Shear bond strength of orthodontic brackets bonded to deciduous teeth with different etching times

**ABSTRACT**

**Aim** This was to compare shear bond strength (SBS) of brackets bonded to deciduous teeth with that of permanent teeth, to evaluate the effect of increasing etching time on the SBS of brackets bonded to deciduous teeth and to evaluate the modes of bond failure after debonding. Study design: ex vivo study.

**Materials and Methods** A total of 120 freshly extracted human maxillary teeth were divided into six groups of 20 teeth each as follows: Group 1, permanent canines with 15-second etching time; Group 2, first premolars with 15-second etching time; Group 3, deciduous canines with 15-second etching time; Group 4, deciduous first molars with 15-second etching time; Group 5, deciduous canines with 30-second etching time; Group 6, deciduous first molars with 30-second etching time. After bonding, all specimens were thermocycled from 5 °C to 55 °C and back to 5 °C 500 times. The modified ARI was used to determine the mode of bond failure. Statistics: Comparison between groups was performed using Univariate General Linear Model (UGLM) and chi-squared tests.

**Results** SBS for permanent and deciduous teeth etched for 15 seconds averaged 106.60 ± 34.69 N and 96.90 ± 28.51 N, respectively. SBS for deciduous teeth etched for 15 seconds (91.90 ± 32.90 N and 101.80 ± 23.12 N for canines and molars respectively) and 30 seconds (110.40 ± 30.11 N and 94.20 ± 25.74 N for canines and molars, respectively). No significant differences were recorded between the different groups. Bond failure at the enamel-adhesive interface occurred more frequently in the deciduous teeth groups, while failure at bracket-adhesive interface occurred more frequently in the permanent teeth group.

**Conclusion** SBS of brackets bonded to deciduous teeth was comparable to that of permanent teeth.

**Keywords** Etching; Orthodontics; Shear.

**Introduction**

Orthodontic problems including Class III malocclusion, anterior cross bites, maxillary incisor crowding and impacted maxillary incisors may require intervention in the early mixed dentition [Tal and Kupietzky, 2000; McKeown and Sandler, 2001; Endo et al., 2004; Lucchese and Manuelli, 2003; Lucchese et al., 2005; Sollazzo et al., 2011; Palmieri et al., 2011]. Correcting these problems at an earlier stage may require bonding of brackets to the deciduous teeth (canines and molars). Regarding the orthodontic fixed appliances, a previous study was carried out to improve some characteristics [Lucchese et al., 2011; Lucchese et al., 2011].

The enamel surface structure of deciduous teeth is different from that of permanent teeth [Lucchese and Storti, 2011]. Areas of prismless enamel have been reported to occur more frequently in deciduous than in permanent teeth [Ripa et al., 1966; Gwinnett, 1966]. Prismless zones may negatively influence the retention of resins [Gwinnett, 1973]. In order to remove such layers, prolonged etching as well as mechanical removal of surface enamel prior to etching has been recommended [Meola and Papaccio, 1986].

Currently, the bonding protocol applied to deciduous teeth in orthodontic clinics is the same applied to permanent teeth regardless of the structural differences between them. The aims of this study were the following.

- To compare SBS of brackets bonded to deciduous teeth with that of permanent teeth.
- To evaluate the effect of increasing etching time on SBS of brackets bonded to deciduous teeth.
- To evaluate the modes of bond failure following debonding using the Adhesive Remnant Index.
- To examine the surface characteristics of the bonding surfaces of debonded brackets using scanning electron microscope.

**Material and methods**

**Teeth**

A total of 120 freshly extracted human maxillary teeth...
(permanent canines, first premolars, deciduous canines and deciduous first molars) were collected from patients for different reasons and stored in 10% thymol solution at room temperature. The buccal crown surface of each tooth was examined under X10 magnification to ensure that it was free of caries and restorations which might affect their resistance to experimental loading.

