An in vitro evaluation of shear bond strength of chemical and light-cured bonding materials with stainless steel, ceramic, and sapphire brackets

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ABSTRACT

Background: This study was intended to compare shear bond strength of chemical and light-cured bonding materials with stainless steel, ceramic, and sapphire brackets, and to measure adhesive remnant index after debonding.

Materials and method: Sixty non-carious, free of cracks upper first premolar teeth, which have been extracted from 18-25 years old Iraqi patients seeking orthodontic treatment were selected. Three types of orthodontic brackets were used in this study: stainless-steel, ceramic, and sapphire brackets. All bracket types used were of standard edgewise system. The teeth were divided into two groups of 30 teeth each. One group was used for testing the chemically-cured primer-activated resin of no-mix type, while the other was used for testing of the light-cured resin. The chemically and light-cured groups were further subdivided according to bracket type into three groups of 10 teeth each. The samples were tested for bond strength using an Instron universal testing machine, while for adhesive remnant index the enamel surface and bracket base of each tooth were inspected under magnifying lens (20X) of a stereomicroscope.

Results: The highest shear bond strength values were found in sapphire brackets followed by stainless steel and ceramic brackets respectively, both in no-mix and light-cured groups as revealed by ANOVA test. T-test showed that the shear strength values were higher for all light-cured groups as compared to no-mix groups.

Conclusions: Sapphire brackets have the highest shear bond strength as compared to stainless-steel and ceramic brackets. Light-cured resin has better bonding properties than no-mix resin.

Key words: Shear bond strength, stainless steel, ceramic, sapphire.

INTRODUCTION

Composite resins form the basis of most orthodontic adhesives. In clinical use, it is important that material used to bond attachments to etched enamel surfaces can change quickly from a fluid to a solid state. Setting polymerization may be achieved either by chemical interaction between components of a resin system or by photo-initiation, the uptake of energy by exposure of resin to a suitable light source. (1-3)

The use of acid etch techniques in the direct bonding of orthodontic brackets was reported in 1965 by Newman (2) and the direct bonding of orthodontic brackets is perhaps the most significant development in orthodontics during the past three decades. Bonding orthodontic brackets to tooth surfaces improves the esthetic aspect of orthodontic appliances, minimizes treatment time, and allows a better standard of oral hygiene to be achieved. (1-3)

Chemically cured composite were the first system developed for bracket bonding (4), while Tavas and Watts (5) described the use of visible light to cure composites used in orthodontic bonding in 1979. Both light-cured and chemically-cured composites have been shown to be clinically acceptable and effective (6). However, several investigations comparing the bond strengths and clinical failures rates of brackets bonded with light-cured and chemically-cured composites have shown conflicting results both in vitro (7-9) and in vivo (10-13). (14)

Bond strength can be defined as force per unite area required to break a bonded assembly with failure occurring in or near the adhesive/adherened interface, it is commonly reported in units of megapascals (MPa). (15, 16) Almost all bond strength tests are categorized as tensile or shear bond strength (17, 18).

The purpose of either a tensile, microtensile or shear bond strength test is to establish a numeric value in order to determine how strong that bond was. (19-21) Shear testing is important since it presents reliable results and because shear stress is more representative in a clinical situation. (19, 20, 22)

Although shear testing is more widely used, it might also be more technique sensitive than
tensile testing, because shear bond strength measurement were significantly influenced by the direction of debonding force, indicating the need for control and standardization of this testing parameter in orthodontic shear bond strength testing. The bond strength of adhesive and attachments should be sufficient to withstand the forces of mastication, the stresses exerted by the arch wires, and patient abuse. Also bond strength should be high enough to resist accidental debonding during treatments and allow for control of tooth movement in all 3 planes of space. At the same time, the bond strength should be low enough to allow for bracket debonding without causing damage to the enamel surface.

The purpose of present study is to compare shear bond strength of chemical and light-cured bonding materials with stainless steel, ceramic, and sapphire brackets, and to measure adhesive remnant index after debonding.

