ORIGINAL ARTICLE

Shear bond strength of rebonded mechanically retentive ceramic brackets

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The purpose of this study was to evaluate the bond strength of rebonded mechanically retentive ceramic brackets. Twenty new and 100 sandblasted rebonded ceramic brackets (Clarity, 3M Unitek, Monrovia, Calif) were bonded to 120 extracted human premolars with composite resin and divided into 6 equal groups according to how the bracket bases were treated: (1) new brackets, (2) rebonded/sandblasted, (3) rebonded/sandblasted/sealant, (4) rebonded/sandblasted/hydrofluoric acid (HF), (5) rebonded/sandblasted/HF/sealant on bracket base, and (6) rebonded/sandblasted/silane. Shear bond strength of each sample was tested with a testing machine. Results showed that the new brackets group had the highest mean strength (15.66 ± 7.05 megapascals [MPa]), followed by the rebonded/sandblasted/sealant group (7.65 ± 5.62 MPa), the rebonded/sandblasted/silane group (5.94 ± 5.33 MPa), the rebonded/sandblasted group (2.97 ± 2.29 MPa), the rebonded/sandblasted/HF group (1.22 ± 1.66 MPa), and the rebonded/sandblasted/HF/sealant group (0.82 ± 1.16 MPa). Statistical analysis showed that only the rebonded/sandblasted/sealant group was comparable with the new brackets group in bond strength ($P > .05$). It was concluded that in the process of rebonding mechanically retentive ceramic brackets, (1) new brackets have the highest mean bond strength when compared with rebonded brackets, (2) the bond strength of sandblasted rebonded brackets with sealant is not significantly different from new brackets, (3) silane does not increase bond strength of rebonded brackets significantly, and (4) HF treatment on sandblasted rebonded brackets significantly decreases bond strength. (Am J Orthod Dentofacial Orthop 2002;122:282-7)

Esthetic ceramic brackets have been available for orthodontic use for over 15 years. They are becoming more popular because an increasing number of adults are seeking orthodontic treatment. The original ceramic brackets used a chemical form of retention. The bases of these ceramic brackets were coated with silane. Unfortunately, enamel fractures occurred when debonding these brackets, because the bond strength between the bracket and the bonding agent was far greater than the bond strength between the bonding agent and the tooth.[1,2] In an effort to prevent enamel fracture, a new generation of ceramic brackets that get their retention from mechanical undercuts were developed, which has significantly less bond strength than the chemical bonding (silane) ceramic brackets.[1,2] The bond strength of these mechanically retentive ceramic brackets is similar to or less than the bond strength of metal (mechanically retentive) brackets.[2,3]

Clinically, bond failure occurs on 5% to 10% of metal brackets bonded with light-cured or chemical-cured composite resins.[4,5] In addition, during orthodontic treatment, the clinician might rebond some brackets that were not well positioned to obtain optimal treatment results.[6] The clinical failure rate of mechanically retentive ceramic brackets has not been reported; however, a similar need for rebonding these brackets would be expected. To rebond a bracket, using the same nondistorted bracket instead of a new bracket seems to be the most cost-effective method, although adequate bond strength must be maintained. To rebond a metal bracket, Sonis[7] and Grabouski et al[8] found that sandblasting before rebonding debonded metal brackets leads to bond strength similar to new metal brackets. However, Chung et al[9] reported that sandblasted rebonded metal brackets showed significantly lower bond strength than new brackets, whereas sandblasted rebonded brackets with adhesion booster (All-Bond 2, Bisco, Schaumburg, Ill) yielded bond strength comparable to new brackets.

In terms of rebonding the ceramic brackets, most reported studies have focused on rebonding the chemically retentive (silane) ceramic brackets. Lew and

