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Original Article

A Comparison of Bond Strength Between Direct- and Indirect-bonding Methods

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ABSTRACT

The purpose of this study was to evaluate and compare the shear bond strength and the sites of bond failure for brackets bonded to teeth, using two indirect-bonding material protocols and a direct-bonding technique. Sixty extracted human premolars were collected and randomly divided into three groups. The direct-bonded group (group 1) used a light-cured adhesive and primer (Transbond XT). One indirect-bonded group (group 2) consisted of a chemical-cured primer (Sondhi Rapid Set) and light-cured adhesive (Transbond XT), whereas the other group (group 3) used a light-cured primer (Orthosolo) and adhesive (Enlight LV). Forty hours after bonding, the samples were debonded. Mean shear bond strengths were 16.27, 13.83, and 14.76 MPa for groups 1, 2, and 3, respectively. A one-way analysis of variance showed no significant difference in mean bond strength between groups ($P = .21$). Furthermore, a Weibull analysis showed all three groups tested provided over a 90% survival rate at normal masticatory and orthodontic force levels. For each tooth, an Adhesive Remnant Index (ARI) score was determined. Group 2 was found to have a significantly lower ARI score ($P < .05$) compared with groups 1 and 3. In addition, Pearson correlation coefficients indicated no strong correlation between bond strength and ARI score within or across all groups. (*Angle Orthod* 2006;76:289–294.)

KEY WORDS: Indirect bonding; Bond strength; Light cure; In vitro

INTRODUCTION

Direct bonding has been in practice since 1965,[1] whereas indirect bonding was first introduced in 1972.[2] Since their introduction to orthodontics, both the direct[3,4] and the indirect[5–7] methods have seen refinements in technique and materials.

Over the years, several studies have been published comparing direct and indirect bonding, either in a clinical setting[8,9] or in vitro.[10–13] Klocke et al[12] compared direct-bonding with indirect-bonding procedures using heat-cured, light-cured, and chemical-cured adhesives in combination with a chemical-cure sealant. They reported that the two groups using a thermally cured base composite, one using the classic Thomas technique and the other using the modified Thomas technique, both showed significantly lower bond strengths and higher probability of failure than the light-cured, direct-bonded control group. On the other hand, the group using light-cured base composite and a chemically cured sealant and the group using a chemically cured base composite as well as sealant, both showed bond strengths comparable with the control group. Klocke et al[12] also noted that both the original and the modified Thomas techniques were able to produce bond strengths similar to direct bonding. Yi et al[13] also found no significant difference in bond strength between a light-cured, direct-bond control group and the Sondhi method.

Although these recent reports indicate that indirect bonding with a light-cured adhesive base with a chemically cured sealant provides bond strength similar to direct bonding, there are no reports of bond strength for any of the entirely light-cured methods. Direct bonding with Transbond XT has been used in various

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Based on research conducted by Dr Linn in partial fulfillment of the requirements for postgraduate certification in orthodontics at Marquette University School of Dentistry.

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TABLE 1. Materials Used in Each Experimental Group

Group	Bonding Technique	Primer	Primer Method of Cure	Adhesive	Adhesive Method of Cure
1	Direct	Transbond XT	Light	Transbond XT	Light
2	Indirect	Sondhi Rapid Set	Chemical	Transbond XT	Light
3	Indirect	Orthosolo	Light	Enlight LV	Light

publications and provided clinically acceptable bond strength.[14] The Transbond XT adhesive and Sondhi Rapid Set Primer used for indirect bonding have also been shown to demonstrate clinically acceptable bond strengths.[12,15] The Enlight LV was chosen because a bonding protocol had been reported in the literature,[16] but no bond strength data had been reported for light-cured adhesive and primer used in an indirect-bonding technique. There is significant variability in the methods used within the orthodontic bond strength literature. As a result, it is difficult to draw any meaningful conclusion when comparing the studies. A standard technique has been suggested by Fox et al,[17] and this study attempts to follow the standard technique as much as possible.

