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# A comparison of shear bond strength of immediate and delayed bonding of brackets to FRC bars using various orthodontic adhesives

Farzin Heravi,* Saied Mostafa Moazzami,† Navid Kerayechian* and Elham Nik+

Department of Orthodontics and Dental Research Center,* Department of Operative Dentistry and Dental Research Center,† Mashhad University of Medical Sciences, Iran and Department of Pediatric Dentistry, School of Dentistry, Ahvaz University of Medical Sciences,+ Ahvaz, Iran

*Background:* Fibre reinforced composite bars (FRC) have applications as bonded retainers, space maintainers and anchorage/movement units. However, the bond strength of attachments to FRC anchorage bars is unknown.
*Aims:* To compare the shear bond strengths of brackets bonded immediately to FRCs with different orthodontic adhesive systems and bonded with the same adhesives after a 48-hour delay, abraded with a diamond bur and etched with phosphoric acid.
*Method:* One hundred and five recently extracted upper premolars were randomly assigned to seven groups (N = 15 teeth per group). FRCs were bonded to the buccal surfaces of the teeth and stainless steel orthodontic brackets were bonded to the FRCs with the following adhesive systems: Group 0 (Tetric Flow); Groups 1, 2 and 3 (Immediate bonding with chemically cured, no-mix and light cured composites, respectively, the bars covered with Tetric Flow); Groups 4, 5 and 6 (Bonding to FRCs delayed 48 hours, then bonded with chemically cured, no-mix and light cured composites, respectively, the bars covered with Tetric Flow). The FRC bars in Groups 4, 5 and 6 were abraded with a coarse-grit diamond bur before bonding the attachments to the bars. The shear bond strengths (SBS) were measured with a universal testing machine, and the adhesive remaining on the teeth after debonding was scored with the Adhesive Remnant Index (ARI). Data were analysed using analysis of variance (ANOVA), Duncan's post-hoc and Fisher's Exact test.
*Results:* There were no statistically significant SBS differences between Groups 0 (Mean SBS: 9.56 MPa), 1 (Mean SBS: 9.74 MPa), 2 (Mean SBS: 10.72 MPa) or 3 (Mean SBS: 9.54 MPa). Groups 4, 5 and 6 (Bonding delayed by 48 hours) had SBSs of 11.79 MPa, 11.63 MPa and 13.11 MPa, respectively, and were significantly higher than the SBSs in Groups 1, 2 and 3 (Immediate bonding). There were no significant differences in ARI scores among the groups.
*Conclusions:* The mean SBSs in all groups fell within the clinically acceptable range (> 7 MPa). The combination of a 48-hour delay between placement of an FRC bar and bonding an attachment, abrading the FRC with a diamond bur and etching with phosphoric acid resulted in higher bond strengths.
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Farzin Heravi: heravif@mums.ac.ir
Saied Mostafa Moazzami: MoazzamiM@mums.ac.ir
Navid Kerayechian: Kerayechiann861@mums.ac.ir
Elham Nik: nike861@mums.ac.ir

## Introduction

Fibre reinforced composite (FRC) is a conglomerate of S-glass fibres, a Bis-GMA matrix and unfilled resins that produce a glass-like, highly resistant structure.[1] It has the same colour as enamel, which appeals to patients who prefer aesthetic appliances. This technology was developed and may be used for periodontal splinting of teeth, endodontic post and cores, fixed prosthodontic appliances and as a mechanism to stabilise traumatised teeth.[2–6]

In orthodontics, FRCs have been used as bonded retainers, space maintainers, splints and as anchorage adjuncts during active tooth movement.[7,8] For anchorage, the FRC bars can unite several teeth into a single unit. The bars are tooth-coloured and attachments can be directly bonded (Figure 1).[9] The

 

Figure 1. FRC used to form posterior anchor units.

Table I. Summary of the adhesive systems and the time delay in bonding attachments.

| Groups | Bonding: Immediate | Bonding: Delayed† |
|---|---|---|
| Group 0 (TF) | * | |
| Group 1 (CC-IB) | * | |
| Group 2 (NM-IB) | * | |
| Group 3 (LC-IB) | * | |
| Group 4 (CC-DB) | | * |
| Group 5 (NM-DB) | | * |
| Group 6 (LC-DB) | | * |

TF, Tetric Flow; CC, chemically cured (Concise); NM, no mix (Unite); LC, light cured (Transbond XT); IB, immediate bonding; DB, delayed bonding

†Delayed 48 hours, abraded with diamond bur and etched with phosphoric acid

disadvantages are that the bars cannot be used in all stages of comprehensive orthodontic treatment and there is limited information on the bond strengths of attachments to the bars, particularly if bonding is delayed and the surface of the FRC bar is abraded before bonding.[9,10]

The present study aimed to determine the SBS values of brackets bonded to FRC bars with a flowable composite and three conventional orthodontic adhesives (chemically cured, no-mix and light cured resin composites).

