involved in FSW retainers, but advocated the use of a transparent bonding material to make the entire bond surface visible for inspection.

Occlusal contact between the retainer and the opposing teeth can lead to abrasion of the composite and faceting of the wire, predisposing to composite bond failure. Zachrisson (1986), and Dahl and Zachrisson (1991) advocated that if the occlusion was tight, the wire could be removed from occlusal forces by placing it in a groove cut in the lingual surfaces of the retained teeth.

The evidence to date is that an intact FSW retainer will maintain an improvement gained by treatment and that, as long as the plaque control remains adequate, the orthodontic requirements can determine the period the retainer remains in situ.

Materials and methods

The experiment was designed to compare 'A'-Company lower incisor pads bonded with two different composites and 'bonds' placed directly upon a flat surface of human enamel. The flexibility of the wire in the inter-bond space was not assessed.

The bonding area of the 'A'-Company pads was determined using an Optimas (Optimas, Bioscan Incorporated, 170 West Dayton, Suite 204, Edmonds, WA 98020) video image capture and digitizing system. The mean surface area of 31 pads was 7.89 mm², with a standard deviation of 0.054 mm².

Extracted human premolars were placed inside blocks of acrylic resin and one face was polished flat with 1000 grit on a Struers polishing table (Sherriff and Ireland, 1991, 1992) to produce a fresh reproducible enamel surface. The flexibility of the wire in the inter-bond space was not assessed.

The pads were bonded to the etched enamel using one of two composites widely used in orthodontics. Right-On® (TP Orthodontics, Inc., PO Box 73, La Porte, IN 46350, USA), a 'no-mix' resin with a low filler content (56 per cent by weight) formulated specifically for orthodontic use, and restorative Concise® (3M Health Care Ltd., Dental Products, Loughborough, England), a composite widely used in dentistry (80 per cent filler content by weight). The pads were placed upon a length of wire from the kit, lying upon the etched enamel and seated with finger pressure through a probe. Excess material was carefully removed from the periphery of the pad before the material set to reflect clinical practice. The pads were left undisturbed for 15 minutes before they were tested.

The comparison was made with a directly bonded flexible spiral wire bonded with a light cured composite, Prisma Fil® (LD Caulk Co., PO Box 359, Milford, DE 19963, USA, 79 per cent filler content by weight). To give a similar area of coverage as the 'A'-Company pads, the etched enamel was masked off with a sheet of tinfoil (thickness 0.20 mm) in which a hole of 3.175 mm diameter had been punched, according to the method of de Groot et al. (1985). The margins of the hole were adapted to the enamel surface with a clean ball-ended burnisher to prevent composite from flowing underneath the tinfoil. A piece of 0.175 multiflex wire was placed over the maximum diameter of the hole in the tinfoil and secured to the tinfoil with a spot of modelling wax at each end. Prisma Fil was then placed around the wire and adapted with a probe to a smooth, domed shape. It was trimmed to the margins of the tinfoil hole, and then light cured for 30 seconds.

Six specimens were prepared at a time and were left undisturbed for 15 minutes at room temperature before testing. Bonds were tested on an Instron 1198 Universal Testing Machine (Instron Limited, High Wycombe, England). Each specimen was debonded using a jig that allowed shear loading of the specimen parallel to the enamel surface by a steel chisel edge (Fig. 3). A cross-head speed of 0.2 cm/min was used, and the force at which debonding occurred was recorded. After debonding, the samples were examined under an optical microscope (×35 magnification) to examine the locus of failure.
Results

The data was analysed using SAS version 6.07 (SAS Institute Inc., Cary, NC 27513-2414, USA) and Stata 3.0 (Computing Resource Center, 1640 Fifth Street, Santa Monica, CA 90401, USA) at a predetermined significance level of $\alpha = 0.05$. The distribution of individual results is shown in Fig. 4, together with a box plot that indicates the minimum, first quartile, median, third quartile, and maximum value for each bonding system. The Shapiro–Wilk test was used to test for normality (Royston, 1993). Summary data and normality statistics are given in Table 1. The effect of the bonding system was investigated using one-way analysis of variance and Bonferroni’s test for the analysis of multiple comparison of means. This test was chosen because it minimizes the ‘experiment-wise’ error rate—the probability making at least one inference error when there is no difference between the group means. The results of this analysis are shown in Tables 2 and 3.

