Effect of arch wire ligation on shear bond strength of metal brackets

Akram F. Al-Huwaizi  B.D.S., M.Sc., Ph.D. (1)
Haitham A. Mohammed  B.D.S., M.Sc. (2)

ABSTRACT

Background: This study evaluated the effect of ligating different arch wires on the amount of force needed to debond a bracket and the effect that has on the bond strength of the adjacent brackets.

Materials and methods: Sets of 5 human maxillary first premolar teeth were attached together by acrylic resin and bonded to .022 slot brackets. The sets were randomly split into five groups. Four test groups were characterized by ligating the 5 brackets by an arch wire (SS .019x.025, SS .021x.025, NiTi .019x.025, and NiTi .021x.025). A fifth group served as control having no ligated arch wire during debonding. The brackets were debonded by a debonding pliers attached to an Intron Universal testing machine. After debonding the middle bracket, the arch wire was removed and the adjacent and terminal brackets were debonded. Then the teeth were examined with enhanced digital images to evaluate the site of failure according to the Adhesive Remnant Index (ARI).

Results: Compared to control, the bond strength of the middle brackets in all the test groups was significantly increased and the adjacent brackets significantly decreased. Higher bond strengths of the middle brackets were associated with the use of SS and .021x.025 arch wires rather than NiTi and .019x.025 arch wires, respectively. The most common type of failure was between the bracket and the adhesive. Enamel cracks were found less frequently in the test groups than in control.

Conclusions: It is advised to start debonding from one side of the arch to the other rather than starting in the middle of the arch to have an adjacent bracket from one side only.

Keywords: Bond strength, arch wire ligation

INTRODUCTION

Debonding may be unnecessarily time consuming and damaging to the enamel if performed with improper technique or carelessly (1). In the majority of orthodontic in-vitro studies, shear and/or tensile bond strengths are determined in order to assess the potential performance of the bracket and the bonding systems during clinical application. Ferguson et al. (2) advocated the use of shear-peel testing to represent the type of forces encountered in the clinical situation.

When comparing the types of bond failure produced by shear and tensile testing, it was found that tensile specimens failed cohesively whereas the shear specimens failed at the enamel cement interface. As a result, it was concluded that the values obtained from tensile testing did not represent the bond to enamel but rather showed the bulk strength of the luting material (cohesive failure); also, demonstrated that the shear test might have an advantage over tensile test in that it appears to be more likely to produce failure at the enamel-cement interface (3).

Leaving the arch wire attached to all the brackets during debonding, has these advantages:

1. Time saving specially for those who recycle because of easy identification of the brackets.
2. Avoid fracturing of enamel
3. Minimize patient discomfort
4. Minimize the danger of the patient swallowing or aspirating brackets (4).

This study was designed to evaluate the bond strength of brackets with and without the presence of an arch wire. Since the vast majority of the previous studies conducting on bond strengths have relied on debonding the bracket by either pushing with a chisel or pulling by a wire attached to an Intron or Zwich testing machines which makes them not simulating the clinical debonding process, a specially designed apparatus was designed to simulate the actual debonding process in the patients mouth by a real debonding pliers.

MATERIALS AND METHODS

More than 200 sound human upper first premolar teeth extracted for orthodontic treatment purpose were collected from the Surgical Department in the College of Dentistry – University of Baghdad. After extraction, the teeth were washed and stored in a closed container at room temperature filled with distilled water containing 0.1% concentration of thymol to prevent dehydration and bacterial growth (5,6).

From these, 134 teeth with a crown height of 9-9.5mm were selected to standardize the distance from the bracket slot to the cusp tip at 4.5mm (7). Twenty teeth were used in the pilot study and 14 for the control group and 100 for the test groups. Standard edgewise stainless steel brackets (Ultratrimm® 713-022-50, slot .022x.030,
Dentauro, Germany) with coarse mesh bases were used.

After polishing the buccal surface of each tooth with slurry of pumice, it was washed, dried and fixed with sticky wax on a glass slab placed on the base of a dental surveyor with the buccal surface directed upwards and parallel to the base which in turn would be parallel to the force during the debonding test (8,9).

The buccal surface was then etched, washed, dried, and primer added. The adhesive was applied to the bracket base and immediately the bracket was seated close to its correct position (in the center of the buccal aspect of the tooth being in the center of the cross marked on the surveyor base which aids bracket orientation) as shown in figure 1.

