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Influence of different self-etching primers on the bond strength of orthodontic lingual buttons

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SUMMARY The aim of this study was to evaluate the influence of six self-etching primers (SEPs) on the shear/peel bond strength (SPBS) of orthodontic lingual buttons. A total of 150 extracted human premolars were randomly divided into six equal groups. In all groups, the lingual buttons were bonded with BeautyOrtho Bond™ and the enamel was conditioned with the following—group I (Control): Primers A & B™; group II: Transbond Plus SEP™; group III: Clearfil Mega Bond FA™; group IV: AdheSE™; group V: Peak SE & Peak LC Bond™; and group VI: Bond Force™. The teeth were stored at 37°C for 24 hours and the SPBS was tested (0.5 mm/minute). The results were calculated in mega pascals (MPa) and statistically analysed [mean, standard deviation, Scheffè, analysis of variance ($P < 0.05$)]. The adhesive remnant index (ARI) was also evaluated and statistically analysed with a chi-square test.

All groups demonstrated higher SPBS than the force suggested as necessary to accomplish orthodontic tooth movement, except group IV (7.7 ± 1.7 MPa), which showed a significantly lower value than groups I (10.7 ± 2.4 MPa), II (11.3 ± 3.1 MPa), and V (10.9 ± 2.8 MPa). The values of groups III (9.9 ± 1.6 MPa) and VI (10.5 ± 1.6 MPa) were comparable with those of groups I and V. Significant differences ($P < 0.05$) were found among the groups in ARI scores.

The SPBS values of all groups could be clinically acceptable and lingual buttons might be successfully bonded with any of these SEPs except AdheSE™ since that conditioner significantly influenced bond strength. As the SPBS was lower in all groups than the value at which enamel fractures have been found, a sound enamel surface might be left after removal of lingual buttons.

Introduction

Direct bonding of orthodontic brackets has been considered as one of the most significant developments in orthodontics during the past decades (D'Attilio *et al.*, 2005). The attachment of orthodontic brackets to the teeth is necessary for the treatment of malocclusions; however, the efficiency of orthodontic fixed appliances is dependent on having adequate bracket bond strength (Wong and Power, 2003). Currently, direct bonding with resin-based adhesives is the most popular method and the clinical standard for attaching orthodontic brackets to teeth (Dunn, 2007). However, despite the advances, demineralization around orthodontic brackets still remains a major problem for the patient (Polat *et al.*, 2005).

In response to the formation of white spot lesions, fluoride-releasing orthodontic adhesive systems (Scougall-Vilchis *et al.*, 2007) and self-etching primers (SEPs) have been introduced (Bishara *et al.*, 2001). Etching with self-etching compounds has proven effective despite the morphological variation of the interfacial properties of conventional and self-etched enamel. Some scanning electron microscopic (SEM) studies have shown that SEPs result in shorter resin tags than conventional phosphoric acid, which nonetheless might be adequate for orthodontic bonding, because resin tag length is not a determinant of bond strength (Eliades, 2006). Consequently, the use of SEPs has increased and their quick and simplified technique has become popular (Paschos *et al.*, 2008).

Since bonding procedures have significantly improved, direct bonding of molar tubes and lingual buttons is frequently practiced in current orthodontics. The bond strength of orthodontic brackets has been widely tested; however, there are no recent studies of the bond strength of lingual buttons. Although Lalani *et al.* (2000) reported that *in vitro* lingual bond strengths are comparable with labial bond strengths, the bond strength of lingual buttons on lingual surfaces might be relevant because they are usually bonded to lingual rather than labial surfaces and the oral condition is completely different in this area, due to the higher risk of contamination with saliva. It is particularly important that the faster application of SEPs can reduce the risk of contamination and orthodontists require scientific evidence to select a suitable SEP for bonding lingual buttons. Hence, this study was conducted to evaluate the influence of six SEPs on the shear/peel bond strength (SPBS) of orthodontic lingual buttons.

