Original Article

The Effect of Repeated Bonding on the Shear Bond Strength of a Composite Resin Orthodontic Adhesive

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Abstract: One of the problems clinicians face during treatment is bracket failure. This is usually the result either of the patient's accidentally applying inappropriate forces to the bracket or of a poor bonding technique. As a result, a significant number of teeth have to be rebonded in a busy orthodontic practice. The purpose of this study was to evaluate the effect of repeated bonding on the shear bond strength of orthodontic brackets. Fifteen freshly extracted human molars were collected and stored in a solution of 0.1% (wt/vol) thymol. The teeth were cleaned, polished, and etched with a 37% phosphoric acid gel. The brackets were bonded with the adhesive and light cured for 20 seconds. The teeth were sequentially bonded and debonded 3 times with the same composite orthodontic adhesive. At each time, all 15 teeth were debonded within a half hour after bonding to simulate the clinical condition at which a newly bonded bracket is attached to the arch wire. The results of the analysis of variance comparing the shear bond strength at the 3 debonding attempts indicated the presence of no significant differences among the 3 groups ($P = .104$). However, when the overall change in shear bond strength within each tooth was evaluated between debonding sequences 1 and 3, 10 teeth had a significant ($P = .001$) decrease (mean $\pm$ SD, -4.6 ± 2.5 MPa) in bond strength, whereas 5 teeth had a significant ($P = .02$) increase (mean $\pm$ SD, 2.8 ± 1.6 MPa). The present findings indicated that in general, the highest values for shear bond strength were obtained after the initial bonding. Rebonded teeth have significantly lower and inconsistent shear bond strength; ie, bond strength may further decrease or increase after the second debonding, and the changes in bond strength may be related to the changes in the morphologic characteristics of the etched enamel surface as a result of the presence of adhesive remnants. (*Angle Orthod* 2000;70:000–000.)

Key Words: Rebonding; Orthodontic brackets; Shear bond strength

INTRODUCTION

Since Buonocore introduced the acid etch bonding technique in 1955, the concept of bonding various resins to enamel has developed applications in all fields of dentistry,[1] including the bonding of orthodontic brackets.[2,3] This approach has several advantages, such as easier plaque removal by the patient, minimized soft tissue irritation and hyperplastic gingivitis, elimination of the need for separation, absence of posttreatment band spaces, facilitation of application of attachments to partially erupted teeth, minimized danger of decalcification with loose bands, easier detection and treatment of caries, and a much more esthetic appearance for the patient.[4] By the late 1970s, bonding of orthodontic brackets became an accepted clinical technique.[5,6] One of the problems clinicians face during treatment is bracket failure. This is usually the result either of the patient's accidentally applying inappropriate forces to the bracket or of a poor bonding technique. As a result, a significant number of teeth have to be rebonded in a busy orthodontic practice.

It is important to realize that the surface layer of enamel,[7] which is lost during etching, is estimated to vary between 10 and 30 μm, whereas the depth of penetration of the resin tags[8] reaches up to 50 μm. In addition, the cleanup procedure of the adhesive after debonding may remove up to 55.6 μm of surface enamel.[9]

The depth of the histological change in the enamel, beyond the complete dissolution of the surface layer, can be estimated from determining the lengths of resin tags. After enamel etching, the acrylic resin applied to the enamel sur-

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face flows into the histologic porosities, thereby forming a mechanical bond. By sectioning the tooth longitudinally, the amount of penetration into the enamel may be quantified. Various studies have examined the depth of these resin tags. They reported that the average depth of penetration ranges between 8 and 15 microns, with maximum tag lengths[8–14] ranging up to 50 microns. As a result, in a freshly etched tooth the surface area available for forming a mechanical bond is increased because the liquid sealant allows for an easy flow into the interprismatic spaces formed during the etching process. Most of these sealant tags remain embedded in the enamel after debonding.[14] On the other hand, a chemical bond occurs between the sealant and the adhesive paste, and in turn the latter mechanically adheres to the recesses available in the bracket base. Altogether, this system provides the strength needed to keep the bracket attached to the tooth during orthodontic force application.

