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Effects of a torsion load on the shear bond strength with different bonding techniques

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SUMMARY The purpose of this study was to test the hypothesis that a torsional load applied after bracket bonding does not affect the shear bond strength (SBS) with different bonding techniques. Sixty human premolars were divided into two groups (experimental and control) to investigate the effects of a torsion load, and the two groups were further subdivided into three groups of 10 for the evaluation of different adhesive systems (one etch-and-rinse adhesive, Transbond XT; two self-etching primer adhesives, Transbond Plus and Beauty Ortho Bond). A torsion load (1.45 N/cm) was applied by beta-titanium wire at 15 minutes after bracket bonding in the experimental groups. All specimens were then thermocycled between 5 and 55°C for approximately 1 week (6000 cycles). The SBS for each sample was examined with a universal testing machine and the adhesive remnant index (ARI) score was calculated. Data were compared by two-way analysis of variance, Student's *t*-test, and a chi-square test. The SBS for Transbond XT after thermocycling with a torsion load was significantly lower than that without a torsion load. For Transbond Plus and Beauty Ortho Bond, there was no significant difference in the mean SBS between specimens thermocycled with and without a torsion load. No significant difference in the distribution of frequencies among the ARI categories was observed among the six groups, although the ARI scores for specimens with a torsion load tended to be higher than those without a torsion load. In conclusion, the SBS of the conventional etch-and-rinse adhesive system significantly decreased under a torsion load with thermocycling.

Introduction

The direct bonding of orthodontic appliances to enamel with epoxy resin was introduced by Newman (1965) and is now widely accepted by most orthodontists (Eliades and Eliades, 2001). The original method of using phosphoric acid for etching is associated with a loss of the enamel surface (approximately 10–20 m; Legler *et al.*, 1990; Hosein *et al.*, 2004). Over the past decade, progress has been made in bonding enamel with a resin-modified glass ionomer adhesive system (Cehreli *et al.*, 2005; Fjeld and Øgaard, 2006) and a self-etching primer (SEP) composite resin adhesive system (Bishara *et al.*, 2006; Fjeld and Øgaard, 2006) and their lower etching abilities might minimize the potential for iatrogenic damage to enamel. An advantage of SEP is that they combine etching and priming in a single step, i.e. SEP contains acidic functional monomers that demineralize the tooth surface, while simultaneously improving the penetration of resin–monomer into the porous enamel substrate (Yamamoto *et al.*, 2006).

Bracket-bonding failure sometimes occurs during orthodontic treatment and is not only frustrating for the practitioner but can also significantly affect treatment efficiency (Northrup *et al.*, 2007). Most previous studies measured bracket bond strength after 24 hours of storage in water and thus failed to simulate the multifactorial intraoral aging of resin composites, which is influenced by pH fluctuation, complex cyclic loading, microbial attack, and enzymatic degradation (Eliades and Bourauel, 2005). The most common aging method for simulating clinical conditions is thermocycling, which has been widely used to investigate bracket bond strength (Trites *et al.*, 2004; Faltermeier *et al.*, 2007; Yuasa *et al.*, 2010). In restorative dentistry, it has been reported that thermocycling and mechanical loading strongly influence the bond strength to dentin (Nikaido *et al.*, 2002; De Munck *et al.*, 2005). Mechanical force, such as orthodontic force produced by an archwire and occlusal force, may also affect the adhesion of resin to enamel since they cause shearing force at the resin–enamel and resin–bracket interfaces. In addition, the initial bond strength of orthodontic attachments should be very important since most orthodontists activate appliances in the mouth at 10–15 minutes after bracket bonding and the bond strength of composite resin adhesive increases with time due to continued polymerization of the resin under the bracket base (Ching *et al.*, 2000). However, limited information is available on the effects of mechanical force on bracket bond strength.

The purpose of this study was to investigate the effects of a torsion load applied by an orthodontic archwire after bracket bonding on shear bond strength (SBS) with different bracket-bonding techniques. We hypothesized that a torsional load does not affect the SBS with different bracket-bonding techniques.

Materials and methods

Materials

Sixty non-caries human premolars were used in this study. The teeth had been extracted for orthodontic reasons with the patients' informed consent. The criteria for tooth selection included the absence of any visible decalcification and cracking of the enamel surface under a stereoscopic microscope (SMZ 1500; Nikon, Tokyo, Japan) at a magnification of ×10 and the absence of any other defects e.g. hypoplasia. The extracted teeth were stored in a 0.5 per cent chloramine solution at approximately 4°C. The buccal surfaces of all teeth were cleaned using non-fluoridated pumice with a rubber cup on a low-speed handpiece for 10 seconds. The enamel surface was rinsed with water to remove any pumice or debris and dried with oil-free compressed air. The 60 teeth were randomly divided into an experimental group (with a torsion load) and a control group (without a torsion load). The two groups of 30 teeth were further subdivided into three groups of 10 for the evaluation of three different bracket adhesive systems.