It is now well recognized that failure data is inadequately described by simple univariate statistics such as the arithmetic mean, and that it is more appropriate to use distributions based upon survival analysis (Kalbfleisch and Prentice, 1980).

In this present work, the bond strength data is presented in terms of the survival function, $S(t)$, the probability that an individual bond strength, $BS$, exceeds a specified value, $bs$.

$$S(t) = \text{Prob}(BS > bs)$$

The results are shown in Fig. 5. This allows the three bonding systems to be directly compared with the probability that a bond will fail at a given load. It can be seen from this figure that as long as the applied load does not exceed...
Table 1 Univariate and summary statistics.

<table>
<thead>
<tr>
<th>Bonding system</th>
<th>n</th>
<th>Mean bond strength (Mpa)</th>
<th>SD</th>
<th>95% CI</th>
<th>W</th>
<th>P &gt; Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-On</td>
<td>30</td>
<td>12.3</td>
<td>2.19</td>
<td>11.4-13.1</td>
<td>0.96</td>
<td>0.32</td>
</tr>
<tr>
<td>Prisma Fil</td>
<td>31</td>
<td>13.9</td>
<td>3.03</td>
<td>12.9-15.1</td>
<td>0.98</td>
<td>0.91</td>
</tr>
<tr>
<td>Concise</td>
<td>32</td>
<td>14.9</td>
<td>4.2</td>
<td>13.4-16.44</td>
<td>0.98</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Key: n, sample size; W, Shapiro–Wilk statistic; P, probability associated with W.

Figure 5 This shows the probability of a bond failing as a function of applied load and composite. At a survival probability of 1 all bonds remain intact, and at a probability of 0 all bonds fail. Thus, no bonds fail below 7 MPa, 50 per cent of Prisma Fil bonds fail at 15 MPa.

Table 2 One-way analysis of variance.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>2</td>
<td>111.31</td>
<td>55.65</td>
<td>5.22</td>
</tr>
<tr>
<td>Error</td>
<td>90</td>
<td>960.27</td>
<td>10.69</td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>92</td>
<td>1071.58</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7 MPa then none of the bonds will fail. However, if the load is increased to 15 MPa then only 2.5 per cent of Right-On bonds will survive, compared to 45 per cent of Prisma Fil and 60 per cent of Concise bonds. This information is not available from simple univariate statistics.

Discussion

This study used a light-cured composite for the FSW retainer, and ‘no-mix’ and chemically activated composites with the ‘A’-Company system. While recognizing that chemically-cured systems can be used with FSW retainers, it was felt that the choice of materials reflected common clinical usage.

Investigations into bond strength are often

Table 3 Bonferroni’s test of multiple comparison of means.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Difference between means</th>
<th>Lower 95% confidence limit</th>
<th>Upper 95% confidence limit</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-On–Prisma Fil</td>
<td>-1.74</td>
<td>-3.87</td>
<td>0.3</td>
<td>***</td>
</tr>
<tr>
<td>Right-On–Concise</td>
<td>-2.65</td>
<td>-4.67</td>
<td>-0.62</td>
<td>***</td>
</tr>
<tr>
<td>Prisma Fil–Concise</td>
<td>-0.91</td>
<td>-2.92</td>
<td>1.1</td>
<td>***</td>
</tr>
</tbody>
</table>

*** Indicates a significant difference at α = 0.05.
difficult to compare and interpret with previous work. This is because:

1. There is no standard protocol for preparation and testing of materials.
2. Measurements of bond strength are known to show a high degree of variability (Bowen, 1966; Jassem et al., 1981).

Buzzita et al. (1982) noted the importance of choosing the composite/bracket combination carefully to obtain optimal results.

Reynolds (1975) suggested that bonded orthodontic attachments should support loads of 60–80 kg/cm² to withstand both normal occlusal forces and the forces generated by orthodontic appliances. The three composites tested were all suitable for orthodontic bonding. It is established that bond strength and bracket base area do not have a simple relationship due largely to variations in the retentive surfaces of different brackets (Dickinson and Powers, 1980). The ultimate success of the bonded retainer will depend upon the size and quality of the abutment tooth, and the occlusal loading upon the retainer. It is obvious that a larger clinical crown can accommodate a larger bond and spread any load over a greater area of enamel, loading to a greater ultimate bond strength. The 'A'-Company pads tested were of standard sizes and the Prisma Fil series was restricted to the same bond area. Clinically, a retainer bonded directly with Prisma Fil would be able to take full advantage of the tooth size and morphology and may show greater bond strengths.