Materials and methods

Teeth

A total of 150 extracted human premolars were collected and stored in a solution of 0.2 per cent (w/v) thymol for 2 months. The teeth were previously used to test the bond strength of orthodontic brackets on labial surfaces (Scougall-Vilchis *et al.*, 2009); however, they were strictly selected with intact lingual surfaces following the criteria described by Bishara *et al.* (2005). The teeth were cleansed and pumiced using a rubber cup with fluoride-free paste for 10 seconds, after which they were thoroughly washed with water and air-dried.

Lingual buttons

Stainless steel lingual buttons (Tomy International, Tokyo, Japan) were used. The average surface area of the buttons base was 9.62 mm^2. This value was obtained by randomly measuring the base of 10 lingual buttons.

Bonding procedure

The teeth were randomly divided into six equal groups. In all groups, the lingual buttons were bonded with BeautyOrtho Bond™ (Shofu Inc., Kyoto, Japan), which is a fluoride-releasing orthodontic adhesive filled with surface pre-reacted glass ionomer particles. The lingual buttons were then light cured using a light-emitting diode light unit (BlueLEX™; Yoshida Dental, Tokyo, Japan) for a total of 20 seconds, with the entire procedure performed by the same author (RJS-V).

The enamel surfaces were conditioned as follows:

Group I (Control): The teeth were conditioned with two bottles of SEP (Primers A & B™ of BeautyOrtho Bond™, Shofu Inc.) according to the manufacturer's instructions. One drop of primer A (colourless) was mixed with one drop of primer B (red colour) until the mixture was homogeneous. The SEP was applied on the enamel surface, rubbed for 3 seconds, and lightly air-dried.

Group II: The teeth were conditioned with Transbond Plus SEP™ (3M Unitek, Monrovia, California, USA), which uses a lollipop system that has two compartments. Both compartments were squeezed to activate the product, after which the contents of each compartment were allowed to mix. The resulting mix was then applied by continuously rubbing the SEP on the enamel surface for 5 seconds. The SEP was then lightly dried using compressed air for 1–2 seconds.

Group III: The teeth were conditioned with Clearfil Mega Bond FA™ (Kuraray Medical, Tokyo, Japan) according to the manufacturer's instructions. This two-step SEP, which is generally used in operative dentistry, is considered the first adhesive with antibacterial properties and has been introduced as Clearfil Protect Bond™ in other countries. The primer was applied on the enamel surface and 20 seconds later the surface was dried with a mild airflow. The bond was distributed evenly using a mild airflow and light cured for 10 seconds.

Group IV: The teeth were conditioned with AdheSE™ (Ivoclar Vivadent AG, Schaan, Liechtenstein) according to the manufacturer's instructions. AdheSE™ is a light-curing, self-etching two-component adhesive for enamel and dentine bonding, commonly used in restorative dentistry. The primer was applied on the tooth surface; once the enamel was completely coated, the primer was brushed over the entire surface for 15 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 light cured for 10 seconds.

Group V: The teeth were conditioned with Peak SE Primer™ (Ultradent™, South Jordan, Utah, USA) according to the manufacturer's instructions. This two-component SEP is commonly used in restorative dentistry. The chemical reaction was activated with a JetMix (syringe-in-syringe) delivery system. The conditioner was then applied on the enamel surface for 20 seconds using a brush tip with moderate pressure, and gently air-dried for 3 seconds. Immediately after, a thin coat of Peak LC Bond Resin™ (Ultradent™) was softly rubbed for 10 seconds onto the etched enamel with a spiral brush tip, gently air-dried, and light cured for 10 seconds.

Group VI: The teeth were conditioned with Bond Force™ (Tokuyama, Osaka, Japan) according to the manufacturer's instructions. This recently developed one-bottle SEP is indicated for bonding light-cure composite materials to uncut enamel. The conditioner was applied and rubbed onto the enamel for 20 seconds; the surface was gently dried with a continuous light air application for 5 seconds and blown with strong air for 5 seconds. The conditioner was then light cured for 10 seconds.

Storage

The teeth were fixed in acrylic resin (Orthodontic Resin; Dentsply Caulk International Inc., Philadelphia USA), with a label bearing the number of each sample. A mounting jig was used to align the lingual surface of the tooth so that it was perpendicular to the bottom of the mould and its lingual surface was parallel to the force during bond strength testing. Afterward, the teeth were stored in distilled water at 37°C for 24 hours.

