Shear Bond Strength and Residual Adhesive after Orthodontic Bracket Debonding

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ABSTRACT

Objective: To compare the shear bond strength and determine the area of residual adhesive on teeth after the debonding of brackets bonded with two types of orthodontic adhesives. These were a resin-modified glass ionomer cement (RMGIC; Fuji ORTHO LC, GC Corporation, Tokyo, Japan) and a resin applied as a precoated bracket (APC™ bracket, 3M Unitek GmbH, Seefeld, Germany).

Materials and Methods: A total of 60 premolar teeth were randomly divided into two groups, and brackets were bonded according to the manufacturers' instructions. In group 1, the teeth were conditioned using 10% polyacrylic acid, and the brackets were bonded using Fuji Ortho LC in wet condition. In group 2, the teeth were etched using 37% phosphoric acid, and the APC brackets were bonded. Bond strength was measured using a testing instrument (2000S, Lloyds Instruments, Fareham, England) at a crosshead speed of 1 mm/min, and the residual adhesive was quantified using a three-dimensional laser scanning instrument.

Results: The Mann-Whitney test showed that the median bond strength of group 1 was significantly lower than that of group 2 ($P < .001$). A Pearson chi-square test of the Adhesive Remnant Index (ARI) revealed a significant difference among the groups tested. All the adhesives in group 1 failed at the enamel/adhesive interface (100%), whereas group 2 exhibited cohesive failure of the adhesive (90%).

Conclusions: The bond strength values obtained with the RMGIC were above the minimum values suggested in the literature to achieve a clinically effective adhesion in orthodontics. (*Angle Orthod* 2006;76:694–699.)

KEY WORDS: Orthodontic brackets; Resin-modified glass ionomer cement; Shear bond strength; Residual adhesive

INTRODUCTION

Direct bonding of orthodontic brackets to etched or conditioned surfaces is achieved by resin adhesives or cements.[1,2] Recently, adhesive systems have been modified from acrylic and epoxies to epoxy-acrylates and from glass ionomer, fluoride-releasing cements, to the current resin-modified glass ionomer cements (RMGICs).

In 1972, Wilson and Kent[3] formulated a new translucent cement for dentistry, the glass ionomer cement (GIC). This was a hybrid of silicate and polycarboxylate cements and could bond physiochemically to both enamel and dentine. Research dealing with the hydrophilic GICs confirmed the advantage of releasing fluoride but conversely has shown a poor bond strength compared with composite resin.[4,5] Bond failure with composite resin has been attributed to moisture contamination arising from saliva, gingival fluids, and water. Improvements in orthodontic bonding materials have led to the advent of resin-modified glass ionomer adhesives. Bishara et al[6] concluded that with etched enamel, and in a wet environment, the light-cured, resin-reinforced glass ionomer adhesive system has comparable shear bond strength with that of the traditional light-cured composite resin system.

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Most clinical orthodontic bonding requires an estimated bond strength of 5.9–7.8 MPa,[1] although bond strengths for RMGICs have been reported ranging from 5.39 to 18.9 MPa.[7–9] Fuji Ortho LC (Fuji ORTHO LC, GC Corporation, Tokyo, Japan) may be used without etching, in the wet condition, and still maintains a clinically useful shear bond strength.[10]

In an effort to enhance the quality of the adhesive system and to save chairside time and to perform faster and easier bonding procedures, the light-cured, adhesive-precoated brackets (APC, 3M Unitek, Monrovia, Calif) were introduced in 1992. Cooper et al[11] listed the following advantages of adhesive-precoated brackets over conventional light-cured systems: consistent quality and quantity of light-cured adhesive, easier cleanup after bonding, reduced waste, improved asepsis, and better inventory control.