Mui et al[15] found that there were no significant differences between the rebond strength and the original shear bond strength if the enamel surface was reconditioned with a tungsten carbide bur. However, Rosenstein and Binder[16] found that rebonding without reconditioning either the bracket or tooth surfaces provided the highest shear bond strength. Jassem et al[17] found that thermal recycling of bonded and rebonded orthodontic attachments adversely affected both shear and tensile bond strength.

The purpose of this study was to evaluate the effect of repeated bonding on the shear bond strength of orthodontic brackets.

MATERIALS AND METHODS

Teeth

Fifteen freshly extracted human molars were collected and stored in a solution of 0.1% (wt/vol) thymol. The criteria for tooth selection included intact buccal enamel not subjected to any pretreatment chemical agents (eg, hydrogen peroxide), no cracks caused by the pressure of the extraction forceps, and no caries. The teeth were cleaned and then polished with nonfluoridated pumice and rubber prophylactic cups for 10 seconds.

The teeth were embedded in acrylic placed in phenolic rings (Buchler Ltd, Lake Bluff, Ill). A mounting jig was used to align the facial surface of the tooth perpendicular with the bottom of the mold; ie, each tooth was oriented so its labial surface would be parallel to the force during the shear strength test.

Brackets

Maxillary central incisor brackets (Victory Series; 3M Unitek, Monrovia, Calif) were used to bond all teeth. The average surface area of the bracket base[2] was determined to be 11.9 mm. New brackets were used for each bonding sequence.

Adhesive

Transbond XT bonding system (3M Unitek) contains a liquid sealant and an adhesive paste. The latter is a composite that contains Bis GMA, Bis EMA, and quartz/silica fillers. The liquid sealant has essentially the same composition as the adhesive paste but without the fillers.

Bonding protocol

The bonding approach followed the manufacturer's instructions. The procedure included acid etching with a 37% phosphoric acid gel for 30 seconds followed by thorough washing and drying. The sealant was placed on the tooth, and the brackets were bonded with the adhesive and light cured for 20 seconds.

Before light curing the adhesive, the brackets were pressed on the tooth with 300 *gm* of force according to a force gauge (Correx Co, Bern, Switzerland), and excess adhesive was removed with a sharp scaler.

Debonding procedure

A steel rod with a flattened end was attached to the crosshead of a Zwick test machine (Zwick GmbH & Co, Ulm, Germany). An occlusogingival load was applied to the bracket, producing a shear force at the bracket-tooth interface. A computer, electronically connected with the Zwick test machine, recorded the results of each test. Shear bond strengths were measured at a crosshead speed of 5 mm/min. Bracket removal was performed within a half hour from the time the teeth were bonded.

Repeated rebonding

After each debonding, all visible residual composite adhesive was removed with a finishing carbide bur (#279; Brassler USA, Savannah, Ga) until the enamel surface regained its gloss. The teeth were then cleaned, and the bonding/debonding procedures were repeated a total of 3 times on the same tooth surface with the same approach detailed earlier.

During each series of bonding and debonding, the order of the teeth was maintained so that it was possible to compare the bond strength of each tooth in its proper sequence. This approach allowed for the evaluation of the changes that occur in the bond strength within each tooth on a longitudinal basis. All debonding was performed within a half hour from the time of bonding to simulate as much as possible the conditions that occur clinically, ie, after a bracket fails and is replaced and tied to the arch wire.

Evaluation of the residual adhesive

After bond failure, the teeth and brackets were examined under 10× magnification. Any adhesive remaining after bracket removal was assessed with a modified adhesive

TABLE 1. Descriptive Statistics and the Results of the Analysis of Variance Comparing the Shear Bond Strengths (in MPa) of the 3 Bonding/Debonding Sequences on 15 Teeth

Debonding Sequences	Mean[a]	SD	Range*
1	6.1	3.4	2.9–12.8
2	4.1	2.3	1.1–7.0
3	4.0	3.3	0.6–11.0

[a] F ratio = 2.38.
* P = .104.

