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Shear bond strength of fibre-reinforced composite nets using two different adhesive systems

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SUMMARY The purpose of this study was to evaluate the effect of two different adhesive systems (Tetric Flow and Transbond XT) in combination with fibre-reinforced composites (FRC) net (Ever Stick) on the shear bond strength (SBS) of orthodontic brackets.

Eighty bovine permanent mandibular incisors were randomly divided into four equal groups. Stainless steel maxillary central incisor brackets with a 0.018 inch slot (DB Leone) were bonded to the teeth using the two different adhesive systems. Fifty per cent of the brackets were bonded without and 50 per cent with a FRC net under the bracket base. After bonding, all samples were stored in distilled water at room temperature for 24 hours and subsequently tested for SBS.

Analysis of variance indicated significant differences among the various groups. Brackets bonded with FRC nets under the base showed a significantly lower SBS than those bonded without nets ($P < 0.05$). Moreover, teeth bonded with Transbond XT showed a significantly higher SBS than the other groups. Additionally, significant differences in debond locations [adhesive remnant index (ARI) score] were found among the various groups. Transbond XT can successfully be used for direct bonding of FRC nets, thus improving their SBS values.

Introduction

Reinforcement of polymers with long continuous fibres has been established as an effective means of developing engineering materials for a wide range of applications (Goldberg and Burstone, 1992). Fibre-reinforced composites (FRCs) have a light-cured thermoset bisphenol-a-glycidyl dimethacrylate matrix, which allows superior bonding since it is identical to adhesives that are commonly used in dentistry (Freilich *et al.*, 1999). Excellent coupling is achieved, followed by an initial stage of polymerization of the matrix. This initial polymerization makes the matrix flexible and adaptable, so it can be contoured to the teeth and easily formed before final polymerization (Burstone and Kuhlberg, 2000). A final cure then stabilizes the shape and produces optimal mechanical properties (Freudenthaler *et al.*, 2001).

The bonding technique of FRCs is easy and fast (no laboratory work is needed), and procedures can be completed in a single appointment. Moreover, there is no need for removal of significant tooth structure, making the technique reversible and conservative. It also meets patients' aesthetic expectations and demands (Karaman *et al.*, 2002).

The use of FRCs has been recommended in orthodontics (Mullarky, 1985; Burstone and Kuhlberg, 2000; Freudenthaler *et al.*, 2001; Karaman *et al.*, 2002) for passive applications, such as space maintainers or splints (Mullarky, 1985; Rose *et al.*, 2002; Karaman *et al.*, 2002). However, the greatest clinical potential lies in active applications, where FRCs can be used as adjuncts for active tooth movement (Burstone and Kuhlberg, 2000).

To be considered as a viable alternative to existing dental materials, a FRC would need to show clinically meaningful improvements in properties over unreinforced resins and the system would have to be easy to manipulate and customize (Goldberg and Burstone, 1992).

The bonding of brackets, hooks, and tubes onto FRCs has been proposed for active orthodontic applications (Burstone and Kuhlberg, 2000). To date, there are no studies that have compared the shear bond strengths (SBSs) of FRC nets bonded under orthodontic bracket bases with different adhesive systems. Accordingly, the purpose of the present study was to evaluate the effect of two different adhesive systems on the SBS and debond locations of orthodontic brackets bonded with FRC nets.

The null hypothesis of the study was that there is no significant difference in SBS values and debond locations among the various groups.

Materials and methods

Eighty freshly extracted bovine permanent mandibular incisors were collected from a local slaughterhouse and stored in a solution of 0.1 per cent (w/v) thymol (an antimicrobial for inhibition of bacterial growth) for 1 week at 4°C. The criteria for tooth selection included intact buccal enamel with no cracks caused by extraction and no caries.

The teeth were randomly assigned to four equal groups. The teeth were cleansed of soft tissue and embedded in cold-curing fast-setting acrylic (Leocryl; Leone, Sesto Fiorentino, Italy). Metal rings (diameter 15 mm) were filled with the acrylic resin and allowed to cure, thus encasing the specimen while allowing the buccal surface of enamel to be exposed. Each tooth was orientated so that its labial surface was parallel to the shearing force.

