ORIGINAL ARTICLE

Shear bond strength of orthodontic brackets bonded with different self-etching adhesives

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Introduction: The purpose of this study was to compare the shear bond strength (SBS) of orthodontic brackets bonded with 4 self-etching adhesives. **Methods:** A total of 175 extracted premolars were randomly divided into 5 groups (n = 35). Group I was the control, in which the enamel was etched with 37% phosphoric acid, and stainless steel brackets were bonded with Transbond XT (3M Unitek, Monrovia, Calif). In the remaining 4 groups, the enamel was conditioned with the following self-etching primers and adhesives: group II, Transbond Plus and Transbond XT (3M Unitek); group III, Clearfil Mega Bond FA and Kurasper F (Kuraray Medical, Tokyo, Japan); group IV, Primers A and B, and BeautyOrtho Bond (Shofu, Kyoto, Japan); and group V, AdheSE and Heliosit Orthodontic (Ivoclar Vivadent AG, Liechtenstein). The teeth were stored in distilled water at 37°C for 24 hours and debonded with a universal testing machine. The adhesive remnant index (ARI) including enamel fracture score was also evaluated. Additionally, the conditioned enamel surfaces were observed under a scanning electron microscope. **Results:** The SBS values of groups I (19.0 ± 6.7 MPa) and II (16.6 ± 7.3 MPa) were significantly higher than those of groups III (11.0 ± 3.9 MPa), IV (10.1 ± 3.7 MPa), and V (11.8 ± 3.5 MPa). Fluoride-releasing adhesives (Kurasper F and BeautyOrtho Bond) showed clinically acceptable SBS values. Significant differences were found in the ARI and enamel fracture scores between groups I and II. **Conclusions:** The 4 self-etching adhesives yielded SBS values higher than the bond strength (5.9 to 7.8 MPa) suggested for routine clinical treatment, indicating that orthodontic brackets can be successfully bonded with any of these self-etching adhesives. (Am J Orthod Dentofacial Orthop 2009;136:425-30)

Despite advances in orthodontic material and treatment mechanics, demineralization around orthodontic brackets remains a problem.[1] In response to the prevalent, undesirable formation of white-spot lesions, fluoride-releasing orthodontic adhesives have been formulated.[2-6] Self-etching primers (SEPs) have been also introduced. These primers combine the conditioning and priming agents into 1 acidic solution and have shown advantages such as reduced loss of enamel, prevention of saliva contamination, and less chair time.[7-9]

Bonding of orthodontic brackets to the tooth surfaces is a necessary procedure in clinical treatment; nevertheless, it is temporary, since the brackets are removed after active treatment.[10] A primary orthodontic goal is to return the enamel surface to its original state after removal of the orthodontic attachments.[11] Moreover, it has been widely reported that etching with phosphoric acid produces greater loss of enamel.[7,11-16] In contrast, a gentler etch has been obtained with SEPs, and scanning electron microscope (SEM) studies have shown that these conditioners yield shorter resin tags.[17,18] Hosein et al[12] found that the least enamel loss occurs when a SEP is used for conditioning and the enamel is cleaned up with a slow-speed tungsten carbide bur. The purpose of this study was to compare the shear bond strength (SBS) of orthodontic brackets bonded with 4 self-etching adhesives. In addition, the enamel surfaces were observed with a SEM after conditioning, and the action of the conditioners was analyzed.

MATERIAL AND METHODS

A total of 175 extracted premolars were collected and stored in a solution of 0.1% (wt/vol) thymol. The criteria for tooth selection were similar to those

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The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.

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Submitted, April 2007; revised and accepted, August 2007.

0889-5406/$36.00

doi:10.1016/j.ajodo.2007.08.024

described by Bishara et al.[3] The teeth were cleansed and pumiced by using a rubber cup with fluoride-free paste for 10 seconds, thoroughly washed with water, and air-dried.

Stainless steel premolar brackets (0.018-in, standard edgewise, Dyna-Lock, 3M Unitek, Seefeld, Germany) were used. The average surface area of the bracket base was determined to be 14.1 mm^2. This value was obtained by randomly measuring 10 bracket bases.