TABLE 3. Frequency Distribution of the Adhesive Residual Index (ARI) Scores and the Results of χ^2 Comparisons of the 3 Bonding/Debonding Sequences Tested on 15 Teeth

Bonding/ Debonding Sequence	ARI Scores[a]*				
	1	2	3	4	5
1	2	6	7	. . .	. . .
2	. . .	6	8	1	. . .
3	1	5	8	1	. . .

[a] The ARI scale has a range between 5 and 1, with 5 indicating that no composite remained on the enamel; 4, less than 10% of composite remained on the tooth surface; 3, more than 10% but less than 90% of the composite remained on the tooth; 2, more than 90% of the composite remained; and 1, all of the composite remained on the tooth, along with the impression of the bracket base. χ^2 = 1.49.
* P = .829.

remnant index (ARI) and scored with respect to the amount of resin material adhering to the enamel surface.[18] The ARI scale has a range between 5 and 1, with 5 indicating that no composite remained on the enamel; 4, less than 10% of composite remained on the surface; 3, more than 10% but less than 90% of the composite remained; 2, more than 90% of the composite remained; and 1, all of the composite remained on the tooth, along with the impression of the bracket base. The ARI scores were used to better define the site of bond failure among the enamel, the adhesive, and the bracket base.

Statistical analysis

Descriptive statistics, including the mean, standard deviation, and minimum and maximum values, were calculated for each of the groups tested. An analysis of variance was used to determine whether significant differences existed in the overall shear bond strength of the 3 bonding/debonding sequences. Student's *t*-tests were used to compare the changes in groups of teeth that experienced either a decrease or increase of force. The chi-square test was used to determine significant differences in the ARI scores between the different groups. For the purpose of the statistical analysis, ARI scores of 1 and 2 were combined, as were ARI scores of 4 and 5. Significance for all statistical tests was predetermined at $P \leq .05$.

RESULTS

Shear bond strength of the total sample

The descriptive statistics for the shear bond strength at the 3 bonding/debonding sequences are presented in Table 1. The results of the analysis of variance comparing the 3 experimental groups (F = 2.38) indicated the absence of significant differences between the groups (P = .104).

Changes in bond strength between debonding sequences

When the changes between debonding sequences were evaluated, the findings (Table 2) indicated that between the first and second debonding sequence, 11 teeth had a significant decrease in shear bond strength (mean ± SD, −3.5 ± 3.4 MPa; P = .008), whereas 4 teeth had an increase in shear bond strength that was not statistically significant (mean ± SD, 2.0 ± 1.3 MPa; P = .057).

Between debonding sequences 2 and 3, 8 teeth had a significant decrease (mean ± SD, −3.4 ± 2.5 MPa; P = .007), whereas 7 teeth had a significant increase (mean ± SD, 3.6 ± 1.4 MPa; P = .001) in shear bond strength.

When the overall change in shear bond strength within each tooth was evaluated between debonding sequences 1 and 3, 10 teeth had a significant decrease (mean ± SD, −4.6 ± 2.5 MPa; P = .001) in bond strength, whereas 5 teeth had a significant increase (mean ± SD, 2.8 ± 1.6 MPa; P = .02).

Adhesive residual index

The ARI scores for the 3 groups tested are presented in Table 3. The chi-square test results (χ^2 = 1.49) indicate the

TABLE 2. Descriptive Statistics and Results of the Student's *t*-test Comparisons of the Changes in Shear Bond Strength Between the 3 Bonding/Debonding Sequences

Change in Bond Strength Between Debonding Sequences		n	Mean	Percentage	SD	Range	*t*-test	*P*
1–2	Decrease	11	−3.5	−50.1	3.5	−1.1 to −5.9	−3.3	.008
1–2	Increase	4	2.0	+55.4	1.3	−0.1 to 4.2	3.0	.057
2–3	Decrease	8	−3.4	−65.1	2.5	−1.2 to −5.5	−3.7	.007
2–3	Increase	7	3.6	+124.6	1.4	2.2 to 4.9	6.6	.001
1–3	Decrease	10	−4.6	−67.3	2.5	−2.8 to −6.4	−5.8	.001
1–3	Increase	5	2.8	+59.4	1.6	−0.7 to −4.8	3.8	.02

