A better understanding of orthodontic bracket bonding
Algera, T.J.

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CHAPTER 5

The influence of different bracket base surfaces on the tensile and shear bond strength

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5.1 Abstract

Fracture of the bracket-cement-enamel system often takes place between the bracket and the cement. Especially for glass ionomer based materials it is therefore helpful if this part of the system can be improved.

The aim of this *in vitro* study is to investigate the influence of different bracket base pre-treatments in relation to three different cements on shear as well as on the tensile bond strength.

Three different cements, Transbond XT, a resin composite, Fuji Ortho LC, a resin modified glass ionomer cement (RMGIC), and Fuji IX Fast, a conventional glass ionomer cement (GIC) were used. Upper incisor brackets with three types of base treatment, sandblasted, silicoated, and tin-plated were bonded to bovine enamel. Untreated brackets were used as the controls. Ten specimens were tested for each group. The brackets were stored for 24 hours after bonding and tested in shear as well as in tensile mode. After fracture the remaining adhesive was scored using the adhesive remnant index (ARI). ANOVA was used to detect statistical differences between the bond strengths at a p-level of 0.05.

Although some of the bracket pre-treatments had a statistically significant effect on the bond strength, no clear improvement was measured. The ARI scores of the test groups do not show a change according to the control groups.

The investigated base pre-treatments did not have such a beneficial influence on the bond strength that improved clinical results can be expected. Improvement of the bond between bracket and cement might be found in other variables of the bracket-cement-enamel system such as the elasticity of the materials.
5.2 Introduction

In the early days of bracket adhesion research, the aim was to achieve a strong and reliable bond between the bracket and the enamel. With the use of the current mesh-based brackets and resin composites these initial problems have mostly been solved. Nowadays, the focus is more on details such as a faster bonding, harmless removing procedures, and antibacterial effects of the bonding materials to help oral hygiene.

For these reasons the popularity of using resin modified glass ionomer cements (RMGICs) for bracket bonding, is increasing. Their bonding properties are acceptable and they have the advantage of fluoride release. Although the influence of the type and amount of fluoride is still not clear, a beneficial effect is assumed.(1, 2)

A second type of material that also releases a substantial amount of fluoride is conventional glass ionomer cement (GIC). Another advantage of this material is the chemical bonding to enamel. COO⁻ groups of the GIC bind to Ca²⁺ ions of the enamel. This results in a non-invasive, superficial bonding. Separation of the bracket at the end of treatment is therefore not within the enamel, but at the surface. This minimizes the chance of enamel damage and reduces the cleaning time. The main disadvantages of this type of material are the low bond strength properties, the slow curing reaction, and the high failure rate.(3, 4)

In contrast with the non-invasive chemical bonding of GIC is the hybrid layer which is formed when resin composite is used as bonding material. Resin composite needs a micromechanical bonding to adhere to enamel. After treatment the hybrid layer has to be removed. This results in damage while on the other hand not all material is removed.

In vitro as well as in vivo debonding usually takes place between the cement and the bracket. It is therefore logical that this part of the bracket-cement-enamel system has to be improved if a lower failure rate is demanded. Several suggestions such as different base geometries (5), mesh sizes (6-8) mesh numbers (9, 10), and surface treatment of the mesh (11-13) are performed for enhancement of this part of the system. The literature does not give a clear answer to the question as to which combination of materials provides the best bonding. Surface enlargement as a result of microabrasion is an advantage found when plane surfaces, such as crowns, are bonded to a tooth structure.(14, 15) For bracket bonding with composite or glass ionomer based materials this benefit is not clear. Chung et al. (16) reported an improvement of the bond as a result of sandblasting the bracket base when composite resin was used as cement. When GIC (Ketac Cem) was used as bonding material in combination with a
sandblasted bracket, a significant improvement of 22% in bond strength was found.\(^{(17)}\) When a RMGIC was used no difference was observed.\(^{(13)}\) Tavares \textit{et al.} \(^{(18)}\) and Sonis \(^{(19)}\) did not find a difference in bond strength between sandblasted brackets and control groups. Willems \textit{et al.} \(^{(20)}\) concluded that the influence of sandblasting on the bond strength is dependent on the bracket base type. From a study of Arici \textit{et al.} \(^{(11)}\) the particle size of the aluminum oxide, the blasting time, and the distance to the object also appears to be of importance.

Micro-abrasion in combination with silicoating is another technique successfully used in prosthetic dentistry.\(^{(21)}\) With this technique a SiO\(_x\) layer is burned onto the metal surface. Subsequently this layer is silanized using Silicoup. This enables a chemical bonding with the oxides of the cement. Newman \textit{et al.} \(^{(22)}\) stated that silicoating the bracket base can be of benefit if a resin composite is used as cement. No data is available concerning bonding silicoated brackets with GICs.