Eighty stainless steel maxillary central incisor brackets with a 0.018 inch slot (DB Leone, Firenze, Italy) were bonded by one operator (AS). The average bracket base surface area was determined to be 11.7 mm^2 by calculating it with a digital calliper (Mitutoyo, Miyazaki, Japan) as a mean of 20 subsequent measurements.

Fibre-reinforced composites

The FRC nets (Ever Stick; Stick Teck Ltd, Turku, Finland—section: 0.6 mm) were cut with scissors to the size of the central incisor bracket base. As suggested by the manufacturer, before bonding, the fibres were impregnated with a liquid primer (Heliobond; Vivadent, Schaan, Liechtenstein).

Bonding procedure

Before bonding, the facial surface of each incisor was cleaned for 10 seconds with a mixture of water and fluoride-free pumice in a rubber polishing cup using a low-speed handpiece. The enamel surface was water rinsed to remove pumice or debris and then dried with an oil-free air stream.

The teeth were randomly divided into four groups, and two different adhesive systems were investigated. The bonding procedure is shown in Table 1.

The teeth in group 1 were etched with 37 per cent phosphoric acid gel (3M/Unitek, Monrovia, California, USA) for 30 seconds, followed by thorough washing and drying. A thin layer of primer (Heliobond) was applied to the etched enamel, followed by a layer of resin (Tetric Flow; Vivadent). A FRC net was then bonded near the centre of the facial surface of the tooth. Another layer of Heliobond primer was applied on the fibre, followed by a layer of Tetric Flow resin. Subsequently, a maxillary central incisor bracket was bonded onto the fibre with sufficient pressure to express excess adhesive, which was removed from the margins of the bracket base with a scaler before polymerization.

In group 2, the brackets were bonded with the same adhesive systems as in group 1 but without the application of a FRC net under the bracket base.

In group 3, the teeth were etched with 37 per cent phosphoric acid gel for 30 seconds, followed by thorough washing and drying. A thin layer of primer (Transbond XT primer, 3M Dental Products) was applied on the etched enamel, followed by a layer of Transbond XT. A FRC net was then bonded near the centre of the facial surface of the tooth. Another layer of Transbond XT primer was applied on the fibre, followed by a layer of Transbond XT resin. Subsequently, a maxillary central incisor bracket was bonded onto the fibre with sufficient pressure to express excess adhesive, which was removed from the margins of the bracket base with a scaler before polymerization.

In group 4, the brackets were bonded with the same adhesive systems as in group 3 but without the application of a FRC net under the bracket base.

The brackets in all groups were light cured for 10 seconds on the mesial and 10 seconds on the distal side (total cure time 20 seconds) with a halogen light–curing unit (Ortholux XT; 3M/Unitek).

Debonding

After bonding, all samples were stored in distilled water at room temperature for 24 hours and subsequently tested in shear mode on a universal testing machine (Model 4301; Instron Corp., Canton, Massachusetts, USA). The specimens were secured in the lower jaw of the machine so that the bonded brackets base was parallel to the shear force direction. The specimens were stressed in an occlusogingival direction at a crosshead speed of 1 mm/minute, according to previous studies (Jobalia *et al.*, 1997; Millett *et al.*, 1999; Cacciafesta *et al.*, 2003a,b). The maximum load necessary to debond or initiate bracket fracture was recorded in Newtons and then converted into megapascals as a ratio of Newtons to surface area of the bracket.

Residual adhesive

Bracket bases and enamel surfaces were examined under an optical microscope (Stereomicroscope SR; Zeiss, Oberkochen,

Table 1 Bonding procedures for the different groups.

Group	Bonding procedure							
1	Etching	Heliobond primer	Tetric Flow	FRC net	Heliobond primer	Tetric Flow	Bracket	Light-curing
2	Etching	Heliobond primer	Tetric Flow	—	—	—	Bracket	Light-curing
3	Etching	Transbond XT primer	Transbond XT resin	FRC net	Transbond XT primer	Transbond XT resin	Bracket	Light-curing
4	Etching	Transbond XT primer	Transbond XT resin	—	—	—	Bracket	Light-curing

Germany) at ×10 magnification. The adhesive remnant index (ARI) was used to assess the amount of adhesive left on the enamel surface (Årtun and Bergland, 1984). This scale ranges from 0 to 3. A score of 0 indicates no adhesive remaining on the tooth in the bonding area; 1 less than half the bonded area covered by the adhesive; 2 more than half the bonded area covered by the adhesive; and 3 adhesive remaining on the entire bonded area.

