Original Article

Bond strengths of composite resins used for the attachment of bonded retainers

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Abstract

Objectives: To compare the bond strengths and survival of flowable and non-flowable composite resins used with bonded retainers.

Setting: Department of Orthodontics, UCL Eastman Dental Institute, United Kingdom.

Methods: Flowable composite resins (Transbond™ Supreme LV, StarFlow™ and Tetric EvoFlow®) and non-flowable control resin (Transbond™ LR) were made into cylinders prior to bonding to hydoxyapatite discs. They were then mounted into jigs and tested in the Instron™ Universal Testing Machine in both shear and tensile modes.

Results: The highest mean shear bond strength was seen with StarFlow™ (14.09 MPa), which was significantly higher than both Transbond™ LR (9.48 MPa) and Transbond™ Supreme LV (8.20 MPa). The mean shear bond strength of Tetric EvoFlow® (11.86 MPa) was also significantly higher than Transbond™ Supreme LV.

The highest mean tensile bond strength was seen with Tetric EvoFlow® (2.14 MPa), which was significantly higher than Transbond™ LR (1.15 MPa) and Transbond™ Supreme LV (0.61 MPa) but not significantly different to StarFlow™ (1.47 MPa).

For shear loading, StarFlow™ had the highest 50th percentile survival estimate at 15.10 MPa, followed by Tetric EvoFlow® (13.00 MPa) and Transbond™ Supreme LV (7.50 MPa). Transbond™ LR had a 50th percentile estimate at 9.00 MPa.

For tensile loading, Tetric EvoFlow® had the highest 50th percentile survival estimate at 2.50 MPa, followed by StarFlow™ (1.30 MPa) and Transbond™ Supreme LV (0.50 MPa). Transbond™ LR had a 50th percentile estimate at 1.00 MPa.

Conclusions: Mean shear bond strengths for all of the resins were significantly higher than the mean tensile bond strengths. StarFlow™ and Tetric EvoFlow® could potentially be suitable clinical alternatives to Transbond™ LR due to its low viscosity flow characteristics and adequate shear and tensile bond strengths.

Keywords: Bonded retainer, composite resin, flowable resin, shear bond strength, tensile bond strength

Introduction

Concern amongst orthodontists and patients regarding the methods and duration of maintaining corrections made during the active orthodontic treatment phase is increasing, and the retention phase is one of the most crucial and challenging aspects of orthodontics. Retention is necessary to permit reorganisation of the periodontal and gingival fibres, to minimise changes due to growth, to allow neuromuscular adaptation to the corrected position of the teeth, or to maintain unstable tooth positions.[1-3] Evidence that changes in dental alignment occur throughout life has led to a move towards increasingly long-term or permanent retention.

Some degree of relapse is considered inevitable subsequent to orthodontic treatment.[4] Therefore, a bonded retainer has been recommended as the appliance of choice for secure retention and for the modern orthodontist.

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There is an increasing trend amongst orthodontists to advocate bonded retainers after orthodontic treatment as they are deemed to be more aesthetic and have less reliance on patient compliance. However, they do need to be closely monitored for failure of any component of the retainer.

Stainless steel or fibre-reinforced composites have been used for the construction of bonded retainers and studies have shown no significant difference between the failure rates of these two types of bonded retainers.[5, 6] Conventional non-flowable or flowable composite resins are commercially available for the attachment of bonded retainers. Flowable composites are a modification of conventional composite resins with lower filler content and more resin matrix.[7] Flowable composites have a number of advantages including no mixing required, direct and precise composite placement, excellent flow characteristics and reduced chair-side time.[8]

A study comparing the shear bond strengths of brackets bonded with a conventional orthodontic adhesive (Transbond™ XT) and three flowable composites (Flows-Rite™, Flow Line™ and Flow™) concluded that, although the bond strengths of all four composites were clinically acceptable, Transbond™ XT produced a significantly higher shear bond strength. There were no significant differences in the mean shear bond strengths between the three flowable composites.[9] A study to investigate the durability of flowable composites involving shear bond testing of 60 extracted sound human premolar teeth in the laboratory found that the flowable composites tested (FlowTain™ XT, Filtek Supreme™ XT and Tetric Flow™) had shear bond strengths comparable with the control composite resin, Light Bond™. It was suggested that it would be acceptable to use flowable composites for bonding lingual retainers.[4]

With the rising trend of providing patients with bonded retainers, it is wise to evaluate the bond strengths of these potentially expensive flowable composite resins, compared with the less expensive non-flowable resins. This will determine if it is advantageous to incorporate flowable composite resins into bonded retainer construction, in terms of strength and the relative cost of the materials.