Groups tested

One etch-and-rinse adhesive system (Transbond XT; 3M Unitek, Monrovia, California, USA) and two SEP adhesive systems [Transbond Plus (3M Unitek) and Beauty Ortho Bond (Shofu, Kyoto, Japan)] were used to bond brackets. In this study, two different SEPs with different pH values and etching abilities (Iijima *et al.*, 2008a) were used for comparison, and they were predicted to show different durabilities. All the adhesive systems were used according to their manufacturers' instructions.

Groups 1 and 4: Transbond XT etch-and-rinse adhesive system. The enamel surfaces were treated with 35 per cent phosphoric acid etching gel (Transbond XT Etching Gel; 3M Unitek) for 15 seconds, washed for 20 seconds, and dried with an oil-free air stream. Transbond XT primer was applied to the etched surface and standard edgewise metal brackets for premolars (Victory Series; 3M Unitek) with a base area of 10.0 mm^2; a slot dimension of 0.022 inch and a mesiodistal width of 3.2 mm were bonded with Transbond XT composite. The base point of the bracket was sited to the crown's FA point (the point on the facial axis that separates the gingival half of the clinical crown from the occlusal half).

Groups 2 and 5: Transbond Plus SEP adhesive system. Transbond Plus SEP was applied and rubbed on the enamel surfaces for 3 seconds. An air jet was lightly applied to the enamel, and the brackets were bonded with Transbond XT composite.

Groups 3 and 6: Beauty Ortho Bond SEP adhesive system. Beauty Ortho Bond primers A and B were mixed. The solution was then rubbed on the enamel surfaces for approximately 3 seconds. An air jet was briefly applied to the enamel, and the brackets were bonded with Beauty Ortho Bond Paste (composite).

Excess bonding material was removed with a small scaler. All samples were light-cured for 20 seconds (10 seconds from each proximal side). Groups 1, 2, and 3 were then thermocycled between 5 and 55°C at 45 second intervals for approximately 1 week (6000 cycles). Figure 1 shows a custom-made jig made of stainless steel for applying a torsion load at approximately 30 degrees to the bracket-bonded specimen during thermocycling. Two brackets were fixed to the jig by laser welding at 30 degrees to the basal surface. In groups 4, 5, and 6, bracket-bonded specimens were fixed to the centre of the jig using Model Repair II (Densply-Sankin, Tokyo, Japan), and the tooth axis was positioned at 90 degrees to the basal surface of the jig. The distance between the centres of the brackets was approximately 7.5 mm. Beta-titanium wires (TMA; Ormco, Glendora, California, USA) with cross-section dimensions of 0.017 × 0.025 inch were ligatured with stainless steel ligature at 15 minutes after bracket bonding. As a result, a torsion load of 1.45 N/cm, as determined by an exploratory experiment using a custom-fabricated device for a torsion test (Iijima *et al.*, 2008b), was applied to the bracket-bonded specimens and groups 4, 5, and 6 were then thermocycled between 5 and 55°C for approximately 1 week.

Debonding procedure

After thermocycling, the SBS of each group was measured. The specimens were fixed to a custom-fabricated acryl resin

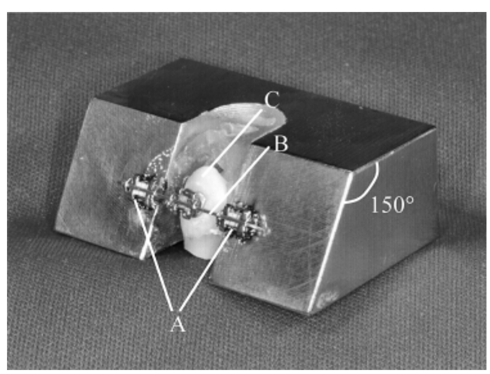

Figure 1 Custom-made jig for thermocycling with a torsion load. A, brackets fixed with laser welding; B, beta-titanium wires with cross-section dimensions of 0.017 × 0.025 inch; C, human premolar.

block using Model Repair II and the block was fixed to a universal testing machine (EZ Test; Shimadzu, Kyoto, Japan). A knife-edged shearing blade was secured to the crosshead with the direction of force parallel to the buccal surface and the bracket base. Force was applied directly to the bracket–tooth interface. The brackets were debonded at a crosshead speed of 0.5 mm/minute.

