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Effect of enamel surface treatment on the bond strength of metallic brackets in rebonding process

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SUMMARY Bond failure after rebonding for newly placed brackets can be reduced by appropriate enamel surface treatment. This *in vitro* study investigated the effect of two enamel surface treatments on the bond strength of metallic brackets in the rebonding process. After debonding the brackets and removing the residual adhesive on the enamel surface of 50 upper premolar teeth, the teeth were divided into two equal groups. In the first group, the enamel surface was etched with phosphoric acid 37 per cent, and in the second group, the teeth were sandblasted prior to acid etching. After bonding of the new brackets, the shear bond strength (SBS), probability of bond failures, and adhesive remnant index (ARI) were determined and compared with the *t*-test, Weibull analysis, and chi-square test.

Mean SBS in both groups did not differ significantly ($P = 0.081$). Most bond failures occurred with ARI scores of 2 and 3, and the difference between the two groups was statistically significant ($P < 0.001$). Weibull analysis showed that for a given stress, the probability of failure differed between groups. Enamel surface preparation with sandblasting prior to acid etching did not significantly improve SBS in bracket rebonding and left more residual adhesive remnants on the enamel surface.

Introduction

Different enamel surface preparation methods have been evaluated for orthodontic bonding. Enamel pre-treatment is based on etching with phosphoric acid, as initially recommended by Buonocore (1955). The main effect of etching is to increase the contact surface and change a low-energy hydrophobic surface to a high-energy hydrophilic one (Reynold, 1975). Another method for enamel preparation is sandblasting or air abrasion, introduced in 1940 for cavity preparation (Olsen *et al.*, 1997). In this method, a high-speed stream of aluminium oxide particles ranging in diameter between 50 and 90 μm is applied under air pressure (van Waveren Hogervost *et al.*, 2000). It has been suggested that air abrasion, by roughening the enamel surface, can be used for orthodontic bonding (Zachrisson and Buyukyilmaz, 1993). A recent study that evaluated the effect of aluminium oxide particle size on the shear bond strength (SBS) of orthodontic brackets after enamel surface treatment with air abrasion and a self-etching primer concluded that enamel air abrasion with larger particle sizes can increase the bond strength (Halpern and Rouleau, 2010).

In orthodontic treatment, bond failure can occur any time but the majority of bond failures occur during bonding visits or some time before the post-bonding visit (Egan *et al.*, 1996). After bond failure and bracket rebonding, the rate of new bond failure has been reported to range from 10 to 25 per cent in different studies (Mizrahi, 1982; Kinch *et al.*, 1988). The reduction in rebond strength compared to bonding strength (Faust *et al.*, 1978; Knoll *et al.*, 1986; Kinch *et al.*, 1988; Bishara *et al.*, 2002) may be related to residual adhesive remaining on the enamel surface even after adhesive removal during surface preparation for the rebonding procedure (Bishara *et al.*, 2002). According to Bishara *et al.* (2002), the shear rebond strength may be as much as 33 per cent less than the bonding strength. Studies in the field of restorative dentistry suggested that air abrasion is an appropriate and effective method to treat old composite surfaces prior to the bonding of new composite (Lucena-Martín *et al.*, 2001; Oztas *et al.*, 2003). On rebond procedures in which the enamel surface is covered with invisible resin patches (Bishara *et al.*, 2002), air abrasion may be the most effective method of surface treatment after adhesive removal (Lucena-Martín *et al.*, 2001; Oztas *et al.*, 2003). To the best of our knowledge, however, no studies have been designed to compare the bond strength of metallic brackets used in rebonding procedures with air abrasion and acid etching to prepare the enamel surface.

The aim of this study was to compare the SBS of metallic brackets in rebonding procedures after enamel preparation with both air abrasion and acid etching versus acid etching alone.

Materials and methods

Fifty freshly extracted human premolars from patients 18–25 years old were used for this *in vitro* study. The teeth had no caries or enamel cracks and were not subjected to pre-treatment with any chemical agent. The teeth were cleaned with water flushing and were disinfected in 0.1 per cent (weight/volume) thymol solution for 24 hours. All samples were transferred to distilled water for a maximum of 6 months before shear testing, and the distilled water was changed every week.

In this study, 0.022 inch standard Dyna-Lock premolar brackets (3M Unitek, Monrovia, California, USA) with the mean surface area of 12.9 mm^2 were used. In the first step of the study, all samples were cleaned and polished using a low-speed hand piece with a rubber cap and non-fluoridated pumice for 20 seconds. Then they were etched with 37 per cent phosphoric acid gel (3M Unitek) for 30 seconds, washed for 20 seconds, and air-dried.