SPBS test

A 0.036 inch stainless steel wire-loop was designed similar to that used by Mojtahedzadeh *et al.* (2006). The samples were tested using a universal testing machine (EZ Graph™, Shimazdu, Kyoto, Japan) in the shear/peel mode. The procedure was similar to the methods described by Oesterle *et al.* (2002) and Nemeth *et al.* (2006). Bond strengths were then measured at a crosshead speed of 0.5 mm/minute and the force at fracture was recorded in Newton and converted into mega pascals (MPa).

Adhesive remnant index

Once the lingual buttons had been debonded, the enamel surface of each tooth was examined under ×10 magnification with a stereomicroscope (Nikon, Tokyo, Japan), to determine the amount of residual adhesive remaining on each tooth. The adhesive remnant index (ARI) scores were recorded as described by Årtun and Bergland (1984), with the following scale used: 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 button mesh.

Statistical analysis

Descriptive statistics including the mean, standard deviation, and Scheffé multiple comparisons (one-way analysis of variance) with significance predetermined at $P < 0.05$ were calculated for SPBS analysis. In addition, the chi-square test was used to evaluate the ARI.

SEM observation of enamel surfaces

The enamel surfaces conditioned with the SEPs were chemically prefixed with 2.5 per cent glutaraldehyde solution (4°C; 2 hours) and rinsed twice with cacodylate buffer (4°C; 20 minutes × 2). They were then chemically fixed with 1 per cent OsO_4 solution (4°C; 1 hour) and rinsed twice with cacodylate buffer (4°C; 20 minutes × 2). The specimens were then dehydrated in a graded series of ethanol, immersed in t-butanol (20 minutes × 2), and freeze-dried (VFD-21S™; Vacuum Device, Ibaragi, Japan). Finally, the samples were placed on aluminium stubs, coated with osmium for 10 seconds (HPC-1S™; Vacuum Device), and observed under a SEM (S-4500™; Hitachi, Tokyo, Japan).

Results

Shear/peel bond strength

The SPBS, expressed in MPa, and descriptive statistics are shown in Table 1. All groups yielded higher SPBS than the force (5.9–7.8 MPa) considered by Reynolds and von Fraunhofer (1976), as sufficient to accomplish orthodontic tooth movement, except group IV (7.7 ± 1.7 MPa), which showed a significantly lower value than groups I (10.7 ± 2.4 MPa), II (11.3 ± 3.1 MPa), and V (10.9 ± 2.8 MPa). The values for groups III (9.9 ± 1.6 MPa) and VI (10.5 ± 1.6 MPa) were comparable with those of groups I and V.

Adhesive remnant index

The scores indicating the amount of adhesive remaining after debonding are presented in Table 2. Chi-square comparison of the ARI scores among all groups ($\chi^2 = 35.42$) indicated that the groups were significantly different (P = 0.0021). The least amount of adhesive remnant was found in group IV. Comparable scores were found in groups II and VI; however, the amount of residual adhesive was slightly higher than that in groups I, III, and V.

SEM observation of enamel surfaces

Figure 1 shows the enamel surfaces viewed under a SEM after conditioning. The images of the surfaces conditioned with Primers A & B™ and Transbond Plus SEP™ (Figure 1b and 1c) show the effect produced by the conditioners directly on the enamel, while the images of the enamel surfaces conditioned with Clearfil Mega Bond FA™, AdheSE™, Peak SE & Peak LC Bond Resin™, and Bond Force™ (Figure 1d–1g) show the appearance of the enamel after the SEPs were light cured.

Discussion

Shear/peel bond strength

In view of the fact that orthodontic buttons are commonly bonded to lingual surfaces, human premolar teeth that were previously used to evaluate the bond strength of orthodontic brackets on labial surfaces (Scougall-Vilchis *et al.*, 2009) were

Table 1 Mean bond strength values (mega pascals) and descriptive statistics.