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Djeng[10] suggested recycling the chemically retentive ceramic brackets by heating the debonded ceramic bracket to cherry red to burn off the residual composite resin from the base and then adding silane to replace the lost chemical retention. Lew et al[11] found that the bond strength of these recycled brackets was about 30% less than new chemically retentive ceramic brackets, yet it might maintain an acceptable bond strength and lead to fewer enamel fractures on debonding. Gaffey et al[12] found that treating the debonded chemically retentive ceramic brackets (heated or nonheated) with hydrofluoric acid (HF) and silane produced unacceptable (< 2 MPa) shear bond strength when compared with new brackets (16.9 MPa) on bovine teeth. Research involving rebonding mechanically retentive ceramic brackets has been much more limited. Harris et al[3] reported that the shear bond strengths of new and rebonded mechanically retentive ceramic brackets (Transcend 2000 brackets, 3M Unitek, Monrovia, Calif) were the same. In their study, the brackets were thoroughly washed after debonding and then rebonded. It is not known whether or how the remaining adhesive on the base was removed. They also reported that treating these debonded brackets with silane before rebonding drastically reduced the shear bond strength to levels of virtual nonbonding and therefore could not be recommended for clinical use.

More recently, a new ceramic bracket that has a metal insert and uses mechanical retention (Clarity, 3M Unitek) has been developed and has become popular among orthodontists. Information regarding the bond strength of rebonded Clarity brackets is still lacking in the literature. The purpose of this study was to evaluate the bond strength of rebonded mechanically retentive ceramic brackets (Clarity) under different treatments of bracket base. The following questions were asked: What effect will sandblasting have on the bond strength of rebonded ceramic brackets? Will further treatment of these sandblasted rebonded ceramic brackets with HF or silane affect their bond strength?

MATERIAL AND METHODS

One hundred twenty extracted human premolars with intact buccal enamel surfaces were collected and stored in 4% formalin solution. Each tooth was mounted in a copper tube that was 20 mm in internal diameter and 32 mm in length with the use of yellow stone. The samples were randomly divided into 6 groups of 20 each and stored in an airtight humid environment to prevent dehydration.

Debonded brackets were made by bonding mechanically retentive ceramic brackets (Clarity, 3M Unitek) with composite resin, Transbond XT (3M Unitek), to unetched and slightly wet tooth surfaces. Excess bonding material was removed carefully, and the brackets were light-cured with an Ortholux curing light (3M Unitek) for 40 seconds. The bonded brackets were then separated from the tooth surface easily with a tweezer with light pressure. A total of 100 debonded ceramic brackets were generated. Subsequently, the base of each debonded bracket was sandblasted at 65 psi for 20 to 30 seconds with aluminum oxide of 50 μm particle size with a Danville Microetcher (Danville Engineering, San Ramon, Calif) until bonding resin was no longer visible to the naked eye. Each sandblasted bracket base was then rinsed with water for 5 seconds and dried with an air spray.

The following procedures were similar in all groups: (1) the facial surface of each tooth was cleaned with nonfluoride oil-free pumice paste placed in a prophy cup attached to a slow-speed hand piece, (2) the tooth was rinsed with water and dried with an oil-free air spray, and (3) the enamel surface was etched with 37% liquid phosphoric acid (Enamel Etch, TP Orthodontics, La Porte, Ind) for 30 seconds and rinsed with water for 5 seconds. Afterwards, the enamel surface was dried with an air syringe. Each tooth was primed with a thin layer of Moisture Insensitive Primer (3M Unitek) and light cured for 10 seconds.

The 6 groups then received the following treatment. Group 1 (control) received new brackets. Transbond XT paste was applied to the new bracket base (Clarity, 3M Unitek).

Group 2 received rebonded sandblasted brackets. Transbond XT paste was applied to the sandblasted, previously debonded bracket base. Group 3 received rebonded sandblasted brackets and sealant. A thin layer of Moisture Insensitive Primer was applied to the sandblasted, previously debonded bracket base and light cured for 10 seconds, and Transbond XT paste was then applied to the bracket base. Group 4 received rebonded sandblasted brackets and HF. The sandblasted, previously debonded bracket base was etched with 9% HF (Porc-Etch, Reliance, Itasca, Ill) for 3 minutes, the bracket base was then rinsed with water for 10 seconds and air dried, and Transbond XT paste was applied to the bracket base. Group 5 received rebonded sandblasted brackets with HF and sealant. A thin layer of Moisture Insensitive Primer was applied to the base of sandblasted, HF-treated previously debonded bracket and light cured for 10 seconds, and Transbond XT paste was applied to the bracket base. Group 6 received rebonded sandblasted brackets and silane. A thin coat of silane (Porcelain conditioner, Reliance) was applied to the base of sandblasted,

