Shear bond strength of different fixed orthodontic retainers

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Objective: To compare the shear bond strength of different fixed retainer wire diameters bonded using a conventional composite resin or a specific retainer composite.
Materials and methods: One-hundred-and-twenty extracted human premolar teeth were divided into six groups. After conventional acid etching with a 37% phosphoric acid gel for 30 seconds, twist flex wires of various diameters (0.0175″, 0.0215″, 0.032″) were bonded as fixed retainers. Conventional bracket adhesive (Filtek Z250) or retainer specific adhesives (Transbond LR) were used. After curing, the specimens were stored for 24 hours in distilled water at 37°C and, thereafter, subjected to 500 thermal cycles. The specimens were then debonded using a Universal Instron machine. The site of failure was recorded for each specimen and the shear bond strength calculated. Statistical analyses were provided using a Chi-square test for failure site and a two-way ANOVA test to assess shear bond strength.
Results: The site of failure was predominantly at the wire composite interface in all groups. The specific retainer composite showed a significantly higher shear bond strength compared with conventional composite ($p < 0.001$). There was a statistically significant difference between the three wire diameters ($p < 0.001$); the 0.0215″ wire had the highest shear bond strength, whereas the 0.032″ wire had the least shear bond strength.
Conclusions: The site of failure was unrelated to wire diameter or adhesive. The optimal combination to maximise the bond strength of fixed retainers appeared to be a specific retainer adhesive and a wire diameter of 0.0215″.
(Aust Orthod J 2015; 31: 178-183)

Received for publication: February 2015
Accepted: September 2015

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Introduction

Many direct-bonded permanent retainers have been described to facilitate the long term retention of orthodontic treatment results. Extended studies conducted by Cerny showed that, over 15 years or more, the overall effectiveness of fixed lingual retainers in maintaining tooth alignment is excellent.[1,2] However, a major disadvantage of bonded retainers is frequent wire detachment, which creates a high maintenance need.[3,4]

Wires of varying diameters have been used in the fabrication of permanent retainers without consensus on the most clinically effective diameter. There is a mixed preference for the bonding of a light wire to all lingual tooth surfaces, while others prefer a more rigid wire bonded only to the canines or premolars.[3,5,6]

Different composite-based adhesives have been recommended for bonding orthodontic fixed retainers and include direct restorative composites[6] and the relatively new flowable composites.[7] The latter composites are claimed to have several advantages related to direct and precise placement, are not sticky and flow toward the bulk of the material rather than disperse.[8]

In contrast to orthodontic brackets, a relatively limited number of in vitro studies have investigated the bonding characteristics of fixed retainers. A possible explanation for this is the inherent difficulty in simulating the intra-oral forces that might act upon these retainers.[8,9]

Bearn et al.[3] showed that increasing the wire diameter from 0.0175” to 0.0215” significantly increased the force needed to detach the wire from the composite. Increasing composite thickness by more than 1.0 mm produced a small increase in the force needed to remove the wire.[3]

Radlanski and Zain[9] found that a flowable composite was significantly better for bonding retainer wires than a conventional composite. Force application directly to the adhesive pad of a wire/bond combination yielded a higher mean force at failure in comparison with the force applied to a cantilevered wire under shear and tensile forces. Tabrizi et al.[8] assessed the differences between flowable composites and an orthodontic adhesive with regards to in vitro shear bond strength and wire 'pull-out' resistance. No statistically significant differences in shear bond strength were found between the groups. In contrast, the conventional orthodontic adhesive yielded significantly higher 'pull-out' values compared with the flowable composites.

The aim of the present study was to compare the shear bond strength between different diameters of multi-stranded wire used as fixed retainers in addition to a comparison of the shear bond strength produced by a conventional composite or a specific retainer composite resin. A final aim was to evaluate the effect of composite type and wire diameter on the site of failure of fixed retainers.

The null hypothesis stated that there was no significant difference in shear bond strength or failure site of different wire diameters of fixed retainers, and that there was no difference between specific retainer and conventional composite resins used to attach fixed retainers.