Few studies have evaluated the bond strength of APC brackets to tooth enamel. The results that have compared the bond strength of APC and conventional brackets are, however, contradictory. Bearn et al[12] and Bishara et al[13] compared the in vitro shear bond strength of APC brackets with that of identical brackets bonded with Transbond and found no significant differences between the two types. In other studies, APC metal brackets have been shown to produce lower bond strengths than uncoated brackets.[14,15] The composite used to precoat the APC brackets is a version of Transbond XT (3 M Unitek, Gmb H, Seefeld, Germany) modified by increased polymer viscosity. The difference between the adhesive used on precoated brackets and that used for bonding uncoated brackets was in the percentage of the different ingredients incorporated in the materials.[14]

Previous studies have used methods, current to the time, for measuring residual adhesive resin after removal of orthodontic attachments. Quantitative measurements were performed either by judging the distance between an intraenamel implant and the enamel surface, before and after bonding, with a miniaturized Boley gauge[16] or by optical profilometric techniques.[17,18] Both techniques allow only a small number of measurements per tooth surface. Recently, a noncontact laser probe has been developed in Germany (Laser Scan 3-D Pro, Willytec GmbH, Gräfelfing, Germany) for evaluating dental surface change. Several studies have shown that this technique has increased the accuracy of oral surface assessment.[19,20] This laser scan machine has been used in this study. According to the manufacturer, the accuracy of this machine, after three-dimensional (3-D) matching, is 8.5 μm.

The main objective of this study was to compare the shear bond strength of two types of orthodontic adhesive system, a RMGIC (Fuji Ortho LC) and an adhesive resin supplied with APC brackets (3M Unitek). Our aim was also to quantify and observe the amount of residual adhesive on the enamel after debonding of brackets, using the 3-D laser scanner.

MATERIALS AND METHODS

Teeth

A total of 60 freshly extracted upper premolar teeth were used for this study. These teeth had been extracted for reasons unrelated to the objective of this study and with the informed consent of the patients. The teeth were selected on visual observation for soundness of the coronal portion, absence of caries, no cracks on the labial surface, and not subjected to any chemical agents. The teeth were stored in distilled water at room temperature.

The roots of teeth were removed using a slow-speed saw (Buehler, Lake Bluff, Ill) to allow the teeth to be placed centrally in mounts, with the labial surface uppermost. The lingual areas of the teeth were embedded in orthodontic self-cure acrylic resin in a custom-made mold. The teeth and molds were placed in distilled water to minimize the temperature rise from the exothermic setting reaction of the orthodontic resin. The teeth were cleaned and polished with nonfluoride pumice with a rubber cup for 10 seconds, sprayed with water, and dried with compressed air.

Bonding procedure

The teeth were randomly divided into two groups of 30 for bracket attachment.

Group 1. Premolar metal brackets (Victory Series, 3M Unitek GmbH, Seefeld, Germany) with 0.022-inch slots were used. The measurement of the area of the bracket bases was made with digital calipers with an accuracy of 0.01 mm and determined to be 10.5 mm^2. The teeth were etched with Fuji Ortho LC conditioner (10% polyacrylic acid solution) for 20 seconds, rinsed with water for 20 seconds, and a thin film of water was brushed on the enamel surface. Fuji Ortho LC adhesive was mixed and applied according to manufacturer's instructions. Each bracket was positioned on the least-curved part of the labial enamel surface and was under a constant load of 3 kg applied by a plunger-type loading device, to standardize the procedure, as described by Bishara et al.[13] The excess adhesive was removed from the margins of the bracket with a dental probe. Each bracket was light cured as per manufacture's instruction.

Group 2. Premolar adhesive-coated metal orthodontic brackets (APC™ bracket, Victory Series, 3M Unitek GmbH) with 0.022-inch slots were used. The enamel was etched with 37% orthophosphoric acid for 30 sec-

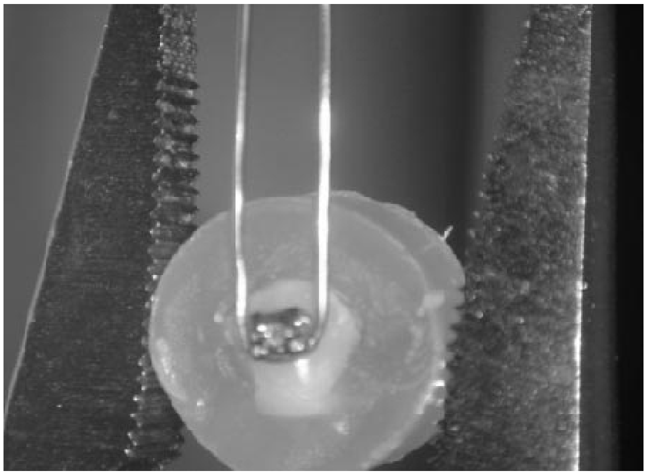

FIGURE 1. Bonded tooth set in acrylic block.

onds, thoroughly rinsed with water for 30 seconds, and dried with oil-free compressed air. The brackets were applied as per the manufacturer's instruction. Each bracket was positioned on the least-curved part of the labial enamel surface and was under a constant load of three kg. The excess adhesive was removed from the margins of the bracket with a dental probe. Each bracket was light cured as per the manufacture's instructions.