The teeth were randomly divided into 5 groups (35 per group). In group I, the control, the teeth were etched (37% phosphoric acid for 30 seconds), washed with water, and dried to a chalky white appearance. An adhesive primer was applied to the etched surface, and the bracket was placed on the tooth and bonded with Transbond XT (3M Unitek, Monrovia, Calif). In all groups, the brackets were light-cured (Coltolux 4, Coltène/Whaledent, Cuyahoga Falls, Ohio) for a total of 30 seconds, with the light beam directed for 10 seconds at each of the mesial, distal, and oclussal faces.

In group II, the teeth were conditioned with Transbond Plus SEP (3M Unitek), which uses a lollipop system with 2 compartments: 1 contains methacrylated phosphoric acid esters, initiators, and stabilizers; the other contains water, fluoride complex, and stabilizers. Both compartments are squeezed out to activate the product, and the contents of each compartment are mixed. The resulting mix is then applied by continuously rubbing the SEP on the enamel surface. The SEP is then lightly dried with compressed air for 1 to 2 seconds. Although the manufacturer recommends 3 to 5 seconds, in this study, the SEP was applied for 15 seconds. After that, the brackets were bonded with Transbond XT as in group I.

In group III, the teeth were conditioned with Clearfil Mega Bond FA (Kuraray Medical, Tokyo, Japan) according to the manufacturer's instructions. This 2-step SEP is generally used in operative dentistry, is the first adhesive with antibacterial properties, and is called Clearfil Protect Bond in other countries. The primer was applied on the enamel surface; 20 seconds later, the surface was dried with a mild air flow. The bond was applied, distributed evenly with a mild air flow, and light-cured for 10 seconds. The brackets were bonded with Kurasper F (Kuraray Medical), a direct bonding orthodontic adhesive that continuously releases small amounts of fluoride ions around the bracket.

In group IV, the teeth were conditioned with Primers A and B (Shofu, Kyoto, Japan) according to the manufacturer's instructions. A drop of Primer A (colorless) was mixed with a drop of Primer B (red) until the mixture was homogeneous. The SEP was applied on the enamel surface and rubbed for 3 seconds. After that, the brackets were bonded with BeautyOrtho Bond (Shofu), a light-cured orthodontic adhesive that contains surface prereacted glass ionomer filler particles, which release and recharge fluoride ions.

In group V, the teeth were conditioned with AdheSE (Ivoclar Vivadent AG, Liechtenstein) according to the manufacturer's instructions. AdheSE is a light-curing, self-etching, 2-component adhesive for enamel and dentin bonding, commonly used in restorative dentistry. An adequate amount of primer was applied onto the tooth surface; once the enamel was completely coated, the primer was brushed on the entire surface for 15 seconds (the total reaction time should not be shorter than 30 seconds) and dried with a strong stream of air until the mobile liquid film was no longer visible. The bond was applied and dispersed with a gentle stream of air, and it was light cured for 10 seconds. The brackets were bonded with Heliosit Orthodontic (Ivoclar Vivadent AG).

A 0.017 $\times$ 0.025-in stainless steel wire was ligated into each bracket slot to reduce any deformation of the bracket during debonding. The teeth were fixed in acrylic resin, and a mounting jig was used to align the facial surface of the tooth to be parallel to the force during the SBS test. Then the teeth were stored in distilled water at 37°C for 24 hours.

An occluso-gingival load was applied to produce a shear force at the bracket-tooth interface. This was accomplished with the flattened end of a steel rod attached to the crosshead of a universal testing machine (Strograph, Toyo Seiki Seisaku-sho, Tokyo, Japan). The bond strengths were measured at a crosshead speed of 0.5 mm per minute, and the load applied at the time of fracture was recorded in kilograms and converted into megapascals.

Once the brackets had been debonded, the enamel surface of each tooth was examined under 10-times magnification to determine the amount of residual adhesive on each tooth. The adhesive remnant index (ARI) scores were recorded according to the original description, with the following scale: 0, no adhesive left on the tooth; 1, less than half of the adhesive left on the tooth; 2, more than half of the adhesive left on the tooth; and 3, all adhesive left on the tooth, with a distinct impression of the bracket mesh.[19] In addition, similar to the modified ARI, enamel fractures (EFs) were also registered.[9]

Statistical analysis

Descriptive statistics including means, standard deviations, ranges, and Scheffé post-hoc multiple comparisons (1-way ANOVA) with significance predetermined at $P < 0.05$ were calculated for the SBS analysis. The chi-square test was also used to evaluate ARI scores.