MATERIALS AND METHOD

The Sample

One hundred seventy five upper first premolar teeth were collected, which have been extracted from 18-25 years old Iraqi patients seeking orthodontic treatment. After extraction, the teeth were washed by water to remove any traces of blood. Then each tooth was thoroughly scaled and rinsed to remove calculus, soft tissue remnants, and debris. The collected teeth were stored in distilled water containing crystals of thymol, and that was changed weekly to prevent dehydration and bacterial growth in closed container at room temperature until preparation and testing. Sixty teeth were selected after examining the teeth first with 10X magnifying lens, and then by a beam of light approach proximally with halogen light cure unit shining through each tooth to be grossly intact enamel surface, with no surface cracks from extraction forcepts, free of caries. Also teeth pretreated with chemical agents, such as hydrogen peroxide were excluded. Three types of orthodontic brackets were used in this study: Stainless-steel (Bionic®) brackets, Ceramic (Reflections®) brackets, and Sapphire (Pure®) brackets. The base surface area of the Bionic®, Reflections®, and Pure® brackets were: 10.9 mm², 12.2 mm², and 11.9 mm² respectively, as provided by the company (Ortho Technology Company, USA).

Method

The selected sixty teeth were divided into two groups of 30 teeth each. One group was used for testing the chemically-cured primer activated resin of no-mix type (Resilience®, Ortho Technology Company, USA), while the other was used for testing of the light-cured resin (Resilience®, Ortho Technology Company, USA). The chemically-cured (no-mix) group was further subdivided into three groups of 10 teeth each:

- **Group A** had stainless steel brackets (SSNM).
- **Group B** had ceramic brackets (CNM).
- **Group C** had sapphire brackets (SNM).

The light-cured group of 30 teeth was similarly subdivided into three groups of 10 teeth each:

- **Group D** had stainless steel brackets (SSLC).
- **Group E** had ceramic brackets (CLC).
- **Group F** had sapphire brackets (SLC).

All the teeth were mounted, retentive wedge shaped cuts were made along the sides of the roots of each tooth to increase the retention of the teeth inside the self-cured acrylic blocks. Each tooth was then fitted on a glass slab in a vertical position using soft sticky wax at the root apex, in a way that the middle third of the buccal surface was oriented to be parallel to the analyzing rod of the surveyor, so that the force could be applied at right angle to the enamel-bracket interface because shear bond strength measurements were significantly influenced by the direction of the debonding force (Fig. 1). Two other teeth were fixed following the above mentioned procedure with 1cm apart between them on the same glass slab. The occlusal surfaces of the three teeth were oriented to same height by cutting from the root apices using a stone disc bur. Then two L-shaped metal plates, were painted with a thin layer of separating medium (Vaseline) and placed opposite to each other to form a box around the teeth (Fig. 1).

Powder and liquid of self-cured acrylic were mixed and poured around the teeth to the level of the cemento-enamel junction of each tooth. After setting of the cold-cured acrylic resin, the two L-shaped metal plates were removed, the sticky wax used for fixation of teeth in the proper orientation removed too and the resulting holes filled with cold-cured acrylic. Each specimen was divided into three cubic blocks holding only one tooth using electrical saw, so that every tooth can be bonded separately. The mounted teeth were stored in distilled water containing thymol crystal to prevent dehydration until bonding. The buccal surface of each tooth polished with slurry non-fluoridated pumice for 10 seconds, then washed with water spray for 10 seconds, and dried with oil-free air for 10 seconds. Phosphoric acid gel was applied for 15 seconds, washed with air water spray for 20 seconds, and then dried with oil-free air for another 20 seconds, until the buccal surface of the etched tooth appeared chalky white in color. A load of about 300g was attached to the
vertical arm of the surveyor to standardize the pressure applied on the brackets during bonding. The bonding agents (chemical and light-cured) were handled according to manufacturer's instruction. Each bracket was placed at the center of the buccal surface, the load was applied for 10 seconds, and any excess material was removed with explorer.

For the light-cured group, the light source was of LED type (light emitting diode) (HANGZHOU SIFANG MEDICAL APPARATUS Co., China) that was applied mesially and distally for 40 seconds (20 seconds for each) with a minimum separation distance (1-2) mm.

Every tooth was left undisturbed for 30 minutes to ensure complete polymerization of adhesive material, then all the bonded teeth were placed in normal saline for 24 hours until bracket debonding.

The samples were tested for bond strength using an Instron universal testing machine. A crosshead speed of 0.5mm/minute was used, readings were recorded in Newtons. The force was divided by the surface area of the bracket base to obtain the stress value in Mega Pascal Units.

Adhesive Remnant Index (ARI)

After debonding procedure, the enamel surface and bracket base of each tooth were inspected under magnifying lens (20X) of a stereomicroscope. ARI scores were assessed by the same operator. The enamel surface was scored according to Wang classification as follows:

Score I: Failure between bracket base and adhesive.
Score II: Cohesive failure within the adhesive itself.
Score III: Adhesive failure between adhesive and enamel.
Score IV: Enamel detachment.