Statistical analysis

Descriptive statistics, including the mean, standard deviation, median, minimum, and maximum values were calculated for each of the four groups. Analysis of variance (ANOVA) was applied to determine whether significant differences in debond values existed among the various groups. For *post hoc* testing, a Scheffé's test was used.

The chi-square test was used to determine significant differences in the ARI scores among the different groups. Significance for all statistical tests was predetermined at $P = 0.05$.

All statistical analyses were performed with Stata 7 program (Stata Corp., College Station, Texas, USA).

Results

Descriptive statistics for SBS are presented in Table 2. ANOVA indicated the presence of significant differences among the various groups ($P = 0.001$). The *post hoc* test had that brackets bonded with FRC nets under the base showed a significantly lower SBS than those bonded without nets ($P = 0.001$). Moreover, teeth bonded with Transbond XT showed a significantly higher SBS than those bonded with the other adhesive system ($P < 0.05$).

The ARI scores for the four groups tested are listed in Table 3. The chi-square test results indicated significant differences in debond location (ARI score) among the various groups ($P < 0.05$). The teeth in groups 1 and 3 showed a significantly higher frequency of ARI score 0, whereas the teeth in groups 2 and 4 showed a significantly higher frequency of ARI score 3 and 1, respectively.

Discussion

The null hypothesis of the study was rejected. As shown in Figure 1, brackets bonded with a FRC net under the base showed a significantly lower SBS than those bonded without nets.

Previous studies have evaluated the mechanical properties (Freudenthaler *et al.*, 2001; Cacciafesta *et al.*, 2007, 2008) and clinical use (Kirzioğlu and Ertürk, 2004) of FRCs for orthodontic purposes.

Freudenthaler *et al.* (2001) evaluated the bond strength of FRC bars for orthodontic attachment. They found that a metal attachment pad FRC strip exhibited superior bond strength compared with a metal attachment pad alone. This is in contrast to the results of the present study. The variability of the results may be due to the differences in the mechanical and physical properties of the materials tested in each study (FRCs and adhesive systems) and to the different experimental settings and acquisition systems. Therefore, a direct comparison between the two studies is difficult.

A previous study evaluated the effect of hand light-curing and secondary oven polymerization on the mechanical properties of FRCs (Cacciafesta *et al.*, 2007). Those authors showed that oven post-curing did not increase the flexural

Table 2 Descriptive statistics in megapascals of shear bond strengths of the four groups tested. Group 1: bracket + fibre-reinforced composite (FRC) + Tetric Flow; group 2: bracket + Tetric Flow; group 3: bracket + FRC + Transbond XT; group 4: bracket + Transbond XT.

	Specimens	Mean	SD	Minimum	Median	Maximum	Significance*
Group 1	20	5.36	1.30	2.56	5.76	6.76	A
Group 2	20	11.29	1.58	7.83	11.06	13.86	B
Group 3	20	8.48	1.49	6.88	7.84	12.73	C
Group 4	20	14.50	1.78	12.32	14.18	18.28	D

**Post hoc* grouping. Means with the same letter are not significantly different.

Table 3 Frequency of distribution of adhesive remnant index (ARI) scores.