Table I. Shear bond strength of 6 test groups

Group	*N*	*Mean strength (MPa)*	*SD*	*Range*
1 New brackets	20	15.66	7.05	4.06-33.01
2 Rebonded/sandblasted	19	2.97	2.29	0.21-7.05
3 Rebonded/sandblasted/sealant on bracket base	20	7.65	5.62	0.85-21.56
4 Rebonded/sandblasted/HF	20	1.22	1.68	0.04-5.12
5 Rebonded/sandblasted/HF/sealant on bracket base	20	0.82	1.16	0-5.02
6 Rebonded/sandblasted/silane on bracket base	19	5.94	5.33	0.21-19.00

Pair-wise comparisons statistically significant ($P < .05$) for groups 1 and 2; 1 and 4; 1 and 5; 1 and 6; 3 and 4; 3 and 5; 4 and 6; and 5 and 6.

previously debonded bracket and left to air dry for 1 minute.

All brackets were placed on the buccal surface of the tooth along the axis of the crown by 1 operator (S.D.F.). Excess bonding material was removed with an explorer without disturbing bracket placement; and brackets were light cured for 40 seconds with an Ortholux curing light. The light intensity was tested with the output gauge on the curing light unit prior to each use to ensure accuracy. The bonded samples were then stored in sealed containers lined with wet paper towels. All containers were placed in an incubator with the temperature set at 37° C. After 24 hours, they were tested in shear mode with a universal testing machine (Instron Corp, Canton, Mass) with a 50-kilonewton load cell, set at a crosshead speed of 1 mm/min. The shear force required to debond each bracket was recorded in newtons and converted into megapascals as a ratio of newtons to surface area of the bracket base. The brackets and enamel surfaces were inspected under a 10× magnifying lens by 2 operators to assess the amount of adhesive remaining on the tooth surface and the site of bond failure. The enamel surfaces were scored from 0 to 3 according to the adhesive remnant index (ARI) of Årtun and Bergland.[13] Score 0 represented no adhesive left on the tooth surface. Score 1 represented less than half of the adhesive left on the tooth surface. Score 2 represented half or more adhesive left on the tooth. Score 3 represented all adhesive left on the tooth surface, with a distinct impression of the bracket base.

To evaluate the surface of the bracket base, a new ceramic bracket, a rebonded/sandblasted bracket, and a rebonded/sandblasted/HF bracket (all randomly selected) were examined under scanning electron microscopy (SEM).

The bond strength data were tested for normality with the Kolmogorov-Smirnov method. Differences between the groups were then evaluated with a 1-way analysis of variance (ANOVA). When the data were not normally distributed, a Kruskal-Wallis ANOVA was performed. Pair-wise multiple comparisons between the various groups were made by the Dunn test. The Fisher exact test was used to determine significant differences in the ARI scores between the different groups. When performing the Fisher exact test, the ARI scores of 0 and 1 were combined, as were groups 2 and 3. Significance for all statistical tests was determined at $P < .05$.

RESULTS

The mean shear bond strengths of all groups are shown in Table I. The new brackets (group 1) had the highest shear bond strength (15.66 ± 7.05 MPa), rebonded/sandblasted/sealant (group 3) had the second highest value (7.65 ± 5.62 MPa), followed by rebonded/sandblasted/silane (group 6, 5.94 ± 5.33 MPa), rebonded/sandblasted (group 2, 2.97 ± 2.29 MPa), rebonded/sandblasted/HF (group 4, 1.22 ± 1.68 MPa), and rebonded/sandblasted/HF/sealant (group 6, 0.82 ± 1.16 MPa).

Statistical analysis among the tested groups showed a significant difference ($P < .05$) only between groups 1 and 2, 1 and 4, 1 and 5, 1 and 6, 3 and 4, 3 and 5, 4 and 6, and 5 and 6 (Table I).

No enamel fracture was noted after testing on the universal testing machine. ARI score showed a similar pattern between the groups, and the Fisher exact test showed no statistically significant differences (Table II).

Figures 1 to 3 are the SEM photographs of the bracket base of a new ceramic Clarity bracket, a rebonded/sandblasted Clarity bracket, and a rebonded/sandblasted/HF Clarity bracket. Figure 1 shows that the new bracket has a well-defined 3-dimensional, mechanically retentive pattern. The rebonded/sandblasted bracket (Fig 2), and the rebonded/sandblasted/HF bracket (Fig 3) showed similar surfaces but did not appear to have as well-defined undercuts as the new bracket.