A bracket positioning device attached to the surveyor was used to position the bracket at a precise distance (4.5mm) from the tip of buccal cusp (10). A load of 200g was attached to the positioner to standardize the pressure applied on the brackets during bonding (11) as brackets must be bonded under sufficient pressure which must be more than 200g to express excess adhesive (12).

The excess material was removed using a sharp dental probe from around the base of the bracket (9) and after one hour the teeth were placed in a container of distilled water stored in an incubator at 37°C for 24 hours (13).

Each 5 teeth were ligated to a .021x.025 straight-length stainless steel arch wire and collected together to leave no space between them (12). They were immersed into a 5x2.5x2.5cm mould with cold cure acrylic. The teeth where covered to the cervical line (14). After complete setting of the acrylic, the arch wire was removed and the assembly stored in an incubator at 37°C. For clarification the second and fourth brackets adjacent to the middle are referred to as 'adjacent brackets and the first and fifth brackets are referred to as terminal brackets (Fig. 2).

Figure 1: The bracket positioning device.

20 six assemblies were made as follows:
1- Three for the pilot study
2- Three used as control left without an arch wire.
3- Twenty used for the 4 experimental groups (five each) in which the teeth were ligated to an arch wires using single ligature ties:
   Group 1: .019x.025 stainless steel wire
   Group 2: .021x.025 stainless steel wire
   Group 3: .019x.025 nickel titanium
   Group 4: .021x.025 nickel titanium

An apparatus was designed to simulate the normal clinical use of the bracket removing pliers. The pliers was fitted perpendicular to the base and secured by two holder mechanisms, one in the hinge area and the other holding the lower arm of the pliers (carrying the fixation pad). The upper arm of the pliers (carrying the debonding chisel) must move unobstructed during debonding. A moveable vertical table on the other end of the apparatus secured the testing assembly. A vertical screw allowed vertical adjustment of the assembly so that the buccal cusp tip of the tooth to be debonded contacts the pad on the fixed arm of the bracket removing pliers. The chisel end on the movable arm of the bracket removing pliers was positioned under the bracket edge without undue trauma to tooth surface to get the peel/shear force as shown in figure 3 (15).

Then the assembly was locked into position. This enabled the chisel end to be placed into position precisely and consistently, to ensure the distance between the surface of the tooth and point of application of force was the same for each specimen (16).

The debonding apparatus was screwed to the base of an Instron machine being parallel to the horizontal plane. The upper arm of the Instron...
machine applied downward force on the movable pliers’ arm to create a gingivo-occlusal peel shear force at the bracket tooth interface. Each bracket was subjected to a compression test by an Instron machine with a crosshead speed of 0.5mm/minute (11,17) and the ultimate magnitude of the Instron machine reading was recorded in Newtons. The force was divided by the surface area of the bracket base (11.02mm²) to obtain the stress value in a Mega Pascal Units.

Figure 3: The assembly screwed to the debonding apparatus.

Figure 4: Debonding apparatus inside the Instron machine.

Adhesive remnant index (ARI)

After debonding, the debonded brackets were kept in labeled containers until the time of examining the Adhesive Remnant Index.

The debonded brackets and the enamel surface of each tooth were inspected under:
A: a 10X magnifying lens by both operators to assess the amount of adhesive remaining on the tooth surface and the site of bond failure (18).
B: a picture was taken to the debonding site on the tooth surface. The picture was embossed so that the remaining adhesive material appeared raised by converting its fill color to gray and tracing the edges with the original fill color giving a 3D texture to the selected area. Options include an embossing angle (from −360° for recessing the surface, to +360° for raising the surface), and an embossing height (from 1% to 500%) for the amount of color within the selection. In this study, an embossing angle of 120° was used with a height of 18% to standardize the readings.

The enamel surface was scored according to Wang classification (19) as follows:
1: Failure between bracket base and adhesive.
2: Cohesive failure within the adhesive itself.
3: Adhesive failure between adhesive and enamel.
4: Enamel detachment.

Figure 5: ARI Score (top: original picture and bottom: embossed picture).

Statistical analysis

Data were collected and analyzed using the Statistical Package of Social Science, version 14 (SPSS Inc., Chicago, Illinois, USA). Student t-test was used to assess difference between the bond strength and Pearson correlation test was used to examine the relation between bond strength and ARI score. P levels of less than 0.05 were regarded as statistically significant.