Seely et al. (1987) showed an increase in bond strength in composite specimens that had been stood in water at 37°C for 30 days. They suggested that this could be related to fluid absorption by the composite, resulting in a degree of expansion of the resin that relieved much of the polymerization stress. Rider (1975) suggested that ultimately water absorption could contribute to a reduction in the bond strength. The 'A'-Company pad is impermeable to oral fluids and only the marginal composite is exposed. Rothermel and Kelly (1984) showed microleakage at metal/composite interfaces that suggested dimensional changes could occur. The Prisma Fil bond is exposed to oral fluids on all sides except the enamel–resin interface. Composite that is axially restricted while setting shows less polymerization shrinkage than a freely contacting composite (Davidson and de Gee, 1984). This may result in a lower residual stress in the composite under an 'A'-Company pad.

The metal pad of the 'A'-Company system will tend to present a lower profile than a directly bonded composite and so may avoid creating an occlusal interference. The pad will tend to transmit loading to the composite evenly and so avoid stress concentration in specific areas that may predispose to bond failure.

The reduction of arch width and arch length that occurs with increasing age is a normal physiological process (Little et al., 1981, 1988; Sinclair and Little, 1983; Little and Riedel, 1989; Little, 1990) in both orthodontically treated and untreated individuals. This process continues well after the cessation of growth and may be quite active throughout the third decade. The degree of crowding that results is both variable and unpredictable, and no useful predictors of late crowding have yet been found. All orthodontic patients are liable to post-treatment change and Little (1990) suggested that 'Indefinite use of removable or fixed retainers, perhaps for life, seems to be the only logical recourse'.

Fixed lingual or palatal retainers have significant advantages for patient comfort and aesthetic acceptability. They can be placed directly (Zachrisson, 1977, 1983) or indirectly (Lee, 1981; Ferguson, 1988).

The placement of a bonded retainer is technique sensitive. The technique advised for the 'A'-Company system involves contouring the retainer wire in the mouth and placing the pads over it with the aid of 45 degrees bracket placing tweezers. Zachrisson (1986) stressed the importance of contouring wire to contact all the teeth properly and in practice, the author (DCB) has found it difficult to get an ideal, passive fit in the mouth, though the wire is easily contoured to a study model. The pads are difficult to hold, even in the bracket placement tweezers advised by the manufacturers, while the adhesive is loaded and the pad placed. It would be helpful if a removable placement aid, similar to those used with ceramic brackets could be provided.

The lower profile of the 'A'-Company pads was clearly demonstrated during the debonding experiments when the chisel edge of the Instron machine was seen to slip from the edge of the pad to the wire housing before debonding occurred.
Failure of the ‘A’-Company pads was an all-or-nothing event. There was no partial failure. However, when testing the Prisma Fil, it was noted that there was often some localized failure of the composite before the enamel-composite bond failed. Clinically, this localized failure may act as a stress-breaker to protect the composite-enamel bond.

This study has shown no significant difference between the ‘A’-Company lingual retainer pads and an equivalent single unit of a widely used composite. There was, however, a statistically significant difference between the ‘A’-Company pads when bonded with Right-On, a lightly filled orthodontic composite, and Concise, a restorative material. The filler content of adhesives has been shown to influence the bond strength (Faust et al., 1978; Guzman et al., 1980; Buzzita et al., 1982).

The bond strengths demonstrated for all three adhesives used showed a range of variation. The greatest variation was seen with Concise, the least with Right-On. The bond strengths achieved in all three methods were adequate for clinical use. Selection of a material for use can therefore be made on grounds of clinical convenience or of cost.

Conclusions

The ‘A’-Company bonded lingual retainer was compared in a shear test with a flexible spiral wire retainer as described by Zachrisson (1977, 1983) using three composites, widely used in orthodontic dental practice.

The results showed that there was no statistically significant difference between the ‘A’-Company system and an FSW retainer bonded with Prisma Fil, but that there was a difference between the ‘A’-Company system bonded with Right-On and Concise. The results should be interpreted with caution due to the different materials involved, but all the methods studied gave clinically adequate results and the choice of retainer system and adhesive could be made on grounds of convenience or cost.

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References


COMPARISON OF BONDED RETAINERS