The aim of this study was to compare the shear and tensile bond strengths of three different flowable composite resins with a conventional non-flowable composite resin, all of which are available for the placement of bonded retainers.

The null hypotheses (H_0) for this study were:

- There is no difference between the shear and tensile bond strengths for each of the materials tested.
- There is no difference in survival between the materials tested

Methods and materials

Commercially available hydroxyapatite powder CAPTAL® R (Plasma Biotal Limited, Tideswell, UK) was compressed at 20 tonnes in a hydraulic compression machine to produce circular discs, which were then fired in a furnace at 1300°C before being left to cool overnight. The discs were embedded in acrylic resin and polished to a standard protocol. This method has been described in detail in similar studies.[10, 11] The composite resins tested were Transbond™ LR (3M Unitek, Monrovia, CA, USA) as the control resin, Transbond™ Supreme LV (3M Unitek, Monrovia, CA, USA), StarFlow™ (Danville Materials, San Ramon, CA, USA) and Tetric EvoFlow® (Ivoclar Vivadent AG, Schaan, Liechtenstein). Each of the four composite resins was made into batches of cylindrical discs using rubber moulds in order to obtain uniform reproducible cylinders. For the shear bond testing, the mould that was used had a height of 4 millimetres and a diameter of 4 millimetres, whereas, for the tensile bond strength testing, a larger mould with a height of 4 millimetres and a diameter of 9.5 millimetres was used. The mould was placed on a clean mixing pad and the selected composite was packed in the central cavity using a flat plastic instrument. Both sides of the mould were light cured with a light-curing machine (3M Unitek, Monrovia, CA, USA) for 20 seconds on each side and the light intensity was checked between curing episodes using the in built light intensity tester. Then, the composite resin cylinder was pushed out of the mould.

The results of previous research[12] were used to determine a clinically relevant difference of 25% and this showed that a sample size of 20 was required for each group in order to provide a statistical power of 80% at a significance level of p<0.05.

For the shear bond strength testing, two composite resin cylinders were bonded to opposing quadrants of a hydroxyapatite disc such that each hydroxyapatite disc was used for two sample tests. For the tensile bond strength testing, a single resin cylinder was bonded between two hydroxyapatite discs, one on the superior and one on the inferior surface of the composite cylinder. Bonding was performed following the manufacturer's protocol using Unitek™ Etching Gel Syringe Delivery System (3M Unitek, Monrovia, CA, USA) which contains 35% phosphoric acid and light-cure adhesive primer which was Transbond™ XT primer (3M Unitek, Monrovia, CA, USA).

The Instron™ Universal Testing Machine (INSTRON Limited, High Wycombe, UK) was used to test the shear and tensile bond strengths of the composite resins. The load cell used was 1 kiloNewton at a crosshead speed of 1 millimetre/minute. The position of the base tray was adjusted and raised to the required height for testing, with the hydroxyapatite disc in place to allow the safety stops to be set. The hydroxyapatite discs were firmly secured in a custom-made jig for shear and tensile testing respectively (Figures 1 and 2) prior to being transferred onto the Instron™ base tray which was then adjusted in height. The machine was re-calibrated and the height of the base tray re-adjusted on the control panel each time the jig was mounted. Then, the computer system was entered to commence the shear or tensile test.

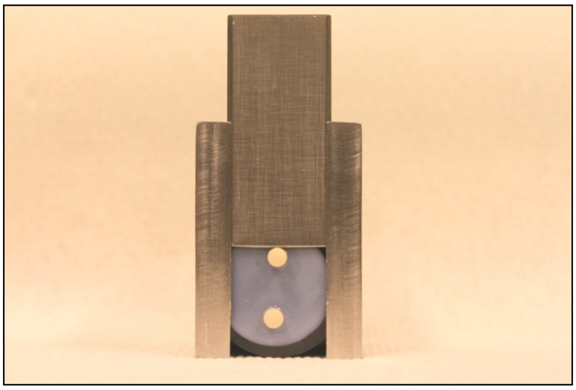

Figure 1: Sample mounted in the custom made jig for shear bond strength testing

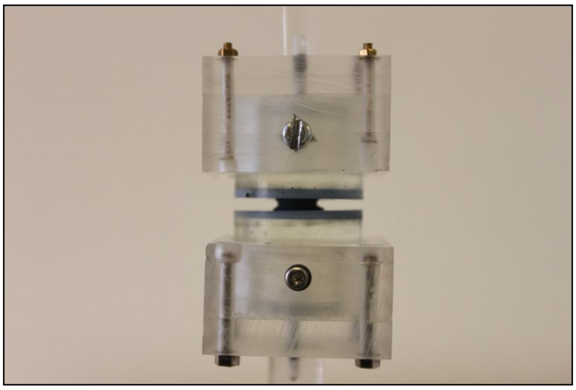

Figure 2: Sample mounted in the custom made jig for tensile bond strength testing