Table II. Frequency distribution of adhesive remnant index and enamel fracture of 6 groups evaluated (average of observations of 2 examiners)

	ARI scores					
Group	*N*	*0*	*1*	*2*	*3*	*Enamel fracture*
1 New brackets	20	0	4	9	7	0
2 Rebonded/sandblasted	19	0	0	7	12	0
3 Rebonded/sandblasted/sealant	20	0	0	6	14	0
4 Rebonded/sandblasted/HF	20	0	0	7.5	12.5	0
5 Rebonded/sandblasted/HF/sealant	20	0	0.5	5.5	14	0
6 Rebonded/sandblasted/silane	19	0	0	6	13	0

0, No adhesive left on tooth surface, failure between adhesive and enamel; 1, less than half of adhesive left on tooth surface; 2, half or more adhesive left on tooth; 3, all adhesive left on tooth surface, failure between adhesive and bracket base.
ARI scores of 0 and 1 were combined (<50 % adhesive left on tooth), as were scores of 2 and 3 (≥50 % adhesive left on tooth) for the Fisher exact analysis. Results showed no statistical difference between the 6 groups.

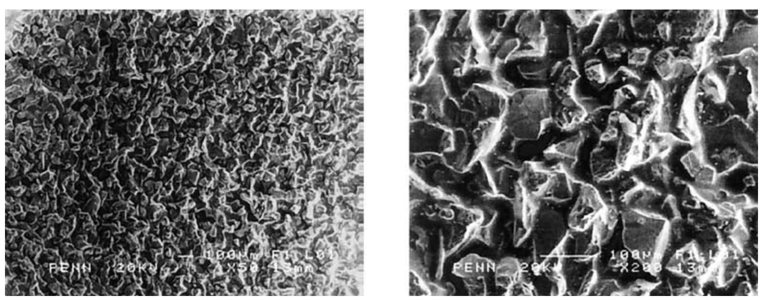

Fig 1. SEM photograph of base of new mechanically retentive ceramic bracket (Clarity). Left, ×50; right, ×200 (original magnification).

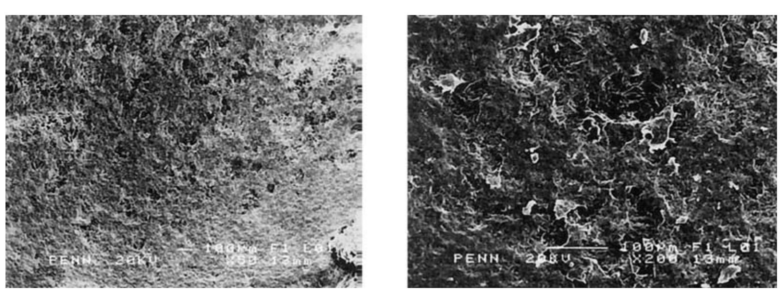

Fig 2. SEM photograph of base of rebonded and sandblasted mechanically retentive ceramic bracket (Clarity). Left, ×50; right, ×200 (original magnification).

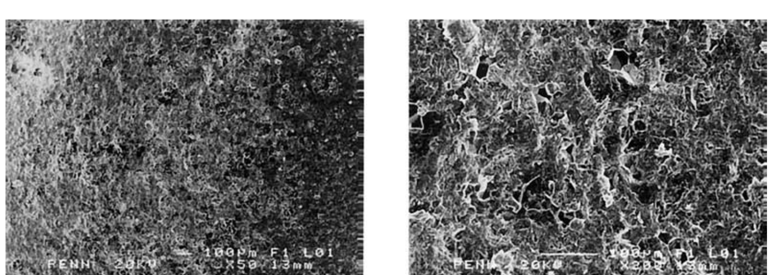

Fig 3. SEM photograph of base of rebonded, sandblasted, and HF- treated mechanically retentive ceramic bracket (Clarity). Left, ×50; right, ×200 (original magnification).

