Determination of optimum adhesive thickness using varying degrees of force application with light-cured adhesive and its effect on the shear bond strength of orthodontic brackets: An in vitro study

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Aim: The thickness of the adhesive layer under a bracket may be an important factor that affects the final tooth position and bond strength. With increasing use of pre-adjusted brackets, it is important to ensure that a consistently even layer of composite is placed under each bracket to take full advantage of bracket design and to avoid the need for compensatory bends to be placed in the archwire. Therefore, the present study is aimed at determining the optimum adhesive thickness by varying the force of application and observing the effect on the shear bond strength of orthodontic brackets. Methods: Sixty premolars extracted for orthodontic purposes were divided into three groups of 20 samples each. Adhesive thickness was measured by varying the force of application while bonding brackets with light-cured adhesive and tested on a universal testing machine to evaluate the shear bond strength. Results: The study showed that adhesive thickness is inversely proportional to applied force. In addition, the shear bond strength has a tendency to increase with a decrease in adhesive thickness up to a certain extent and then decrease. Conclusion: Adhesive thickness between bracket base and tooth surface decreases with an increase in the amount of force application from 1 to 3 oz. Mean shear bond strength increases when adhesive thickness decreases from 0.99 to 0.83 mm, and then it has a tendency to decrease when adhesive thickness decreases to 0.72 mm. Optimum adhesive thickness should be considered to be 0.83 mm, which is the thickness required to achieve sufficient bond strength to prevent chances of bond failure. ORTHODONTICS (CHIC) 2013;14:e40–e49. doi: 10.11607/ortho.919

Key words: adhesive thickness, force application, shear bond strength
Imperfect adaptation of a bracket base to the tooth surface results in a variable thickness of adhesive. A minimal adhesive thickness has been reported necessary to achieve optimal bond strength, but increased thickness also has been reported to weaken the joint because of the introduction of imperfections and increased polymerization shrinkage. With increasing use of preadjusted brackets, it is important to ensure that a consistently even layer of composite is placed under each bracket to take full advantage of bracket design and to avoid the need for compensatory bends to be placed in the archwire.

Schechter et al reported that with increased adhesive thickness tensile bond strength was not affected, whereas shear bond strength decreased as thickness increased. Mackay reported that increasing the thickness of two chemically cured and two light-cured composite resins from 0 to 0.26 mm had no statistically significant effect on their mean shear bond strength, although the trend was for decreased strength.

Jost-Brinkmann et al investigated the effect of adhesive layer thickness on bond strength. He recommended that macrofilled, chemically cured paste-paste composite should be used if the adhesion layer thickness must be greater than 0.2 mm. Arici et al studied the adhesive thickness effects on the tensile and shear bond strength of a light-cured modified glass-ionomer cement. He concluded that the light-cured, resin-modified glass-ionomer cement had its highest mean bond strength at a thickness of 0.25 mm in both tensile and shear test modes.

These studies investigated the effect of adhesive thickness on the bond strength of orthodontic brackets. However, to date, there is no data available concerning the optimum adhesive thickness needed to obtain clinically relevant shear bond strength. Therefore, this investigation is intended to determine optimum adhesive thickness using varying degrees of force application with conventional light-cured adhesive and evaluate the effect on shear bond strength.

**METHODS**

A total of 60 maxillary premolars extracted for orthodontic purpose were collected and stored in distilled water for 48 hours. The criteria for tooth selection included intact premolars without any caries, restoration, enamel cracks, hypoplasia, or abnormal anatomy. The teeth were thoroughly cleaned of any soft tissue debris or blood and were stored immediately in distilled water at room temperature. The selected teeth were mounted in self-curing color-coded acrylic blocks to permit subsequent identification. All 60 specimens were divided into groups A (clear acrylic), B (green acrylic), and C (orange acrylic), with 20 samples in each group. The specimens in each group were subjected to a specific amount of force while bonding: group A, 1 oz; group B, 2 oz; and group C, 3 oz.

The teeth were rinsed under tap water and cleaned with oil-free, nonfluoridated fine pumice using a micromotor; rinsed; and dried with a three-way syringe. Etching was done using 37% orthophosphoric acid gel etchant (Viscous Etch, Orthosource) for 30 seconds. The teeth were then rinsed and dried using absolute alcohol and acetone solution (dehydrating agent) until the buccal surface of the etched teeth appeared to be chalky white in color.