Group (SEP)	Mean ± SD	Scheffé test*
I (Primers A & B™)	10.7 ± 2.4	A
II (Transbond Plus SEP)	11.3 ± 3.1	B
III (Clearfil Mega Bond FA™)	9.9 ± 1.6	C
IV (AdheSE™)	7.7 ± 1.7	A, B, and D
V (Peak SE & Peak LC Bond™)	10.9 ± 2.8	D
VI (Bond Force™)	10.5 ± 1.6	E

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

Table 2 Distribution frequency and percentages of adhesive remnant index (ARI) scores.

Group (SEP)	ARI scores (%)				
	0	1	2	3	*n*
I (Primers A & B™)	3 (12)	20 (80)	2 (8)	0 (0)	25
II (Transbond Plus SEP)	5 (20)	12 (48)	6 (24)	2 (8)	25
III (Clearfil Mega Bond FA™)	2 (8)	23 (92)	0 (0)	0 (0)	25
IV (AdheSE™)	10 (40)	15 (60)	0 (0)	0 (0)	25
V (Peak SE & Peak LC Bond™)	10 (40)	11 (44)	2 (8)	2 (8)	25
VI (Bond Force™)	6 (24)	13 (52)	5 (20)	1 (4)	25

$\chi^2 = 35.428$; df = 15; $P = 0.0021$.