The bonding agent was Transbond XT adhesive (3M Unitek), which was used according to the manufacturer's instructions. A thin film of primer was first applied to the etched surface. The adhesive paste was applied to the bracket base and the bracket was positioned on the tooth and seated with firm pressure to minimize the thickness of the resin film. A probe was used to remove excess resin from around the brackets. Then, the teeth were light cured with halogen light XL300 (3M Unitek) for 20 seconds. After the bonding procedure, all teeth were stored in distilled water for 48 hours at room temperature and then the brackets were debonded with Lift-off debonding pliers (3M Unitek). Visible residual adhesive on the tooth surfaces was removed with a no. 1172 finishing carbide bur at slow speed (25 000rpm) until a glossy surface of the enamel was regained.

For the second step, samples were randomly divided into two equal groups of 25 teeth each. In one group, the teeth were etched with 37 per cent phosphoric acid and new brackets were rebonded as in the first step, with Transbond XT. In the second group, the teeth were sandblasted with micro-etcher (Micro-Etcher ERC II, Danville Engineering, San Ramon, California, USA), using 50 µm aluminium oxide particles at 60 psi for 3 seconds. The distance between the nozzle of the instrument and the enamel surface during air abrasion was 10 mm for all samples. Then, the samples were washed with water for 20 seconds and dried. All teeth were then etched and rebonded as in the previous group with new brackets.

The teeth in both groups were embedded in an acrylic mould (Ortocryle, Dentaurum, Ispringen, Germany) with a mounting jig.The mounting jig was used to align the direction of debonding force parallel to the labial surface of the teeth during shear strength measurements. Before shear testing, all teeth were stored in distilled water for 48 hours at room temperature.

For shear testing, an occluso–gingival force was applied with a mechanical testing machine (Instron Corp, Canton, Massachusetts, USA) to the upper surface of the bracket between the upper wings and bracket base. Shear rebond strength was measured at a crosshead speed of 0.5 mm/minute. The force required for bracket dislodgement was measured in Newton (N) and SBS was calculated by dividing the force value by the bracket base area (1 MPa = 1 N/mm^2).

After the shear test, the brackets and teeth were examined to determine bond failure mode by the same operator under a light stereomicroscope at ×10 magnifications. The adhesive remnant index (ARI; Artun and Bergland, 1984) was used to characterized bond failure sites on the enamel surfaces, adhesive surfaces, and the bracket bases. According to the ARI system, scores ranging from 0 to 3 are used to indicate:

0: no adhesive remaining on the tooth surface.
1: less than half the adhesive remaining.
2: more than half the adhesive remaining.
3: all the adhesive remaining.

Descriptive statistics including the mean, standard deviation, and minimum and maximum values were calculated for both test groups. Differences in mean values between the groups were analysed with the *t*-test. Weibull analysis was done to calculate the Weibull modulus, characteristic strength, and the required stress for 5 and 10 per cent probabilities of bond failure. The chi-square test was used to determine the significance of differences in ARI scores between the two groups. The significance level for all statistical tests was pre-determined at 0.05.

Results

The results of SBS measurements, including the mean, standard deviation, and minimum and maximum, are presented in Table 1. Mean shear rebond strength was higher in teeth prepared with both acid etching and air abrasion than with acid etching alone (Figure 1), but the *t*-test failed to confirm a significant difference in bond strength between the two groups ($P = 0.081 > 0.05$). The results of Weibull analysis are presented in Table 2. The

Table 1 Descriptive statistics for shear rebond strength in the study groups.

Study group	Minimum (Mpa)	Maximum (Mpa)	Standard deviation (Mpa)	Mean (MPa)	Mean (N)
Etching	8.09	20.07	3.06	13.07	158.01
Air abrasion + etching	10.72	24.22	3.92	16.00	193.44

Weibull modulus was slightly larger in teeth prepared with acid etching alone than with both air abrasion and acid etching. The plot illustrates that for a given probability of failure, more force would be required to debond the bracket in the group treated with both air abrasion and acid etching than in the group treated with acid etching alone (Figure 2).

The high correlation coefficients for linearized least square fit show that the data are well fitted to the Weibull distribution function.

The failure modes in the two groups are presented in Tables 3 and 4. Comparison of the ARI scores indicated that in both groups, most bond failures occurred with scores of 2 and 3 (Figure 3). However, the percentage of bond failures with scores of 2 and 3 in teeth treated with air abrasion and etching was higher than in teeth treated with etching alone, and this difference was statistically significant ($P < 0.001$).

