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Effect of applying a sustained force during bonding orthodontic brackets on the adhesive layer and on shear bond strength

Mona A. Montasser
Orthodontic Department, Faculty of Dentistry, University of Mansoura, Egypt

Correspondence to: Dr Mona A. Montasser, Orthodontic Department, Faculty of Dentistry 35516, University of Mansoura, Mansoura, Egypt. E-mail: mmontasser11@yahoo.com

SUMMARY The objective of this research was to investigate the effect of applying a sustained seating force during bonding on the adhesive layer and on shear bond strength (SBS) of orthodontic brackets. Forty human premolars divided into two groups were included in the study. Stainless steel brackets were bonded to the premolars with Transbond XT light cure adhesive and Transbond Plus Self Etch Primer (SEP). The brackets in both groups were subjected to an initial seating force of 300 g for 3 seconds, sufficient to position the bracket. The seating force was maintained throughout the 40 seconds of light curing in group 2. SBS was tested 24 hours after bracket bonding with a shear blade using an Instron testing unit at a crosshead speed of 2 mm/minute. A Student's *t*-test was used to compare the bond strength of the two groups and a chi-square test to compare the frequencies of the adhesive remnant index (ARI) scores.

The mean SBS was significantly different between the two groups ($P = 0.025$). The bond strength was higher (mean 8.15 ± 0.89 MPa) in group 2 compared with group 1 (mean 7.39 ± 1.14 MPa). There was no significant difference ($P = 0.440$) in the ARI scores between the two groups. Applying a sustained seating force during orthodontic bracket bonding improves bond strength but does not change the distribution of the ARI scores.

Introduction

As the bond strength of orthodontic brackets is a primary concern of both clinicians and researchers, laboratory testing of bond strength provides a guide to the selection of bracket–adhesive combinations and allows comparison of the bonding performance of different adhesive systems (Guzman *et al.*, 1980; Miyazaki *et al.*, 2001).

The quality of the adhesive layer has been considered as an important contributing factor to the bond strength of orthodontic brackets and thus has been extensively studied. The thickness of the adhesive layer (Evans and Powers, 1985; Arici *et al.*, 2005), the degree of monomer conversion of the adhesive layer (Shinya *et al.*, 2009), and the integrity of the marginal bracket–adhesive–enamel complex (Ulker *et al.*, 2009) are all factors that have been investigated.

Studies in operative dentistry have shown that the application of a sustained force during the bonding process affects the adhesive layer and improves the bond strength mainly because it reduces fluid interference from the underlying dentine (Chieffi *et al.*, 2006, 2007; Goracci *et al.*, 2006). It has been shown that water, mainly from the dentine, but may be also from the outside environment of the tooth, results in the presence of globules and irregular features along the adhesive–composite interface when using hydrophilic self-etch primer (SEP) systems (Mark *et al.*, 2002; Tay and Pashely, 2003; Garvalho *et al.*, 2004).

Although bonding to enamel may be different than bonding to dentine as the histological structure of the enamel is primarily inorganic in nature (Bhaskar, 1976; Bonte *et al.*, 1988), water contamination could occur during sample retrieval in laboratory studies, while clinical contamination could occur with saliva or water when washing the enamel after prophylaxis. This is one reason for the introduction of hydrophilic SEP systems into orthodontics (Bishara *et al.*, 1998; Rajagopal *et al.*, 2004) because complete isolation and dryness of the enamel during orthodontic bracket bonding are not always possible. The objective of this study was to investigate the effect of applying a sustained force during bonding of orthodontic brackets on the adhesive layer and on bond strength.

Materials and methods

Forty human premolars, extracted for orthodontic purposes and stored in an aqueous solution of thymol (0.1 per cent wt/vol), were used after research approval according to the institution guidelines. Sample size was determined with EpiCalc 2000 software version 1.02 (Brixton Books, Brixton, London, UK) for calculation of sample size and power. Using two means comparison at a power 80 per cent and a confidence interval of 95 per cent, the total sample size was 40, i.e. 20 for each group.

The teeth were randomly divided into two equal groups and then embedded in self-curing acrylic resin placed in plastic rings, 30 mm in diameter, with only the buccal surface exposed and orientated parallel to the base of the ring. Before bonding, the enamel surface of each tooth was cleaned with non-fluoride oil-free pumice paste using a nylon brush attached to a slow-speed handpiece for 5 seconds, rinsed with water for 10 seconds, and dried with an oil-free air spray.