Group	ARI = 0 (%)	ARI = 1 (%)	ARI = 2 (%)	ARI = 3 (%)	χ^2*
1—Heliobond primer, Tetric Flow resin, FRC net	20 (100)	0 (0.0)	0 (0.0)	0 (0.0)	A
2—Heliobond primer, Tetric Flow resin	0 (0.0)	1 (5.0)	7 (35.0)	12 (60.0)	B
3—Transbond XT primer, Transbond XT resin, FRC net	20 (100)	0 (0.0)	0 (0.0)	0 (0.0)	A
4—Transbond XT primer, Transbond XT resin	7 (35.0)	11 (55.0)	2 (10.0)	0 (0.0)	C

**Post hoc* grouping. Means with the same letter are not significantly different.

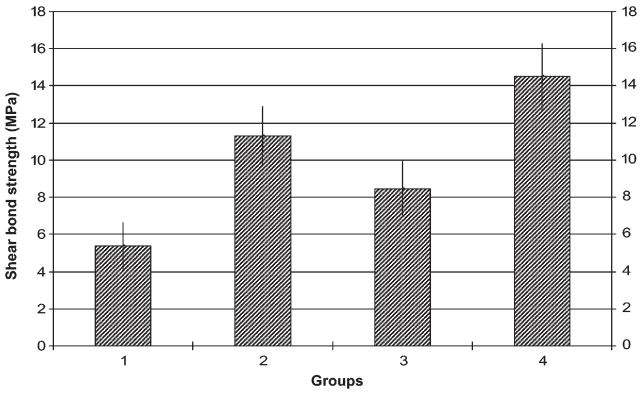

Figure 1 Mean shear bond strengths (MPa) of the four groups. Group 1: bracket + fibre-reinforced composite (FRC) + Tetric Flow; group 2: bracket + Tetric Flow; group 3: bracket + FRC + Transbond XT; group 4: bracket + Transbond XT.

strength values of 0.6 and 1.2 mm FRCs compared with conventional hand light-curing. Thus, hand light-curing of FRCs is recommended directly in the oral environment for orthodontic purposes (Cacciafesta *et al.*, 2007).

Cacciafesta *et al.* (2008) evaluated the force levels of FRCs of two sizes (diameters 0.6 and 1.2 mm) compared with orthodontic stainless steel wires (sections 0.016, 0.018, 0.017 × 0.025, and 0.019 × 0.026 inches). The results showed that FRCs can be considered a viable aesthetic alternative to full-size stainless steel wires for joining dental segments to form anchorage units.

In the present investigation, FRCs bonded with the Transbond XT adhesive system showed a significantly higher SBS than FRCs bonded with Tetric Flow. A previous study that evaluated the effects of various adhesive systems on the SBS of FRC (Scribante *et al.*, 2006) also showed that FRCs produced a significantly higher SBS when bonded using Transbond XT rather than other adhesives. To date, there are no studies in the literature that have compared the SBS of FRCs bonded with different adhesive systems.

Bovine lower incisors were used in the present investigation because they are readily available, inexpensive, and have a close morphological similarity to human enamel. Bovine and human enamel are similar in their physical properties, composition, and bond strengths (Nakamichi *et al.*, 1983; Oesterle *et al.*, 1998). Bovine enamel has been reported to be a reliable substitute for human enamel in bonding studies (Nakamichi *et al.*, 1983; Oesterle *et al.*, 1998, Barkmeier and Erickson, 1994).

Reynolds (1975) suggested that a minimum bond strength of 6–8 MPa was adequate for most clinical orthodontic needs because these values are considered to be able to withstand masticatory and orthodontic forces. In the present research, the bond strengths of groups 2 and 4 (brackets bonded without FRC nets) were above these limits. When FRCs were bonded with Tetric Flow (group 1), the SBS were below these limits.

Significant differences in debond locations (ARI score) were found among the various groups. The teeth in groups 1 and 3 showed a significantly higher frequency of ARI score 0, whereas those in groups 2 and 4 showed a significantly higher frequency of ARI score 3 and 1, respectively. Groups that showed a significantly lower SBS also presented an ARI score of 0, whereas groups that showed higher SBS were associated with higher ARI values, as reported in previous studies (Sfondrini *et al.*, 2001; Cacciafesta *et al.*, 2003b, 2004).

Conclusions

The present study demonstrated:

1. Brackets bonded with FRC nets under the base showed a significantly lower SBS than those bonded without nets.
2. Teeth bonded with Transbond XT demonstrated a significantly higher SBS than those bonded with Tetric Flow.
3. Teeth that showed a significantly lower SBS (groups 1 and 3) presented an ARI score of 0, whereas those that had a higher SBS (groups 2 and 4) were associated with higher ARI scores.

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