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Bond Strength of Direct and Indirect Bonded Brackets After Thermocycling

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ABSTRACT

Thermocycling simulates the temperature dynamics in the oral environment. With direct bonding, thermocycling reduces the bond strength of orthodontic adhesives to tooth structure. The purpose of this study was to evaluate the shear bond strengths (SBS) of one direct and two indirect bonding methods/adhesives after thermocycling. Sixty human premolars were divided into three groups. Teeth in group 1 were bonded directly with Transbond XT. Teeth in group 2 were indirect bonded with Transbond XT/Sondhi Rapid Set, which is chemically cured. Teeth in group 3 were indirect bonded with Enlight LV/Orthosolo and light cured. Each sample was thermocycled between 5°C and 55°C for 500 cycles. Mean SBS in groups 1, 2, and 3 were not statistically significantly different (13.6 ± 2.9, 12.3 ± 3.0, and 11.6 ± 3.2 MPa, respectively; $P > .05$). However, when these values were compared with the results of a previous study using the same protocol, but without thermocycling, the SBS was reduced significantly ($P = .001$). Weibull analysis further showed that group 3 had the lowest bonding survival rate at the minimum clinically acceptable bond-strength range. The Adhesive Remnant Index was also determined, and group 2 had a significantly ($P < .05$) higher percentage of bond failures at the resin/enamel interface.

KEY WORDS: Indirect Bonding, Bond strength, Thermocycling.

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INTRODUCTION Return to TOC

With increasing use of the straight-wire or preadjusted appliance in orthodontics, practitioners are switching their focus from wire bending to bracket positioning. The indirect bonding method was introduced in 1972 by Silverman et al[1] to increase accuracy with bracket placement. Since then, several technique modifications have been made.[2–5] Sondhi[4] introduced a new resin with increased viscosity developed specifically for indirect bonding, which was designed to fill in any imperfections and decrease the chance of bracket drift. It also exhibited a quicker setting time, which required less chair time holding the transfer tray.

Regardless of modification, the goal of indirect bonding is to deliver accurate bracket placement with minimal chair time and sufficient bond strength. The current technique involves a custom base of composite on each bracket that is transferred to the mouth via a transfer tray and bonded to the teeth with a sealant that is either light or chemically cured.

Several studies have looked at indirect bonding compared with direct bonding as it relates to bond strength.[6–8] Klocke et al[9] found that the bond strengths of light-cured composite (Transbond XT) and a chemically cured sealant (Sondhi Rapid Set), manufactured specifically for indirect bonding, and chemically cured composite (Phase II) and a chemically cured sealant (Maximum Cure) compared favorably with a direct bonded, light-cured control group (Transbond XT). The bond strength of a thermally cured custom base composite (ThermaCure), however, was significantly lower.

Yi et al[10] found no significant difference in bond strength between indirectly bonded brackets with Transbond XT and Sondhi Rapid Set and a light-cured direct bonded control group. Polat et al[11] found no difference in bond strength between the light-cured direct bonded control and the ThermaCure protocol, whereas the bond strengths for the Sondhi protocol were significantly lower. Linn et al[12] found no statistically significant difference in bond strength between the Sondhi protocol, a protocol using a light-cured composite (Enlight LV) with a light-cured sealant (Ortho Solo), and a direct bonded light-cured group.

Orthodontic adhesives are routinely exposed to temperature variations in the oral cavity. Air temperature, humidity, and air velocity when breathing can also alter resting mouth temperature.[13] Although these variations are erratic and hard to anticipate when testing, it is important to determine whether they introduce stresses in the adhesive that might influence its bond strength. Therefore, Bishara et al[14] have suggested that thermal cycling should be part of the testing protocol of new adhesives.

Although the International Organization for Standardization[15] has provided criteria to follow when thermocycling samples in bonding studies, there has been a lack of consistency in methodology between various thermocycling studies. Klockowski et al[16] observed a significant decrease in bond strength after thermocycling using brackets bonded with three different glass-ionomer cements and an autopolymerizing composite resin, with the resin showing the greatest decrease. Arici and Arici[17] found an 11.1% and 26.5% reduction in bond strength after 200 and 20,000 thermocycles, respectively, for a resin-modified glass ionomer and a 5.7% and 17.9% reduction for a composite resin. Bishara et al[14] found an 80% decrease in bond strength of a cyanoacrylate orthodontic adhesive after thermocycling.