Premolar stainless steel brackets (Mini Twin; American Orthodontics, Sheboygan, Wisconsin, USA) were bonded to the specimens with Transbond XT light cure adhesive and Transbond Plus Self Etch Primer (SEP; 3M Unitek, Monrovia, California, USA). The SEP was rubbed onto the enamel surface for 3 seconds and then smoothed with a gentle burst of air. The bracket was then bonded with Transbond XT adhesive under a 300 g compressive force (Bishara *et al.*, 2001) applied with a force gauge (Correx Co, Bern, Switzerland); the feeler arm of the gauge was used as a bracket positioner to seat the bracket and to keep it under a sustained force in group 2. The 300 g force was applied to each bracket in both groups; in group 1, it was applied for 3 seconds which was sufficient to securely seat the bracket on the tooth surface, while in group 2, the force was applied to seat the bracket and was then maintained during light curing. The brackets were light cured for 40 seconds with a bluephase light-curing unit (Ivoclar Vivadent, Schaan, Liechtenstein) at a wave length of 380–515 nm, 220 V by directing the curing light for 20 seconds approximately 5 mm above the interproximal sides of the bracket. The specimens were then stored in distilled water at 37°C for 24 hours.

Bracket debonding was performed using a blade inserted parallel to the tooth surface, producing a shear force at the bracket tooth interface. A material testing unit (Model No 5500; Instron Corp., Canton, Massachusetts, USA) at a crosshead speed of 2 mm/minute was used. The failure load in Newtons was divided by the bracket bonding surface area which, according to the manufacturer, is 10.26 mm^2 to determine the SBS in Mega Pascal (MPa).

For scanning electron microscopy (SEM), a random sample of the two groups was selected after SBS testing for examination of the adhesive layer. The examined area represented the site of separation between the orthodontic bracket and the adhesive layer remaining on the tooth surface. To prepare the specimens for SEM analysis, the roots of the teeth were removed and the crowns were sectioned mesiodistally with a diamond separating disc leaving only a thin layer of the underlying dentine. Specimens were mounted on metal stubs, sputtered with gold/palladium and then observed at ×1000 and ×4000 magnification (JXA-840; Jeol, Tokyo, Japan).

Adhesive remnant index (ARI) score evaluation was undertaken immediately after debonding under ×20 magnification. The ARI evaluation used the four-point scale of Årtun and Bergland (1984), where 0 indicates no adhesive left on the tooth surface, implying bond fracture occurred at the adhesive–enamel interface; 1 indicates less than half the adhesive left on the tooth surface, implying bond fracture occurred predominantly at the adhesive–enamel interface; 2 indicates more than half of the adhesive left on the tooth surface, implying bond fracture occurred predominantly at the bracket–adhesive interface; and 3 indicates all adhesive left on the tooth surface, with a distinct impression of the bracket base, implying bond fracture occurred at the bracket–adhesive interface.

Descriptive statistics, including the mean, standard deviation, and minimum and maximum values of SBS were calculated for each group. The data were tested for normality using the Statistical Package for Social Sciences version 10 (SPSS Inc., Chicago, Illinois, USA). As the Kolmogorov–Smirnov test showed a normal distribution of the data (P = 0.313), a Student's t-test was used to compare SBS results and chi-square test to compare the differences in ARI score distribution. The confidence level was set at 0.05.

Results

Descriptive statistics of the SBS of the two groups are presented in Table 1. The results of the Student's t-test showed a significant difference (P = 0.025) in SBS between the two groups. SBS was higher (mean 8.15 ± 0.89 MPa) in group 2 compared with group 1 (mean 7.39 ± 1.14 MPa). While there were differences in the distribution of ARI scores between the two groups, the results of the chi-square test for the frequencies of the ARI scores showed no significant difference (P = 0.440) between the groups (Table 2).

Photomicrographs of the specimens from group 1 (Figure 1A and 1B), where the seating force was not maintained during the whole polymerization period, showed structural defects. These structural defects were not seen in group 2 (Figure 2A and 2B), where the seating force was maintained during the whole polymerization period. In both groups, resin globules were observed throughout the specimens.

Discussion

This appears to be the first study to investigate the effect of applying a sustained seating force during orthodontic bracket bonding on bond strength, although this has previously been investigated in operative dentistry.

The SBS in group 2 was higher compared with that in group 1, indicating that maintaining the seating force throughout the entire polymerization period improves bond strength compared with the traditional method of bracket bonding where the force is applied only for a few seconds, sufficient to seat the bracket in the correct position. These findings are in agreement with those in operative dentistry on bonding to dentine where the application of a sustained

Table 1 Descriptive statistics of the *in vitro* shear bond strength.

