Effect of early orthodontic force on shear bond strength of orthodontic brackets bonded with different adhesive systems

Yasser Lotfy Abdelnaby and Essam El Saeid Al-Wakeel
Mansoura, Egypt

Introduction: This study was conducted to evaluate the effect of applying early orthodontic force on the shear bond strength (SBS) of orthodontic brackets bonded with 4 adhesive systems. Methods: Eighty stainless steel brackets were bonded to the enamel surfaces of extracted premolars with 4 adhesive systems. For each adhesive, 10 brackets were bonded without application of force (groups 1, 3, 5, and 7), and another 10 were subjected to a 120-g force with a coil spring (groups 2, 4, 6, and 8). This force was applied 30 minutes after bonding and maintained for 24 hours. Groups 1 and 2 had Rely-a-bond primer and Rely-a-bond adhesive (Reliance Orthodontic Products, Itasca, Ill). Groups 3 and 4 had Transbond XT primer and Transbond XT adhesive (3M Unitek, Monrovia, Calif). Groups 5 and 6 had Transbond Plus Self Etching Primer and Transbond XT adhesive (3M Unitek). Groups 7 and 8 had RelyX Unicem (3M ESPE, Seefeld, Germany). After thermocycling, SBS testing was performed by using a universal testing machine (Type 500, Lloyd Instruments Ltd, Fareham Hants, UK). The results of SBS testing for all adhesives were analyzed by 2-way analysis of variance and the Duncan test. The unpaired Student t test was used to compare the effect of force on the SBS of each adhesive. Results: Transbond XT primer and its adhesive had the highest values (without force, 11.2 ± 3.1 MPa; with force, 10.7 ± 2.7 MPa), and RelyX Unicem had the lowest (without force, 5.8 ± 1.5 MPa; with force, 5.7 ± 1.6 MPa). Application of force yielded nonsignificant reductions in SBS for all adhesives; this reduction was less pronounced with RelyX Unicem. Conclusions: For all studied adhesive systems, orthodontic force up to 120 g can be applied within the first hour after bonding with no deleterious effects on bond strength. (Am J Orthod Dentofacial Orthop 2010;138:208-14)

Since 1970, bonding of orthodontic brackets to tooth enamel has become an accepted clinical technique. A typical bonding procedure is based on alteration of the enamel surface by acid etching followed by application of adhesive primer and resin. The reduction of the number of steps for bonding procedures, reducing harm to the enamel surface, and minimizing bond failures during orthodontic treatment are of important clinical concerns. Self-etching primers (SEPs) were introduced to reduce clinical bonding steps and chair time because they combine the etching and priming steps. In addition, the use of acidic primers decreases the amount of residual adhesive on the enamel surface after debonding. Currently, a 1-step adhesive system has been introduced and used in restorative dentistry. It combines etchant, primer, and adhesive resin in 1 paste. It has several advantages, including a decrease in the possibility of contamination during bonding procedures and save chair time. Many factors can affect bond strength between tooth enamel and orthodontic brackets, including type, composition and mode of curing of the adhesive, etching time and concentration of the etchant, bracket material and base design, loading mode, and oral environment. In addition, polymerization shrinkage and degree of conversion of orthodontic adhesives have a pronounced effect on the durability of bonding. In general, data collected after 24 hours have been used to determine the bond strength of orthodontic adhesives. However, materials used in the oral environment should be strong enough to withstand both short- and long-term forces. Some studies evaluated the effect of different testing times on the shear bond strength (SBS) of orthodontic brackets with various adhesive systems. These studies reported that bond strength increased over a short period of time. Although bond strength of orthodontic
adhesives increased over the storage time, their initial stable times differed. In clinical orthodontic practice, bonding of the brackets and placement of archwires might be done in the same visit. Hence, force could be applied to the bracket within the first hour after bonding, and, regardless of the relatively low magnitude of this force, it could have an adverse effect on bond strength. It was reported that polymerization of the adhesive should quickly reach a minimum value to enable the adhesive to resist bonding failure when tying in the initial archwire. In 1997, Ireland and Sherriff studied the effect of the timing of archwire placement on SBS, both in vitro and in vivo using a no-mix adhesive system. They found that preloading of the brackets 2 weeks before testing had no significant effect on SBS. At the same time, no significant difference on SBS was observed in patients who had archwires fitted in the same visit as bracket placement and those who had archwire placement delayed for at least 1 week after bonding. Ching et al investigated the influence of early loading on both shear and tensile bond strengths of a no-mix orthodontic adhesive. A static load of 78 g was applied 15 minutes after bonding and maintained for 2 weeks. They reported that the applied load had no significant effect on either shear or tensile strength of the studied adhesive. The aim of our study was to evaluate the effect of applying a continuous orthodontic force for 24 hours (30 minutes after bonding) on the SBS of orthodontic brackets bonded with 4 adhesive systems.