The specimens were chemically fixed by a method similar to that previously described and coated with osmium for 10 seconds (HPC-1S, Vacuum Devices, Ibaragi, Japan).[5] Enamel surfaces etched with phosphoric acid and conditioned with the 4 SEPs were observed under a SEM (S-4500, Hitachi, Tokyo, Japan), and an untreated surface was used to compare the action of the conditioners.

RESULTS

The SBS values (in MPa) and descriptive statistics are shown in Table I. The SBS values in all groups were higher than the 5.9 to 7.8 MPa considered by Reynolds[20] to be adequate for routine clinical use. The mean SBS values for groups I and II were significantly higher than those for groups III, IV, and V.

The ARI scores for adhesive remaining after debonding are shown in Table II. The chi-square comparisons (75.13) of the ARI scores among all groups indicated that the groups were significantly different ($P = 0.001$). The least adhesive was in group IV, in which there were 18 scores of 0; in other words, 51.4% of the sample had no residual adhesive after debonding, and 48.5% had less than half of the adhesive left on the tooth. In contrast, group I showed the highest ARI scores: 40% of the teeth retained all adhesive, with a distinct impression of the bracket mesh; however, 48.5% retained less than half. EFs were found in groups I and II.

DISCUSSION

The use of SBS inherently presumes a uniform shear stress across the interface, whereas in actuality stress-concentration effects and local defects are major factors in failures.

Tooth-conserving and time-saving adhesive methods of retaining orthodontic attachments are replacing traditional methods and procedures[21]; however, in recent studies, the use of 37% phosphoric acid and Transbond XT is probably the most selected protocol for the control group. Our finding that the control group had the highest SBS value (19 MPa) was expected, because phosphoric acid increases bond strength.[5]

Researchers have been working hard to achieve the best quality and gentlest procedures for bonding orthodontics brackets. The use of a SEP for enamel conditioning has become popular among orthodontists because it produces a gentler etch pattern. Under the conditions of this in-vitro study, the brackets bonded with any of the 4 self-etching adhesives showed higher

Table I. Mean SBS values (MPa) and descriptive statistics

Group	*Mean*	*SD*	*Minimum*	*Maximum*	*n*	*Group differences**
I	19.0	6.7	7.6	29.2	35	A
II	16.6	7.3	7.3	28.5	35	A
III	11.0	3.9	4.8	21.9	35	B
IV	10.1	3.7	3.4	17.0	35	B
V	11.8	3.5	4.5	18.7	35	B

*Groups with different letters are significantly different from each other.

Table II. Distribution frequency and percentages of ARI scores and the incidence of enamel fracture (EF)

	ARI score (%)					
Group	*0*	*1*	*2*	*3*	*EF (%)*	*n*
I	2 (5.7)	17 (48.5)	2 (5.7)	14 (40)	5 (14.2)	35
II	6 (17.1)	9 (25.7)	9 (25.7)	11 (31.4)	5 (14.2)	35
III	13 (37.1)	18 (51.4)	1 (2.8)	3 (8.5)	0 (0.0)	35
IV	18 (51.4)	17 (48.5)	0 (0.0)	0 (0.0)	0 (0.0)	35
V	14 (40)	21 (60)	0 (0.0)	0 (0.0)	0 (0.0)	35

Chi-square = 75.13; df = 12; $P = 0.001$.

SBS values than those minimally required for orthodontic treatment, although the SBS values obtained with brackets such as Dyna-lock are reportedly lower than those for other brackets.[22] Under clinical conditions, the force at debonding is the critical factor. This is particularly important when various brackets have different bonding surface areas. The mean SBS value for group II was significantly higher than that for group III, IV, or V; this result could have been because Transbond Plus SEP was applied for 15 seconds instead of the 3 to 5 seconds recommended by the manufacturer. Transbond Plus SEP has been shown to provide higher survival rates than conventional acid etching when it is applied for a longer time[23]; however, when it was applied for only 3 seconds and debonded at 24 hours, the orthodontic brackets had higher SBS values than those whose enamel had been etched with 37% phosphoric acid.[24] Moreover, Transbond Plus SEP has suitable bond strength even with salivary contamination.[25]

In orthodontic practice, demineralization around orthodontic brackets is still a major problem.[1] Fluoride has been shown to prevent caries,[26] and orthodontic adhesives have been formulated to release fluoride ions.[5,6] The success of fluoride as a cariostatic agent can be attributed to at least 2 separate functions: a bacteriocidal effect at higher concentrations and the ability of fluoride to aid in remineralization by shifting solution thermodynamics to favor the formation of fluorohydroxyapatite, which is less soluble to an acidic challenge than