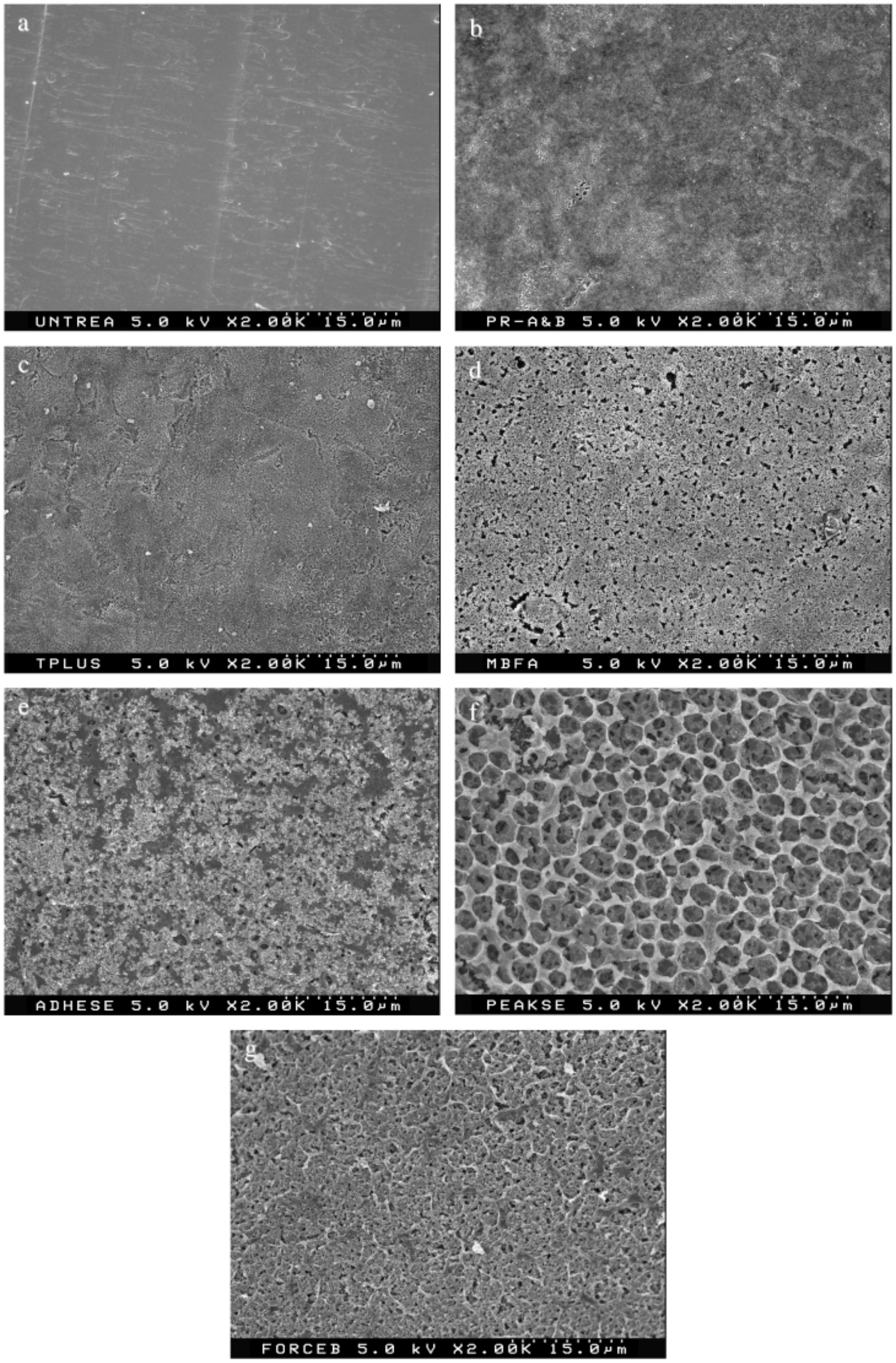

Figure 1 Scanning electron microscopic images of human enamel surfaces. (a) Unconditioned surface after pumicing with prophylactic paste and a rubber cup. Conditioned with self-etching primers (SEPs): (b) Primers A & B™ for 3 seconds (group I); (c) Transbond Plus SEP for 5 seconds (group II); (d) Clearfil Mega Bond FA™, primer applied for 20 seconds and light cured for 10 seconds (group III); (e) AdheSE™, primer applied for 30 seconds and light cured for 10 seconds (group IV); (f) peak SE Primer applied for 20 seconds and Peak LC Bond Resin™ rubbed for 10 seconds and light cured for 10 seconds (group V); (g) Bond Force™ applied for 20 seconds and light cured for 10 seconds (group VI).

used. They were preferred to test the SPBS of lingual buttons rather than freshly extracted bovine teeth (Oesterle *et al.*, 1998). This factor cannot affect the results because buttons are placed on lingual surfaces during orthodontic active treatment, when patients are wearing brackets on the labial surfaces. While Lalani *et al.* (2000) reported that *in vitro* lingual bond strengths are comparable with labial bond strengths and the parameter for labial and lingual bonding should be identical, the bond strength of buttons might be relevant because they are bonded to lingual rather than labial surfaces, and oral conditions such as higher humidity are different.

Under the conditions of this *in vitro* study, the SPBS in all groups might be considered clinically acceptable since the 'ideal' orthodontic bond strength is not merely the greatest bond strength possible; it should withstand orthodontic and masticatory forces, allow for easy bracket or lingual button removal when desired, and principally the force needed to remove the orthodontic attachment should be sufficiently low to prevent enamel fracture (Elvebak *et al.*, 2006).

Usually, BeautyOrtho Bond™ is used with two bottles of SEP (Primers A & B™); however, lingual buttons can be successfully bonded by combining this orthodontic adhesive with the other SEPs tested in this study, except AdheSE™, which had a significantly lower bond strength than groups I, II, and V. In this context, clinicians should consider that AdheSE™ is a two-step SEP and the chair-side time required is longer than that for one-step SEPs; nonetheless, it could be used as an alternative, but only when extremely light force is to be applied.