	N	Mean (MPa)	SD	Minimum	Maximum
No sustained force	20	7.39	1.14	5.73	9.47
Sustained force	20	8.15	0.89	6.15	9.43

$t = -2.33$; significance = 0.025.

Table 2 Frequencies of adhesive remnant index (ARI) scores for the two groups.

	N	ARI scores			
		0	1	2	3
No sustained force	20	3	7	2	8
Sustained force	20	4	11	1	4

Chi-square = 2.70; significance = 0.440.

seating pressure during luting was found to improve the final bond strength of resin cements (Chieffi *et al.*, 2006; Goracci *et al.*, 2006). Based on SEM examination, the improvement in the bond strength in these operative studies was basically attributed to the suppression of water absorption from the hydrated dentine or water that may have contaminated the dentine during sample retrieval (Tay *et al.*, 2004a,b; Chieffi *et al.*, 2007). Chieffi *et al.* (2007) observed material discontinuity (presence of globules) and irregular features along the adhesive–composite interface that were reported to result from the incompatibility between water that contaminated the dentine and the hydrophobic component in the resin cement.

In the present study, SEM evaluation showed structural defects and resin globules throughout the composite layer in group 1 (Figure 1A and 1B) where force was applied only for a few seconds to seat the brackets. These structural defects characterized all the examined specimens in this group. These structural defects were absent in the micrographs of the specimens in group 2 (Figure 2A and 2B) where the seating force was maintained throughout polymerization. The resin globules observed throughout the specimens in group 1 were also observed in group 2 but to a lesser degree which suggests that the main effect of applying a sustained force is the prevention of structural defects and material discontinuity in the adhesive layer.

In the present study, water contamination could have occurred as the samples were retrieved and bonded in their normal hydrated state. As Transbond Plus SEP is hydrophilic, it attracts water, which affects the bond strength by compromising the bond at the interface between the primer and the hydrophobic adhesive that is Bis-phenol-A-diglycidylmethacrylate resin based.

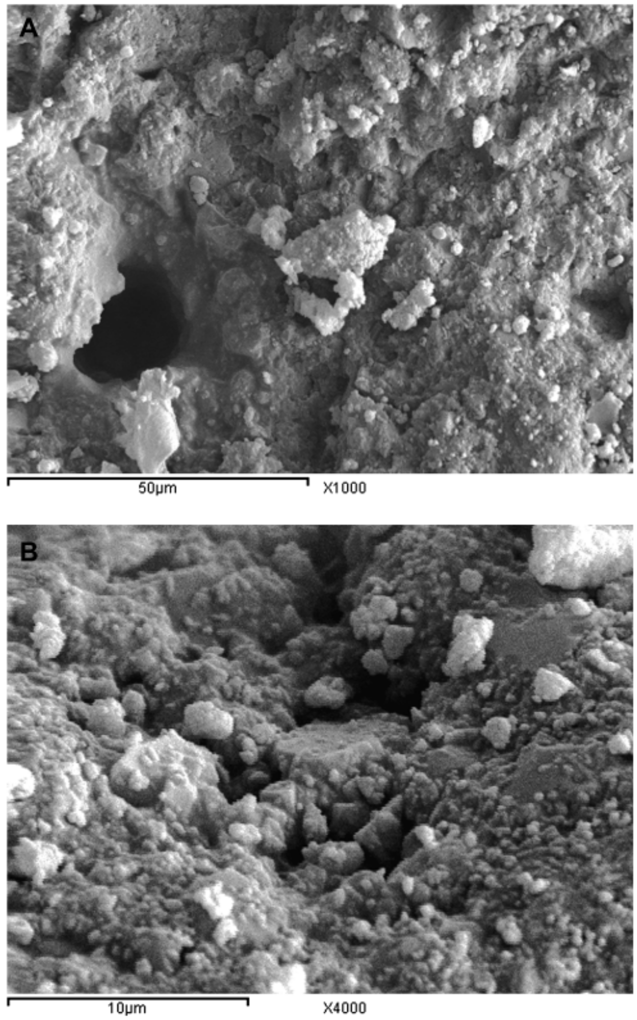

Figure 1 Scanning electron photomicrographs of the composite remaining on the enamel surface of a specimen from group 1, where the seating force was not maintained during the polymerization ×1000 (A) and ×4000 (B).