## Material and methods

One hundred and five non-carious human upper premolars were used in this study. Teeth with hypoplastic areas, enamel cracks or irregularities or treated with chemical agents were excluded. The extracted teeth were randomly divided into seven equal groups and were stored in distilled water at room temperature until required. All teeth were bonded and tested within 2 months of extraction.

The teeth were carefully mounted in self-cure acrylic blocks so that their labial surfaces were parallel to the shearing force. The buccal surfaces were cleaned and polished with a non-fluoridated pumice and rubber prophylactic cups, washed with water and air dried. The buccal surfaces of the teeth were etched for 30 seconds with 37 per cent phosphoric acid gel (3M Dental products, St. Paul, MN, USA), rinsed with water for 30 seconds and dried with a blast of oil-free air for 20 seconds, until the etched surfaces appeared frosty white.

A thin layer of Margin Bond (Coltène/Whaledent, Altstatten, Switzerland) was applied to the etched surface and thinned by gently blowing air on the resin for 10 seconds. The resin was cured with an Astralis 7 visible light unit (Ivoclar, Vivadent, Schaan, Liechtenstein) with the intensity of 780 mW/cm$^2$ for 20 seconds. A layer of flowable resin (Tetric Flow, Ivoclar, Vivadent, Schaan, Liechtenstein) was applied to the enamel. A glass fibre FRC bar, pre-impregnated with Bis-GMA (Interlig – Ângelus, Londrina, PR, Brazil), was cut with scissors to the size of an upper central incisor stainless steel edgewise bracket and placed in the centre of the crown. Pressure was applied to the FRC to express excess resin, which was removed with an explorer. The flowable resin was then light cured for five seconds.

Stainless steel, central incisor edgewise brackets (3M Unitek, St. Paul, MN, USA) with a mean bonding surface area of 12.54 mm$^2$ were bonded to the FRCs (Table I):

1. Group 0 (TF: Tetric Flow): a flowable composite resin was applied to the bracket base and the bracket positioned on the FRC. The composite resin was light cured on the mesial (20 seconds) and distal (20 seconds) sides of the bracket bases.

2. Group 1 (CC-IB: chemically cured, immediate bonding): a layer of Tetric Flow resin was applied to the FRC to completely cover the fibre bar and light

Table II. The shear bond strengths of the groups.

| Groups | N | Mean (MPa) | SD (MPa) | Range (MPa) | Test* |
|---|---|---|---|---|---|
| Group 0 (TF) | 15 | 9.56 | 3.08 | 5.71 - 16.31 | a |
| Group 1 (CC-IB) | 15 | 9.74 | 1.52 | 8.09 - 13.05 | a |
| Group 2 (NM-IB) | 15 | 10.72 | 1.67 | 8.15 - 14.50 | a, c |
| Group 3 (LC-IB) | 15 | 9.54 | 1.87 | 6.58 - 13.39 | a |
| Group 4 (CC-DB) | 15 | 11.79 | 1.82 | 8.41 - 15.37 | b, c |
| Group 5 (NM-DB) | 15 | 11.63 | 2.33 | 8.51 - 17.06 | b, c |
| Group 6 (LC-DB) | 15 | 13.11 | 1.98 | 8.88 - 16.52 | b |

*Groups with the same letters are not significantly different from each other

cured for 40 seconds. The brackets were bonded to the FRC bar with a chemically cured composite resin (Concise, 3M Dental Products, St Paul, MN, USA). During curing the brackets were pressed firmly in place and excess adhesive was removed with an explorer.

3. Group 2 (NM-IB: no-mix, immediate bonding): the FRC was covered with Tetric Flow and light cured for 40 seconds as in Group 1. The brackets were bonded to the FRC bars with a no-mix composite resin (Unite, 3M Unitek, Monrovia, CA, USA). Primer was applied to the surface of the FRC bar and the bracket. The adhesive was then applied to the base of the bracket and the bracket positioned on the covered FRC bar.