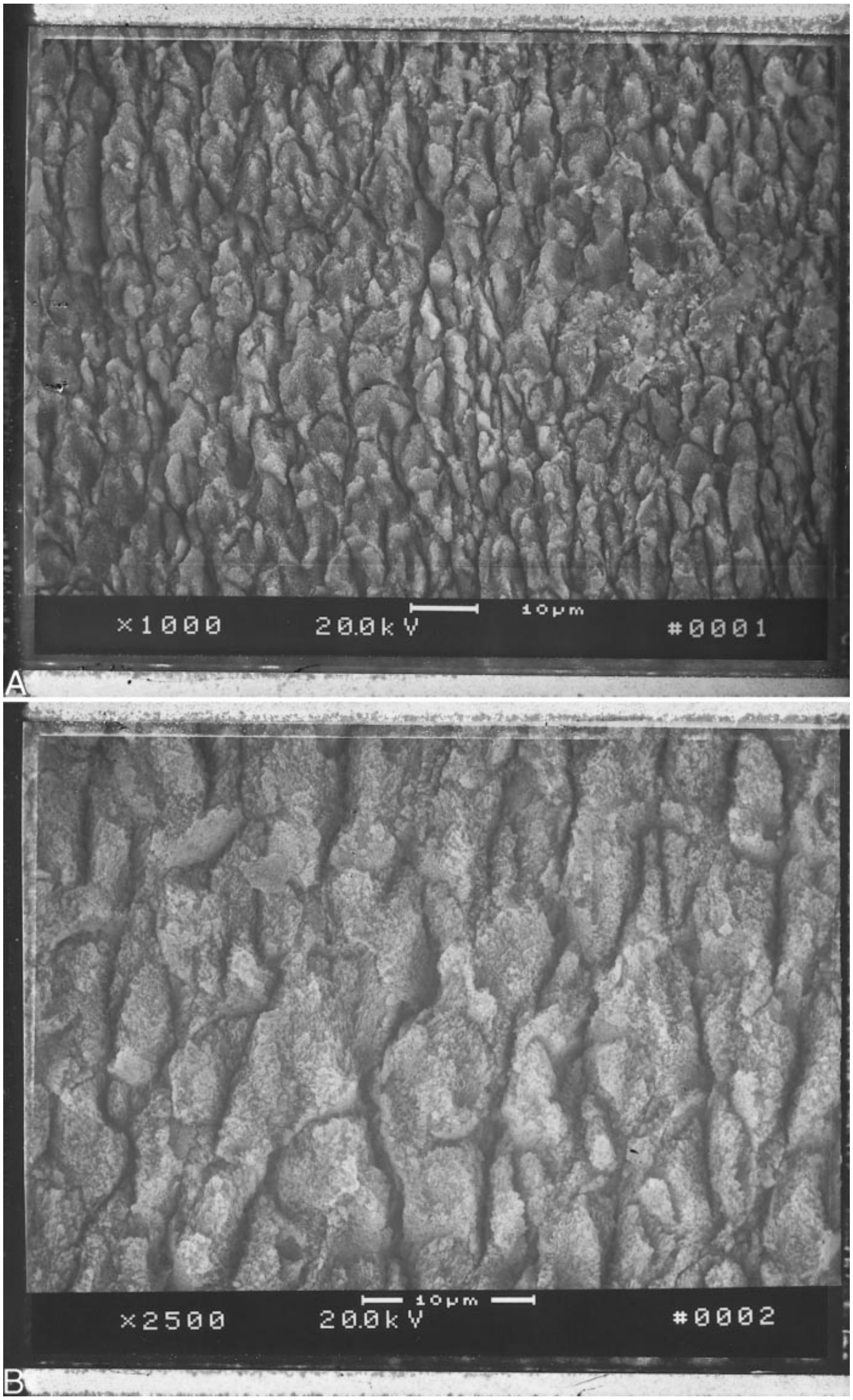

FIGURE 1. Scanning electron microscope photographs of surface enamel etched with 37% phosphoric acid at (a) 1000× and (b) 2500×. Notice the roughness of the etched enamel surface that provides significant mechanical retention during the bonding process.