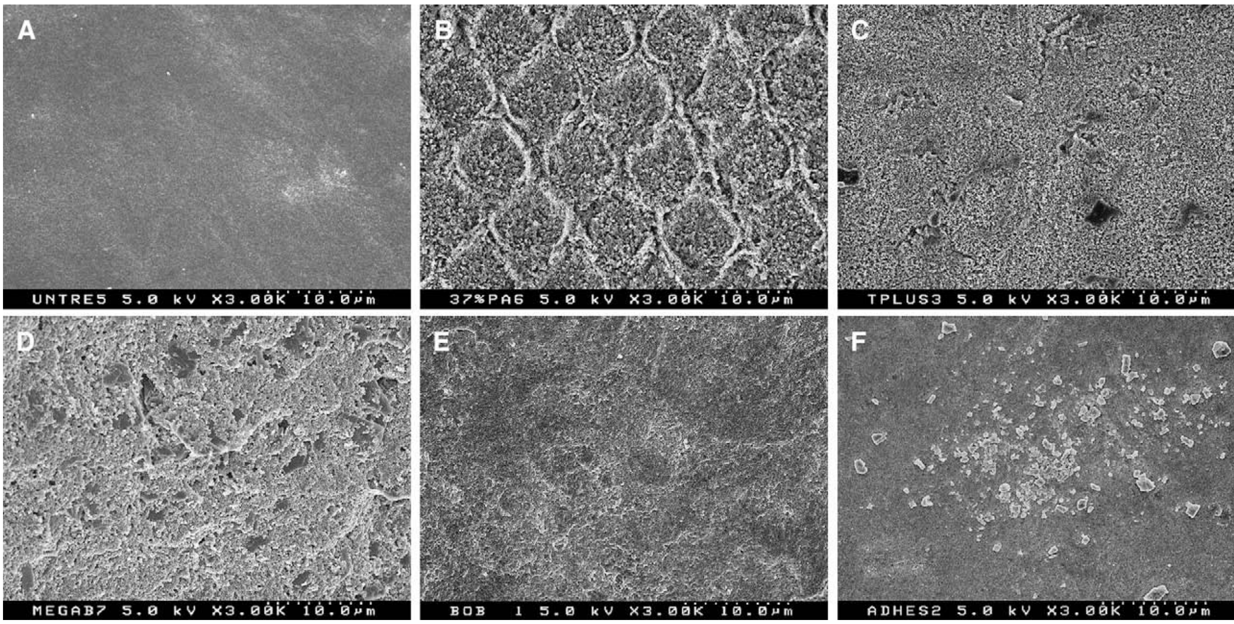

Fig. SEM images of enamel surfaces: **A,** untreated; **B,** etched with 37% phosphoric acid (group I). SEPs: **C,** Transbond Plus SEP (group II); **D,** Clearfil Mega Bond FA (group III); **E,** Primers A and B (group IV); **F,** AdheSE (group V) (original magnification, 3000 times).

hydroxyapatite.[27] Therefore, the application of fluoride near the bracket might help to prevent white spot lesions on the enamel. The fluoride-releasing adhesives (groups III and IV) showed lower but still clinically acceptable SBS values. Transbond Plus SEP also releases fluoride, and group II showed a significantly higher SBS value than did group III, IV, or V. The mean SBS value in group III was between the values reported in previous studies.[28,29] Clearfil Mega Bond FA is a 2-step fluoride-releasing and antibacterial SEP that is marketed as Clearfil Protect Bond in other countries.[28,29] Attar et al[29] concluded that its properties make it a good choice for orthodontic bonding. On the other hand, BeautyOrtho Bond, another fluoride-releasing adhesive, also showed suitable SBS. This adhesive had a slightly lower SBS value than Transbond XT (Transbond Plus SEP, used as conditioner) when the brackets were bonded to premolars.[5] In contrast, when the brackets were bonded to bovine incisors, BeautyOrtho Bond showed a slightly higher SBS than Transbond XT (Transbond Plus SEP) or Kurasper F (phosphoric acid).[30] Although the process of fluoride release is complex and the amount of fluoride released decreases dramatically after 7 or 10 days, probably some protection for the enamel can be obtained; however, more studies must evaluate the clinical benefits of the fluoride released from the adhesives. Also, a fluoride-releasing adhesive is contraindicated in patients with fluorosis; in that case, the bonding procedure might need to be enhanced with additional bonding agents. AdheSE is a 2-step SEP for enamel and dentin bonding that covers all indications of adhesive dentistry. However, to our knowledge, no studies have yet tested it for orthodontic applications. Our results indicate that AdehSE could be successfully used with Heliosit Orthodontic as an alternative to the conventional etching technique of 37% phosphoric acid.