There is a lack of studies in which these materials are subjected to thermocycling. The purpose of this study was to compare the shear bond strengths (SBS) of two methods and materials used for indirect bonding relative to a direct bonded group after being thermocycled. It is a follow-up to a previous study[12] using the same materials and bonding techniques in which the samples were not thermocycled.

MATERIALS AND METHODS Return to TOC

Sixty human premolars, extracted for orthodontic reasons with no decay, restorations, or infections, were collected and stored in fresh distilled water at room temperature. The teeth were randomly assigned to one of three groups on the basis of bonding procedure.

Twenty teeth (group 1) were bonded directly according to manufacturer's recommendations, using a light-cured, highly filled orthodontic adhesive Transbond XT (3M/Unitek, Monrovia, Calif) and Transbond XT Light Cure Adhesive Primer (3M/Unitek). Group 2 consisted of 20 teeth bonded indirectly with Transbond XT, as the adhesive, and Sondhi Rapid Set A/B Primer (3M/Unitek), a filled resin primer. Group 3, also consisting of 20 teeth bonded indirectly, used a low viscosity, light-cured adhesive Enlight LV (ORMCO, Glendora, Calif) and light-cured primer, Orthosolo (ORMCO) following a protocol similar to that of McCrostie.[18] These protocols were used to be consistent with a previous study[12] to determine the effect thermocycling has on bond strengths. One of the indirect protocols (Transbond XT/Sondhi) has been shown to have clinically acceptable bond strengths,[9] whereas bond strengths for the other, which is based on an entirely light-cured primer and adhesive system, had not been reported previously.

All teeth were bonded using a Victory Series universal bicuspid bracket, (3M/Unitek), a stainless steel miniature mesh twin bracket with a projected base surface area of 10 mm^2. Before bonding, teeth in groups 2 and 3 were mounted in cold-cure acrylic in groups of five in interproximal contact along an approximate Dentec arch form. An alginate impression was made of the mounted teeth and poured up in hard orthodontic stone (Snow White Stone, Heraeas Kulzer, Hanau, Germany). The working models were allowed to set overnight, and a layer of Al Cote separating medium (Dentsply Trubyte, York, Pa) diluted with water at a 1: 1 ratio was placed on each model and allowed to dry for 20 minutes.

Group 2 brackets were placed on the model with Transbond XT and the excess removed with a hand instrument. For group 3, Enlight LV adhesive was used. The model was then placed into a Triad light-curing unit (Dentsply Trubyte) for 3 minutes at a 45° angle to the light source, 4 minutes directly facing the source, and then 3 minutes at the opposite 45° angle to the light source. A transfer tray was fabricated using a clear polyvinyl siloxane material, Memosil 2 (Heraeas Kulzer). After allowing the material to set for 5 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 1 minute, with the bracket bases facing the light source. The bracket bases were scrubbed with a toothbrush under running water and blown dry with oil-free air.

All the teeth were cleaned using coarse pumice with a rubber prophylaxis cup and etched with Transbond XT 35% phosphoric acid gel for 15 seconds, rinsed for 15 seconds, and dried with oil-free air for 20 seconds. Teeth in group 1 were bonded directly using Transbond XT adhesive and primer one at a time in the center of the crown, with the bracket over the long axis of the teeth. Excessive adhesive was removed with a hand instrument, and the bracket was cured with an Optilux 501 light-curing unit (SDS Kerr, Danbury, Conn) for 10 seconds from the mesial and distal.

For groups 2 and 3, five teeth were bonded at a time. After etching and drying, the teeth in group 2 were painted with a thin layer of primer A and the brackets with a thin layer of resin B. The transfer tray was placed and held with finger pressure for 30 seconds and then left on the teeth without pressure for 2 minutes before tray removal. The teeth in group 3 were painted with a thin layer of Orthosolo primer and the brackets with a very thin layer of Enlight LV adhesive. The tray was 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 before tray removal. After bonding, the teeth were sectioned 2–3 mm below the cementoenamel junction, and the crowns were mounted in acrylic cylinders with the facial surface of the tooth and the bracket exposed.

Teeth were stored at 37°C in distilled water for 24 hours. After 24 hours, the samples were thermocycled according to the ISO 11405 recommendation.[15] Each specimen underwent 500 complete cycles in distilled water between 5°C and 55°C, with a dwell time in each bath of 30 seconds and a transfer time between baths of 15 seconds. The SBS was tested using an Instron Universal Testing Machine (Instron Corporation, Canton, Mass).