Shear force was applied to one of the composite resin cylinders and the hydroxyapatite disc interface until the bond failed, while, tensile force was applied when the base tray moved away from the load cell until failure occurred at one of the two composite resin cylinder and hydroxyapatite disc interfaces. The shear and tensile force to failure values were obtained from the computer in kiloNewtons and were converted to bond strength in MegaPascals by taking into account the mean surface area of the base of the composite resin cylinders.

Statistical analysis was performed using one-way and two-way analyses of variance (ANOVA) to compare the mean shear and tensile bond strengths of the composite resins. T-tests, with a Bonferroni *post-hoc* correction, were used to compare the mean shear and tensile bond strengths of each composite resin. Kaplan-Meier analysis and Cox regression were used to assess the bond reliability and survival of the various composite resins.

Results

The highest shear bond strength was displayed by StarFlow™ (Mean: 14.09 MPa), and this was significantly higher than both the control resin Transbond™ LR (Mean: 9.48 MPa; p=0.002) and Transbond™ Supreme LV (Mean: 8.20 MPa; p<0.001).

The highest tensile bond strength was displayed by Tetric EvoFlow® (Mean: 2.14 MPa), and this was significantly higher than both the control resin Transbond™ LR (Mean: 1.15 MPa; p=0.012) and Transbond™ Supreme LV (Mean: 0.61 MPa; p<0.001). The mean shear bond strength was significantly higher than the mean tensile bond strength for all composites.

The effects on mean bond strengths resulting from shear versus tensile testing and changes in the composite were evaluated using a two-way analysis of variance (ANOVA). The assumptions for use of ANOVA were checked by a study of the residuals which, although normally distributed, did not exhibit constant variance. Therefore, the analysis was repeated using log-transformed data. The assumptions were subsequently satisfied for the use of this analysis.

The ANOVA showed that there was a significant interaction between composite and type of test (shear or tensile), therefore, a separate analysis was performed to compare the composites for each type of test and the types of test for each composite.

The mean shear bond strengths and mean tensile bond strengths were compared for each composite using a two sample t-test and this showed that the mean shear bond strength of each of the composite resin was significantly greater than the mean tensile bond strength. The multiple comparisons of mean shear and tensile bond strengths with their respective p-values are shown in Table 1 and 2.

Composites	Composites	p-value (with Bonferroni correction)
Transbond™ LR	Transbond™ Supreme LV	0.396
	StarFlow™	**0.002**
	Tetric EvoFlow®	0.210
Transbond™ Supreme LV	StarFlow™	**< 0.001**
	Tetric EvoFlow®	**0.001**
StarFlow™	Tetric EvoFlow®	0.695

Table 1: Multiple comparisons of mean shear bond strengths with a Bonferroni *post-hoc* correction applied (significant p-values are in bold)

Composites	Composites	p-value (with Bonferroni correction)
Transbond™ LR	Transbond™ Supreme LV	**0.009**
	StarFlow™	>0.999
	Tetric EvoFlow®	**0.012**
Transbond™ Supreme LV	StarFlow™	**0.001**
	Tetric EvoFlow®	**<0.001**
StarFlow™	Tetric EvoFlow®	0.151

Table 2: Multiple comparisons of mean tensile bond strengths with a Bonferroni *post-hoc* correction applied (significant p-values are in bold)

Kaplan-Meier survival curves were plotted for shear and tensile bond strengths of the four composites considered together, which provides a guide to the survival of the composites under increasing shear or tensile load.[13] As there was a significant difference between median shear and tensile bond strength when the composites were considered together, a separate survival curve was plotted for each resin for shear and tensile strengths respectively (Figure 3 and 4), and this showed significant differences between the resins for both shear and tensile bond strength.