**Bonding**

The 120 teeth were divided into six groups each counting 20 teeth. Each tooth was mounted in cold curing, fast setting acrylic (Leocryl; Leone, Sesto Fiorentino, Italy). The teeth were aligned so that their labial surface was exposed and paralleled the force during shear bond testing. Each tooth was given a number to ease identification. The buccal surface of each tooth was polished with fluoride-free pumice slurry for 15 seconds, rinsed and dried. The labial enamel surfaces of the teeth were etched with 37% phosphoric acid gel (3M ESPE). Each tooth was rinsed thoroughly with water spray for 15 seconds and dried with oil-free compressed air until the etched surface exhibited a frosty white appearance with no traces of moisture. Transbond XT primer (TransbondTM XT Adhesive, 3M Ltd, Monrovia, California, USA) was applied on the etched surface in a thin film. Subsequently, the adhesive was applied to the base of preadjusted edgewise metal orthodontic bracket (Omni 0.022” Roth, GAC International Inc., New York, USA). Upper canine brackets were used in Groups 1, 3 and 5 and upper premolar brackets were used in Groups 2, 4 and 6. Brackets were positioned and pressed firmly onto the tooth using a dental probe. The excess adhesive was removed from around the bracket base and the adhesive was cured with curing light (BioluxTM, CFON 1163, BIO-ART Dental Equipment Ltd, São Carlos, Brazil) which was applied on the mesial and distal sides of the bracket for 10 seconds each as recommended by the manufacturer.

The teeth were divided into six groups as follows.

- **Group 1**: Permanent canines with 15 sec etching time.
- **Group 2**: First premolars with 15 sec etching time.
- **Group 3**: Deciduous canines with 15 sec etching time.
- **Group 4**: Deciduous first molars with 15 sec etching time.
- **Group 5**: Deciduous canines with 30 sec etching time.
- **Group 6**: Deciduous first molars with 30 sec etching time.

To prevent deformation of the bracket during testing, a 1 cm long 0.019"x 0.025" rectangular stainless steel archwire (TrueForce™ Stainless Steel Archwire, Ortho Technology®, Florida, USA) was ligated into the orthodontic bracket slot using elastomeric ligature (Power Sticks™ Elastomeric Ligature, Ortho Technology®, Florida, USA). After bonding, all specimens were thermocycled from 5 °C to 55 °C and back to 5 °C 500 times. The dwell time at each temperature level was 30 seconds and the transfer time between baths was 10 seconds. Subsequently, they were stored in distilled water at 37 °C for 24 hours prior to testing.

The SBS testing was done using a computer controlled electromechanical universal testing machine (WDW-20, JINAN testing Equipment I E Corporation, China) at the solid Material Testing Laboratory, Department of Mechanical Engineering, Jordan University of Science and Technology. The specimens were clamped vertically in the testing machine so that the bracket base was parallel to the direction of the shear force. A thin ligature wire loop (0.030”, TruForce™ Stainless Steel Preformed Ligature Ties, Ortho Technology®, Florida, USA) was placed under the gingival wings of the bracket to apply the debonding force in a gingivo-occlusal direction by movement of the crosshead of the testing machine at a speed of 1 mm/minute. The force required to debond the brackets was recorded in Newton. The surface area of premolar bracket was 10.66 mm² and that of canine bracket was 10.8 mm². Subsequently the shear bond strength in Mega Pascal (Mpa) was calculated by dividing the reported failure force in Newton over the projected base surface area in mm². Shear Bond Strength (Mpa) = Force (N)/ Bracket Surface Area (mm²).

The bracket bases and the bonding areas of the teeth were inspected visually by the same operator (S.I.) using a magnifier with 88 mm diameter lens and 2.5x magnification (Number: G-777-090, Shenzhen Guanyida Optical Production Corp., Ltd., China) to determine the amount of composite resin left on the enamel surfaces according to the modified Adhesive Remnant Index (ARI) [Artun and Bergland, 1984; Bishara et al., 1999]. According to Bishara et al. [1999], the ARI scale ranges from 1 to 5:
1. the entire composite remained on the tooth with distinct impression of the bracket base.
2. more than 90 % of the composite remained.
3. more than 10 % but less than 90 % of the composite remained.
4. less than 10 % of composite remained on the surface.
5. no composite remained on the enamel.

In order to evaluate the type of bond failure at the bracket adhesive interface in each test group, the debonded bracket bases were examined using scanning electron microscopy (FEI, Quanta 200 SEM, Göteborg, Sweden).

**Method error**

Twenty randomly selected teeth were re-examined by the same examiner (S.I.) after a period of one week, and the kappa test was applied to test intra-examiner reliability for ARI scores. Kappa values were above 92%.