An identification number was attached to each specimen to provide a basis for blinded testing. The specimens for both groups were stored in water at 37°C for 24 hours before testing.

Shear bond strength test

Debonding of the brackets was carried out, 24 hours after bracket bonding, on a testing instrument (2000S, Lloyds Instruments, Fareham, England), using a looped rectangular, 0.018 × 0.025–inch, stainless steel wire at a crosshead speed of 1 mm/min. The wire passed beneath the bracket wing with the labial surface perpendicular to the horizontal plane (Figure 1). This was not pure shear because the load was applied some distance from the bonding interface. This method has been described by Fox et al.[21] The bond force were recorded in Newtons and then divided by the bracket base area, 10.5 mm^2, and converted to megapascals (MPa) (one MPa = N/mm^2).

Bond-failure assessment

After bracket debonding, impressions of the teeth were taken in light-bodied polyvinyl-siloxane material (PROVIL® novo, GmbH and CoKG, Hanau, Germany) and poured in die stone (Silky-Rock, Whip Mix Corporation, Louisville, Ky). (Stone models are preferred for scanning because tooth surfaces, plastics, metals, and ceramics cause scattering of the laser beam and consequent loss of resolution.) The resulting models were scanned using the 3-D laser scanner, and the resulting images were examined to view the bond-failure interface.

The adhesive remnants left on the enamel surface were scored and classified using a modified Adhesive Remnant Index (ARI). Score 0 = more than 75% of adhesive was left on tooth; score 1 = 75% of adhesive left on tooth; score 2 = 50% of adhesive left on tooth; score 3 = 25% of adhesive left on tooth; score 4 = less than 25% of adhesive left on tooth; and score 5 = no adhesive left on the tooth image (Figure 2). The modified ARI was expanded from the original ARI scale,[22] which considered adhesive on the tooth surface. Excess resin outside the bracket base area was not considered.

Statistical methods

Bond strength of the two groups was compared using the Mann-Whitney test. The residual adhesive was compared using the chi-square test. A significance level of 0.05 was used.

RESULTS

Shear bond strength

The shear bond strength of the orthodontic adhesives and the testing conditions are shown in Table 1. The Mann-Whitney test revealed a significant difference in shear bond strength amongst the two groups ($P < .001$). The median shear bond strength (7.91 MPa) of group 1 (Fuji Ortho LC in wet condition) was significantly lower than that (10.66 MPa) of group 2 (adhesive bonding agent in dry condition).

Bonding-failure interface

Figure 3 and Table 2 show the failure site for both groups. Most of the adhesive resin in group 2 exhibited cohesive failure (90%), whereas only 7% exhibited bracket/adhesive failure. In one case, enamel fracture was observed. All the adhesive resins in group 1 failed at the enamel/adhesive interface (100%).

Comparison of ARI

Table 3 shows the distribution of ARI scores for the two adhesives. The adhesive left on the enamel in group 1 had an ARI score of 5. The adhesive left on the enamel in group 2 had ARI scores ranging from 1 to 4. The Pearson chi-square test showed a significant difference in the ARI score amongst the two groups ($P = .02$)