4. Group 3 (LC-IB: light cured, immediate bonding): the FRC was covered with Tetric Flow as in Groups 1 and 2 and light cured for 40 seconds. The brackets were bonded to the FRC bars with Transbond XT (3M Unitek, Monrovia, CA, USA). A thin layer of primer (Transbond XT primer, 3M Unitek) was applied to the covered FRC bar and a layer of Transbond XT composite resin placed on the base of the bracket. The brackets were positioned on the FRC bar and pressed firmly into place. Excess adhesive was removed with an explorer before curing. The complex was cured for 40 seconds with the light-curing protocol used in Group 0 (20 seconds on the mesial side and 20 seconds on the distal side of the bracket base).

5. Group 4 (CC-DB: chemically cured, delayed bonding): the FRC was again covered with Tetric Flow as in Groups 1, 2 and 3. The samples were then stored in distilled water at room temperature for 48 hours. The surface of the covered FRC bars was abraded with a high-speed coarse-grit diamond bur (No.534, SS White Lakewood, NJ, USA) irrigated with a water spray, 'etched' with 37 per cent phosphoric acid for 10 seconds, washed thoroughly with water and air dried. A thin layer of primer (Margin bond) was applied to the surface and thinned by gently blowing air on the resin for 10 seconds. The primer was then light cured for 20 seconds and the brackets were bonded to the surface with the chemically cured composite resin (Concise) used in Group 1.

6. Group 5 (NM- DB: no-mix, delayed bonding): the FRC bar was covered in Tetric Flow as in Group 4. The brackets were bonded to the covered FRC bars (after the surface of the bars had been abraded) with a no-mix composite resin (Unite), according to the manufacturer's instructions.

7. Group 6 (LC-DB: light cured, delayed bonding): the procedure used in Groups 4 and 5 was followed. The brackets were bonded to the FRC bars (after the bars had been abraded) with the light cured composite resin (Transbond XT) used in Group 4 and according to the manufacturer's instructions.

### *Debonding procedure*

After bonding, all samples were stored in distilled water at room temperature for 24 hours. The specimens were mounted in a universal testing machine (Zwick GmbH, Ulm, Germany) and the brackets debonded with shear load applied to the bracket base by a blade at a crosshead speed of 1 mm/min. The maximum load required to debond the fibre bar was recorded in newtons (N) and converted to megapascals (MPa).

### *Residual adhesive*

After debonding the brackets, the buccal surfaces were examined at x10 magnification and the amount of adhesive remaining on the tooth recorded using adhesive remnant index (ARI).[11] The criteria for scoring were 0, no adhesive on the tooth; 1, less than half of adhesive on the tooth; 2, more than half of the adhesive on the tooth; and 3, all adhesive on the tooth.

### *Statistical method*

The Kolmogorov-Smirnov test was used to determine if the data were normally distributed. The mean SBSs were compared with an analysis of variance

Table III. Distribution of ARI scores.

| Groups | ARI 0 (Per cent) | ARI 1 (Per cent) | ARI 2 (Per cent) | ARI 3 (Per cent) | Fisher's Exact test* |
|---|---|---|---|---|---|
| Group 0 (TF) | 1 (6.7) | 3 (20) | 8 (53.3) | 3 (20) | a |
| Group 1 (CC-IB) | 1 (6.7) | 3 (20) | 11 (73.3) | 0 (0.0) | a |
| Group 2 (NM-IB) | 1 (6.7) | 6 (40) | 8 (53.3) | 0 (0.0) | a |
| Group 3 (LC-IB) | 1 (6.7) | 4 (26.7) | 8 (53.3) | 2 (13.3) | a |
| Group 4 (CC-DB) | 1 (6.7) | 6 (40) | 8 (53.3) | 0 (0.0) | a |
| Group 5 (NM-DB) | 1 (6.7) | 7 (46.7) | 7 (46.7) | 0 (0.0) | a |
| Group 6 (LC-DB) | 1 (6.7) | 5 (33.3) | 8 (53.3) | 1 (6.7) | a |
| Total | 7 | 34 | 58 | 6 | |

ARI scores: *0*, no adhesive remaining on tooth; *1*, less than half of adhesive remaining on tooth; *2*, more than half of adhesive remaining on tooth; *3*, all adhesive remaining on the tooth

* Groups with the same letter are not significantly different from each other. Fisher's Exact test: 12.24, $p = 0.83$

(ANOVA) and Duncan post-hoc test. The ARI scores among the different groups were compared with Fisher's Exact test. All statistical analyses were performed using the SPSS software package (SPSS for windows, version 15, SPSS Inc, Chicago IL, USA). A $p < 0.05$ was considered significant.