Discussion

Although acid etching is the main method for enamel preparation in orthodontic bonding, a number of studies have investigated the usefulness of another method, namely air abrasion (Reisner *et al.*, 1997; Olsen *et al*., 1997; Sargison *et al.*, 1999; Canay *et al*., 2000; van Waveren Hogervost *et al.*, 2000; Clark *et al.*, 2003; Abu Alhaija and Al-Wahadni, 2004; Halpern and Rouleau, 2010). Different studies have reported that the latter method should not be used as a substitute for acid etching because of the lower bond strength after air abrasion. Most bond failures in teeth treated with air abrasion occur at the enamel–adhesive interface (Reisner *et al.*, 1997; Olsen *et al.*, 1997; van Waveren Hogervost *et al.*, 2000; Abu Alhaija and Al-Wahadni, 2004). Other studies reported that the combined use of air abrasion and acid etching can increase bond strength compared with acid etching alone (Reisner *et al.*, 1997; Canay *et al.*, 2000).

Scanning electron microscopy (SEM) studies have shown that after debonding and adhesive removal on a microscopic scale, some adhesive remains on the enamel surface in the form of discrete patches (Sheykholeslam and Brandt, 1979; Perry, 1980; Bishara *et al.*, 2002; Montasser *et al.*, 2008). According to research in restorative dentistry, one of the best methods for surface preparation when a new composite layer is to be bonded to an old composite is air abrasion and acid etching together (Lucena-Martín *et al.*, 2001; Oztas *et al.*, 2003). The phosphoric acid used in rebonding has no effect on residual resin patches and tags (Perry, 1980) but only cleans the surface (Oztas *et al.*, 2003).

In this study, surface preparation using both air abrasion and etching increased shear rebond strength compared with acid etching alone, but the difference was not statistically significant. The greater mean rebond strength in teeth treated with air abrasion and etching compared with etching alone may be related to the roughening effect of air abrasion on the adhesive patches and enamel surface. However, this effect was not statistically significant. Therefore, in rebonding processes, another factor seems to be more important than surface roughening in bond strength.

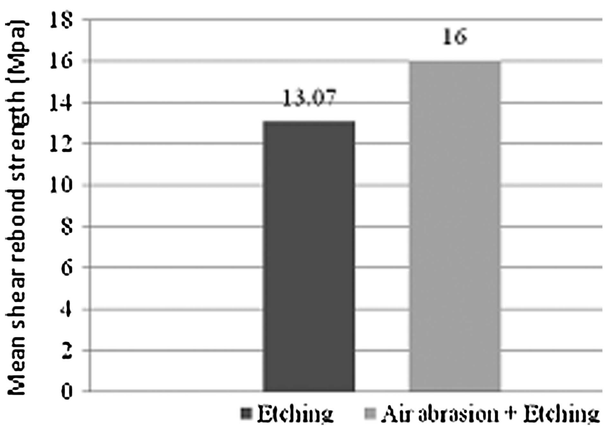

Figure 1 Mean shear rebond strength in each group.

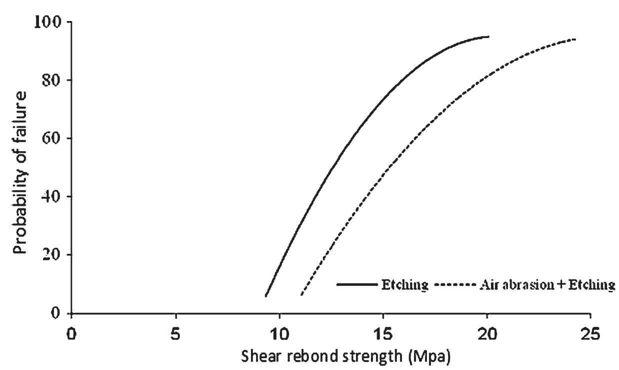

Figure 2 Probabilities of failure at different shear rebond strengths in each group.

Table 2 Parameters of the Weibull analysis in the study groups.

Study group	Weibull modulus	Correlation coefficient	Characteristic strength (Mpa)	Shear stress at 5% probability of failure (Mpa)	Shear stress at 10% probability of failure (Mpa)
Etching	4.69	0.97	13.59	8.46	9.43
Air abrasion + etching	4.47	0.96	16.86	10.81	11.08

Table 3 Distribution of adhesive remnant index (ARI) scorings in the study groups.

	ARI scores				
Study group	0	1	2	3	Sum
Etching	3	5	9	8	25
Air abrasion + etching	4	2	11	8	25

Table 4 Distribution of percentage adhesive remnant index (ARI) scorings in the study groups.