Firstly, to determine adhesive thickness for group A, the buccolingual thickness of each tooth along with the bracket was measured three times, and the mean value was calculated to compensate for irregular tooth shape associated with premolars using a digital vernier caliper (Mitutoyo USA) (Fig 1). Then, Transbond XT primer (3M Unitek) was applied using an applicator tip and light cured for 5 seconds. Preadjusted edgewise premolar brackets (Gemini series
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0.022-inch Roth, 3M Unitek) were placed in the center of the tooth, parallel to the long axis with Transbond XT composite resin. After the bracket was properly positioned on the tooth, each bracket was subjected to a 1-oz force applied at the center of the bracket using the fork end of a force gauge (dontrix gauge) (Fig 2), and excess bonding resin was removed using a scaler. The adhesive was light cured using a TURBO Bee Cool light-curing unit (Confident Dental Equipments Ltd) with a 5 W light-emitting diode with an average light intensity of 950 mW/cm² and wavelength of 450 to 490 nm (intensity maximum at 460 nm) for 40 seconds according to the manufacturer’s instructions. The buccolingual thickness of each sample was recorded again with a digital vernier caliper (Fig 3). Hence, the difference in buccolingual thickness of each tooth prior to and after bonding the bracket was measured, and adhesive thickness was determined for a 1-oz force application. All steps were performed by the same operator.

The adhesive thickness of specimens in groups B and C was determined in a similar manner as used for group A but with force applications of 2 and 3 oz, respectively. After bonding, all the specimens were stored in distilled water for 24 hours, at room temperature, before the shear bond strength testing was done.
Shear bond strength testing was performed with a universal testing machine (model no. 3366, Instron). The machine was set and calibrated according to the manufacturer’s instructions. The acrylic blocks with embedded tooth and bonded bracket were secured in the lower jaw (crosshead) of the universal testing machine, with the long axis of tooth and bracket base parallel to the direction of shear force applied. A loop was made using 0.017 × 0.025–inch stainless steel wire, and the ends of the wire were gripped in the upper jaw (crosshead) and under the gingival tie wings by adjusting the crosshead. The specimens were stressed in the occlusogingival direction with a crosshead speed of 0.5 mm/s (Fig 4).

STATISTICAL ANALYSIS

The test statistics were performed using a statistical package for social sciences (SPSS version 13, IBM). Descriptive statistics including the mean, standard deviation, and confidence interval for mean were calculated for each group of teeth tested. Analysis of variance (ANOVA) was used to determine whether significant differences existed between the various groups compared. The Bonferroni multiple comparison test was applied to find the group with a significant difference. Significance of level was predetermined at $P$ value < .001. Pearson correlation test was performed to correlate the relationship between adhesive thicknesses and shear bond strength. The Weibull analysis was performed to calculate characteristic bond strength and the Weibull modulus.

RESULTS

The mean, standard deviation, and 95% confidence interval of adhesive thickness values for all three groups are given in Table 1. The mean adhesive thickness was found to be 0.99 ± 0.05 mm for group A. In the group B, the mean adhesive thickness observed was 0.83 ± 0.04 mm. Group C shows the mean adhesive thickness of 0.72 ± 0.07 mm. Table 2 depicts multiple comparisons of adhesive thickness between the groups using the Bonferroni test.
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Table 3 shows the mean, standard deviation, and 95% confidence interval of shear bond strength values for all the groups. The mean shear bond strength for group A was 6.36 ± 1.27 MPa. Group B showed a mean shear bond strength of 9.55 ± 1.44 MPa, while group C had a mean shear bond strength of 8.57 ± 1.73 MPa. Table 4 depicts multiple comparisons of shear bond strength between the groups using the Bonferroni test.

Table 5 shows the correlation between adhesive thickness and shear bond strength using the Pearson correlation test. Tables 6 and 7 show the Weibull analysis for adhesive thickness and shear bond strength, respectively. Figures 5 and 6 show the Weibull curves demonstrating probability of failure against force and adhesive thickness, respectively, for each group.
DISCUSSION

Shear bond strength is influenced by many variables that may or may not be under the control of the clinician. Therefore, it is important for the clinician to be aware of how these variables affect shear bond strength and apply this knowledge in their selection of the optimal bonding/adhesive technique.

Orthodontists commonly believe that a minimal amount of composite between bracket base and enamel is necessary to achieve the optimum bond strength and to have a close adaptation of the bracket to the tooth surface. A couple of studies have investigated the effect of adhesive thickness on the bond strength of orthodontic brackets. However, to date, there is no data

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<th>Table 5</th>
<th>Pearson correlation test for adhesive thickness (mm) and shear bond strength (MPa)</th>
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<td>C</td>
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*Significant difference.
†Nonsignificant difference.