Statistical analyses

Data were collected and analyzed using SPSS (statistical package of social science) software version 15 for windows XP Chicago, USA. The following statistics were used:

A. Descriptive statistics: including mean, standard deviation, minimum and maximum values.
B. Inferential statistics: including the following tests;

1. One way analysis of variance (ANOVA): to test any statistically significant difference between the shear bond strength of different bracket types for each one of the two resin groups.
2. Least significant difference (LSD): to compare between each two groups of bracket types when ANOVA showed a statistically significant difference.
3. Independent samples t-test: to compare statistically between the means of the shear bond strength for each similar bracket type between no-mix and light-cured group.

In the statistical evaluation, the following levels of significance are used:

<table>
<thead>
<tr>
<th>Levels of Significance</th>
<th>Probability Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-significant (NS)</td>
<td>P &gt; 0.05</td>
</tr>
<tr>
<td>Significant *</td>
<td>0.05 ≥ P &gt; 0.01</td>
</tr>
<tr>
<td>Highly significant **</td>
<td>0.01 ≥ P &gt; 0.001</td>
</tr>
<tr>
<td>Very highly significant ***</td>
<td>P ≤ 0.001</td>
</tr>
</tbody>
</table>

P= probability value.

RESULTS

Shear bond strength values were compared between two bonding techniques: chemical-cured of no-mix type and light-cured using three bracket types namely: stainless steel, ceramic, and sapphire.

Effect of bracket type

The highest shear bond strength values were found in sapphire brackets followed by stainless steel and ceramic brackets respectively, both in no-mix and light-cured groups. ANOVA test revealed a very high significant difference in no-mix and high significant difference in light-cured groups (table 1). The LSD test showed that for no-mix group, highly significant differences were found between all bracket types; while light-cured group had significant differences only when comparing sapphire to the other two bracket types (table 2).

Effect of bonding technique

The shear bond strength values were higher for all light-cured groups as compared to no-mix groups. T-test showed that there were very high significant differences between light-cured and no-mix groups for both stainless steel and ceramic brackets. On the other hand the difference had a lower level of significance in sapphire brackets, as compared to stainless steel and ceramic brackets (Table 1).

Adhesive Remnant Index

Stainless steel brackets bonded with no-mix were mainly showed cohesive failure within the adhesive itself (score II 80%), while that bonded with light-cured were debonded with 50% cohesive failure within the adhesive itself and 40% failure between bracket base and adhesive (score I). Ceramic brackets bonded with no-mix showed 70% score I and 30% score II, when compared to that bonded with light-cured which debonded with 60% of score II and 40% of score III (adhesive failure between adhesive and
enamel). Regarding the sapphire brackets the major scores illustrated during debonding were within score II and III whether bonded with no-mix or light-cured, but there was 10% of enamel detachment (score IV) within the no-mix group (Table 3).

DISCUSSION

With the exception of CNM (ceramic, no-mix) group, all "bracket type-adhesive" combination had a shear bond strength exceeding the minimum limits suggested by Reynolds(43) which is 6-8 MPa; to be able to withstand masticatory and orthodontic forces, which would be adequate for most clinical orthodontic needs.

The results may be viewed in light of the retention means provided with each bracket base. The sapphire bonding base is coated with zirconia powder creating millions of undercuts that mechanically lock with the bracket adhesive. Ceramic bracket has three dove tail grooves only. Stainless steel is equipped with 80 Gauge Foil Mesh Bonding Base (Fig. 2) (Ortho technology product catalog).

It seems that the design of sapphire bracket base allowed for a better retention of the resin to the base, which also accounted for that none had resin-bracket base failure (score I), 60% had all resin removed with the bracket (50% score III and 10% score IV) in no-mix group, and 50% in light-cured group (score III). The shear bond strength of sapphire brackets was the highest in light-cured and no-mix groups. The presence of zirconia particles coating the bracket base creates millions of undercuts that secure the bracket in place, due to the micro mechanical retention means. This revealed a significant difference in light-cured group and in no-mix group when compared to other bracket types. In more practical words, it was greater by 1.32 times than stainless steel brackets, and 2.91 times than ceramic brackets in the light-cured group and in no-mix group; and it was 1.24 times that of stainless steel and 1.47 times that of ceramic brackets in the no-mix group. The translucency that sapphire brackets have gives a better chance for a more complete polymerization with light curing as compared to other bracket types. This gives the operator more confidence to use sapphire brackets keeping in mind that it has a lower possibility of failure as compared to other bracket types.