## Results

The results of this study demonstrated that Group 6 had a higher mean SBS value (13.11 ± 1.98 MPa) compared with the other groups (Table II). Groups 4, 5 and 6 had similar SBS values ($p > 0.05$). Group 0 (TF) had a mean SBS value of 9.56 ± 3.08 MPa which differed significantly from Groups 4 , 5 and 6, but not Groups 1, 2 and 3. The mean shear bond strengths of all groups exceeded 7 MPa, the shear bond strength regarded as clinically acceptable.[12]

The ARI scores for the 7 groups are given in Table III. There were no significant group differences in the locations of the bond failures ($p = 0.8$), regardless of the adhesive material, and the delay in bonding and surface treatment of the FRC. Bond failure occurred mainly within the bonding material.

## Discussion

The bond strengths of orthodontic attachments bonded to FRC bars with conventional orthodontic adhesives was examined in the present study. Previous studies have assessed the physical properties but not the effectiveness of different methods of bonding attachments to the bars.[2,13–19] It was found that the bond strengths of the six orthodontic adhesives that were examined exceeded the minimum 7 MPa bond strength for clinical use.[12] The combination of delaying bonding for 48 hours, abrading the surface of the bar with a coarse grit diamond bur and then etching with phosphoric acid resulted in high SBSs, but the delay is unlikely to be acceptable to many clinicians and patients.

Orthodontic attachments and FRC bars may be bonded in a one-step procedure with the flowable composite resin used in the study, but the attachments were inclined to drift until the resin was cured.[9] Contradictory reports exist in the literature regarding the shear bond strengths of flowable resins compared with conventional orthodontic adhesives. Several investigators have reported that the SBSs of flowable resins are significantly lower than the SBS of Transbond XT while others have reported similar bond strengths to Transbond XT.[20–23] The findings of the present study support the view that attachments bonded to FRC bars with conventionally chemically cured, no-mix and light cured orthodontic adhesives (Concise, Unite, Transbond XT) will result in acceptable SBSs.

In several groups, bonding to the FRC bar was delayed for 48 hours, in order to mimic clinical situations. In this circumstance, the bar was abraded with a diamond bur and its surface etched with phosphoric acid to determine changes in bond strength. Together these steps resulted in significantly higher bond strengths for the chemically cured (Concise) and light cured resins (Transbond XT) but not the no-mix resin (Unite). It was considered that the abrasion and etching removed by-products of the polymerisation process and/or contamination by foods and drinks in the 48-hour period.[24] For the no-mix adhesive, the delay and subsequent surface treatment had little effect on bond strength, possibly because the solvents in this adhesive were ineffective in preparing the surface of the FRC for bonding and enhancing bond strength.

Etching the surface of an orthodontic adhesive with phosphoric acid has been advocated by clinicians for making composite additions and bonding orthodontic attachments.[24] Abrasion with a diamond bur may have smoothed the surface of the bars and enhanced micromechanical retention and also may have removed food, polymerisation and degradation products. The solvents in the uncured orthodontic resins appear to have removed the products as no significant differences in the bond strengths of the immediate (Group 2) and delayed (Groups 4 and 5) groups were found.

The majority of the attachments failed cohesively and there were no significant ARI differences between the groups. However, in Groups 3 (Transbond XT, immediate bonding) and 6 (Transbond XT, delayed bonding), all of the adhesive was left on the tooth surface in 13 and 6 per cent of the teeth, suggesting that the curing light may not have reached the resin in the deepest parts of the bonding pad. Of the brackets bonded immediately with Tetric Flow, 20 per cent also failed at the bracket interface, suggesting that this adhesive did not have the cohesive strength of the orthodontic adhesives.

## Conclusions

The following conclusions may be drawn from this study:

Orthodontic brackets bonded immediately to FRC bars with either a flowable adhesive or various orthodontic adhesive systems that had adequate bond strengths.

The bond strengths were significantly greater for the chemically cured (Concise) and light cured (Transbond XT) adhesives when bonding was delayed 48 hours and the surfaces of the Tetric Flow covered bars were abraded with a diamond bur and etched with phosphoric acid.

No significant differences in ARI scores were found among the groups.

## Corresponding author

Dr Navid Kerayechian
Department of Orthodontics
School of Dentistry
Mashhad University of Medical Sciences
Mashhad
Iran
Tel: +98 511 8419814
Fax: +98 511 8829500
Email: Kerayechiann861@mums.ac.ir

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