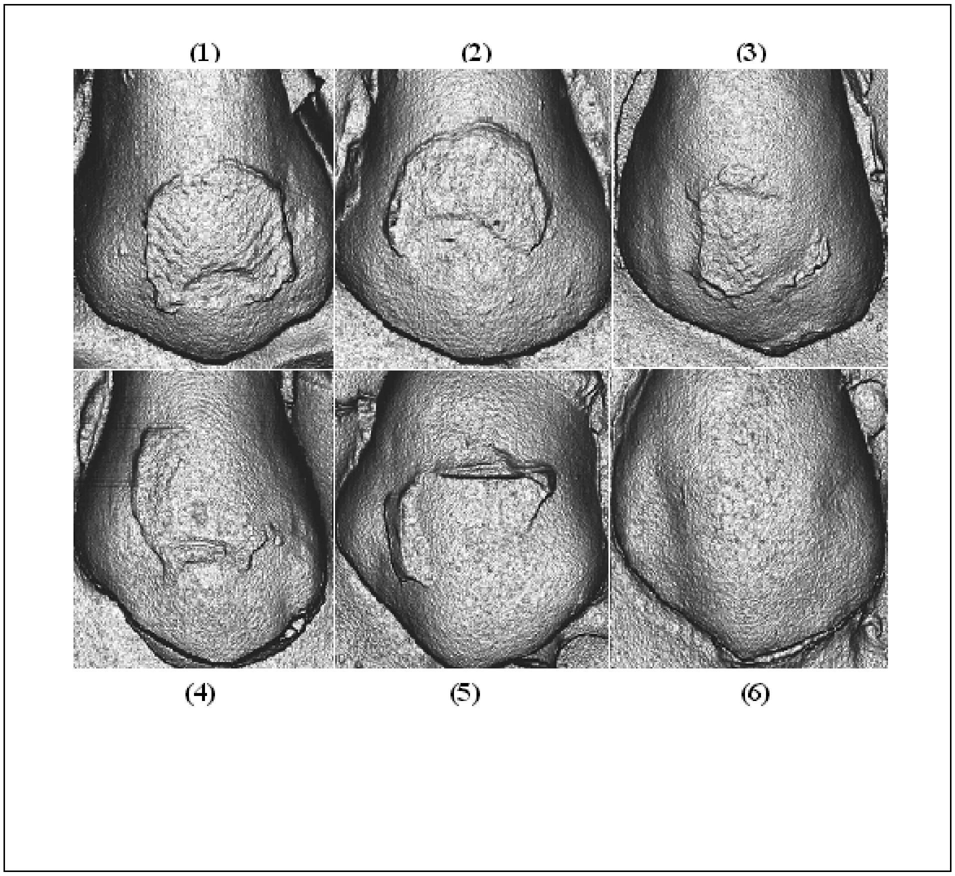

FIGURE 2. Scanned images showing enamel surfaces with modified Adhesive Remnant Index (ARI) scores of 0 through 5. (1) ARI = 0. (2) ARI = 1. (3) ARI = 2. (4) ARI = 3. (5) ARI = 4. (6) ARI = 5.

TABLE 1. Descriptive Statistics for the Shear Bond Strength Test (in MPa), $P < .001$ Amongst the Two Groups

Group	Condition	n	Minimum	Maximum	Median	SD
1	Wet	30	4.38	11.27	7.91	2.16
2	Dry	30	5.41	17.06	10.66	2.26

TABLE 2. Failure Interface for the Two Groups

	Area of Bonding Failure				
Group	Enamel/ Adhesive	Cohesive Failure	Bracket/ Adhesive	Enamel Fracture	Cohesive Failure, %
1	30	—	—	—	0
2	—	27	2	1	90

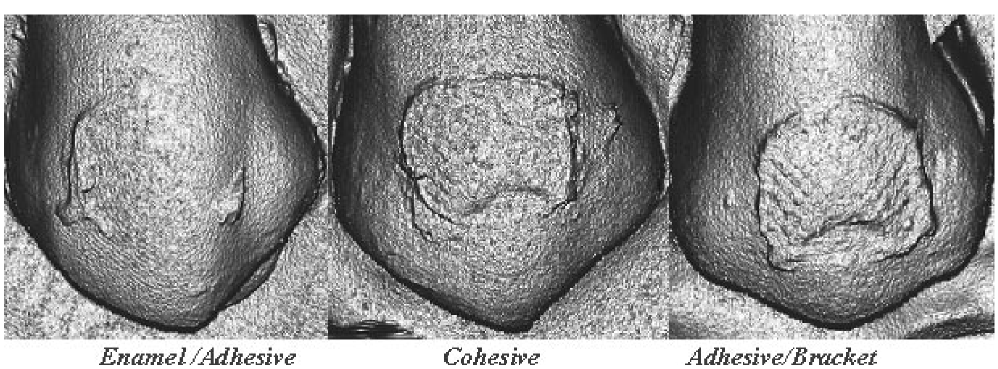

FIGURE 3. Scanned images showing bond-failure interface.