On the other hand ceramic brackets had the lowest shear bond strength in both light-cured and no-mix groups. Its shear bond strength has a non significant difference in light-cured group when compared to stainless steel bracket, being about 0.85 times that of stainless steel bracket. This may be attributed to that it is only provided with three relatively large dove tail grooves to hold the bracket in place (Fig. 2). In the no-mix group, this may account for a portion of composite being left unexposed to the bonding agent, in other words it is non polymerized which provide a site for gap formation and poor bond strength. This can be highly correlated to the adhesive remnant index findings. In the no-mix group; 70% had the site of failure located at the resin-base interface (with a very small remnant trapped in the dovetails) (score I), while 30% had a site of failure within the resin material itself (score II). In the light-cured group, with the increased degree of polymerization, we can see that none had a score I, and all of the brackets fall between score II and III, indicating that the force retaining the composite into the base is equal to or higher than the retentive force of the resin to the tooth surface.

Stainless-steel brackets had good shear bond strength with a minimum value approaching the highest limit set by Reynolds(43) in the no-mix group, and exceeding it in the light-cured group.

Light-cured group recorded higher shear bond strength values for all bracket types when compared to the no-mix group. Combined with the "on-command curing", light-cured resin provide a better choice for bonding fixed appliances, we should keep trying to find a way to reduce the time required for curing the resin (for ex. using halogen arc). There were several studies with controversial results regarding whether light-cured resin is weaker than no-mix resin(8, 12), both acceptable with no difference(11, 13), or is stronger than the no-mix resin(9) this may be due to variation in methodology, materials, and equipment used in the course if each research.

REFERENCES


Orthodontics, Pedodontics and Preventive Dentistry

Table 1: Descriptive Statistics, ANOVA and T-test for shear bond strength according to bracket types and bonding techniques

<table>
<thead>
<tr>
<th>Bracket Type</th>
<th>No-Mix (n=10)</th>
<th>Light Cure (n=10)</th>
<th>t-test (df= 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
</tr>
<tr>
<td>Shear Bond</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceramic</td>
<td>7.80</td>
<td>9.08</td>
<td>8.624</td>
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<tr>
<td>Sapphire</td>
<td>2.79</td>
<td>5.00</td>
<td>3.918</td>
</tr>
<tr>
<td>ANOVA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>Mean Square</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>143.744</td>
<td>28.208</td>
</tr>
</tbody>
</table>

Table 2: LSD test for shear bond strength between bracket types in no-mix and light-cured groups

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>p</th>
<th>Group 1</th>
<th>Group 2</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSNM</td>
<td>CNM</td>
<td>-4.706</td>
<td>.000***</td>
<td>SSLC</td>
<td>CLC</td>
</tr>
<tr>
<td>SSNM</td>
<td>SNM</td>
<td>-2.796</td>
<td>.010**</td>
<td>SSLC</td>
<td>SLC</td>
</tr>
<tr>
<td>CNM</td>
<td>SNM</td>
<td>-7.502</td>
<td>.000***</td>
<td>CLC</td>
<td>SLC</td>
</tr>
</tbody>
</table>


Table 3: Scores of Adhesive Remnant Index for each of the six groups

<table>
<thead>
<tr>
<th>Bracket-Bonding Type</th>
<th>Score I (%)</th>
<th>Score II (%)</th>
<th>Score III (%)</th>
<th>Score IV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSNM</td>
<td>0 (0)</td>
<td>8 (80)</td>
<td>2 (20)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>CNM</td>
<td>7 (70)</td>
<td>3 (30)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SNM</td>
<td>0 (0)</td>
<td>4 (40)</td>
<td>5 (50)</td>
<td>1 (10)</td>
</tr>
<tr>
<td>SSLC</td>
<td>4 (40)</td>
<td>5 (50)</td>
<td>1 (10)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>CLC</td>
<td>0 (0)</td>
<td>6 (60)</td>
<td>4 (40)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SLC</td>
<td>0 (0)</td>
<td>5 (50)</td>
<td>5 (50)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

Figure 1: A, fitting of the tooth on a glass slab with a soft sticky wax in a way that the middle third of the buccal surface was oriented to be parallel to the analyzing rod of the surveyor. B, mounting of the teeth with a retentive wedge shaped cuts were made along the sides of the roots of each tooth. C, the two L-shaped metal plates placed opposite to each other to form a box around the teeth.

Figure 2: Bracket bases of sapphire brackets (showing zirconia particles in higher magnification). Ceramic brackets (showing the dove tail grooves), and the stainless steel bracket (with its 80 gauge foil mesh).