	ARI scores		
Study group	0 or 1	2 or 3	Sum
Etching (%)	32	68	100
Air abrasion + etching (%)	24	76	100

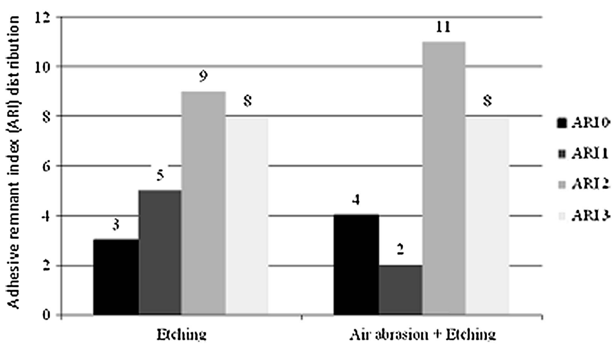

Figure 3 The distribution of adhesive remnant index (ARI) scorings in different groups.

Potential factors were evaluated by Sheykholeslam and Brandt (1979) and Perry (1980) in their SEM studies. According to the results of one rebonding study, the conditioning solution may flow underneath the resin patches and promptly dissolve the enamel prisms that support the bonding agent. This undermines the resin, creating a mushroom effect. In this effect, numerous resin extension tags are exposed after the acid dissolves their enamel support, giving rise to a mushroom-like appearance. This effect may be responsible for retention in the rebonding process because the resin can extend under the mushroom-shaped resin tags and this can increases bond strength (Sheykholeslam and Brandt, 1979). Perry (1980) concluded that when the enamel surface is re-etched in rebonding, some enamel is dissolved from around the adhesive tags, which will consequently protrude from the surface. These remnants can provide some mechanical retention for secondary bonding. Considering the minor effect of air abrasion on the increase in bond strength in rebonding procedures, the mushroom effect in both of our study groups may have played a more important role than surface roughening.

We used Weibull analysis to predict the probability of bond failure at various stress levels (McCabe and Carrick, 1986). Weibull analysis is an efficient tool to relate survival in clinical trials to data obtained from *in vitro* studies (Sargison *et al.*, 1995). This analysis indicated that debonding was probable at low shear forces in both groups and that for a given forces, this probability was higher in the group treated with acid etching alone than in the group treated with both air abrasion and etching (Figure 2). The Weibull modulus of the group treated with acid etching alone was slightly larger than in the group treated with air abrasion and acid etching. The higher Weibull modulus in the group treated with acid etching alone indicated a closer grouping of SBS values (Nkenke *et al.*, 1997).

In the present study, ARI evaluation showed that most bond failures in both groups occurred with scores of 2 and 3. In the air abrasion and etching group, the prevalence of these types of bond failure was higher than in the acid-etching group. This may have been the result of enamel roughness, which was probably greater in teeth treated with both methods. Canay *et al.* (2000) evaluated the tensile bond strength of metallic brackets with a no-mix adhesive and different methods of enamel surface preparation. They reported that when air abrasion and acid etching were used together, tensile bond strength was significantly higher than when acid etching alone was used. Reisner *et al.* (1997) reported that the bond strength of metallic brackets in their air abrasion and acid etching group was higher than in the acid etching group, although the difference was not significant. In their study, a dual cure adhesive (Reliance) was used, and the debonding force applied by the Instron machine was a combination of shear, tensile, and torsion force. Their ARI scores showed that the majority of bond failures occurred at the bracket–adhesive interfaces. In the two studies mentioned above, the bond strengths of different enamel conditioning methods were compared with two different methods. Canay *et al.* (2000) reported that the difference between two enamel conditioning methods was statistically significant. In our study, however, the differences between two enamel conditioning methods were not statistically significant. These discrepant results may be due to the fact that in our study, SBSs were compared in an experimental model of rebonding, whereas in the study by Canay *et al.* (2000), tensile bond strengths were compared in bonding processes.

Different factors can affect bond strength measurements, including the mode of the debonding force (shear, tensile, and torsion), crosshead speed, and bracket type (Fox *et al.*, 1994; Tüfekçi *et al.*, 2007). Moreover, the type of surface preparation can also influence the data. These factors differed between our study and the studies mentioned above, and the differences in the findings may be related to these factors.

Conclusions

This study showed that the use of air abrasion followed by acid etching to prepare enamel surfaces had no major benefit in terms of increasing the shear rebond strength compared with acid etching alone. Weibull analysis demonstrated that for a given applied force, the probability of failure was higher in the group treated with acid etching alone than in group treated with air abrasion and acid etching together. Moreover, the combined method of enamel pre-treatment led to more bond failures with ARI scores of 2 and 3 than acid etching alone. These findings indicate that more adhesive remained on the enamel surface in the group of teeth treated with air abrasion and etching compared with the acid-etching only group after bond failure. We recommend the future research focus on SEM studies of rebonding after surface treatment with etching and air abrasion to more accurately evaluate the enamel and residual adhesive surfaces. Also, further studies are recommended to assess these surface treatments in clinical situations with orthodontic patients.

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