Materials and methods

One-hundred-and-twenty human premolar teeth extracted for orthodontic purposes were used for this study. Teeth identified with hypoplasia, extensive carious lesions, extensive wear, fractured cusps and enamel cracks were excluded. Calculus and debris were removed with a scaler and the teeth were cleaned using dental pumice (S.S. White, Gloucester, England). All teeth were stored at 4°C in a 0.1% thymol solution, which was replaced daily. Storage was no longer than four months after extraction. The sample was divided into six groups containing 20 teeth each.

The tooth roots were vertically encased up to the cement-enamel junction in a cylindrical block of self-curing acrylic resin (Leocryl; Leone, Sesto Fiorentino, Italy). All teeth were etched using 37% phosphoric acid gel (Super etch, SDI, Victoria, Australia) for 30 seconds. The etchant was removed with water spray and the enamel dried with oil free compressed air (washing time 10 seconds, drying time 5 seconds). Spiral fixed retainer wires (3M Unitek, CA, USA) of three diameters (0.0175”, 0.0215”, 0.032”) were cut to a standardised length of 6 cm per segment. The two ends of each wire segment were drawn and wound together using a hemostat. Cold cure acrylic resin was applied to re-enforce the severed wire ends. The wire segments were subsequently bonded to the enamel surfaces of each group using either conventional composite (Filtek Z250, 3M Unitek, CA, USA) or a retainer-specific adhesive (Transbond LR, 3M Unitek, CA, USA) using a standardised application template. The template had a cylindrical cross section to a depth of 2 mm and a diameter of 4 mm which was used to bond the 0.0175” and the 0.0215” wires, whereas for bonding the 0.032” wires, the template was adjusted by increasing the diameter to 4.5 mm to compensate for the larger wire diameter. Grooves at the sides of the template were cut to accommodate the wire during bonding. The wire-composite combination for each group was:

Group 1: wire diameter 0.0175”, bonded using restorative composite.

Group 2: wire diameter 0.0215”, bonded using restorative composite.

Group 3: wire diameter 0.032”, bonded using restorative composite.

Group 4: wire diameter 0.0175”, bonded using specific composite.

Group 5: wire diameter 0.0215”, bonded using specific composite.

Group 6: wire diameter 0.032”, bonded using specific composite.

In all groups, the primer was applied to the etched enamel. The application template was packed with the adhesive composite and the wire segment was placed onto the etched surface. The template was pressed firmly onto the wire and the enamel and excess composite was cleaned from around the template using a sharp probe prior to curing. All resins were cured using the same light-emitting diode (LED) light curing unit (Huaer, sitel number HR-DC219, Henan, China) with an output of 1200 mw/cm2. This output was checked after five curing cycles using a digital radiometer. The adhesives were light cured by positioning the light guide on each inter-proximal side for 10 seconds. Figure 1 demonstrates a specimen after bonding. Following curing, the specimen teeth were stored in distilled water at 37°C for 24 hours.[10]

The teeth were then subjected to thermal cycling to simulate the intra-oral environment following the ISO 11405 recommendations.[10] The thermo-cycling test consisted of 500 thermal cycles in distilled water. The temperature range was between 5 and 55°C. Each bath exposure lasted for 20 seconds, with a transfer time of 5 to 10 seconds between baths.