Brackets were debonded with the loading blade contacting between the tie wing and the bracket base as close to the base as possible at a speed of 0.1 mm/ min. The tooth was aligned so that the center of the blade moved parallel to the buccal surface and contacted the bracket evenly mesiodistally. The maximum load was recorded.

After debonding, the samples were inspected under a 10× stereomicroscope to score each sample according to the Adhesive Remnant Index (ARI). The ARI determines the bond failure site by assessing the amount of adhesive left on the tooth. An ARI score of 0 indicates no adhesive was left on the tooth; 1, less than half of the adhesive was left on the tooth; 2, more than half of the adhesive was left on the tooth; 3, the entire adhesive was left on the tooth, with a distinct impression of the bracket mesh.

Recommendations for a standardized technique for bond strength testing as suggested by Fox et al[19] were followed as closely as possible.

RESULTS Return to TOC

The mean SBS of all three groups are shown in Table 1. Brackets directly bonded in group 1 with Transbond XT showed a mean bond strength of 13.6 ± 2.9 MPa. Group 2, with brackets bonded indirectly and chemically cured, had a mean SBS of 12.3 ± 3.0 MPa. Group 3, with brackets bonded indirectly and light cured, had a mean SBS of 11.6 ± 3.2 MPa. Analysis of variance comparisons among the groups showed no statistical differences between the groups (P = .134).

When comparing mean SBS of the thermocycled samples to the nonthermocycled samples obtained previously[12] using the same materials and methods under the same set of circumstances, the mean SBS significantly decreased after thermocycling (P = .001). The mean SBS decreased by 16.7%, 11.1%, and 15.4% in groups 1, 2, and 3, respectively.

A Weibull analysis was also performed to look at bond reliability at specific loads (Figure 1), and the modulus and characteristic strength values are shown in Table 2.[19] Furthermore, a Weibull analysis was carried out to examine bond survival at a 7.8 MPa load. This number was chosen because the minimum bond strength required in a clinical setting has been shown to be 5.9 to 7.8 MPa.[20] Groups 1, 2, and 3 had a 95.2%, 92.1%, and 84.5% chance, respectively, of surviving a 7.8-MPa load (Figure 1), compared with values of 94.5%, 91.0%, and 95.6% obtained in a previous study.[12]

The ARI values are shown in Table 3. Multiple comparisons determined via the Mann-Whitney test after using the Cochran-Mantel-Haenszel test showed that no statistical difference was found between groups 1 and 3 (P = .524). However, group 2 was shown to be statistically different from groups 1 and 3 (P < .05). Comparison with nonthermocycled data[12] showed that the relationship between thermocycling and ARI after adjusting for bonding method was not significant (P = .22), indicating thermocycling did not alter the site of bond failure.

DISCUSSION Return to TOC

This study investigated the effect of thermocycling on the SBS of one currently used direct and two currently used indirect bonding resins. These results suggest that there are no statistically significant differences in mean SBS between conventional direct bonding and the indirect bonding technique after thermocycling.

Further interesting findings are obtained with the Weibull analysis, which showed that the light-cured indirect bonding material had the lowest survival rate at 7.8 MPa of force after thermocycling. This is significant because a high survival rate in the mouth of any adhesive system is probably more important clinically than a high mean SBS. Comparison with previous survivability data[12] shows that although the mean for groups 1 and 2 decreased with thermocycling, the probability of failure at the clinically relevant 7.8-MPa force level remained relatively unchanged. This would indicate that thermocycling had a greater effect in diminishing the moderate to strong bond strengths in these two groups. However, group 3 showed a greater than 10% drop in probability of withstanding the 7.8 MPa force level. The reason for this lower survival rate warrants further research, but could be because of increased sensitivity of those materials to the combined effect of water absorption and temperature variation, as discussed below.

