Original Article

In Vitro Evaluation of Shear Bond Strengths and In Vivo Analysis of Bond Survival of Indirect-Bonding Resins

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Abstract: In this study we evaluate the shear bond strengths (SBS) of indirect-bonding systems available on the market. For the in vitro study, 60 extracted premolars were divided into three groups. In indirect group I, the brackets were bonded to models using Therma Cure laboratory resin and transferred to the teeth using Custom IQ resin for indirect bonding. For indirect group II, the teeth were attached to models using Transbond XT and transferred using Sondhi Rapid Set. In the direct-bonding group, the brackets were bonded to teeth directly using Transbond XT. The SBS were evaluated, and the comparisons were made. In the in vivo study, left half of the upper arch and right half of the lower arch were bonded using Sondhi's indirect-bonding resin and right half of the upper arch and left half of the lower arch were bonded using Therma Cure as a laboratory resin and Custom IQ as a clinical bonding resin. The failure rates of the brackets were followed for nine months. Analysis of variance and Tukey tests were performed. Mean SBS values (MPa) were 10.3 ± 4.2, 6.1 ± 1.6, and 12.8 ± 5.4 for the indirect groups I and II and for the direct-bonding group, respectively. There were no significant differences between indirect group I and direct group ($P > .05$), whereas both yielded significantly higher SBS values compared with indirect group II. In vivo bond survival evaluation showed no differences between the two indirect-bonding systems available. (*Angle Orthod* 2004;74:405–409.)

Key Words: Indirect bonding; Shear bond strength; In vivo bond survival

INTRODUCTION

For the past 50 years, since the introduction of acid etching by Buonocore[1,2] in 1955, major improvements were achieved in bonding brackets to the teeth. In 1964, Newman[3,4] first tried to bond orthodontic brackets to teeth using the acid-etch technique and an epoxy-derived resin. Acid-etching and bisGMA resin was first used for direct bonding of orthodontic brackets by Weisser[5] and Silverman et al.[6]

The improvements were carried out not only in the development of bonding resins but also in the bonding methods to find out the best material that meets the following requirements[7]:

1. Minimal time required for bonding.
2. Accurate bracket positioning.
3. Adequate adhesive working time.
4. Sufficient bond strength to withstand the forces of the masticatory system.
5. Convenient removal of excess bonding material.
6. Comfortable bracket application for the patient.

To reach these goals, Silverman and Cohen[8] introduced the first indirect-bonding method in 1974. They used methylmethacrylate adhesive to attach plastic brackets to model casts in the laboratory. An unfilled bisGMA resin was used as an adhesive between the etched enamel and a previously placed adhesive. The same reseachers updated this technique in 1975 using perforated mesh bases and ultraviolet light–activated bisGMA resin.[9]

In 1979, Thomas introduced a simple and efficient way of bonding the brackets indirectly.[10] In his technique the laboratory procedure involved the placement of a filled bisGMA resin on bracket base. After hardening of the filled resin, brackets were carried to the mouth using a flexible transfer tray. Brackets were bonded using a liquid catalyst resin applied to the etched enamel surface, and a base resin was applied to the bracket base. The tray was removed when polymerization was completed.

Several studies were made to modify this technique[10–18] and compare the bond strengths of direct and indirect methods.[7,19–21] Milne et al[7] compared the shear and tensile bond strengths and the accuracy of bracket placement of these

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two methods. Highly filled restorative Concise adhesive was used for both direct and indirect methods, where 96 human incisors and premolars were bonded. The results revealed no statistically significant differences between the bond strengths, but indirect method was superior in accuracy of bracket placement. Because indirect bracket placement involves the use of a composite that has been placed previously, Shiau et al[19,20] investigated whether a loss in bond strength occurs when the base composite is placed seven days before placement in the mouth and found no differences in bond strength.

Hocevar and Vincent[21] compared the shear bond strength (SBS) of brackets attached by the Thomas indirect technique[10] and the direct-bonding technique. They mention about the problem of inaccurate placement of the right amount of adhesive in the indirect-bonding method and draw attention to voids or excess adhesive that often occurs during indirect bonding. They bonded 41 premolars (18 directly and 23 indirectly) using restorative Concise. Their results show no differences in SBS when there are no marginal voids or when the voids were covered in indirect technique. However, SBS decreased significantly when the voids were not covered with an unfilled resin.