The specimens were tested using an Instron universal testing machine (Instron Ltd, Buckinghamshire, UK) in tensile mode with a crosshead speed of 0.5 mm/minute until failure occurred. The maximum load (N) was recorded and then divided by the surface area (mm^2) of the matrix to determine bond strength in megapascals. The location of failure for each specimen was inspected visually by one operator (J.A.) using a magnifier with an 88 mm diameter lens and 2.5× magnification (Number: G-777-090, Shenzhen Guanyida Optical Production Corp. Ltd., Guangdong, China) and the amount of composite resin left on the enamel surfaces recorded according to the adhesive remnant index (ARI).[11] The ARI scale ranges from 1 to 3: A score of 0 indicated that no adhesive was left on the enamel, 1 indicated less than half of the adhesive remained, 2 more than half of the adhesive remained, and 3 all adhesive remained on the enamel surface.[11]

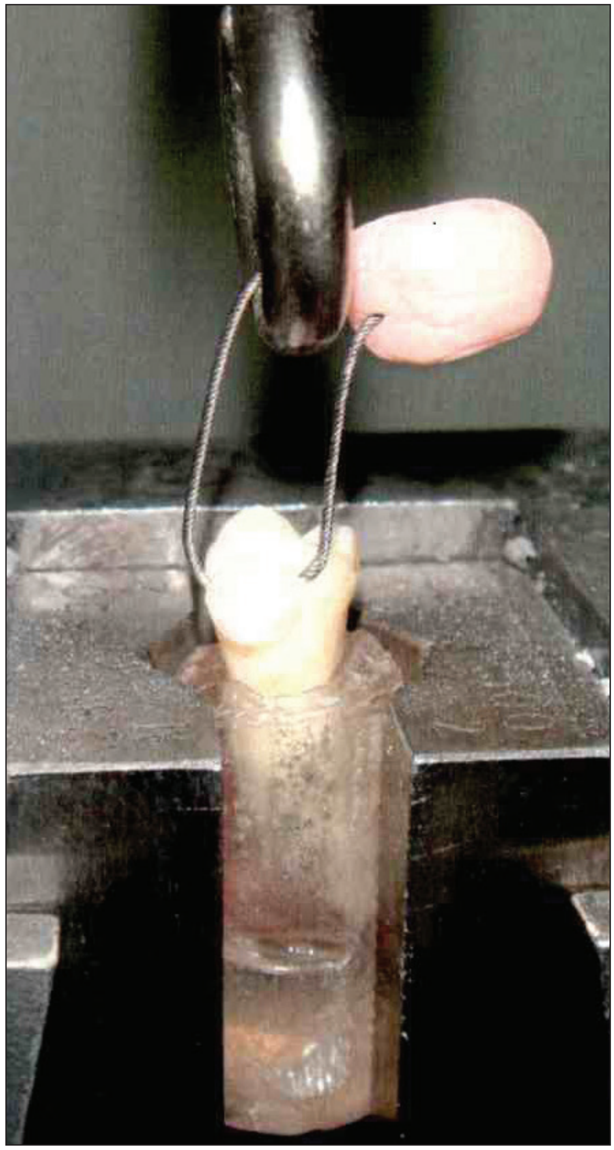

Figure 1. Bonded specimen loaded in the Instron machine.

Statistical analysis

Statistical analysis was accomplished by the Chi-square test for failure site and by the two-way ANOVA test and a Tukey HSD test for post hoc analysis to assess shear bond strength. All data analyses were executed using the Statistical Package for Social Sciences (IBM SPSS, version 20, IL, USA). The level of significance was set at $p < 0.05$.

Results

The ARI score frequencies for the groups tested are presented in Table I. There was no significant difference between the distribution of the ARI scores between the groups ($p = 0.416$), and there was no relation between the site of failure and the wire diameters ($p = 0.368$), or the composite type ($p = 0.317$).

The average shear bond strengths for the different groups are shown in Table II. The 0.0215" wire-specific retainer composite group had the highest shear bond strength, whereas the 0.032" wire-conventional composite group had the lowest shear bond strength. The mean shear bond strength of the various groups was compared using the two way ANOVA test. The shear bond strength for specific retainer composite (11.47 ± 4.05) was significantly higher than the shear bond strength of conventional composite (8.35 ± 3.93, $p < 0.001$). There was a statistically significant difference between the three wire diameters ($p < 0.001$). A Tukey HSD test was carried out for post hoc analysis for the three wire diameters and the results are presented in Table III.