Orthodontic practitioners are continually looking for the most conservative treatment for their patients' well-being. The minimal intervention of the bonding procedure suggests the use of a SEP for enamel conditioning, and thereby decalcification from phosphoric acid might be avoided.[29]

In this study, significant differences were found in the ARI scores. It was demonstrated that the amount of adhesive tends to be greater with a high SBS.[12,31] In accordance with those reports, groups I and II showed significantly higher SBS values than the other groups, and the amounts of residual adhesive were greater. Moreover, the use of acid conditioners complicates the removal of residual adhesive on the enamel after debonding and can also lead to surface scratches, cracking, and loss of sound enamel.[16,32,33] Conversely, less residual adhesive was found in groups IV and V, and there were no scores of 2 or 3 in these groups. This could be clinically advantageous, since, when brackets fail at the enamel-adhesive interface, less adhesive remains, and tooth cleanup is likely to be easier and faster.[34,35]

EFs have been found when the adhesion force exceeds 14 MPa,[11] and the frequency of EFs goes up with increased bond strength.[2,9,11,13] Our findings agree with those reports, since 5 EFs were observed in group I and 5 in group II. Nonetheless, in-vitro debonding increases the frequency of EFs,[2] and orthodontists can avoid this side effect with gentler clinical debonding.[5] In addition, in-vivo bond strength has been shown to be significantly lower than the in-vitro one, suggesting that the frequency of EFs might be lower under clinical conditions.[36] Transbond Plus SEP was applied for 15 seconds (group II), and, probably for that reason, EFs were observed. Perhaps if the conditioner had been applied for 3 to 5 seconds as the manufacturer recommends, this undesirable effect could have been prevented. However, Ostby et al[37] reported that increasing the SEP application from 3 to 5 seconds to 15 seconds does not result in a significant increase in SBS. Likewise, etching with phosphoric acid for 30 seconds in group I could exaggerate the frequency of EFs because the manufacturer recommendations 15 seconds for etching.

The use of SEPs is reported to produce a more conservative etch pattern than 37% phosphoric acid.[5,7,14,15,34] In agreement with those studies, the smooth and sound surface of untreated enamel changed dramatically when it was etched with phosphoric acid; and the action of any of the 4 SEPs seemed more conservative (Fig). Although all SEPs produced a gentler etch than did phosphoric acid, their action was different. Primers A and B and AdheSe showed enamel surfaces more similar to an untreated surface, but these observations warrant additional studies to find the gentlest conditioner. The enamel surfaces conditioned with Clearfil Mega Bond FA and AdheSe (both 2-step SEPs) had some kind of particles that seemed to be microfillers. Those particles were easier to identify on the surface conditioned with AdheSE, because the enamel was less affected by this conditioner. The SEM findings can be related to the values of SBS and ARI, because, when the enamel surface was more affected by the conditioner, greater bond strength and more adhesive remnants were found, as in group I. On the other hand, when the gentler etch pattern of some SEPs was observed, there were lower mean values of SBS and ARI scores (groups IV and V).

CONCLUSIONS

In this in-vitro study, we found the following.

1. The 4 self-etching adhesives had favorable mean values of SBS, and thus orthodontic brackets can be successfully bonded with any of these systems.
2. Brackets bonded after a longer application of Transbond Plus SEP showed a significantly higher bond strength than that obtained with the other 3 SEPs. However, EFs were found; clinicians should follow the manufacturer's instructions to avoid undesirable effects.
3. Enamel surfaces conditioned with Primers A and B or AdheSe seemed more similar to an untreated enamel surface. However, when these conditioners were applied, significantly lower bond strengths and significantly less residual adhesive were observed.
4. Orthodontists can use suitable and conservative enamel conditioners from many SEPs, including those with fluoride-releasing and antibacterial properties.

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