Swartz \textit{et al.} \(^{(21)}\) evaluated the influence of surface treatment of high-noble alloys, used for porcelain fused to metal crowns. A benefit of tin-plating in combination with RMGIC was found when tensile tests were performed. An explanation for the results was an improved chemical bonding of the cement to the oxides formed at the tin surface. The doubts and contradictions in research results on this topic led to the conduction of this study.

The aim of this \textit{in vitro} study was to investigate the influence of different bracket base pre-treatments, sandblasting, silicoating, and tin-plating, in relation to three different cements. The bonding properties were evaluated with shear as well as tensile bond strength testing.

### 5.3 Materials and methods

#### Specimen preparation

The brackets used in this research were stainless steel, mesh based (Mini Twin, “A”Company Orthodontics, San Diego, California, USA), bonded to bovine enamel. Enamel from 240 freshly extracted bovine teeth, randomly collected from two-year-old cattle, was used as the substrate. The crowns were sectioned from the roots and embedded in cylindrical Polymethyl methacrylate moulds. The vestibular enamel surface was ground on wet silicon carbide paper up to grit 1200 to create a flat standard bonding surface.
Table 5.1 Materials used in this study.

<table>
<thead>
<tr>
<th>Material</th>
<th>Manufacturer</th>
<th>Cement type</th>
<th>Batch nr</th>
<th>Exp. Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji IX Fast</td>
<td>GC Corporation</td>
<td>Conventional glass ionomer cement</td>
<td>0506083</td>
<td>2007-06</td>
</tr>
<tr>
<td>Fuji Ortho LC</td>
<td>GC Corporation</td>
<td>Resin modified glass ionomer cement</td>
<td>0309253</td>
<td>2005-09</td>
</tr>
<tr>
<td>Transbond XT</td>
<td>3M-Unitek</td>
<td>Resin composite</td>
<td>3 JF</td>
<td>2006-10</td>
</tr>
</tbody>
</table>

The cements investigated are shown in Table 5.1. All cements were handled according to the manufacturers’ prescriptions with the exception of Fuji IX Fast. For this cement the conditioning step was not performed. Prior to the use of Fuji Ortho LC the enamel was conditioned with a polyacrylic acid-gel (GC Dentin Conditioner, GC Corp., Tokyo, Japan) for 20 seconds following which extensive rinsing and air drying of the enamel took place. Before bonding with Transbond XT, 35% phosphoric acid (Ultradent Products, South Jordan, Utah, USA) was applied to the enamel for 30 seconds, followed by rinsing, air drying, and application of adhesive primer (3M Unitek, Monrovia, California, USA).

If light curing was required, the Elipar Trilight curing unit (3M-ESPE Dental Products, Seefeld, Germany) was used in the standard mode at 750 mW/cm².

Bracket pre-treatment

Brackets with a bonding area size of 2.9 mm x 4.2 mm, intended for use on central upper incisors, were cemented to the enamel substrates. The brackets were bonded in the same way: the cement was applied to the bracket, the bracket was placed and firmly pressed with a probe at the bonding area. Excessive material was removed prior to curing. The specimens were stored for 24 hours at 37°C tap water.

Prior to bonding four groups were created: a sandblasted-, a silicoated-, a tin-plated-, and a control group. The bases of the brackets from the sandblasted group were roughened with aluminum oxide particles <50 µm for 3 seconds. The brackets used in the silicoated group were also sandblasted followed by the application of a Silicon-oxide layer using a Siliflame coater (Heraeus-Kulzer GmbH, Wehrheim, Germany). Subsequently a silane layer was applied using Silicoup (Heraeus-Kulzer GmbH). The brackets of the third group were electrolytically plated with a layer of tin less then 10 µm thick.
Figure 5.1  Photographs showing the set-up for the shear stress determinations. A lateral view (left) and a frontal view (right) of the specimen and the specimen container.

Tensile and shear strength determination

For tensile testing the set up used has been described previously (23). A round stainless steel wire, with a diameter of 1 mm, was bent in a U-form and tied with a harness ligature to the bracket. The free ends of the wire were clamped in the connecting piece of the crosshead. A hinge in the connecting piece together with the round wire made vertical alignment of the specimen in the pre-test phase possible. Vertical alignment is necessary for homogeneous stress distribution over the specimen during the test. For shear testing the specimens were placed in a brass block so that the bracket base was located exactly at the edge of this holder (Figure 5.1). A metal plate, intended to guide the specimen, was placed parallel to the specimen, just not touching it. An extension connected to the crosshead was placed at the top of the specimen, performing a compressive force in line with it. In this way the enamel is sheared off the bracket.