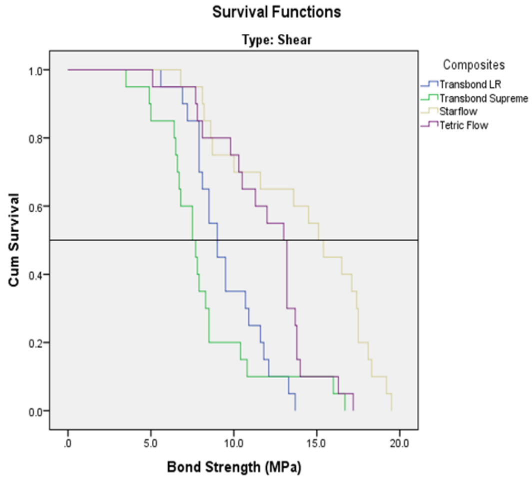

Figure 3: Kaplan-Meier survival curves for shear loading of all 4 composite resins

The Cox Regression analysis is a survival analysis that compares the relationship of several variables to survival.[13] When used in conjunction with a Kaplan-Meier survival analysis, it can identify the significance of apparent differences in survival behaviour. In this study, a Cox Regression was carried out to compare each flowable resin (StarFlow™, Tetric EvoFlow®, and Transbond™ Supreme LV) against the non-flowable control resin (Transbond™ LR) for both shear and tensile testing (Table 3). For shear bond strength, survival was significantly better with StarFlow™ and Tetric EvoFlow® than with Transbond™ LR. There was no significant difference in survival between Transbond™ Supreme LV and Transbond™ LR. For tensile bond strength, survival was significantly better with Tetric EvoFlow® than with Transbond™ LR. There was no significant difference in survival between StarFlow™ and Transbond™ LR. Survival was significantly poorer with Transbond™ Supreme LV than with Transbond™ LR.

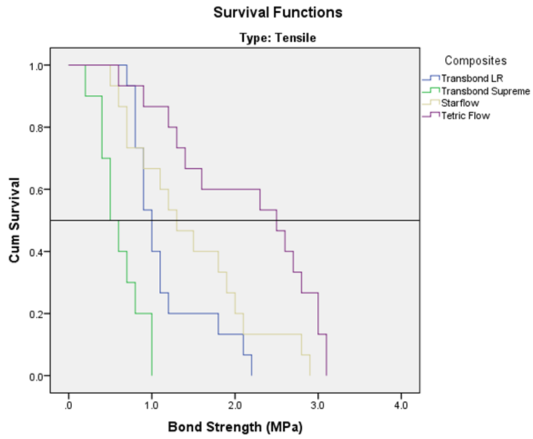

Figure 4: Kaplan-Meier survival curves for tensile loading of all 4 composite resins

Transbond™ LR (Non-Flowable Control)	Flowable Composite Resin	95% Confidence Interval		p-value
		Lower Limit	Upper Limit	
Shear	Transbond™ Supreme LV	0.69	2.48	0.414
	Starflow™	0.09	0.43	**<0.001**
	Tetric EvoFlow®	0.27	0.98	**0.044**
Tensile	Transbond™ Supreme LV	1.63	9.17	**0.002**
	Starflow™	0.27	1.207	0.139
	Tetric EvoFlow®	0.09	0.52	**0.001**

Table 3: Cox Regression Results

Discussion

Transbond™ LR has traditionally been used as an adhesive of choice in conjunction with bonded retainers, but due to its viscosity it lacks the ability to readily flow into and around the wire retainer. With recent development of flowable composite resins in restorative dentistry, there is scope to utilise the flowable composite resins as an alternative adhesive for bonded retainers. In this study, three commercially available flowable composite resins (Transbond™ Supreme LV, Tetric EvoFlow®, and StarFlow™) were compared with Transbond™ LR. Shear bond strength was investigated to mimic shear failure due to masticatory or occlusal forces, while tensile bond strength was investigated to mimic tensile failure due to sticky food particles pulling the retainer from the tooth surface.

In this study, the results of previous research[12] were used to calculate that a sample size of 20 for each group would be required in order to provide a statistical power of 80% and a significance level of 0.05. This fulfilled guidelines which have suggested that a minimum sample size of 20 specimens should be used per test for a standardised research protocol for bond strength studies if valid conclusions are to be extracted from the study.[14] For shear bond strength testing, 20 composite resin cylinders were tested for each of the four different composite. However, for tensile bond strength testing, this figure of 20 was not achieved because unsuccessful trials of methodology to decide which method would be best suited for this part of the study meant that there was insufficient material left from the same batch code. This left a shortfall in the materials needed to achieve a sample of 20 in each group. In retrospect, it would have been prudent to ensure a successful methodology with non-test materials prior to utilising the limited batch samples. Hence, for the tensile bond strength testing there were only 15 cylinders for the Transbond™ LR, StarFlow™, Tetric EvoFlow® groups, and 10 cylinders for the Transbond™ Supreme LV group. Statistical advice confirmed that this would be a valid sample size for tensile testing and that the statistical tests used were sufficiently robust to accept unequal sample sizes in the groups.