**Statistical analysis**

Statistical analysis was performed using Statistical Package for Social Science (SPSS) computer software (SPSS 15.0, SPSS Inc., Chicago, USA). The mean and standard deviation (SD) of each group were calculated. Comparison between groups was performed using
Univariate General Linear Model (UGLM) with SBS as the dependent variable and the type of tooth and etching time as fixed variables. Bonferroni post hoc multiple comparisons were used. Comparison between the different groups in modes of bracket failure was carried out using the Chi square test.

Results

The means and standard deviations (SD) for the SBS of different groups studied are shown in Table 1. The highest mean SBS was recorded when metal brackets were debonded from deciduous canines etched for 30 seconds (10.22 ± 2.79MPa) while the lowest mean SBS was observed when metal brackets were debonded from deciduous canines etched for 15 seconds (8.51 ± 3.04MPa). The mean SBS of permanent canines and premolars groups was 9.57 ± 3.05MPa and 10.30 ± 3.46MPa respectively. Deciduous molars etched for 15 seconds had a mean SBS of 9.55 ± 2.17MPa and those etched for 30 seconds had a mean SBS of 8.84 ± 2.41MPa. No significant differences were found between the different groups.

Mean SBS for permanent and deciduous teeth etched for 15 seconds averaged 9.94 ± 3.24MPa and 9.03 ± 2.66MPa, respectively (P=0.174). Mean SBS for deciduous canines etched for 15 and 30 seconds averaged 8.51 ± 3.04MPa and 10.22 ± 2.79MPa respectively. Whereas, it was 9.55 ± 2.17MPa and 8.84 ± 2.41MPa for deciduous molars with 15 and 30-second etching times. No significant differences were recorded between the different groups.

Adhesive Residual Index (ARI)

The ARI scores for the six groups tested are shown in Table 2. The results indicated the presence of a significant difference between the groups (P<0.001). Scanning electron Microscopy (SEM) of the bracket bases of the different tested groups are shown in Figure 1.

Results revealed that the deciduous teeth groups had greater ARI scores of 4 and 5. Fifty and 40% of permanent canines and premolars, respectively had bond failure at bracket-adhesive interface (scores 1 and 2) compared with 10 and 15% of deciduous canines and molars. Bond failure at enamel-adhesive interface (scores 4 and 5) were recorded in 30 and 45% of deciduous canines and molars, respectively compared with 10% of the permanent teeth (P<0.05).

Increasing etching time in deciduous teeth groups from 15 to 30 seconds increased bond failure at the enamel-adhesive interface (scores 4 and 5) in the molars group (65%, P=0.177) and bond failure at the bracket-adhesive interface (scores 1 and 2) in the canines group (30%, P<0.05).

No significant correlation was found between SBS values and ARI scores (Table 3). This finding was true for all groups except for deciduous canines with 30 seconds etching time (group 5), where significant correlation was found (P<0.05). However when total group was taken

<table>
<thead>
<tr>
<th>SBS (N)</th>
<th>SBS (MPA)</th>
<th>SBS (N)</th>
<th>SBS (MPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent teeth (15 s etch time)</td>
<td>106.60 ± 34.69</td>
<td>9.94 ± 3.24</td>
<td>103.40 ± 32.97</td>
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<tr>
<td>Deciduous teeth (15 s etch time)</td>
<td>96.90 ± 28.51</td>
<td>9.03 ± 2.66</td>
<td>91.90 ± 32.90</td>
</tr>
<tr>
<td>Deciduous teeth (30 s etch time)</td>
<td>102.30 ± 28.84</td>
<td>9.53 ± 2.66</td>
<td>110.40 ± 30.11</td>
</tr>
</tbody>
</table>

TABLE 1 Means and standard deviations (SD) for the SBS of the tested groups.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Group 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>NS</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Group 2</td>
<td>*</td>
<td>NS</td>
<td>*</td>
<td>*</td>
<td>***</td>
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</tr>
<tr>
<td>Group 3</td>
<td>*</td>
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<td>NS</td>
<td>*</td>
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<td>NS</td>
</tr>
<tr>
<td>Group 4</td>
<td>*</td>
<td>*</td>
<td>NS</td>
<td>**</td>
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<tr>
<td>Group 6</td>
<td>***</td>
<td>***</td>
<td>NS</td>
<td>NS</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

NS: not significant, *P<0.05, **P<0.01, ***P<0.001

TABLE 2 Comparison between ARI scores of different groups.
collectively, no significant correlation was found between mean SBS values and ARI scores (R²=0.006, P=0.415).