Twenty four hours after the start of the bonding procedure the specimens were measured in a universal testing machine (Hounsfield Ltd., Redhill, Surrey, UK). Each group consisted of 10 specimens. The crosshead speed during testing was 0.5 mm/minute. The loads at fracture were recorded in Newtons and converted to Mega Pascals. After testing, the type of fracture was scored using the adhesive remnant
index (ARI) (24) to identify the weakest point in the bracket-adhesive-enamel system. The scores were determined with a stereomicroscope at a magnification of 25x.

Statistical analysis

Two-way analysis of variance (ANOVA) was used to test the effect of the different bracket base pre-treatment methods in combination with different cements on the debonding force. Furthermore, one-way analysis of variance (ANOVA) was used to determine differences in debonding force between the base pre-treatments within the materials. P<0.05 was considered significant. Tukey’s post hoc test was performed to show individual differences. The software used was SigmaStat Version 3.0 (SPSS Inc, Chicago, Illinois, USA).

5.4 Results

Bond strength

Table 5.2 shows the results of the shear and tensile bond strengths. The results of the ANOVA demonstrated statistical differences between Transbond XT, Fuji Ortho LC, and Fuji IX Fast (P<0.001). Transbond XT showed the highest results, while Fuji IX Fast gave the lowest results. There was also a clear difference between the shear and tensile strength results, with the shear strength results being significantly higher (P<0.05). No clear difference in bond strength was found between the four different pre-treatment methods of the bracket bases. Regarding the shear test results, the control group of Transbond XT showed significantly higher values compared with the tin-plated group. For Fuji Ortho LC the tin-plated group gave the highest results. The tensile test results showed less variation.
Table 5.2  Shear and tensile bond strengths (in MPa) together with the standard deviations for the different variables.

<table>
<thead>
<tr>
<th>Shear bond strength</th>
<th>Control</th>
<th>Sandblasted</th>
<th>Silicoated</th>
<th>Tin-plated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transbond XT</td>
<td>18.3\textsuperscript{Aa} (4.3)</td>
<td>16.3\textsuperscript{ABa} (5.1)</td>
<td>14.0\textsuperscript{ABa} (5.3)</td>
<td>12.4\textsuperscript{Ba} (3.8)</td>
</tr>
<tr>
<td>Fuji Ortho LC</td>
<td>8.5\textsuperscript{Bb} (3.4)</td>
<td>11.1\textsuperscript{ABb} (7.8)</td>
<td>9.8\textsuperscript{Bab} (5.6)</td>
<td>15.1\textsuperscript{Aa} (3.1)</td>
</tr>
<tr>
<td>Fuji IX Fast</td>
<td>3.7\textsuperscript{Ac} (2.5)</td>
<td>2.6\textsuperscript{Ac} (1.6)</td>
<td>4.3\textsuperscript{Ab} (1.4)</td>
<td>4.3\textsuperscript{Ab} (2.6)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tensile bond strength</th>
<th>Control</th>
<th>Sandblasted</th>
<th>Silicoated</th>
<th>Tin-plated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transbond XT</td>
<td>5.6\textsuperscript{Aa} (1.0)</td>
<td>6.7\textsuperscript{Ba} (0.5)</td>
<td>6.1\textsuperscript{Aa} (0.9)</td>
<td>6.2\textsuperscript{Aa} (0.4)</td>
</tr>
<tr>
<td>Fuji Ortho LC</td>
<td>4.5\textsuperscript{ABb} (0.5)</td>
<td>4.9\textsuperscript{Ab} (0.6)</td>
<td>4.0\textsuperscript{Bab} (1.0)</td>
<td>3.2\textsuperscript{Cb} (0.5)</td>
</tr>
<tr>
<td>Fuji IX Fast</td>
<td>1.5\textsuperscript{Ac} (0.4)</td>
<td>1.6\textsuperscript{Ac} (0.6)</td>
<td>1.6\textsuperscript{Ac} (0.5)</td>
<td>1.9\textsuperscript{Ac} (0.5)</td>
</tr>
</tbody>
</table>

Equal capital characters indicate statistical equality within the material (horizontal).
Equal small characters indicate statistical equality within the pre-treatment (vertical).

ARI scores

Table 5.3  Frequency distribution together with the averages of the adhesive remnant index-scores of the shear and tensile measurements.