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available concerning the optimum adhesive thickness needed to obtain clinically satisfactory shear bond strength. Therefore, this investigation was intended to determine optimum adhesive thickness using varying degrees of force application with conventional light-cured adhesive and evaluate the effect on shear bond strength.

In the present study, technique inconsistencies were minimized by using the same kind of bracket and adhesives for all three groups and by developing easily reproducible test methods.

Farmarz and Akhoundi reported that debonding with a shear blade produced higher and more dispersed bond strengths compared with the wire loop method when subjected to similar clinical loads. Hence, in the present investigation, the wire loop method was used to debond the brackets.

Fig 5  Probability of failure against force for each group (Weibull curves).

Fig 6  Probability of failure against adhesive thickness for each group (Weibull curves).
The direction of the wire loop can also influence the bond strength, as shown by Klocke and Kahl-Nieke, who concluded that mean shear bond strength decreased from an angle of +15 degrees (directed toward bracket base) to −45 degrees (directed away from bracket base). In the present study, the direction of the wire loop was consistently held parallel to the long axis of the tooth and bracket base–adhesive tooth interface.

Mean adhesive thickness obtained by applying a force of 1, 2, and 3 oz to group A, B, and C samples were 0.99, 0.83, and 0.72 mm, respectively (see Table 1). Thus, the increase in the applied pressure results in the decreased thickness of the adhesive between bracket base and tooth surface. Adhesive thicknesses achieved in the three groups are highly statistically significant \((P < .001)\) when they are compared with each other using Bonferroni multiple comparisons test (see Table 2). Most of the studies performed previously used firm pressure while placing the bracket on the enamel surface with the assumption that uniform thickness of adhesive is achieved, but as shown in Table 1, even a change of 1 oz of force brings about significant change in adhesive thickness. Eliades and Brantley stated that efforts to adjust the pressure by applying a fixed load to the bracket will yield more consistent results.

Adhesive thickness obtained in this study by varying the force of application relates only to the adhesive Transbond XT, as thickness of adhesive between enamel surface and bracket depends on the type of adhesive used, as suggested by Mackay. He also noted that the stiffness of each material is in turn dependent on the size, type, and amount of the filler content and the monomer used. Therefore, different types of adhesive resins will produce different thicknesses under the same amount of force.

Mean shear bond strengths obtained for groups A, B, and C are 6.36, 9.55, and 8.57 MPa, respectively (see Table 3). This suggests that as the thickness of the adhesive reduces, shear bond strength increases from group A (6.36 MPa) to group B (9.55 MPa) but decreases in group C (8.57 MPa). ANOVA test results shows that there is a statistically highly significant \((P < .001)\) relationship between adhesive thickness and shear bond strength. However, Mackay reported that increasing the thickness of adhesives had no statistically significant effect on their mean shear bond strength, although the trend was for it to decrease.

Similar results were obtained by Schechter et al, who showed that shear bond strength decreased as thickness increased, while tensile bond strength remained unaffected. However, in another study, the tensile bond strength was decreased with increased adhesive thickness with both chemically cured and no-mix composite resins. These results are similar to that reported by Jost-Brinkmann et al. Although these findings are quite similar to our findings, this cannot be compared directly because the material and methodology in these studies were different from the present study.

As suggested by Buonocore and Alster et al, increasing the thickness of the adhesive layer between enamel surface and bracket base results in a weaker joint because of the increased polymerization shrinkage seen in thicker layers, along with the imperfections that lead to an increase in stress concentrations and hence decreasing strength.

These conclusions correlate with the present findings, where group A (0.99 mm) had less shear bond strength (6.36 MPa) in comparison to group B (0.83 mm) showing bond strength of 9.55 MPa. This is also supported by the Bonferroni multiple comparison test (see Table 4), which shows a highly statistically significant \((P < .001)\) difference in shear bond strength between groups A and B as well as between groups A and C.

An interesting finding to be noted here is that shear bond strength reduces in group C (8.57 MPa), although its thickness is minimum (0.72 mm). An
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explanation of this finding could be that strength of any material depends on its volume to a larger extent, and since the thickness of group C is minimum, bond failure can be expected to occur early. Li et al.\textsuperscript{12} also reported that volume of filler had a greater effect on physical and mechanical properties than filler size. Similar to this finding, Arici et al.\textsuperscript{6} reported that the mean shear bond strength increased as adhesive thickness increased; they tested shear bond strength at intervals of 0.25-mm thickness from 0 to 0.5 mm. Thus, it can be inferred that optimum adhesive thickness is required because bond strength has a tendency to decrease with decreasing thickness.