Adhesive remnant index

After bond failure, the bracket bases and enamel surfaces were examined with a stereoscopic microscope at a magnification of ×10. Adhesive remnant index (ARI) scores were used to assess the amount of adhesive left on the enamel surface (Årtun and Bergland, 1984).

Statistical analysis

Statistical analysis was performed using the Statistical Package for Social Science software (version 16.0J for Windows; SPSS, Chicago, Illinois, USA). The bond strength data were tested for normality with the Kolmogorov–Smirnov test. The mean SBS, along with the standard deviation (n = 10), for the groups of bonding materials was compared by two-way analysis of variance (ANOVA), followed by the Tukey–Kramer honestly significant difference test. The two factors for ANOVA were the adhesive materials (Transbond etch-and-rinse adhesive system, Transbond Plus SEP adhesive system, and Beauty Ortho Bond SEP adhesive system) and the torsion load (thermocycled with or without a torsion load). The effect of the torsion load for each adhesive system was also compared using Student's t-test. The chi-square test was used to evaluate the significance of differences in the ARI scores among the different groups. For the purpose of the statistical analysis, ARI scores of 1 and 2 as well as 4 and 5 were combined. For all statistical tests, significance was predetermined at $P < 0.05$.

Results

The results regarding SBS are shown in Figure 2. Two-way ANOVA showed that the adhesive systems (Transbond XT etch-and-rinse adhesive system, Transbond Plus SEP adhesive system, and Beauty Ortho Bond SEP adhesive system; P = 0.000) and the torsion load (P = 0.000) were statistically significant factors. Specimens bonded with the Beauty Ortho Bond SEP adhesive system showed a significantly lower mean SBS (6.1 MPa) than those bonded with the Transbond XT etch-and-rinse adhesive system (8.4 MPa) or the Transbond Plus SEP adhesive system (8.9 MPa). The SBS for the Transbond XT etch-and-rinse adhesive system after thermocycling with a torsion load was significantly lower than that for thermocycling without a torsion load (P = 0.001). A chi-square analysis that compared the ARI scores for the three adhesives revealed no significant difference in the distribution of frequencies among the ARI categories for the six adhesive groups (Table 1).

Table 1 Frequency distribution of adhesive remnant index (ARI) scores. SEP, self-etching primer.

	Group	Torsion load	ARI scores				
			1	2	3	4	5
Transbond XT etch-and-rinse adhesive	1	No	—	6	3	1	—
	4	Yes	—	3	6	1	—
Transbond Plus SEP adhesive	2	No	1	4	4	1	—
	5	Yes	1	2	6	1	—
Beauty Ortho Bond SEP adhesive	3	No	—	5	4	1	—
	6	Yes	—	—	9	1	—

ARI scores: 1, all of the composite, with an impression of the bracket base, remained on the tooth surface; 2, more than 90 per cent of the composite remained on the tooth surface; 3, more than 10 per cent but less than 90 per cent of the composite remained on the tooth surface; 4, less than 10 per cent of the composite remained on the tooth surface; 5, no composite remained on the tooth surface.

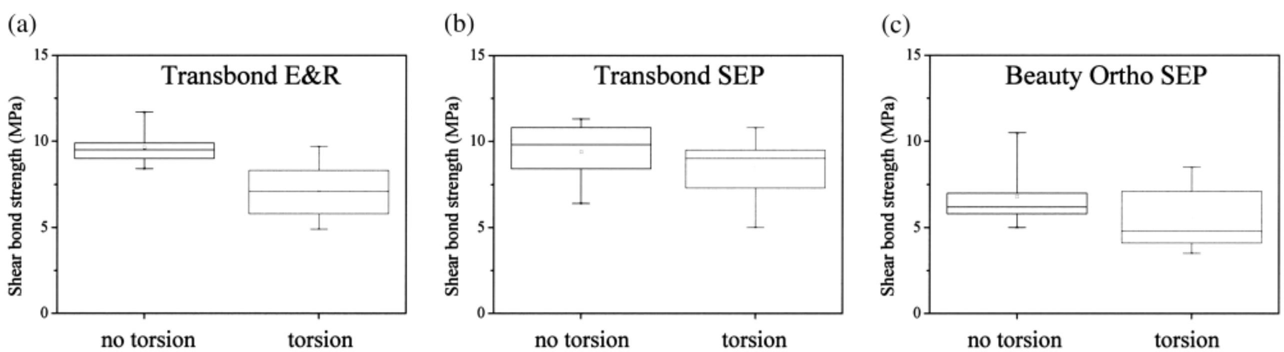

Figure 2 Shear bond strength (MegaPascal) of specimens after thermocycling without and with a torsion load for the (a) Transbond XT etch-and-rinse adhesive system, (b) Transbond Plus self-etching primer (SEP) adhesive system, and (c) Beauty Ortho Bond SEP adhesive system. Horizontal short bars represent the complete range of values. Dots within the boxes are average values.