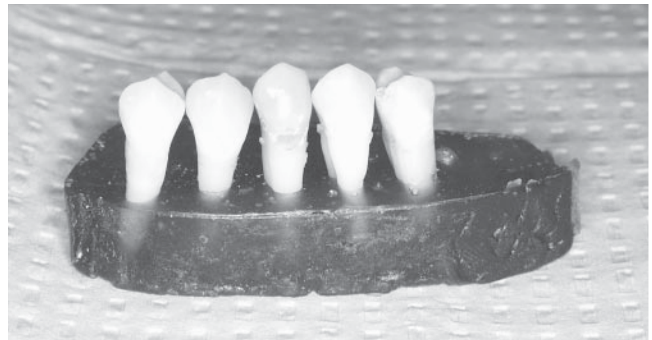

FIGURE 1. Indirect-bonding sample preparation after acrylic application.

MATERIALS AND METHODS

Sixty extracted human premolars without restorations were collected and stored in distilled water at room temperature. The samples remained submerged in distilled water at all times except when the brackets were being bonded or debonded. The teeth were randomly divided into three groups of 20 (Table 1).

Group 1 used a light-cured, highly filled orthodontic adhesive, Transbond XT (3M/Unitek Corporation, Monrovia, Calif), and Transbond XT Light Cure Adhesive Primer (3M/Uniteck) and used the direct-bonding protocol recommended by the manufacturer.

Group 2 used an indirect-bonding technique and also used Transbond XT for the adhesive but used Sondhi Rapid Set A/B Primer, a filled resin primer.

Group 3, also bonded by an indirect method, used a low viscosity, light-cured adhesive Enlight LV (Ormco Corporation, Glendora, Calif) and light-cured primer Orthosolo (Ormco).

A universal bicuspid bracket with a 0.022-inch slot with 0° of tip and 0° of torque was used in this study (Victory Series, 3M/Unitek). This bracket is a stainless steel miniature mesh twin bracket with a base surface area of 10 mm^2.

Groups 2 and 3 working model preparation and transfer tray fabrication

Before bonding the indirect samples, groups of five teeth were attached to a 0.040-inch stainless steel wire with sticky wax so that the interproximal surfaces of adjacent teeth were in contact. The wire was prebent to an approximate Dentec archform. A similar archform template of boxing wax was luted to a flat surface, and the wire with the attached teeth was balanced on the top edge of the boxing wax template. The teeth were then mounted in cold cure acrylic (Figure 1).

An alginate impression of the mounted teeth was made, and a working model was poured using orthodontic stone. The stone models were allowed to set overnight, and a layer of separating medium diluted with water at a 1:1 ratio was placed on each model and allowed to dry for 20 minutes. For group 2, the brackets were placed on the working model with Transbond XT and the excess removed with a hand instrument. For group 3, Enlight LV was used as the adhesive. The model was placed into a Triad light-curing unit (Dentsply Trubyte, York, Pa) at three angles to the light source and cured for a total of 10 minutes.

At this point, the transfer tray was fabricated using a polyvinyl siloxane material, Memosil 2 (Heraeus Kulzer, Hanau, Germany). After allowing the material to set for five minutes, the working model with the transfer tray was soaked in warm water for 20 minutes. The transfer tray was carefully removed from the working model and placed back into the Triad machine for one minute with the bracket bases facing the light source. The bracket bases were scrubbed with a toothbrush under running water to ensure the complete removal of separating medium and blown dry with oil-free air.

Bonding

All teeth were cleaned using coarse, oil-free pumice with a rubber prophylaxis cup for 10 seconds and rinsed with water for 10 seconds. The teeth were dried using an air-water syringe for 10 seconds. The etchant (Transbond XT etching gel, containing 35% phosphoric acid from 3M/Unitek Corporation) was applied to the bonding area of the tooth for 15 seconds, rinsed for 15 seconds, and dried with an oil-free air source for 20 seconds. All bonding was performed by the same operator (Dr Linn).

For group 1, the brackets were bonded by the direct method, one at a time. A thin layer of Transbond XT light-cured primer was applied to the tooth, Transbond XT adhesive was applied to the bracket base, and the bracket was placed onto the tooth. The bracket was placed in the center of the crown, with the center of the bracket over the long axis of the tooth. The excess adhesive was removed with a hand instrument, and the bracket was cured with the Optilux 501 light-curing unit (Kerr, Danbury, Conn) for 10 seconds from the mesial and 10 seconds from the distal.