RESULTS

The mean bond strengths were higher for the middle brackets of all the groups followed by the terminal brackets and finally the adjacent brackets (Table 1). The bond strength of the control group was significantly lower than that of the middle brackets and higher than that of the adjacent brackets, in the four experimental groups. Terminal brackets also showed lower bond strengths than control but only being statistically significant in the NiTi .019x.025 and SS .021x.025 arch wire groups (Figure 6).

Effect of arch wire gauge

For all groups, the middle brackets showed lower bond strength with .019x.025 than with .021x.025 wires. However, adjacent and terminal brackets showed a different picture. For SS wires, the bond strength was significantly higher with .019x.025 than with .021x.025 wires, while the reverse was true for NiTi wires. This was more pronounced in the terminal bracket...
which showed a highly significant statistical difference (Figure 7).

**Table 1: Descriptive statistics for bond strength for the five groups.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Bracket</th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (no arch wire)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>5</td>
<td>6.860</td>
<td>0.491</td>
<td>6.171</td>
<td>7.532</td>
</tr>
<tr>
<td></td>
<td>Adjacent</td>
<td>10</td>
<td>3.126</td>
<td>0.325</td>
<td>2.677</td>
<td>3.539</td>
</tr>
<tr>
<td></td>
<td>Terminal</td>
<td>10</td>
<td>4.188</td>
<td>0.215</td>
<td>3.811</td>
<td>4.537</td>
</tr>
<tr>
<td>SS .019x.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>5</td>
<td>7.804</td>
<td>0.267</td>
<td>7.577</td>
<td>8.258</td>
</tr>
<tr>
<td></td>
<td>Adjacent</td>
<td>10</td>
<td>2.722</td>
<td>0.271</td>
<td>2.359</td>
<td>3.221</td>
</tr>
<tr>
<td></td>
<td>Terminal</td>
<td>10</td>
<td>3.671</td>
<td>0.286</td>
<td>3.176</td>
<td>4.083</td>
</tr>
<tr>
<td>SS .021x.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>5</td>
<td>5.454</td>
<td>0.320</td>
<td>5.082</td>
<td>5.898</td>
</tr>
<tr>
<td></td>
<td>Adjacent</td>
<td>10</td>
<td>2.509</td>
<td>0.346</td>
<td>1.996</td>
<td>2.904</td>
</tr>
<tr>
<td></td>
<td>Terminal</td>
<td>10</td>
<td>3.879</td>
<td>0.327</td>
<td>3.539</td>
<td>4.537</td>
</tr>
<tr>
<td>NiTi .019x.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>5</td>
<td>6.153</td>
<td>0.152</td>
<td>5.944</td>
<td>6.352</td>
</tr>
<tr>
<td></td>
<td>Adjacent</td>
<td>10</td>
<td>2.809</td>
<td>0.155</td>
<td>2.632</td>
<td>3.085</td>
</tr>
<tr>
<td></td>
<td>Terminal</td>
<td>10</td>
<td>4.229</td>
<td>0.301</td>
<td>3.993</td>
<td>4.809</td>
</tr>
<tr>
<td>NiTi .021x.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>5</td>
<td>7.804</td>
<td>0.267</td>
<td>7.577</td>
<td>8.258</td>
</tr>
<tr>
<td></td>
<td>Adjacent</td>
<td>10</td>
<td>2.722</td>
<td>0.271</td>
<td>2.359</td>
<td>3.221</td>
</tr>
<tr>
<td></td>
<td>Terminal</td>
<td>10</td>
<td>3.671</td>
<td>0.286</td>
<td>3.176</td>
<td>4.083</td>
</tr>
</tbody>
</table>

**Figure 6: T-test between mean bond strength of the tested groups with the control group.**

**Figure 7: T-test between mean bond strength of the different arch wire gauges.**

**Effect of arch wire material**

For all groups, the middle brackets showed lower bond strength with NiTi than with SS arch wires. However, adjacent and terminal brackets showed a different picture. For .019x.025 wires, the bond strength was significantly higher with NiTi than with SS wires, while the reverse was true for .021x.025 wires (Fig. 8).

**Figure 8: T-test between mean bond strength of the different arch wire materials.**

- **p<0.05; *** p<0.001; NS, not significant**

**Adhesive remnant index (ARI)**

The most common type of failure was adhesive between the bracket and the composite (Score 1). Cohesive failure (Score 2) and adhesive failure between the tooth and the composite (Score 3) were infrequently found in this study. However, enamel cracks were found in 14% (2 teeth) of the control group and in 10% (1 tooth per group) of two adjacent groups and all terminal groups. While none of the middle brackets showed enamel cracks (Fig. 9).