MATERIAL AND METHODS

Eighty freshly extracted maxillary first premolars were collected, cleaned, and stored in a 0.1% aqueous thymol solution. The teeth selected had no cracks, caries, attrition, or restorations. They were embedded in autopolymerizing acrylic resin (Duracryl, SpofaDental, Prague, Czech Republic) poured in plastic rings with the buccal surface up. The teeth were cleaned and then polished with pumice and rubber cups. A hook made of 0.9-mm stainless steel round wire was fixed in the acrylic toward the apex of the teeth. Standard twin edge-wise metal orthodontic brackets (American Orthodontics, Sheboygan, Wis) were used in this study with an average base area of 0.0184 in² (11.85 mm²). The teeth were divided randomly into 8 equal groups of 10 premolars each. The brackets were bonded to the teeth by using 1 of 4 adhesive systems according to the manufacturers’ instructions. These adhesive systems are described in Table I. In groups 1 and 2, the enamel surfaces were etched with 37% phosphoric acid gel (Total Etch, Ivoclar, Vivadent, Schaan, Liechtenstein) for 30 seconds, thoroughly rinsed with oil-free air-water spray for 15 seconds, and dried with oil-free compressed air. A coat of liquid Rely-a-bond primer (Reliance Orthodontic Products, Itasca, Ill) was applied on the etched enamel surface with a brush tip. Rely-a-bond adhesive (Reliance Orthodontic Products) was applied to the base of the bracket and pressed firmly onto the tooth. Excess adhesive was removed around the base of the bracket before setting.

<table>
<thead>
<tr>
<th>Adhesive system</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Batch number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rely-a-bond primer, Rely-a-bond adhesive</td>
<td>Chemical-cured, total etch, 2-component system</td>
<td>Reliance Orthodontic Products, Itasca, Ill</td>
<td>0706277, primer 0707032, adhesive</td>
</tr>
<tr>
<td>Transbond XT primer, Transbond XT adhesive</td>
<td>Light-cured, total etch, 2-component system</td>
<td>3M Unitek, Monrovia, Calif</td>
<td>6EC, primer 6XL, adhesive</td>
</tr>
<tr>
<td>Transbond Plus SEP, Transbond XT adhesive</td>
<td>Light-cured SEP, 2-component adhesive system</td>
<td>3M Unitek, Monrovia, Calif</td>
<td>D 4775 261899, SEP 6XL, adhesive</td>
</tr>
<tr>
<td>RelyX Unicem</td>
<td>Dual-cured, self-etching, self-priming, 1-component system</td>
<td>3M ESPE, Seefeld, Germany</td>
<td>286940</td>
</tr>
</tbody>
</table>

In groups 3 and 4, the etching, rinsing, and drying procedures were similar as in groups 1 and 2. A thin coat of Transbond Plus SEP (3M Unitek) was applied on the etched enamel surface with a brush tip. Rely-a-bond adhesive (Reliance Orthodontic Products) was applied to the base of the bracket and pressed firmly onto the tooth. Excess adhesive was removed around the base of the bracket before setting. In groups 3 and 4, the etching, rinsing, and drying procedures were similar as in groups 1 and 2. A thin coat of Transbond XT primer (Reliance Orthodontic Products, Itasca, Ill) was applied on the etched enamel with a brush tip. Rely-a-bond adhesive (Reliance Orthodontic Products) was applied to the base of the bracket and pressed firmly onto the tooth. Excess adhesive was removed around the base of the bracket before setting. In groups 3 and 4, the etching, rinsing, and drying procedures were similar as in groups 1 and 2. A thin coat of Transbond XT primer (Reliance Orthodontic Products, Itasca, Ill) was applied on the etched enamel with a brush tip. Rely-a-bond adhesive (Reliance Orthodontic Products) was applied to the base of the bracket and pressed firmly onto the tooth. Excess adhesive was removed around the base of the bracket before setting. In groups 5 and 6, the unconditioned enamel was treated with Transbond Plus SEP (3M Unitek). The contents of the package were mixed together, applied, and rubbed on the enamel surface for 3 to 5 seconds. A moisture-free air source was used to deliver a gentle burst of air to the primer. The surface was lightly air dried for 5 seconds. The bracket was bonded with the same bonding resin and curing light as used for groups 3 and 4.
In groups 7 and 8, the RelyX Unicem capsule was activated in the Aplicap Activator (3M ESPE, Seefeld, Germany); then the capsule was mixed for 15 seconds in a high-frequency mixing unit. The capsule was placed in the Aplicap Applier (3M ESPE), and the cement was applied to the base of the bracket, which was pressed firmly onto the tooth surface. Excess adhesive was removed around the base of the bracket, and the adhesive was light cured for 10 seconds on each interproximal side.