For groups 2 and 3, indirect-bonding methods were used. Five teeth were bonded at a time. For group 2, the Sondhi Rapid Set Primer was used. After etching and drying the teeth as described above, a thin layer of primer A was painted on each tooth and a thin layer of resin B was painted on each bracket's custom adhesive base. The transfer tray was placed and held with finger pressure for 30 seconds and then left on the teeth without any pressure for two minutes before removal of the tray.

For group 3, a thin layer of Orthosolo primer was placed on each tooth after etching and drying. A very thin layer of Enlight LV adhesive was placed on each bracket's custom adhesive base. The tray was then seated over the teeth and held in place while the adhesive was light cured for 10 seconds from the occlusal and 10 seconds from the gingival. The tray was carefully removed.

Specimen preparation and shear bond testing procedure

After bonding, the teeth were sectioned 2–3 mm below the cementoenamel junction, with a separating disk and a low-speed handpiece and mounted in acrylic. After the brackets were bonded to the teeth, the teeth were stored in fresh distilled water at 37°C for approximately 40 hours (±2 hours) before being debonded. An Instron Universal Testing Machine (Instron Corporation, Canton, Mass) was used to debond the brackets from all the brackets with a shear load applied to the bracket at a crosshead speed of 0.1 mm/min. The maximum load was recorded. The samples were placed into the Instron machine so that the loading blade moved parallel to the long axis of the tooth and contact was as close to the bracket/tooth interface as possible to provide the shearing force (Figure 2).

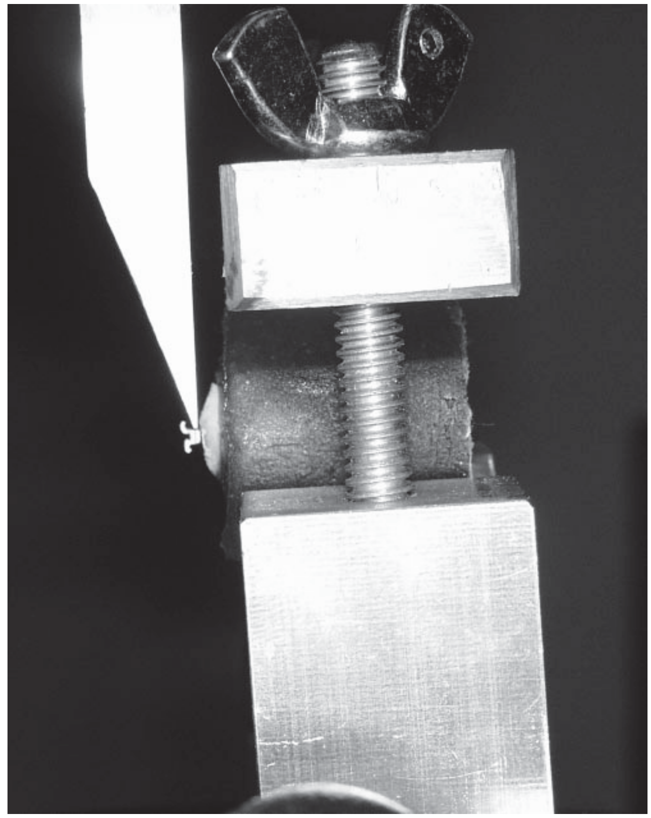

FIGURE 2. Sample in Instron before testing, lateral view.

Classification of adhesive remnant index

After the samples had been debonded, they were individually inspected under a Spenser optical stereomicroscope, with an external light source and scored according to the Adhesive Remnant Index (ARI).[18] There are four possible scores[18]:

0, no adhesive left on the tooth.
1, less than half of the adhesive left on the tooth.
2, more than half of the adhesive left on the tooth.
3, the entire adhesive left on the tooth, with a distinct impression of the bracket mesh.

Statistical analysis

The difference in shear bond strength between groups was analyzed by a one-way analysis of variance (ANOVA) statistical analysis at a 0.05 level of significance. A Weibull analysis was also performed to determine bond reliability at specific loads. Furthermore, a Kruskal-Wallis test was performed to determine whether there were any statistically significant differences in ARI scores between groups, and a

TABLE 2. Mean Shear Bond Strength

Group	Bond Strength (MPa)				
	Mean	SD	Minimum	Maximum	Range
1, Direct, light cure	16.27	4.74	7.74	24.07	16.33
2, Indirect, chemical cure	13.83	4.27	5.32	21.50	16.18
3, Indirect, light cure	14.76	4.06	6.48	23.56	17.08