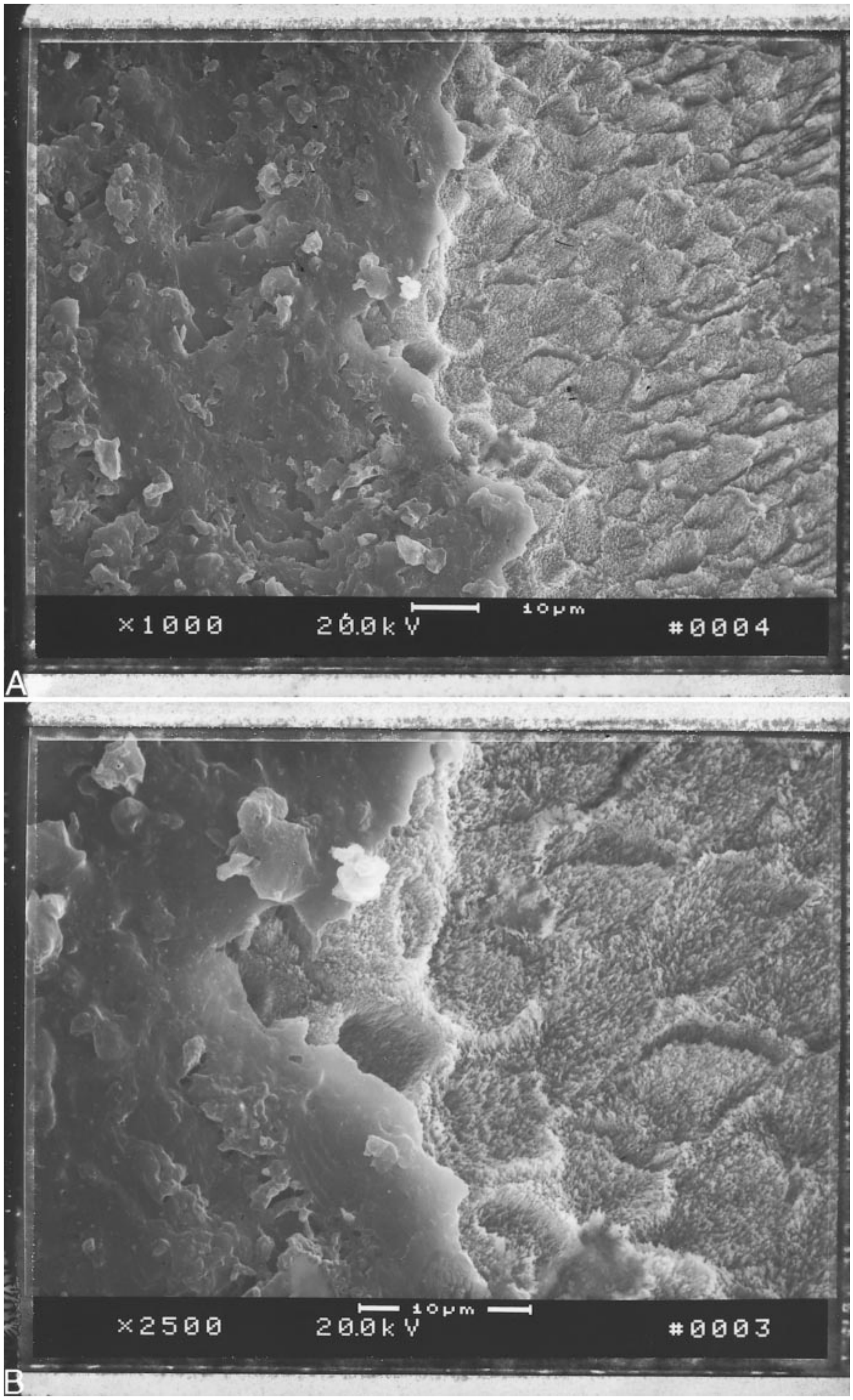

FIGURE 2. Scanning electron microscope photographs of surface enamel etched after the bracket was debonded and all visible residual adhesive was removed with a carbide finishing bur at (a) 1000× and (b) 2500×. Notice the islands of residual adhesive that still remain on the surface and diminish the overall roughness of the enamel surface.

absence of a significant difference among the 3 groups ($P = .83$). In general, the ARI scores did not shift significantly within each tooth among the various debonding sequences.