Discussion

This study used a custom-made jig to apply a torsion at approximately 30 degrees to the bracket-bonded specimen during thermocycling, and a beta-titanium wire with cross-section dimensions of 0.017 × 0.025 inch was ligatured after bracket bonding. A previous study using a plaster model of severe crowding (mandibular incisor irregularity index score: 12.9) showed that the maximum labiolingual or buccolingual angle of malposed teeth relative to normal values was less than 28 degrees (Muguruma *et al.*, 2007). Both nickel–titanium and beta-titanium wires have improved springback (quotient of the yield strength and elastic modulus), which markedly increases their working range for tooth movement. However, nickel–titanium is extremely temperature sensitive, which could lead to unpredictable force during thermocycling. Therefore, beta-titanium wire was chosen and the torsional angle used in this study was within the elastic deformation of the beta-titanium wire. The torsion load used in this study did not simulate actual clinical conditions because the combination of stainless steel wire and a smaller torsional angle should be applied during another treatment period.

In this study, the mean bond strength obtained for the Transbond SEP adhesive system was 8.4 MPa for specimens with a torsion load and 9.4 MPa for specimens without a torsional load. These values are similar to published values (without a torsion load), which ranged from 5.9 to 10.4 MPa (Bishara *et al.*, 2006, 2007; Yamamoto *et al.*, 2006) although these studies used different experimental conditions. Most studies refer to an article by Reynolds (1975), who proposed 6–8 MPa as a clinical acceptable value of bracket bond strength. However, clinical aging was not considered in the experiment. In addition, it is difficult to compare the values in the orthodontic literature due to the multiple test configurations and the assumptions and approximations integrated into the experimental methodologies (Eliades and Bourauel, 2005).

In this study, the torsion load was applied by a beta-titanium wire after bracket bonding. A previous study (Yamamoto *et al.*, 2006) investigated the rate of development of SBS at various storage times between 5 minutes and 24 hours and concluded that bond strength increased with storage time in water and the initial stable times differed for different materials. The combination of thermocycling and a torsion load in this study significantly decreased the mean SBS for the specimen bonded with the conventional etch-and-rinse adhesive system, which indicates that the torsion load contributed to degradation of the etch-and-rinse composite resin adhesive. In contrast, for both self-etching adhesive systems, there was no significant difference in the mean SBS between specimens thermocycled with and without a torsion load, although the mean SBS values after thermocycling with a torsion load (8.4 MPa for Transbond Plus SEP and 5.5 MPa for Beauty Ortho Bond SEP) tended to be lower than those without a torsion load (9.4 MPa for Transbond Plus SEP and 6.8 MPa for Beauty Ortho Bond SEP). The mechanism of bonding between the enamel and adhesive for the conventional etch-and-rinse adhesive system (Transbond XT) largely depends on a micromechanical retention principle with enamel etching (Fjeld and Øgaard, 2006; Iijima *et al.*, 2008a). The infiltration of water into the enamel–resin interface for the specimen with the etch-and-rinse composite resin adhesive might be accelerated by a torsion load and thermocycling. On the other hand, the phosphate group of the methacrylated phosphoric acid ester (Transbond Plus) and phosphoric acid monomer (Beauty Ortho Bond) in the SEP adhesive systems modifies the enamel surface to achieve chemical bonding (Fjeld and Øgaard, 2006; Iijima *et al.*, 2008a). This difference in the mechanism of adhesion may explain the present result that the SEP adhesive systems showed a higher SBS after thermocycling with a torsion load.

A comparison of the ARI scores revealed no significant differences among the ARI categories for the six adhesive groups. However, the ARI scores for the specimens thermocycled with a torsion load (groups 4, 5, and 6) tended to be higher than those without a torsion load, which indicates that a torsion load applied by an orthodontic archwire after bracket bonding might reduce the residual adhesive on teeth. This may have been due to degradation of the interface components by hydrolysis. To explore this hypothesis, further research with a scanning electron microscope is required to investigate debonded enamel.

Conclusions

Under the conditions in this study, the following conclusions can be drawn:

1. The SBS of the conventional etch-and-rinse adhesive system was significantly decreased by a torsion load.
2. The SBS of the SEP adhesive systems was unaffected by a torsion load.

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