<table>
<thead>
<tr>
<th>ARI score</th>
<th>Shear tests</th>
<th>Tensile tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 1 2 3 Av.</td>
<td>0 1 2 3 Av.</td>
</tr>
<tr>
<td>Transbond XT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0 2 5 3 2.1</td>
<td>0 1 1 8 2.7</td>
</tr>
<tr>
<td>Sandblasted</td>
<td>0 5 0 5 2.5</td>
<td>0 1 0 9 2.8</td>
</tr>
<tr>
<td>Silicoated</td>
<td>1 0 7 2 2.1</td>
<td>1 7 1 1 1.2</td>
</tr>
<tr>
<td>Tin-plated</td>
<td>2 1 5 2 1.7</td>
<td>1 1 1 7 2.4</td>
</tr>
<tr>
<td>Fuji Ortho LC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1 0 3 6 2.4</td>
<td>0 0 2 8 2.8</td>
</tr>
<tr>
<td>Sandblasted</td>
<td>0 1 6 3 2.2</td>
<td>0 0 1 9 2.9</td>
</tr>
<tr>
<td>Silicoated</td>
<td>0 0 6 4 2.4</td>
<td>0 0 2 8 2.8</td>
</tr>
<tr>
<td>Tin-plated</td>
<td>0 0 2 8 2.6</td>
<td>0 0 0 10 3</td>
</tr>
<tr>
<td>Fuji IX Fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1 2 4 3 1.9</td>
<td>0 0 1 9 2.9</td>
</tr>
<tr>
<td>Sandblasted</td>
<td>6 4 0 0 0.4</td>
<td>1 1 8 0 1.7</td>
</tr>
<tr>
<td>Silicoated</td>
<td>3 4 1 2 1.2</td>
<td>1 1 1 7 2.4</td>
</tr>
<tr>
<td>Tin-plated</td>
<td>4 0 0 6 1.8</td>
<td>0 0 0 1 9 2.9</td>
</tr>
</tbody>
</table>

A score of 0 indicates that no adhesive was left on the enamel, 1 that less than half of the adhesive remained, 2 more than half remained, and 3 all adhesive remained on the enamel surface.

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The ARI scores for the shear and tensile measurements are presented in Table 5.3. The average ARI scores for Transbond XT and Fuji Ortho LC were between 2.1 and 3.0. This means that fracture occurred mainly between the bracket and the cement. Combined with the bond strength results, no improvement of the pre-treatment procedure could be discovered. Fuji IX Fast showed, for most of the tests, a low ARI score.

5.5 Discussion

The use of glass ionomer based cements for bracket bonding is gaining popularity because of the believed cariostatic effect. It is not however a commonly used material for bracket bonding because of the assumed inferior bonding properties compared with resin composite. This assumption is supported in the present study. The specimens composed with resin composite provide significantly stronger bonding, while the brackets bonded with conventional GIC gave the lowest results.

The main purpose of the present study was to evaluate the influence of modifying the mesh base on the bond strength. The different cements were evaluated in relation to different bases. The results show that only tin-plating had a positive effect on the shear strength of Fuji Ortho LC. This is partly in line with the results of Swartz et al. (21), who found an improvement in the tensile strength when tin-plating in combination with a RMGIC was used. The tensile strength of the RMGIC bonded to the tin-plated bases in the present study did not improve.

Except for the RMGIC group bonded with tin-plated brackets, neither the shear nor the tensile strength changed dramatically. Therefore, the conviction is still that no clinically significant influence of any of the modification procedures can be expected.

Regarding the ARI scores, most specimens fractured at the bracket-cement interface. This was more pronounced in the tensile than in the shear tests. One explanation may be that the stress distribution over the specimens is different in both tests. The bracket-cement interface is more resistant to compressive then to tensile stress. The ARI scores did not change as a result of the base pre-treatments when they were compared with the control groups.

The type of material is of influence on the bonding of a bracket to the cement. In the shear groups the GIC showed more breakage inside the cement or at the enamel interface compared with the RMGIC or composite groups.

The bond strength results as well as the ARI scores found in this study support the theory that not only the internal strength of the cement plays a role in the bracket-cement bonding, but also the elasticity of the cement and the other components of the
bracket-cement-enamel system. To find bond strength improvements the scope of research might be primarily on this property of the bracket-cement-enamel system.

5.6 Conclusions

No clear improvement was found in relation to the pre-treatments of the bracket bases. This means that surface enlargement by means of sandblasting or establishing a chemical bonding between the bracket and the cement was not successful. It is likely that other factors are responsible for the resistance to fracture.
5.7 References