**Discussion**

In the present study, each group was composed of 20 teeth as recommended by Fox et al. [1994] who suggested that at least 20 specimens should be used per test if valid conclusions are to be drawn from ex vivo bond strength testing. Maxillary bicuspid teeth are the most common extracted teeth as an integral part of orthodontic treatment. Therefore, they were selected to allow comparison of the results of the present study with previously reported results [Ergas et al., 1995; Endo et al., 2007; 2008] and to act as a control group for the deciduous first molars because of the morphological similarity. Permanent canines were selected as a control group for deciduous canine group for the same reason.

In this study, natural teeth were stored in 10% thymol solution at room temperature. Thymol solution has the advantage of having an antifungal action, which is the reason for choosing this substance as a storage media [Abu Alhaija and AlWahadni, 2004]. The specimens in the present study were thermocycled from 5°C to 55°C and back for 500 cycles to stimulate the temperature fluctuation present in the oral cavity [Øilo, 1993].

In the present study, SBS values of different groups were higher than the clinically sufficient minimum value of 58N [Tavas and Watts, 1984]. Deciduous teeth had similar SBS to that of permanent teeth irrespective of the etching time. This finding was supported by Ergas et al. [1995] who reported a comparable SBS values for premolars and deciduous molars. However, other studies reported differences in SBS between deciduous and permanent teeth. Endo et al. [2007] found that shear bonding strengths for maxillary deciduous canines and second molars were lower than those for maxillary permanent first and/or second premolars. They speculated that the reason for this was the presence of the prismless enamel layer. However they studied a small sample size (seven per group). In addition, the bracket type which was used for all groups was identical (premolar bracket). Also, Endo et al. [2008] found significant differences between SBS of premolars group and deciduous teeth group (canines, first and second molars). However, deciduous teeth in their study were not homogeneous canines and molars.

Johnston et al. [1998] reported that using a 30-second etching time increased bond strengths significantly over a 15 sec etch time for permanent first molars. However, in the present study, increasing etching time from 15 to 30 sec did not increase the shear bond strength of deciduous teeth. This was in agreement with Gwinnett and Garcia-Godoy [1992] who found no statistically significant difference between SBS of composite bonded

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>MODEL</th>
<th>UNSTANDARDISED COEFFICIENTS</th>
<th>STANDARDISED COEFFICIENTS</th>
<th>P VALUE</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>B</td>
<td>SE</td>
<td>Beta</td>
</tr>
<tr>
<td>Group 1</td>
<td>ARI</td>
<td>7.68</td>
<td>7.56</td>
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<td>5.44</td>
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<td>0.02</td>
<td>8.31</td>
<td>0.001</td>
</tr>
<tr>
<td>Group 4</td>
<td></td>
<td>8.14</td>
<td>4.54</td>
<td>0.39</td>
</tr>
<tr>
<td>Group 5</td>
<td></td>
<td>24.46</td>
<td>8.69</td>
<td>0.55</td>
</tr>
<tr>
<td>Group 6</td>
<td></td>
<td>-5.82</td>
<td>8.03</td>
<td>-0.17</td>
</tr>
<tr>
<td>All Groups</td>
<td></td>
<td>2.15</td>
<td>2.62</td>
<td>0.08</td>
</tr>
</tbody>
</table>

*P<0.05

**Table 3** Regression coefficients, t values and significance with SBS as dependent variables and ARI scores as predictor variables.
to deciduous teeth with 15 s and 60 s etching time and between permanent and deciduous teeth. Wang and Lu [1991] confirmed this finding for the permanent teeth and reported no significant differences in tensile strength of orthodontic brackets bonded to premolars with 15, 30, 60, 90 sec etching times. Other studies [Nordenvall et al., 1980] involving SEM study of resin impression of 15 and 60 sec etched deciduous enamel demonstrated that there were no statistically significant
difference in degree of surface irregularity (retentive conditions) between two etching times.
To represent the adhesive bond strength to the etched enamel surface, bond failures must occur in the adhesive interface and not cohesively [Zachrisson et al., 1996]. In the present study, although no significant differences in SBS values were found between groups, bond failure at bracket adhesive interface (scores 1 and 2) occurred more frequently in the permanent canines and premolars.