In all these studies where nonsignificant differences were reported between the two methods, only the direct-bonding adhesives were evaluated. The literature lacks studies evaluating the strengths of indirect-bonding resins. There are only two studies that investigate the bond strengths of indirect-bonding resins. One of them compared the retention rates of thermally cured and light-cured custom bases attached to metal and clear brackets.[22] The results showed no significant differences in the retention rates of either of the custom-base materials when used with metal brackets.

Klocke et al[23] investigated the bond strengths of indirect-bonding resins and found that indirect bonding with Sondhi Rapid Set showed similar strength compared with a control group bonded directly with Transbond XT, and indirect bonding with Custom IQ showed lower values compared with the other groups.

Today, there are two adhesive systems specifically developed for indirect bonding. The first system (Reliance Orthodontics, Itasca, Ill) recommends the use of Therma Cure as laboratory resin, Enhance adhesion booster, and Custom IQ as clinical resin. The second one (3M Unitek, Monrovia, Calif) recommends the use of Transbond XT as base adhesive and Sondhi Rapid Set in the clinic.[24] This study evaluates the in vitro differences in SBS of these two systems with a commonly used direct-bonding adhesive Transbond XT and compares the bond survival rates in vivo.

MATERIALS AND METHODS

For the in vitro study, 60 extracted human premolars, both maxillary and mandibular extracted for orthodontic purposes, were used. They were stored in 0.5% aqueous thymol solution (Sygma-Aldrich Chemie, Steinheim, Germany) before bonding. The collection of all the premolars took four months. After all the teeth were collected, they were divided into three groups, 20 teeth each. To simulate indirect bonding, 40 of these teeth were fixed in four upper acrylic models, five premolars at each quadrant, 10 teeth in one model (Figure 1). Alginate impressions were taken, and hard-stone working models were obtained. The stone models were isolated with a separating medium (Divosep, Vertex, Dentimex BV, Zeist, The Netherlands), and 10 stainless steel premolar brackets (Victory Series, 3M Unitek) were attached to teeth on each model. Upper premolar brackets were placed for upper premolars, and lower premolar brackets were placed for lower premolars. All the indirect-bonding procedures were carried out by the same operator. For the indirect group I, Therma Cure (Reliance Orthodontics), a thermally polymerized resin specially manufactured for laboratory procedures of indirect-bonding method, was used in the left quadrant. The model is then placed into an oven at 176°C for 15 minutes. For the indirect group II, Transbond XT (3M Unitek) light-cured resin was used in the right quadrant to attach the brackets to the stone model. After all the brackets were placed to the buccal surface of the teeth along the long axis of the crown, a transfer tray is made from putty silicone impression material (Zetaplus, Zhermack, Badia Palestine, Italy). After the putty has hardened, the models were placed in water for 20 minutes to dissolve the separating medium. The transfer tray was removed, and the adhesive bases were gently sandblasted avoiding any disturbance in the base resin, as advised by Sondhi,[24] washed, and dried. Acetone was applied to the adhesive bases to dissolve the remaining separating medium. Enhance adhesion booster (Reliance Orthodontics) was painted on the bases where Therma Cure was used, and the tray was left to dry for 30 seconds.

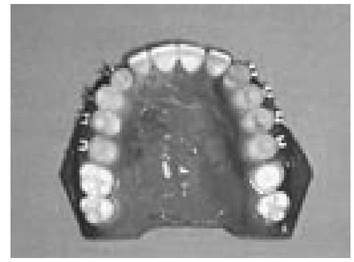

FIGURE 1. Premolar teeth in acrylic model.

The teeth in typodonts were pumiced, washed, and dried as usual. The etching procedure was done using 35% orthophosphoric acid for 15 seconds. After washing and drying, in the left quadrant where Therma Cure was used, Enhance adhesion booster was painted on etched enamel. At the same side after 60 seconds, Custom IQ (Reliance Orthodontics) resin B was applied to teeth and Custom IQ resin A was applied to the bracket base. At the right quad-

TABLE 1. Descriptive Statistics and the Results of the Tukey Test Comparing the Shear Bond Strengths of the Three Groups Tested

Groups Tested	n[a]	Mean	SD	Range	Tukey Test[b]
Reliance	20	10.3	4.1	8.3–12.2	A
Sondhi	20	6.1	1.6	5.3–6.8	B
Transbond	20	12.8	5.4	10.2–15.3	A

[a] n, sample size; SD, standard deviation.
[b] Groups with different letters are significantly different from each other.