Although the mean shear bond strength of group C (8.57 MPa) is less than that of group B (9.55 MPa), the difference is not statistically significant (see Table 4). However, both groups show shear bond strength greater than the clinically acceptable range of 5.9 to 7.9 MPa, as suggested by Reynolds.\textsuperscript{13}

The Pearson correlation test (see Table 5) shows that there is an inverse correlation between adhesive thickness and shear bond strength in group A (\(\rho = -0.528\)) that is statistically significant. This suggests that as adhesive thickness decreases, shear bond strength increases. However, there is weak correlation present between adhesive thickness and shear bond strength in group B (\(\rho = 0.408\)), while group C does not show any correlation. Therefore, shear bond strength has a tendency to increase to a certain extent of adhesive thickness. However, a further decrease in adhesive thickness, as seen in group C, does not have any major impact on bond strength.

As indicated by Fox et al.,\textsuperscript{14} mean and standard deviation values of bond strengths are not the best indicators of the performance of bonding material. Therefore, a survival analysis, ie, the Weibull analysis, was performed to analyze the characteristic bond strength and the probability of failure for each of the materials. This analysis takes into account the tail values of bond strength in a distribution because they may be the ones that would fail in a clinical situation.

The reliability of the material is a function of the Weibull modulus and characteristic strength. The predictability of a group is given in the Weibull modulus (\(\beta\)). Higher modulus indicates a more predictable system and, possibly, a more clinically reliable system. In Weibull analysis of both adhesive thickness and shear bond strength (see Tables 6 and 7), group B produced higher modulus (\(\beta\)) values than the other groups; therefore, group B could be considered to be a more predictable and clinically reliable system.

The characteristic strength (\(\alpha\)) in the Weibull analysis refers to the adhesive thickness/bond strength at which 63.2\% of the samples fail and is similar to the mean derived from the ANOVA, which assumes a normal distribution. The ranking of the characteristic strengths of all groups was the same as those of their mean adhesive thickness/shear bond strengths.

It can be seen from Weibull analysis for shear bond strength (see Table 7) that the force needed for 99.9\% failure is maximum for group B (13.18 MPa) and minimum for group A (9.62 MPa). This means that group B can withstand higher forces when compared with all other groups.

If 5\% bond failure rate is considered clinically acceptable, it was shown that the force needed for 5\% failure is maximum for group B (6.83 MPa) and minimum for group A (4.08 MPa) (see Table 7). It again shows that group B can withstand greater forces when compared with all other groups.

There is not much difference between the mean shear bond strengths of group B (9.55 MPa) and group C (8.57 MPa), and both values are beyond the range recommended by Reynolds\textsuperscript{13} for clinical orthodontic purposes. However, as in group B, which had a mean shear bond strength of 9.55 MPa, a mean adhesive thickness of 0.83 mm could be considered an optimum adhesive thickness required to achieve sufficient bond strength to prevent bond failure. This could be supported by the fact that group B has a more predictable and
reliable clinical combination, as proved by the Weibull modulus and its shear bond strength, which is greater than that of group C. As stated earlier, thickness of the adhesive is subject to variable factors, such as the amount and viscosity of the adhesive resin, pressure applied during the bonding, changes in temperature, and humidity in the oral environment. Since the amount and type of adhesive used and patient oral environment remains the same most of the time in clinical practice, it can be concluded that pressure applied during bonding plays an important role in bond strength. Therefore, application of controlled bonding pressure (2 oz, as was obtained in this study) through a bracket holder that has a pressure gauge could be the correct way to gain a uniform optimum adhesive thickness (0.83 mm) between the bracket and enamel. Another clinical use of optimum adhesive thickness is in the field of adhesive precoated brackets, where the manufacturers can coat the bracket uniformly with the optimum thickness that will provide sufficient bond strength.

CONCLUSIONS

The adhesive thickness between the bracket base and tooth surface decreases with increasing amount of force application from 1 to 3 oz. Mean shear bond strength increases when adhesive thickness decreases from 0.99 to 0.83 mm, and then it has a tendency to decrease when adhesive thickness decreases to 0.72 mm. An adhesive thickness of 0.83 mm could be considered to be the optimum amount required to achieve sufficient bond strength and prevent bond failure.

REFERENCES