For all groups, the brackets were placed in their correct positions on the enamel surface and pressed with a compressive force of 300 g for 10 seconds by using a force gauge. After bonding, the specimens were allowed to bench set for 30 minutes. In groups 2, 4, 6, and 8, a 120-g force was applied to the bonded brackets with a closed titanium coil spring (American Orthodontics). One end of the coil spring was ligated to the bracket, and the other end was stretched and ligated to the metal hook (Fig 1) until the desired force was reached according to the force gauge. After preparation, all specimens were stored in distilled water at 37°C for 24 hours.33 Before testing bond strength, all specimens were thermocycled 500 times between 2 water baths at 5°C and 55°C with a dwell time of 30 seconds in each bath.

SBS testing was carried out for all groups with a universal testing machine (Type 500, Lloyd Instruments Ltd, Fareham Hants, UK). The specimens were fixed horizontally in a specially designed steel base anchored to the fixed member of the testing machine. A knife-edged steel rod was fixed to the movable upper member of the machine. The specimens were subjected to a shear load at a crosshead speed of 2 mm per minute until failure. The load was applied under the incisal wings of each bonded bracket and parallel to the long axis of each mounted tooth. The load required to dislodge each bracket was recorded in newtons, and SBS was calculated in megapascals by dividing the load by the cross-sectional area of the bracket base.

After debonding, the teeth and brackets were examined under 10-times magnification. The amount of the adhesive on the enamel surface of the teeth was assessed by using the adhesive remnant index (ARI). The ARI has a range of 0 (no adhesive left on the enamel surface) to 3 (all adhesive left on the enamel surface). Less than 50% of the adhesive left on the enamel is scored 1; more than 50% of adhesive left on the enamel is scored 2.

### Statistical analysis

Mean SBS values and standard deviations were calculated for all groups. The data obtained for all adhesive systems with and without application of force were subjected to 2-way analysis of variance (ANOVA) and the Duncan multiple range test to compare their mean values. Unpaired Student $t$ tests were used to determine the significance of force on SBS for each adhesive system. The chi-square test was used to determine significant differences in the ARI scores between groups and for each adhesive with and without application of force. Significance for all statistical tests was predetermined at $P <0.05$.

### RESULTS

The results of the 2-way ANOVA are given in Table II. Mean SBS values, standard deviations, and the results of the Duncan and $t$ tests for the adhesive systems with and without application of force are shown in Table III. A graphic presentation of these values is shown in Figure 2.

![Fig 1. A bonded bracket with the coil spring applying force.](image)
Regarding SBS without application of force, Transbond XT primer and its adhesive system had the highest value (11.2 ± 3.1 MPa), whereas RelyX Unicem showed the lowest value (5.8 ± 1.5 MPa). Rely-a-bond primer and its adhesive system and Transbond Plus SEP and Transbond XT adhesive had intermediate values of 8.8 ± 2.0 and 7.8 ± 2.6 MPa, respectively. The results of 2-way ANOVA (Table II) indicated that, generally, there was a statistically significant difference (P < 0.0001) in SBS among the 4 adhesive systems. There was no significant effect of the applied force (P = 0.3970). There was no significant interaction between applied force and type of adhesive (P = 0.9599). The results of Duncan test (Table III) indicated a statistically significant difference between the SBS of Transbond XT primer and its adhesive system and the other adhesive systems. There was also a significant difference between Rely-a-bond primer and its adhesive system and RelyX Unicem (P < 0.05). On the other hand, there was no statistically significant difference between the SBS values of Rely-a-bond and Transbond Plus SEP systems and between RelyX Unicem and Transbond Plus SEP systems (P > 0.05).