TABLE 2. Frequency Distribution of the Adhesive Remnant Index (ARI) Scores of the Three Groups Tested[a]

Groups Tested	ARI Scores						Multiple Comparison	
	1	2	3	4	5	n	Sondhi	Trans-bond
Reliance	2	1	5	4	8	20	NS	NS
Sondhi	1		1	3	15	20		NS
Transbond	2			4	14	20		

[a] $P > .05$; n, sample size; NS, not significant.

rant, Sondhi resin A was applied to the teeth and resin B was applied to the base of the brackets, where Transbond XT had been applied previously. The tray is then placed over the acrylic model, and 2.5 minutes of firm pressure was applied. The trays were then removed, and excess hardened flash was cleaned with a scaler or a handpiece. All the teeth on the four models were placed in acrylic for shear bond testing.

For the direct-bonding control group, 20 teeth that were placed in acrylic previously were pumiced, etched, and dried as usual. Transbond XT primer was painted to the etched enamel. Brackets were attached using Transbond XT, and the adhesive was light cured for 40 seconds. The brackets in this group were bonded by a different operator. All 60 teeth that were immersed in distilled sterile water were stored in an incubator with the temperature set at 37°C. After 72 hours, the samples were tested in shear mode with a universal testing machine (Micro 500, Testometric, Maywood Instruments Limited, Basingstroke Hants, UK). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned so that the leading edge aimed at the enamel-adhesive interface before being brought into contact at a crosshead speed of 0.5 mm/min. The maximum force required to take off the bracket was recorded in newtons and converted to megapascals (MPa) as a ratio of load to surface area (10.61 mm^2). The enamel surfaces were inspected under a 10× magnifying lens by one operator to assess the amount of adhesive remaining on the tooth. The enamel surfaces were classified from score 1 to 5 according to the adhesive remnant index (ARI).[25] The ARI scale 5 indicates no composite left on the enamel; 4, less than 10%; 3, more than 10% but less than 90%; 2, more than 90%; and 1, all the composite remained on the tooth.

The differences between the groups in SBS were evaluated using analysis of variance and Tukey honestly significant difference test. The chi-square test was used to determine the differences in the ARI scores between the groups. Significance for all tests were predetermined as $P < .05$. All statistical analyses were made using SPSS statistical package for Windows.

For the in vivo study, both maxillary and mandibular teeth, except the molars, were bonded in 15 patients. A split-mouth design was used where the left half of the upper arch and the right half of the lower arch were bonded using Sondhi's indirect-bonding resin and the right half of the upper arch and the left half of the lower arch were bonded using Therma Cure as a laboratory resin and Custom IQ as a bonding resin. Indirect-bonding procedures were completely the same as the in vitro setup.

The same operator did all the bonding procedures. The selected patients had similar malocclusions. Nickel titanium wires of 0.016 inch were placed as leveling arches in all patients. The failure rates of the brackets were followed for nine months.

RESULTS

The mean SBS of all groups are shown in Table 1. Brackets bonded directly with Transbond XT showed the highest bond strength (12.8 ± 5.4 MPa). Brackets bonded indirectly in indirect group I had the second highest value (10.3 ± 4.1 MPa) followed by indirect group II (6.1 ± 1.6 MPa).

Pairwise comparisons among the groups showed no significant differences between the direct-bonding group and the indirect group I; however, a significant difference existed between these two groups and the indirect group II ($P \leq .05$).

Pearson chi-square test showed no significant differences in ARI scores among the groups (Table 2). In vivo bracket failure rates are given in Table 3. There were six failures

TABLE 3. Bond Survival Rates In Vivo

Groups	Number of Bonded Teeth (n)	Location of Failures						Total Number of Failures
		First Premolar		Second Premolar		Canine		
		Lower	Upper	Lower	Upper	Lower	Upper	
Indirect I	148	0	2	0	3	1	0	6
Indirect II	147	0	0	3	3	1	0	7

in indirect group I and seven failures in indirect group II. Among the total 13 failures, only two were at mandibular canines for the same patient bilaterally. All the failures occurred during the first month.