TABLE 3. Distribution of the Modified Adhesive Remnant Index (ARI)

	Modified ARI Score						
Group	0	1	2	3	4	5	n
1	—	—	—	—	—	30	30
2	—	6	7	8	8	—	29

DISCUSSION

The bond strength values for both groups in this study were lower than those determined by Sunna and Rock[23] (22.08 MPa), Sfondrini et al[24] (13.2 MPa), and Ip and Rock[25] (13.6 MPa). The shear bond strength (10.87 ± 2.26 MPa) for APC adhesive brackets in this study was similar to that (11.03 ± 3.05) reported by Newman et al[26] of metal brackets bonded with light-cured composite with properties similar to the precoated resin.

It has been reported that the minimum bond strength of 6–8 MPa was adequate for most clinical orthodontic needs.[1] In this study, the shear bond strength of the groups tested ranged from 8.05 to 10.87 MPa. The Fuji Ortho LC is a light-cured, resin-reinforced glass ionomer and is formulated to bond orthodontic brackets in a wet environment. This eliminates the need to maintain the teeth in a completely dry condition during the bonding procedure.[12] It has been suggested that the continued release of fluoride from GICs helps prevent caries and decalcification.[27]

These results of this study indicate that the Fuji Ortho LC adhesive, when used on conditioned enamel in a wet environment, has a bond strength (8.05 ± 2.16 MPa) similar to the traditional light-cured composite adhesive. It was also found that the majority of bracket failure for the group 1 adhesive was at the enamel/adhesive interface. This suggests that the bond to the bracket is stronger than the bond to enamel. This is in agreement with previous reports.[28,29] The weaker bonding between the resin-modified glass ionomer (RMGI) and the enamel should make it easier for clinicians to cleanup the adhesive on the enamel surface after debonding. This finding may make Fuji Ortho LC more desirable for use in orthodontic therapy.

With the precoated metal brackets, Bishara et al[14] found a greater frequency of an ARI score 1 (all the adhesive remained on the enamel surface), suggesting a relatively weaker bond between the adhesive and the bracket. It was found, for group 2 in our study, that the cohesive failure occurred within the resin with the resin remaining on both the tooth and the bracket. Consequently, cohesive failure can be considered undesirable because the removal of remnant adhesive from the tooth surface may lead to enamel damage and may increase chairside time.

A study by O'Brien et al[30] suggested that the ARI score depended on many factors, which included the bracket base design and the adhesive type, and not only the bond strengths at the interfaces. The ARI was useful in determining the percentage of bond-failure sites by ranking the amount of resin remaining on scanned tooth images after debonding. The ARI scores for this study revealed enamel fracture on debonding for the adhesive resin (group 2) on one tooth. Rix et al[31] indicated that the increase in enamel fracture might be related to the extraction force. It was previously reported that enamel failure occurred when the bond strength exceeded 13.5 MPa.[32] The results of this study agreed with this observation in that the enamel fracture occurred at higher stress. The bond strength, when using the polyacrylic acid, showed clinically acceptable bond strength for use in orthodontic treatment.

On the basis of the above observation, Fuji Ortho LC adhesive may be ideal for orthodontic bonding purposes because it provided adequate bond strength and the most desirable location for bond failure at enamel/adhesive interface. In addition, this material can be used in a wet environment.

CONCLUSIONS

- Both bonding systems provide adequate bond strengths. There was significantly greater shear bond strength between brackets and enamel after 37% orthophosphoric acid etching and composite bonding (group 2) compared with 10% polyacrylic acid etching and RMGI cement (group 1).
- Fuji Ortho LC could be useful when the enamel surface is contaminated with water before the application of bonding materials. The ARI result for Fuji showed that the predominant bracket-failure interface was at the enamel/adhesive interface.
- The weaker chemical bonding between the RMGI and the enamel should make it easier for clinicians to clean up the adhesive on the enamel surface after debonding.
- The residual adhesive assessment and the bonding-failure interface examination can be quantified by this novel laser scanning technique.
- This study suggests a benefit in using Fuji Ortho LC cement as the coating on precoated brackets. This may be considered by the manufacturers of orthodontic brackets.

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