<table>
<thead>
<tr>
<th>AUTHORS</th>
<th>SAMPLE SIZE</th>
<th>SUBSTRATE</th>
<th>BRACKET TYPE</th>
<th>BONDING PROTOCOL</th>
<th>THERMO-CYCLING</th>
<th>RESULTS</th>
<th>ADHESIVE REMNANT INDEX</th>
</tr>
</thead>
</table>
| Ergas et al., 1995 | 20          | 1. Premolars  
2. Deciduous canines  
3. NiCr crowns | Not mentioned | 60-s etching time  
Half of samples with Clearfil new bond (primer) | Yes | - Shear bond strength of brackets bonded to deciduous molars was comparable to that of premolars (without Clearfil for both)  
- Shear bond strength of brackets bonded to NiCr crowns with Clearfil was comparable to that of deciduous molars and premolars without Clearfil. | Increased frequency of cohesive bond failure with the use of Clearfil. |
| Endo et al., 2007  | 7           | 1. First premolars  
2. Second premolars  
3. Deciduous canines  
4. Deciduous second molars | Metal premolar bracket | 15-s etching time | No | Shear strengths for deciduous canines and second molars were significantly lower than that for first and/or second premolars. The shear bond strengths of all four tooth types were higher than 6 - 8 Mpa | Bond failure at the enamel-adhesive interface occurred more frequently in the deciduous second molars than in first premolars. The ARI scores and shear bond strength values were not related. |
| Endo et al., 2008  | 17          | 1. First and second premolars  
2. Deciduous canines, first and second molars | Metal premolar bracket | 15-s etching time  
Two groups with conventional primer, the other 2 with Self Etching Primer | No | Shear bond strengths of the brackets bonded to the deciduous teeth with either adhesive system were lower than those to the permanent teeth. Shear bond strengths of all 4 groups were higher than 6 to 8 Mpa | Bond failure occurred at the enamel-adhesive interface more frequently in the self-etching adhesive system than in the conventional acid-etching adhesive system. The ARI scores and shear bond strength values were not related. |
| Present study     | 20          | 1. Permanent canines  
2. First premolars  
3. Deciduous canines  
4. Deciduous first molars | Metal upper premolar and upper canine bracket | 15-s and 30-s etching time | Yes | Shear bond strength values for permanent teeth were comparable to those for deciduous teeth. Shear bond strengths of all groups were higher than 58 N and 6-8 Mpa | Bond failure at the enamel-adhesive interface occurred more frequently in the deciduous teeth groups, while failure at bracket-adhesive interface occurred more frequently in the permanent teeth group. Increasing etching time increased the frequency of bond failure at bracket adhesive interface for deciduous canines but not for molars. The ARI scores and shear bond strength values were not correlated. |

**TABLE 4** Comparison between different studies involving bracket bonding to deciduous teeth.
groups respectively. Whereas failure at the enamel adhesive interface (scores 4 and 5) occurred more frequently in the deciduous canines and molars group respectively. This might have reflected the insufficient penetration of adhesive resins into the surfaces of the deciduous teeth because of prismatic enamel layer. On the other hand, increasing etching time for deciduous canines from 15 to 30 s, increased the frequency of bond failure at bracket adhesive interface (scores 1 and 2). This improved the bond between the adhesive and the enamel surface. However, increasing etching time for deciduous molars, did not affect ARI scores. The finding of the present study regarding the presence of significant differences in ARI scores but not in shear bond strength values were supported by previous reports [O’Brien et al., 1988; Endo et al., 2008] who suggested that the amount of residual adhesive resin might not be related to SBS. Table 4 compares the results, number and types of specimens used and bonding protocol for some reported bond strength studies in addition to that reported in the present study. Although ex vivo bond strength studies are useful to provide information about new adhesive materials and bonding techniques, ex vivo bond strength data should be interpreted with caution. A major drawback of ex vivo bond strength studies is the difficulty to simulate the complex nature of the oral environment. Variations in temperature, stresses, humidity, acidity and plaque are impossible to reproduce in the laboratory. 

Conclusions

The SBS of brackets bonded to deciduous teeth etched for 15 sec was comparable to that of permanent teeth etched for the same time.

Using 30 sec etching time does not increase the SBS for deciduous teeth.

Bond failure at the enamel-adhesive interface occurred more frequently in the deciduous teeth groups, while failure at bracket-adhesive interface occurred more frequently in the permanent teeth group.

Increasing the etching time for deciduous canines increased the frequency of bond failure at the bracket-adhesive interface but it did not affect bond failure pattern of molars.

Acknowledgements

The study was supported by grant number 15/2009 from the Deanship of Research/ Jordan University of Science and Technology.

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