DISCUSSION

This study evaluates the SBS of currently used indirect-bonding resins using a light-cured direct-bonding control group and compares the bond survival rates of these two indirect groups in 15 patients that were followed for nine months. These two indirect-bonding groups both need a custom base—either light cured or thermally cured—prepared in the laboratory and after several base preparation procedures to be carried to the mouth using a transfer tray. Both the clinical resins of the groups have two components, one acts as a primer and the second as a catalyst.

Indirect-bonding method has several advantages compared with direct bonding. These are correct placement of the attachments,[24,26] less chair time spent,[24] and improved patient comfort.[24]

Despite these advantages, there are disadvantages that include technique sensitivity, increased laboratory time,[13] and risk of adhesive leakage to gingival embrasures that could disturb the management of oral hygiene.

According to the results of the in vitro study, the mean SBS of indirect group I and direct group were comparable with each other, but indirect group II showed significantly different results. Reynolds[27] suggested that minimum bond strength sufficient for orthodontic bonding purposes is 5.9–7.8 MPa. Although group II showed an almost minimum value according to these data, all the groups tested in this study were above this level. Previous studies evaluating the differences in SBS of direct- and indirect-bonding methods showed no differences. However, all these studies were conducted using direct-bonding resins for indirect purposes. A recent study by Klocke et al[23] investigated the SBS of the same materials used in this study. In their study, the SBS in the Therma Cure and Custom IQ group was lower than our findings, ie, 7.0 ± 4.1 vs 10.3 ± 4.1, respectively. On the other hand, their SBS values in the Transbond XT and Sondhi Rapid Set group were higher than our findings, ie, 14.9 ± 2.8 vs 6.1 ± 1.6, respectively. The difference in results may be explained by the different methodology used in the studies. The experimental method used in this study represents the indirect method similar to those occurring in the mouth. Unlike other investigators, using single trays for each tooth, full-arch trays similar to those used by Milne et al[7] were used in our study. Single-tooth trays are prepared under ideal conditions compared with full-arch trays because full-arch trays cause a decrease in bond strength because of both the placement of thicker adhesive and the movement of the tray during initial setting of the adhesive, and single-tooth trays do not completely represent the indirect-bonding method performed in vivo.

In single-tooth trays, pressure is applied from a single point, right to the bracket that provides firmer attachment. However, in full-arch trays, the clinician has to apply the pressure from multiple points, but it is impossible to hold the tray from each bracket area. This limitation may affect the adhesive thickness and the bond strength.

In vitro studies are carried out under idealized laboratory conditions without the risk of moisture or saliva contamination. When evaluating the bond strengths of orthodontic adhesives, in vivo evaluation should also be carried out.

The clinical bracket failure rates of 15 patients whose teeth were fully bonded indirectly using a split-mouth design with the two indirect methods showed no differences. Although longer observation periods are probably needed to reach final clinical conclusions, our nine-month observation period may be sufficient to give an idea about the failure modes and the survival rates.

The ARI scores showed no differences between the investigated groups, and they were mostly between 4 and 5. The results of ARI scores of this study are not in agreement with the previous studies.[21,28] In indirect bonding, it seems reasonable to hope that at debonding the lower filled resin layer would fracture and most of the composite resin would be removed with the bracket. However, in the direct-bonding group, it was hoped that more adhesive would remain on the enamel. These differences may have occurred because of operator differences. The ARI scores of the three groups showed favorable results. If more adhesive remained on the teeth, the risk of damage to the enamel surface would increase and the clinician would have consumed extra chairside time for cleanup procedure.

CONCLUSIONS

Indirect bonding failed to gain popularity despite the promising advantages. The main reasons are the need for a very sensitive technique and the lack of data concerning the strengths of the adhesives designed for indirect-bonding purposes. This article aimed to fulfill the need for sufficient results concerning both in vitro and in vivo data. When reaching the final decision in choosing the appropriate indirect-bonding system, the failure rates in vivo should also be evaluated. The results of this study, which used an observation period of nine months, showed a similarity between the two indirect methods. These data lead us to the conclusion that bonding teeth indirectly using any of the two systems provides sufficient strength for optimal clinical performance. Still, further studies with longer clinical observation periods are needed.

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