Discussion

Approximately 40 years have passed since fixed retainers were first described.[12] Since that time, a variety of wire types, wire diameters and adhesives have been suggested for bonded retainer construction, and clinical investigations conducted to determine the most suitable. For practical reasons, clinical trials have only compared a limited number of wire/adhesive combinations[5,12,13] and so in vitro studies provide a better means of assessment of available materials.

The aim of the present study was to determine which in vitro combination of wire diameter and composite type would result in the highest shear bond strength for fixed retainers, and determine whether a conventional composite resin may be used as an alternative to a specific composite for retainer bonding.

Commonly, in vitro investigations of fixed retainers apply an isolated interface which separately studies the wire-adhesive and the adhesive-tooth interfaces.[3,4,8,14] Using that model, failure at the wire-adhesive

Table I. Adhesive remnant index (ARI) score frequency according to groups.

Group	N*	ARI = 0	ARI = 1	ARI = 2	ARI = 3
0.0175″ regular composite	20	1	4	12	3
0.0215″ regular composite	20	1	2	14	3
0.032″ regular composite	20	1	4	10	5
0.0175″ specific composite	20	1	4	13	2
0.0215″ specific composite	20	0	5	11	4
0.032″ specific composite	20	1	3	11	5

*N indicates sample size.

Table II. Descriptive statistics for shear bond strength according to groups.

Group	N*	Minimum (MPa)	Maximum (MPa)	Mean (MPa)	Standard deviation
0.0175″ regular composite	20	3.18	19.17	9.02	3.82
0.0215″ regular composite	20	5.81	19.25	10.81	3.45
0.032″ regular composite	20	2.47	9.39	5.22	2.09
0.0175″ specific composite	20	5.17	19.33	11.31	4.32
0.0215″ specific composite	20	3.66	20.84	13.57	3.78
0.032″ specific composite	20	4.61	15.67	9.53	3.09

*N indicates sample size.

Table III. Post hoc analysis for wire diameter effect using Tukey HSD test. Dependent variable: shear bond strength.

Wire diameter		Mean difference	Std. error	Sig.	95% confidence interval Lower bound	95% confidence interval Upper bound
0.0175″	0.0215″	-2.03	0.781	0.029*	-3.88	-0.17
	0.032″	2.80	0.781	0.002*	0.93	4.65
0.0215″	0.0175″	2.029	0.781	0.029*	0.17	3.88
	0.032″	4.82	0.781	0.0001**	2.96	6.67
0.032″	0.0175″	-2.79	0.781	0.002*	-4.65	-0.93
	0.0215″	-4.82	0.781	0.0001**	-6.67	-2.96

* $p < 0.05$
** $p < 0.001$

interface is determined by wire pull-out tests and failure at the adhesive-tooth interface is determined by shear bond strength tests that apply debonding forces. The appropriateness of this model is questioned as Radlanski and Zain[9] have reported that force applied directly to the adhesive pad of a wire/bond combination yielded a higher mean value at failure in comparison with the placement of a cantilevered wire, bonded at one end, under shear and tensile forces. Therefore, it may be speculated that a clinical simulation model that uses extracted teeth as a substrate would be more accurate, as failure is more likely due to the force applied to the wire rather than the adhesive pad.

The present study investigated three wire diameters of 0.0175”, 0.0215” and 0.032”, which reflect the clinical range of proposed wires for use as fixed retainers.[6,15] A conventional restorative composite was compared with a retainer-specific adhesive. The structural similarity between the two materials is marked, which raises questions about the need for a specific retainer adhesive. Using a conventional restorative composite would confer the obvious advantages of cost reduction and inventory control.

Each test group was composed of 20 teeth. Although the lower anterior region is the most frequent site for a bonded retainer,[6] the lower incisors display more variation in their lingual morphology and tooth size,[9] and so premolars were used in this investigation because of availability and convenience.