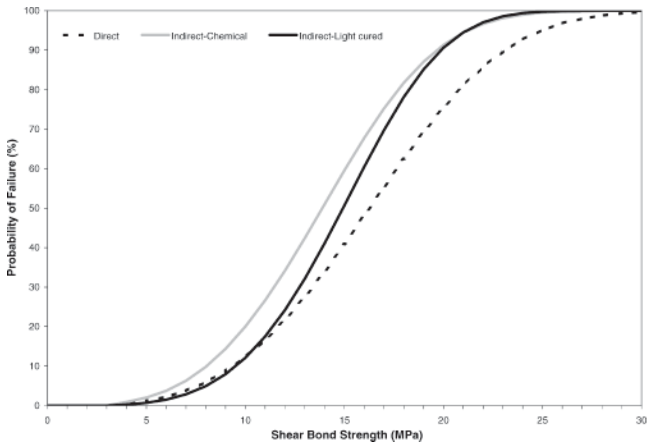

FIGURE 3. Weibull curves for shear bond strength of bonded brackets.

Mann-Whitney test was performed to determine multiple comparisons. Pearson correlation coefficients were calculated to determine whether there was any correlation between the bond strength data and the ARI numbers. The statistical analyses were performed using SPSS 12.0.1 for Windows (SPSS Inc, Chicago, Ill).

RESULTS

Shear bond strengths were measured for 20 samples in each experimental group. The mean shear bond strength, standard deviation, and minimum/maximum values for each group are shown in Table 2. A one-way ANOVA showed no significant difference in mean bond strength between the groups ($P = .21$).

However, mean shear bond strength (and standard deviation) may not be the best performance indicator for evaluating bonding materials and methods because, frequently, it is the weaker values in a distribution of values that would be most clinically important (and possibly result in clinical debonding of brackets).

TABLE 4. Adhesive Remnant Index (ARI) Scores by Group

Group	ARI Scores*			
	0	1	2	3
1, Direct, light cure	1	13	4	2
2, Indirect, chemical cure	5	15	0	0
3, Indirect, light cure	0	13	7	0

* Group 2 was statistically different from groups 1 and 3 ($P < .05$).

Weibull analysis is a useful survival analysis tool that has been used in many fields in addition to orthodontic bond strength testing. The survival analysis graph shown in Figure 3 was derived from the Weibull cumulative distribution function $F(x) = 1 - e^{(-\sigma/\alpha)^{\beta}}$, where F(x) is the probability of failure, e is the exponential function, σ is the applied stress, α is known as the normalizing parameter or characteristic strength, and β is the Weibull modulus or shape parameter. For a more detailed discussion regarding the use of Weibull analysis in the study of orthodontic bonding, the reader is referred to Fox et al.[19] The Weibull modulus and characteristic strength can be seen in Table 3. Furthermore, a Weibull analysis was performed to test bond reliability, which showed that groups 1, 2, and 3 had a 94.5%, 91.0%, and 95.6% chance, respectively, of surviving a 7.8 MPa load (Figure 3). This value was chosen because the range of clinically acceptable bond strength should exceed 5.9 to 7.8 MPa.[20]

The results of the ARI testing are recorded in Table 4. A Kruskal-Wallis test showed a significant difference in ARI existed between the groups ($P = .002$). Subsequently, a Mann-Whitney test was performed to determine which groups did in fact differ. Group 2 was found to have a significantly lower ARI score than both group 1 ($P = .004$) and group 3 ($P = .001$). Groups 2 and 3 did not differ in ARI score ($P = .760$). Additional computation of Pearson correlation coefficients

TABLE 3. Weibull Modulus and Characteristic Strength Results

Group	Weibull Modulus (β)	Characteristic Strength (α)	Shear Bond Strength (MPa) at 10% Probability of Failure	Shear Bond Strength (MPa) at 90% Probability of Failure
1, Direct, light cure	3.4	18.1	9.4	23.1
2, Indirect, chemical cure	3.5	15.4	8.1	19.7
3, Indirect, light cure	4.2	16.3	9.5	19.9

showed no strong correlation between bond strength and ARI score within or across all groups.