DISCUSSION

The occurrence of bond failure during orthodontic treatment is relatively frequent and undesirable. The time it takes to clean, prepare, and bond a new bracket can be disruptive in a busy practice and might also lengthen the overall patient treatment time. As a result it is important to better understand what to expect when a tooth is rebonded 1 or more times, since the literature provided contradictory findings regarding the shear bond strength of rebonded attachments.[15,16]

It needs to be emphasized that, in the present study, the change in the bond strength among the 3 debonding sequences was followed longitudinally within each tooth. This approach was instrumental in explaining some of the results. When all the teeth were compared as a group with the analysis of variance, there was no significant difference in the shear bond strength among the 3 bonding/rebonding sequences, in spite of the large differences in the mean values between the first debonding and the 2 subsequent sequences. This is attributed to the large variation in the shear bond strength between the teeth at each sequence. But when the change in the shear bond strength of each tooth was evaluated on a longitudinal basis, the findings became more interesting and meaningful.

The present findings indicated that the shear bond strength during the second debonding significantly decreased by 50.1% in most teeth (11 of 15), whereas it increased by 55.4% in a fewer number of teeth (4 of 15). Between debonding sequences 2 and 3, almost an equal number of teeth showed either an increase or a decrease in shear bond strength. Finally, the overall change between debonding sequences 1 and 3 indicated that in 10 teeth, there was a 67.3% decrease in bond strength, whereas in 5 teeth there was a 59.4% increase. How can these findings be explained?

Examination of the enamel surface with the scanning electron microscope (SEM) suggested that greater shear bond strength was attained during the first debonding sequence because the initial etched enamel surface provided for a significant amount of mechanical retention (Figure 1a,b). In the 2 subsequent bonding/debonding sequences, islands of composite were seen embedded in the enamel surface (Figure 2a,b), thus decreasing the overall roughness of the enamel and in turn decreasing bond strength to different degrees. It should be emphasized that these islands of composite seen with the SEM were not apparent clinically after the residual adhesive was carefully removed from the enamel surface with a carbide finishing bur. The presence of these islands of composite on the enamel surface as well as between the enamel prisms could also explain why the mean shear bond strength did not significantly change between the second and third bonding/debonding sequences. Furthermore, the lack of consistency in the change in bond strength between the second and third rebonding (8 decreased and 7 increased) can be the result of the presence of various amounts of this hard-to-detect residual adhesive.

From a clinical perspective the present findings suggest the following:

1. In most cases, a rebonded tooth has weaker bond strength than it had when initially bonded.
2. It is clinically difficult to determine how much residual adhesive is still on or embedded in the enamel surface before rebonding. It should be noted that after re-etching, washing, and drying, the enamel surface of the teeth to be rebonded consistently showed the characteristic chalky frosted appearance, in spite of the presence of various amounts of residual adhesive.
3. The shear bond strength for teeth that have been rebonded more than once lack a consistent pattern; ie, half showed an increase and the other half showed a decrease in bond strength. Therefore, in addition to carefully removing any residual adhesive, the clinician should consider using a stronger bonding agent or an adhesion booster with teeth that have been bonded more than once in order to produce a more consistent and adequate bond strength.[19]

CONCLUSIONS

The present findings indicated the following:

1. In general, the highest values for shear bond strength were obtained after the initial bonding.
2. Rebonded teeth have significantly lower and inconsistent shear bond strength; ie, bond strength may further decrease or increase after the second debonding.
3. The changes in bond strength may be related to the changes in the morphologic characteristics of the etched enamel surface as a result of the presence of adhesive remnants.

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