A uniform cylindrical-shaped template with a depth of 2 mm and a diameter of 4 mm was used to bond the 0.0175” and the 0.0215” groups. Using a standardised template ensured a consistent thickness of composite resin covering the wire in all test groups. The dimension of the template was chosen to approximate the bulk of the composite resin used to clinically bond a multi-stranded wire to a tooth. The diameter of the template was increased to 4.5 mm in bonding the 0.032” wire groups. Bearn et al.[3] previously showed that an increase in bonded composite thickness greater than 1.0 mm produced a minimal increase in the force needed to remove the wire from the composite material. However, it was considered that standardising the thickness of the material would improve the validity of the current investigation.

The coefficient of thermal expansion (α) of dental enamel, metal wires, and different adhesive systems show considerable differences[16,17,18] (for resin composites α = 14–50 ppm/K, 316L stainless steel α = 16 ppm/K, and enamel α = 12 ppm/K). The expansion coefficient differences may stress the adhesive interfaces during the service life of the retainer. Thermocycling is commonly used in in vitro dental studies when testing the performance of adhesive materials. It aims to thermally stress the adhesive interfaces by subjecting the bonded teeth to extreme temperatures comparable with temperatures encountered intra-orally.[19] None of the reported in vitro studies of fixed retainers included thermocycling in their methodologies.[3,4,8,9,15,20] Although not conclusive, there is evidence to suggest a negative impact of thermocycling on shear bond strength.[21] Therefore, the current investigation included thermocycling to more closely simulate the oral environment.

The predominant site of attachment failure was at the wire-composite interface. This finding was consistent for all tested groups. Previous clinical and in vitro studies reported mixed failure results but primarily reported either enamel-composite failures[9,22,23] or wire-composite failures.[13,16,21] The latter result is consistent with the finding of the present study, in which more than 90% of all debonds were wire-composite failures.

The specific retainer adhesive was significantly better than the conventional restorative composite. Based on their composition, this finding defies explanation. However, the improved adaptability of the specific retainer composite might result in closer adaptation of the material to the wire and enamel at the adhesive interfaces and so increase bond strength.

Of the tested wires, the 0.0215” wire provided the highest shear bond strength. Bearn et al.[3] showed that increasing the wire diameter from 0.0175” to 0.0215” increased the force needed to detach the wire from the composite to a statistically significant level. While this is consistent with the present finding, surprisingly the 0.032” wire exhibited the lowest shear bond strength. This matches the clinical findings of Årtun et al.,[5] who reported a higher failure rate (30.8%) for ‘thick spiral wire bonded only to the canines’, in comparison with a ‘thin, flexible spiral wire bonded to each tooth’ (27.3%). In contrast, Al-Nimri et al.[13] reported a clinical failure rate of 29% for 0.015” twist flex retaining wires bonded to each tooth and a failure rate of 13% for 0.036” round wire bonded only to canines. For the present in vitro study, it might be considered that the stiffer 0.032” wire offered less chance of elastic deformation that would have absorbed some of the applied force. In this circumstance, the applied force would be more readily transferred to the adhesive interface and therefore decrease the threshold for bond failure. The possibility of this effect occurring clinically warrants further clarification.

A limitation of the present study is the dissimilarity in the length of the wire compared with clinical use. Ideally the length of the wire adjacent to the bonded composite during the shear bond strength test should be 2–4 mm, which would simulate the average clinical setting. However, it was extremely difficult to manipulate such a short length of wire during the in vitro shear bond test and so the results of the present study must be taken as a guide until further investigations are undertaken.

Conclusions

- The prevailing site of failure was at the composite-wire interface.
- The specific retainer composite (Transbond LR) produced significantly higher shear bond strength than the conventional composite (Filtek Z250), regardless of wire diameter.
- For each of the tested adhesives, the 0.0215” wire diameter produced significantly higher shear bond strength than the other wire diameters, whereas the 0.032” wire diameter produced the least shear bond strength.
- The best combination to optimise the bond strength of fixed retainers appears to be a specific retainer adhesive (Transbond LR) and a wire diameter of 0.0215”.

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