DISCUSSION

Reynolds[20] stated that for brackets bonded to teeth to overcome intraoral and orthodontic forces, shear bond strengths in the range of 5.9 to 7.8 MPa were required. The mean bond strengths of 16.27, 13.83, and 14.76 MPa for groups 1, 2, and 3, respectively, are all well over this clinically acceptable range. The results of this research show that there was no statistically significant difference in shear bond strength between the groups. Regarding groups 1 and 2, this finding agrees with several previous publications.[7,12,13] Read and O'Brien[21] used a different light-cured adhesive with the Thomas method of indirect bonding in a clinical study. They reported an overall bond failure rate of 6.5% after a six-month treatment time. This is similar to the failure rate (4.6%) for group 3 determined with the Weibull survival analysis at 7.8 MPa. Because of the significant differences between the protocols, however, one must be careful about drawing conclusions on the basis of comparisons of the two studies.

This study suggests that the indirect-bonding protocol using a light-cured adhesive and primer (group 3) can provide similar bond strength in vitro as direct bonding or indirect bonding using a chemical-cure primer. The results of the ARI scores indicate that there was no strong correlation between bond strength and ARI scores within or between groups. This finding also agrees with a previously published article.[13] Although this data suggest that indirect bonding with a light-cured adhesive could provide similar bond strength as direct bonding, this was an in vitro investigation and one must be cautious about extrapolating these results into a clinical situation. More in vivo research on the effectiveness of indirect bonding is needed to evaluate the true clinical success of any bonding method.

Although the mean bond strengths were reported for each group, the information from the Weibull analysis may provide more clinically relevant information. For the practicing orthodontist, one goal of evaluating bond strength studies is to learn how a material might perform clinically. As noted previously, the Weibull modulus (β) values are a measure of the reliability of the data, with larger values indicating a closer grouping of results.[19]

In Table 3, the light–cured, indirect-bond samples exhibited less scatter in data (higher β), and, therefore, the bond strength values were more consistent. In this study, the light-cured, indirect-bonding protocol (group 3) provided for more consistent bond strengths compared with the chemically cured technique that was tested (group 2), but further research in this area may be warranted. Furthermore, the Weibull analysis indicated group 2 had a 9% probability of failure at clinically relevant force levels, which is in good agreement with a clinical study showing a 9.9% failure rate using Sondhi Rapid Set.[22] This failure rate was greater by several percent than those of the two other groups. Although a significant difference in mean bond strength was not found in this study, it should be noted that perhaps with a larger sample size, group 2 may show a lesser bond strength as suggested by the Weibull analysis. With this in mind, however, the number of samples used in this study is consistent with recommendations by Fox et al[17] and is similar to those of other comparative bond strength studies.[10,12]

In orthodontics, a lower ARI score is favorable because the clinician must remove the remaining adhesive after debonding. The more adhesive that remains on the bracket base, the less adhesive there is for the orthodontist to remove from the tooth. For all three groups, a majority of the samples scored a 1 on the ARI, indicating that most of the adhesive remained on the bracket. Overall, group 2 exhibited a significantly lower ARI score compared with groups 1 and 3, which did not differ.

Several previous studies have shown differences in ARI score between direct and indirect-bonding methods after debonding.[10,12,23] Of those studies, only the Klocke et al study used the groups evaluated in this study. Contrary to this study, the ARI of their Transbond XT/Sondhi group was greater than that of the Transbond XT direct-bonded group, although multiple comparison significance values were not indicated. It is interesting to note that although group 2 had a significantly lower ARI score and a lower mean bond strength (not to a significant level, however), the Pearson correlation coefficients determined that there was no significant correlation between ARI scores and bond strength within group 2 or across all groups.

CONCLUSIONS

- Indirect bonding with Transbond XT adhesive/Sondhi primer (chemical cure) or Enlight LV adhesive/ Orthosolo primer (light cure) and direct bonding with a light-cured adhesive (Transbond XT), all produce clinically acceptable in vitro bond strengths.
- According to the Weibull analysis, all three groups tested provided over a 90% survival rate at normal masticatory and orthodontic force levels.
- Indirect bonding with Transbond XT adhesive/Sondhi primer (chemical cure) exhibited lower ARI scores compared with indirect bonding with the Enlight LV adhesive/Orthosolo primer (light cure) and

direct bonding with a light-cured adhesive (Transbond XT).
- No strong correlation was found between bond strength and ARI scores within or between groups.

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