When bond strength was correlated with ARI score for each group a non-significant correlation was found due to the small sample number. Hence, groups were merged to give larger sample numbers and significant correlations were found for the control, adjacent and terminal groups. Pearson correlation could not be computed for the middle brackets because they all registered a score 1 ARI (Table 2).

**DISCUSSION**

Previous studies have used a variety of test designs. This diversity in test design is due to the fact that there is no standard method for evaluating shear bond strength in orthodontics (20). Therefore comparison of data obtained from different studies is almost impossible. Moreover, the results of this study can not be compared numerically with the results of previous studies as
the bond strength measured here is the force on the plier arms and not on the bracket itself.

Figure 9: ARI scores for all groups (% from the number for each group).

Table 2: Pearson correlation test for the four test groups between the debonding force and the score of the ARI.

<table>
<thead>
<tr>
<th>Group</th>
<th>Control</th>
<th>Middle</th>
<th>Adjacent</th>
<th>Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>r value</td>
<td>0.677</td>
<td>-</td>
<td>0.327</td>
<td>0.423</td>
</tr>
<tr>
<td>p value</td>
<td>0.008**</td>
<td>-</td>
<td>0.039*</td>
<td>0.007**</td>
</tr>
<tr>
<td>N</td>
<td>14</td>
<td>15</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

* p<0.05; ** p<0.01

Unlike most previous studies which used a wire or a chisel on an Instron or Zwich machine our study used a debonding pliers. Hence, the force on the plier arms will be transformed into a momentum at the bracket side affected by the magnitude of the applied force and the length of the arms (21).

The force on the lower jaw will finish in a chisel end shape. As the pliers needs to be opened 7mm to be placed on the bracket the angle between the chisel end and the middle of the pad on the other plier arm seated on the tip of the buccal cusp of the tooth will be 8 degrees to generate peel/shear force (22). This angle has been shown to significantly reduce the required debonding force in comparison with true shearing force on the plier arms and not on the bracket itself.

Orthodontics, Pedodontics and Preventive Dentistry 85
debonding pliers as described above. While, for 0.021x.025 wires, more force was needed to debond the adjacent brackets with NiTi arch wire than SS ones because greater debonding force being transmitted to the adjacent brackets by the stronger SS arch wires, however the difference was statistically insignificant. The occlusal movement of the middle bracket after debonding carried by the plier arm explained for .019x.025 wires is less effective in the tight fit .21x.025 wires.

**Adhesive remnant index (ARI)**

The most common type of failure found in this study was score 1, score 2 and 3 were much less common to find. This is in agreement with several previous studies (26-28). However, the differences between the percentages found may be attributed to the different bracket type and debonding technique.

The significant correlations between the bond strength and ARI score is in accordance with Ghafari and Chen (29) who stated that enamel fracture on debonding seems to be associated with loading by the debonding instrument.

Enamel cracks were found in 14% of the control group. This is close to the 10% of Al Shamsi et al. (30) but higher than that found by others (27,31). This difference in percentages of enamel fractures may be explained by the difference in debonding technique and force direction as enamel can resist relatively high forces before fracturing. Forces applied along the long axis of the enamel prisms must exceed 25 to 30 MPa to induce fractures. However, when occurring at an angle to the prisms, forces as low as 13 MPa may fracture the enamel (32).

None of the 20 middle brackets tested in this study exhibited enamel fracture in spite of the high debonding forces used. This is attributed to the presence of the arch wire which would:

1. transmit part of the debonding force to the adjacent teeth making the actual force on the middle bracket less than registered, and

2. create an axis around which the debonding force will change to a momentum aiding in debonding of the middle bracket.

Of the adjacent teeth, 10% of the SS 0.19x.0.25 and NiTi 0.021x.0.25 groups showed enamel fracture which was lower than that found in the control group. This may be attributed to that these two groups showed a higher mean bond strength for the adjacent brackets than the other groups. However, this conclusion should not be over emphasized as they represent only one tooth from ten samples which may be a subject of chance.

Ten percent (1 tooth per group) of all the terminal groups showed enamel fracture which was lower than the 14% showed in the control group. This may be because of cracks initiated by the forces transmitted through the arch wire during debonding of the middle bracket making the final debonding easier.

**REFERENCES**