DISCUSSION

The objective of this study was to evaluate the bond strength of rebonded mechanically retentive ceramic brackets (Clarity). Our intention was to find an acceptable method of rebonding the undamaged debonded ceramic brackets in the same patient. No attempt was made to advocate recycling brackets from 1 patient to another. Our data show that the new brackets (group 1) had a higher mean bond strength (15.66 MPa) than any rebonded brackets group. Among the 5 rebonded groups (groups 2-6), group 3 (sandblasted/sealant) showed the highest mean bond strength (7.65 MPa). This group was the only rebonded group that had bond strength comparable to the new bracket group ($P >$ .05). Thus, sandblasting and placing a sealant on the bracket base is recommended when rebonding a debonded mechanically retentive ceramic bracket.

Interestingly, sandblasted rebonded brackets without sealant on the base (group 2) showed lower bond strength (2.97 MPa) than did the group with sealant on the base (7.65 MPa). Sandblasting the base of the debonded brackets not only removes the remaining adhesive, it might also roughen the ceramic surface to allow better bonding.[14] Thus, sealant applied on the sandblasted ceramic bracket base can flow and fill the microetched surface and increase the bond strength.

We tested the effect of HF on bond strength of the rebonded ceramic brackets because HF etching on ceramic surfaces has been a standard procedure when bonding a bracket to a ceramic crown.[15] However, our data showed that the mean bond strengths of both rebonded/sandblasted/HF (1.22 MPa) and rebonded/sandblasted/HF/sealant on base (0.82 MPa) groups were lower than the sandblasted groups without HF treatment, although the SEM photographs showed similar surface morphology between them. Our results did not lead us to recommend the use of HF in the process of rebonding ceramic brackets.

Silane has been known to increase bond strength of composite resin to porcelain.[16] Our data showed that the rebonded/sandblasted/silane group (group 6; 5.94 MPa) had a similar bond strength to the rebonded/sandblasted/sealant on base group (group 3, 7.65 MPa) yet was still significantly lower than new brackets group ($P < .05$). Our results are different from a previous report by Harris et al,[3] who found silanization of rebonded mechanically retentive ceramic brackets (Transcend 2000, Unitek) lowered shear bond strength to levels of virtual nonbonding. It is unknown in the literature what the clinically acceptable shear bond strength is, although a tensile bond strength of approximately 4.9 MPa has been suggested as sufficient for clinical success.[17] Further clinical study is needed to determine if rebonded/sandblasted/sealant on base or rebonded/sandblasted/silane could provide successful clinical bonding.

In our study, the ranges of shear bond strength were high in all groups. This might be a result of the anatomic variation in the buccal curvature of the teeth. The range was also affected by the inability of the operator to place the testing machine's blade precisely. Many in vitro studies have also shown a wide range in variation.[15,18,19]

Our ARI data showed a similar pattern of tooth-bracket interface failure in all 6 groups. Thus, similar adhesive removal on tooth surfaces is needed for all 6 groups when debonding. Interestingly, all the new brackets and 3 of the silane-treated brackets fractured on debonding with the testing machine. Thus, the bond strength of these brackets might have been higher than recorded because the machine could detect the ceramic fracturing before the bond failed. The fracture of these brackets could have occurred because the metal insert into the slot of the ceramic bracket caused the middle portion of the bracket to be particularly thin and thus prone to fracture. Another possible explanation is that the brackets are scored along the center of the base and therefore might encourage the base to fracture under normal clinical debonding procedures. This characteristic of the bracket base might have contributed to the bracket fracture during Instron testing. Two samples from each of groups 2 and 6 were removed because the brackets were debonded during storage and handling of the samples before testing. The failure might be related to extremely low bond strength of the brackets.

The SEM photographs (Figs 1-3) of the bracket bases help to explain the results of our study. It is apparent that the new bracket (Fig 1) has more significant micromechanical undercuts in the bracket base than the rebonded/sandblasted (Fig 2) and rebonded/sandblasted/HF (Fig 3) brackets. This might explain why the new brackets had a higher shear bond strength than the rebonded brackets.

CONCLUSIONS

With respect to the process of rebonding a mechanically retentive ceramic bracket onto a tooth surface:

- New brackets have the highest mean bond strength when compared with rebonded brackets.
- The bond strength of sandblasted rebonded brackets with sealant applied on bases is not significantly different from new brackets.
- Silane does not significantly increase the bond strength of rebonded brackets.

- Hydrofluoric acid treatment on sandblasted rebonded brackets significantly lowers bond strength.

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