Applying a sustained force during orthodontic bracket bonding could also contribute to the improved bond strength through different effects, including preventing air voids and ensuring a compressed body of the composite layer during polymerization, complete composite penetration of the bracket base undercuts, and keeping the brackets undisturbed. Knox *et al.* (2001) found that the quality of an orthodontic attachment is primarily determined by the stress distribution generated in response to the applied load in the cement and impregnated wire mesh of the bracket–cement–tooth interface. Therefore, improving the quality of this attachment improves the bond strength.

Orthodontic composite materials bond mechanically to both enamel and orthodontic metal brackets, and as it has been reported that the bracket base–adhesive resin interface is the weakest point in orthodontic bonding (Dickinson and Powers, 1980; Surmont *et al.*, 1992), applying a sustained

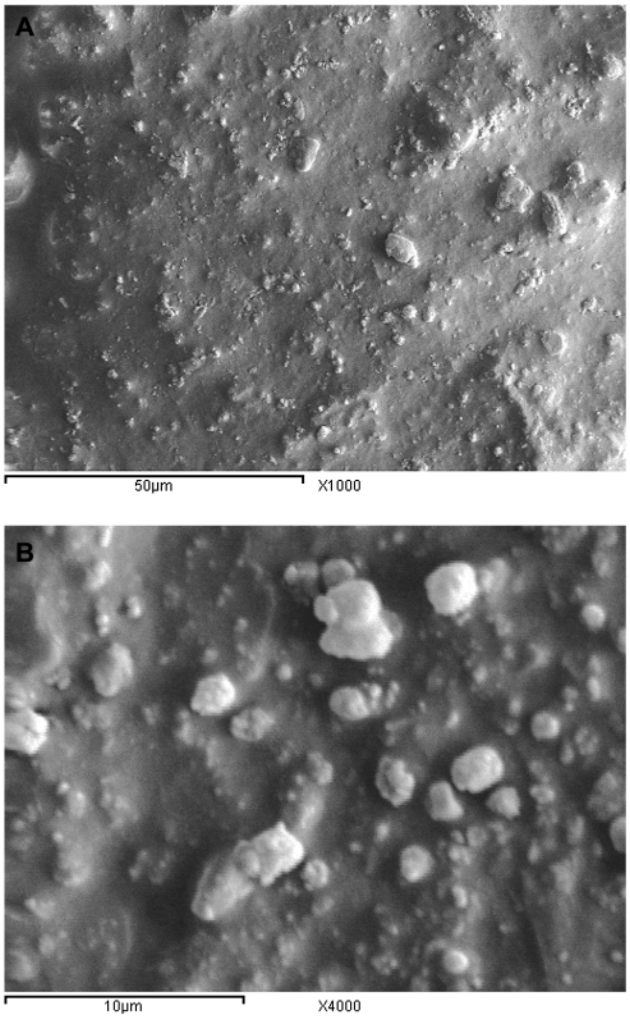

Figure 2 Scanning electron photomicrographs of the composite remaining on the enamel surface of a specimen from group 2, where the seating force was maintained during the polymerization ×1000 (A) and ×4000 (B).

seating force during bonding may contribute to an improved bond between the bracket and adhesive resin. Application of such a force during bonding squeezes the adhesive through the mesh and reduces air trapped in the mesh, a condition that improves the bond. This effect, in addition to that on the adhesive layer, may leave the weakest bond between the enamel and adhesive layer. However, the effect of applying a sustained seating force on the distribution of the ARI scores in the two groups was not statistically different. This may be due to the fact that bonding in this study was carried out under optimum conditions for bracket positioning and moisture isolation; thus, the effect on bond strength and ARI scores was not significant, but clinically, this is not always possible.

The increase in bond strength was approximately 0.76 MPa and the distribution of the ARI scores was not different between the two groups. The findings of this study are of importance when bonding in critical areas or situations where complete isolation is not possible. The present results and those in operative dentistry suggest an effect of water on the quality of the adhesive layer. This is of interest because the effect will be evident even with the use of hydrophilic SEPs. The role of moisture contamination in orthodontic bond failure has been attributed to its effect on surface energy making it more difficult to wet the surface (Anusavice, 2003), which should be overcome with the use of hydrophilic SEPs. Additionally, with hydrophilic SEP systems, clinical long-term stability of the adhesive is a matter of concern; improving the quality of the adhesive layer improves the capability of these hydrophilic adhesives to provide long-lasting bonds. Further research is needed to investigate the extent to which applying a sustained seating force could control the effect of water on the adhesive layer and on bond strength.

Conclusions

1. Applying a sustained seating force during orthodontic bracket bonding improves the quality of the adhesive layer and increases bond strength.
2. The improved bond strength when applying a sustained seating force was not reflected in statistically significant differences in ARI score distribution.

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