With application of force, a slight reduction in the bond strength was shown for all adhesive systems. The results of the Duncan test indicated statistically significant differences between SBS values of Transbond XT primer and its adhesive system (10.7 ± 2.7 MPa) and the other adhesive systems, and between Rely-a-bond primer and its adhesive system (7.9 ± 2.8 MPa) and RelyX Unicem (5.7 ± 1.6 MPa). There was also a significant difference between Transbond Plus SEP and Transbond XT adhesive system (7.5 ± 1.3 MPa), and RelyX Unicem (P <0.05). There was no statistically significant difference between SBS values of Rely-a-bond primer and its adhesive system and Transbond Plus SEP and Transbond XT adhesive system (P >0.05).

When we compared the mean SBS values for each adhesive system with and without application of force, although all adhesive systems had a reduction in the SBS, the results of the unpaired Student t test showed no statistically significant differences (P >0.05). The frequency distribution of ARI scores of the 4 adhesive systems with and without application of force is shown in Table IV. In general, failure was mostly cohesive with
Rely-a-bond primer and its adhesive, and Transbond XT and its adhesive systems; it was mainly adhesive for Transbond Plus SEP and Transbond XT adhesive system, and RelyX Unicem. The results of the chi-square test indicated a statistically significant difference ($22.41; P < 0.05$) in the ARI scores between the adhesives without application of force, but there was no statistically significant difference ($15.63; P > 0.05$) between them with the application of force. For all adhesive systems, no statistically significant difference ($P > 0.05$) was obtained with and without application of force.

**DISCUSSION**

In clinical orthodontic practice, bonding of brackets and placement of the archwires can be done in the same visit, particularly after rebonding of debonded brackets. Hence, force could be applied to the bracket within the first hour after bonding. This force could affect polymerization of the orthodontic adhesive and subsequently its bond strength. The purpose of this study was to determine the development of bond strength of 4 adhesive systems subjected to a force similar to clinical situations. Four adhesive systems with different modes of activation (chemical, light, and dual) were selected from different generations. The force magnitude used for orthodontic tooth movements varies depending on the type of movement. In this study, 120 g was applied to the brackets 30 minutes after bonding and maintained for 24 hours. This force is considered the maximum optimal orthodontic force.

In this study, the SBS value obtained for Transbond XT primer and its adhesive system (11.2 MPa) was comparable with values reported by Bishara et al and Faltermeier et al of 7.1 and 8.7 MPa, respectively. On the other hand, our value was lower than that reported by Arnold et al (11.0 MPa). Regarding the SBS value of RelyX Unicem, we found a lower value (5.8 MPa) compared with other studies that reported values of 8.2 and 7.1 MPa. These variations in bond strength of the same adhesive system in different studies might be attributed to different methodologies.

Regardless the applied force, total-etch adhesive systems (Transbond XT primer and its adhesive, and Rely-a-bond primer and its adhesive) had the highest SBS values compared with the self-etch ones (Transbond Plus SEP and Transbond XT adhesive, and RelyX Unicem). This was probably because phosphoric-acid etching produces rough etched enamel surfaces. Bonding brackets to such a surface results in thick and uniform resin tags that deeply penetrate the enamel. On the other hand, shallower and fewer resin tags are obtained with SEP systems. This can be clearly seen in the analysis of the ARI scores; there was a tendency to have less residual adhesive on the enamel surface when self-etch adhesives were used. The site of failure provides information about the quality of the bond between the adhesive and the tooth, and the adhesive and the bracket base.

An important requirement of an orthodontic adhesive is its ability to debond by clear separation from the enamel surface, leaving no residue. This makes debonding and subsequent polishing much easier. It was reported that greater bond strength was associated with higher ARI scores. On the other hand, it was found that these scores depend not only on bond strength of the adhesive but also on many other factors, including bracket base design, etching procedures, and adhesive type. The results of the chi-square test for the ARI scores of the studied adhesive systems showed a significant difference without application of force ($22.41$), but there was no significant difference between them with

### Table IV. Frequency distribution and results of the chi-square analysis of the ARI scores of the adhesive systems with and without application of force