Group II (Transbond Plus SEP™) presented a slightly higher bond strength than the other groups but it should be borne in mind that this SEP and Primers A & B™ (group III) are both one-step SEPs marketed for orthodontic purposes, and they need to be applied for only 3 or 5 seconds. On the other hand, in group III the enamel was conditioned with Clearfil Mega Bond FA™, a two-step fluoride-releasing and antibacterial SEP (Korbmacher *et al.*, 2006; Attar *et al.*, 2007). This SEP has been recommended to reduce cariogenic bacteria around brackets and decrease the risk of demineralization (Attar *et al.*, 2007; Bulut *et al.*, 2007). Unfortunately, the application of fluoride-releasing conditioners or adhesives is contraindicated in patients with fluorosis or in those exposed to high concentrations of fluoride. In these cases the bonding procedure may need to be enhanced with additional bonding methods (Gange, 2006; Noble *et al.*, 2008). Peak SE & Peak LC Bond™ are two-step SEPs generally used in operative dentistry; additionally, Bond Force™ is a seventh-generation single-component SEP, fluoride-releasing bonding agent designed to be used on both cut/uncut enamel and dentine. To date, however, no previous studies have tested Peak SE & Peak LC Bond™ or Bond Force™ for orthodontic application. The results indicate that they could be successfully used with BeautyOrtho Bond™ for bonding lingual buttons as an alternative to 37 per cent H_3PO_4 or other SEPs; however, the major disadvantage is the increased time required for application to the enamel surface.

The use of phosphoric acid has the advantage of increasing the bond strength of orthodontic brackets (Scougall-Vilchis *et al.*, 2007). Nevertheless, the application of SEP is recommended rather than 37 per cent H_3PO_4 to obtain a more conservative etch pattern and similar bond strength. In addition, SEPs have shown lower sensitivity to humidity than conventional phosphoric acid (dos Santos *et al.*, 2006), and this could be clinically relevant for bonding lingual buttons in which saliva contamination is 'expected', mainly in the lower arch.

Adhesive remnant index

A strong correlation between bond strength and adhesive remnant has been found (Scougall-Vilchis *et al.*, 2007). In this context, group IV presented the lowest SPBS as well as the lowest ARI scores both with significant differences. Moreover, it has been reported that the amount of adhesive remaining tends to be less when SEPs are used (Faltermeier *et al.*, 2007; Montasser *et al.*, 2008). In this study, groups I, III, and V presented lower ARI scores with the average amount of adhesive remaining being less than 50 per cent (score 1). This could be clinically advantageous since in those cases when the brackets fail at the enamel/adhesive interface, less residual adhesive remains and clean-up is likely to be easier and faster (Al Shamsi *et al.*, 2006). Conversely, higher amounts of adhesive remnants complicate clean up of the enamel and may also lead to surface scratches, cracking, and loss of sound enamel (Vicente *et al.*, 2006).

There were no enamel fractures after debonding, which could be explained by the fact that bond strength values were lower than 14 MPa in all groups, and the risk of enamel fractures increases when the force exceeds this value (Eminkahyagil *et al.*, 2006).

SEM observation of enamel surfaces

The application of SEPs is reported to produce a more conservative etch pattern than phosphoric acid (Summers *et al.*, 2004; Cal-Neto and Miguel, 2006). In this context, the sound surface of the untreated enamel changed slightly when it was conditioned with Primers A & B™ and Transbond Plus SEP™ (Figure 1b and 1c); however, the enamel conditioned with Primers A & B™ appeared similar to the untreated enamel. The enamel surface morphology when conditioned with two-step SEPs (AdheSE™, Peak SE & Peak LC Bond™, and Clearfil Mega Bond FA™), including Bond Force™ (one-bottle SEP), showed interesting differences (Figure 1d–1g). The conditioners left some microretentions on the enamel surface that enhanced bond strength. When the microretentions were greater, such as those produced by Peak SE & Peak LC Bond™, the SPBS tended to increase. Conversely, when microretentions were shallower, the bond strength was less (AdheSE™).

Conclusions

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

1. The SPBS of orthodontic lingual buttons in all groups are clinically acceptable. However, application of AdheSE™ resulted in significantly lower bond strength.
2. The two newly tested materials for orthodontic use (Peak SE & Peak LC Bond™ and Bond Force™) have the disadvantage of the longer time required for application to the enamel.
3. Since SEPs present a gentler etch pattern, lower sensitivity to humidity, and suitable bond strengths, their application for bonding orthodontic lingual buttons is recommended.
4. Different SEPs can significantly affect the amount of residual adhesive, and the SEM images showed an interesting diversity of etch patterns.
5. In all cases, the mean SPBS values were lower than the value at which enamel fractures have been found; therefore, a sound enamel surface might be left after the removal of lingual buttons.

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