Results for the mean shear bond strength suggested that all three of the flowable composites, StarFlow™, Tetric EvoFlow® and Transbond™ Supreme LV showed a satisfactory shear performance in relation to the market standard Transbond™ LR. Mean shear bond strength for Tetric EvoFlow® found in the current study was slightly lower than that found in a previous study.[4] However, the standard deviation of that study was high at 11.8 MPa, suggesting their results were less consistent than the current study. Differences may also reflect differences in testing protocols and in particular the difference between enamel and hydroxyapatite as a bonding substrate.

Results of the mean tensile bond strength testing showed that the flowable composites, StarFlow™ and Tetric EvoFlow® again showed a satisfactory performance in relation to the market standard Transbond™ LR. In contrast, Transbond™ Supreme LV demonstrated the lowest mean tensile bond strength, significantly lower than Tetric EvoFlow®, StarFlow™ and Transbond™ LR. This suggests that it would not be a suitable replacement for Transbond™ LR for bonded retainer placement without significantly prejudicing tensile bond strength.

In this study, the mean shear bond strengths were consistently higher than the mean tensile bond strengths for all resins, which is in agreement with a previous study which compared the shear and tensile bond strengths for brackets bonded using different enamel preparation methods on human enamel.[15] However, the current findings are in contrast with a study which compared the shear and tensile bond strengths of adhesives used to bond brackets to bovine teeth, where mean shear bond strengths were lower than mean tensile bond strengths.[16] This variation could be due to the differences in methodology using different types of teeth.

All of the materials tested in the current study were significantly stronger in shear than in tensile loading, by approximately a factor of tenfold. This implies that in clinical use, the materials might withstand the shearing effect of occlusal forces and mastication more effectively than tensile forces from food. These findings support the need for instructions to patients who have been fitted with a bonded retainer to be careful with certain food.

Kaplan-Meier survival analysis tests the effects of time on failure, however, in this study it was extrapolated to test the effect of load on failure. The Y-axis represents the cumulative survival whereby a survival of 1.0 denotes 100% survival and 0.0 denotes 100% failure. The X-axis represents the bond strength at which failure occurs. The horizontal line depicts the 50th percentile (median) survival. There was a significant difference in the survival rate of the resins for both the shear and tensile loading.

A Cox Regression analysis compared each of the flowable composite resins against the non-flowable control resin to identify if any differences between them were significant. For shear bond strength, the chance of failure of StarFlow™ and Tetric EvoFlow® was reduced by about 80% and 48% respectively, when compared with Transbond™ LR. However, there was no significant difference when Transbond™ Supreme LV was compared with Transbond™ LR. For tensile bond strength, the chance of failure of Transbond™ Supreme LV was nearly 4 times greater than Transbond™ LR. There was a 78% reduction in the chance of failure of Tetric EvoFlow® when compared with Transbond™ LR. However, there was no significant difference when StarFlow™ was compared with Transbond™ LR.

Therefore, the survival analysis suggests that when shear bond strength is considered, StarFlow™ and Tetric EvoFlow® may be suitable alternative resins for bonded retainers when compared with the widely used Transbond™ LR. Similarly, when tensile bond strength is considered, Tetric EvoFlow® and StarFlow™ performed as well as Transbond™ LR. Transbond™ Supreme LV performed poorly and must be considered a less suitable alternative.

Conclusions

- Within the limitations of this laboratory based study, it can be concluded that the flowable composites Tetric Evo Flow® and Starflow™ could be suitable alternatives to the non-flowable market standard Transbond™ LR for use with bonded retainers, due to the low viscosity flow characteristics which could help the resin to mechanically key to the retainer wire, and provide adequate bond strength to the lingual enamel in order to resist shear and tensile loads.

- The low viscosity flowable nanofilled composite Transbond™ Supreme LV performed poorly in comparison with Transbond™ LR and the other flowable composites, particularly under tensile loading. Therefore, its use cannot be recommended for bonded retainers despite its flow characteristics.

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