<table>
<thead>
<tr>
<th>Adhesives tested</th>
<th>Without application of force</th>
<th>With application of force</th>
<th>For each adhesive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rely-a-bond primer, Rely-a-bond adhesive</td>
<td>0  3  4  3</td>
<td>1  3  3  3</td>
<td>Chi-square 1.14; P = 0.767</td>
</tr>
<tr>
<td>Transbond XT primer, Transbond XT adhesive</td>
<td>1  2  3  4</td>
<td>2  3  2  3</td>
<td>Chi-square 0.88; P = 0.831</td>
</tr>
<tr>
<td>Transbond Plus SEP, Transbond XT adhesive</td>
<td>6  3  1  0</td>
<td>5  4  1  0</td>
<td>Chi-square 0.23; P = 0.890</td>
</tr>
<tr>
<td>RelyX Unicem</td>
<td>6  4  0  0</td>
<td>7  3  0  0</td>
<td>Chi-square 0.22; P = 0.639</td>
</tr>
</tbody>
</table>

0, No adhesive left on the enamel; 1, less than 50% of the adhesive left on the enamel; 2, more than 50% of adhesive left on the enamel; 3, all adhesive left on the enamel.
application of force (15.63). This might indicate that application of force could have some effect on polymerization and the subsequent bond strength of the adhesive. However, no significant difference in ARI scores was recorded for any adhesive with and without application of force; this might indicate that ARI scores depend on complicated factors.

Comparing the results of SBS values for each adhesive system with and without application of force showed that application of force produced a nonsignificant reduction in SBS values. These findings agree with the results of other studies. These studies concluded that preloading of the brackets before testing had no significant effect on the bond strength of a no-mix adhesive. In our study, the reduction in SBS was more pronounced with the chemically cured adhesive system and less noticeable with the dual-cured one. This could be attributed to the difference in each adhesive’s degree of conversion, which is better in the dual-cured system. It was found that, when standard orthodontic bonding procedures were followed, the degree of conversion of light-cured and chemically cured adhesives does not differ significantly. However, a high degree of conversion is important to ensure adequate polymerization to sustain the orthodontic forces that might be immediately applied to the tooth at placement and initial ligation of the archwires. It is critical that all components at the adhesive interface undergo maximum polymerization to ensure adequate bond strength. In addition, more effective early curing of the adhesive could produce less stress at the adhesive-enamel interface during the application of early orthodontic force. This can be noticed with the dual-cured adhesive system when curing starts immediately upon exposure to light, whereas the chemical portion of the adhesive will eventually reach high levels even in parts where the curing light cannot reach. In clinical situations, polymerization is seldom complete, and the degree of conversion of monomer to polymer ranges from 50% to 70%. It was reported that the strength of a cured adhesive depends on its composition, the degree of conversion, and the length of the polymer chain. Any unreacted resin monomer remaining in the adhesive might alter its mechanical properties. Evaluating the mechanical properties of an adhesive resin is therefore important in predicting its bonding ability to enamel. Polymers can influence the durability of bonding the bracket to the tooth structure. It might create contraction stresses in the adhesive material that can disrupt the marginal seal between the adhesive and the tooth structure. It was found that, although polymerization shrinkage depends on time, most shrinkage occurs in the first 10 minutes from the start of the reaction, and little change occurs after 1 hour. This could explain why applying the force after 30 minutes had an insignificant effect on SBS.

As discussed earlier, although RelyX Unicem had the least reduction in SBS among the studied adhesive systems by applying early force, it showed the lowest mean SBS values. This is probably because RelyX Unicem is a dual-cured, self-etching, and self-priming adhesive cement that contains bifunctional acrylate and inorganic filler of about 72% of its weight, with a grain size of 9.5 μm. This makes it highly viscous and difficult to penetrate into the etched enamel. In addition, self-etching adhesives produce shallower and ill-defined etch patterns compared with conventional etchants. However, it was found that the adhesive strength of a resin bonded to an etched enamel surface mainly depends on the resin’s ability to penetrate between the enamel crystallites and not necessarily to the depth of enamel etched.

CONCLUSIONS

Regardless of the application of force, the Transbond XT primer and Transbond adhesive system yielded a significantly higher bond strength compared with the other studied systems. RelyX Unicem had the lowest value. Application of orthodontic force 30 minutes after bonding for 24 hours gave a nonsignificant reduction in SBS for all studied adhesive systems. However, the effect of such a force was less noticeable with RelyX Unicem. Therefore, orthodontic forces up to 120 g can be applied within the first hour after bonding without causing bond failure. Further investigation is needed to evaluate the effect of applying a greater force for a longer time on the SBS of other adhesive systems.

REFERENCES