The decrease in bond strength after thermocycling with several different adhesives has been noted in the literature.[16,21,22] It has been theorized[17] that the reduction in bond strength for thermally cycled specimens could be because of differences in the coefficient of thermal expansion between the adhesive, the metal bracket, and enamel.[23] These differences and alternating stressing of the system could adversely affect the adhesion of the resin to the bracket and tooth. The cyclical stress of thermocycling at two different temperature extremes could also cause any weakened areas within the bond to grow progressively in size.[17]

Another possibility for the decrease in bond strength after thermocycling could be attributed to increased water absorption or solubility of the composite, or both. Many dental materials are known to interact with components of the oral environment. In terms of composite resin, the principal interaction occurs with water, which diffuses into the matrix causing hygroscopic expansion of the material as well as a chemical degradation of the material.[24] The amount of water absorbed and the rate of absorption are diffusion controlled[25] and are dependent on several factors, many of which are material dependent. SBS studies have shown a decrease in bond strength of orthodontic composites after immersion in water. The greatest loss of bond strength occurs initially, yet the longer the composite is immersed, the lower the bond strength and the greater the degradation of the composite resin.[26] Another study showed that if thermocycling is added to water immersion, the process is accelerated and composites absorb even more water than control groups that were not thermocycled.[24] How thermocycling affects the solubility and water absorption of indirect bonding resins requires further research. Different resins may be affected differently, as the results in this study appear to show with regard to group 3 and the probability analyses.

Previous studies have found lower ARI scores with indirect bonding vs direct bonding.[6,27] The ARI values found in this study show that there was no statistically significant difference in the location of bond failure in the direct bonded and light-cured indirect bonded groups. The chemically indirect bonded group differed in that it had a significantly higher number of samples that failed at the resin/enamel interface, leaving more composite on the bracket than on the tooth. Similar results were also found in the nonthermocycled samples.[12] Reduced remnant resin on the tooth is clinically desirable because it requires less cleanup on debonding and reduces the risk of enamel damage.[27]

The clinical relevance of these results is that thermal stresses, which do take place in the oral environment, reduced the mean bond strength in all the materials tested. It also appears that some indirect protocols, particularly the light-cured adhesive/primer, may be more susceptible to this thermal stress than others. This reduced bond strength could result in bond failure under the forces placed on brackets during orthodontic treatment. A limitation of the study, however, is that one must be cautious about extrapolating these results clinically from this in vitro investigation. The samples were thermocycled in water, which does not fully represent the dynamic environment of the oral cavity presented by saliva and the introduction of food and beverages.

CONCLUSIONS Return to TOC

- No significant difference in SBS was found between teeth bonded directly and indirectly after thermocycling.
- The thermocycling process resulted in a significant decrease in SBS. When evaluating bond strength studies, it is important to be aware of the stresses that the intraoral environment induces with time.
- Weibull analysis shows that teeth indirectly bonded and light cured had a lower bond survival rate at a minimum clinically acceptable bond strength value as compared with the other two groups after thermocycling.
- No statistically significant difference in the location of bond failure as determined by the ARI occurs between the direct bonded and light-cured indirect bonded groups. The chemically cured indirect bonded group differed in that it had a significantly higher number of samples that failed at the resin/enamel interface.

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TABLES Return to TOC

TABLE 1. Mean Shear Bond Strength[a]

Group	Bond Strength (MPa)				
	Mean	SD	Minimum	Maximum	Range
1 Direct, light cure	13.56	2.91	9.29	19.29	9.99
2 Indirect, chemical cure	12.29	3.01	5.82	17.81	11.98
3 Indirect, light cure	11.62	3.23	6.61	16.98	10.37

[a] Means were not significantly different from each other (analysis of variance, $P > .05$).

TABLE 2. 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	Probability of Survival at 7.8 MPa
1 Direct, light cure	4.8	14.7	9.2	17.5	95.2
2 Indirect, chemical cure	4.6	13.5	8.2	16.2	92.1
3 Indirect, light cure	3.6	12.8	6.8	16.2	84.5

TABLE 3. ARI Scores by Group[a,b]

Group	ARI Scores			
	0	1	2	3
1 Direct, light cure	0	11	9	0
2 Indirect, chemical cure	4	14	2	0
3 Indirect, light cure	0	13	7	0

[a] Group 2 was significantly different ($P < .05$) from groups 1 and 3.
[b] ARI indicates Adhesive Rennant Index.

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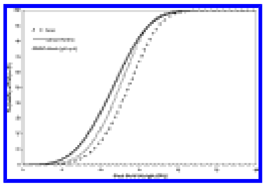

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FIGURE 1. Percentage of orthodontic brackets failing at respective bond strength

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