Original Article

Bond Strength with Custom Base Indirect Bonding Techniques

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Abstract: Different types of adhesives for indirect bonding techniques have been introduced recently. But there is limited information regarding bond strength with these new materials. In this in vitro investigation, stainless steel brackets were bonded to 100 permanent bovine incisors using the Thomas technique, the modified Thomas technique, and light-cured direct bonding for a control group. The following five groups of 20 teeth each were formed: (1) modified Thomas technique with thermally cured base composite (Therma Cure) and chemically cured sealant (Maximum Cure), (2) Thomas technique with thermally cured base composite (Therma Cure) and chemically cured sealant (Custom I Q), (3) Thomas technique with light-cured base composite (Transbond XT) and chemically cured sealant (Sondhi Rapid Set), (4) modified Thomas technique with chemically cured base adhesive (Phase II) and chemically cured sealant (Maximum Cure), and (5) control group directly bonded with light-cured adhesive (Transbond XT). Mean bond strengths in groups 3, 4, and 5 were 14.99 ± 2.85, 15.41 ± 3.21, and 13.88 ± 2.33 MPa, respectively, and these groups were not significantly different from each other. Groups 1 (mean bond strength 7.28 ± 4.88 MPa) and 2 (mean bond strength 7.07 ± 4.11 MPa) showed significantly lower bond strengths than groups 3, 4, and 5 and a higher probability of bond failure. Both the original (group 2) and the modified (group 1) Thomas technique were able to achieve bond strengths comparable to the light-cured direct bonded control group. (*Angle Orthod* 2003;73:176–180.)

Key Words: Thomas technique; Sealant; Bond strength; In vitro

INTRODUCTION

Indirect bonding was introduced by Silverman and coworkers in 1972.[1] An earlier report found more bond failures and more excess adhesive with the new method.[2] Most current indirect bonding techniques are based on a method, which was introduced by Thomas.[3] In this technique, brackets with attached composite are bonded to teeth with a chemically cured sealant, the unfilled catalyst resin is applied to the tray and the universal resin is painted on the enamel. Therefore, the sealant is cured when the two components are brought in contact when the bonding tray is seated in the patients mouth. One of the criticisms of this procedure is that curing of the sealant might be incomplete. Therefore, the ''modified Thomas technique'' was presented and uses a sealant, which is mixed before application on the enamel and on the bonding tray, thus ensuring complete mixing of the two components of the sealant. The use of the Thomas technique has eliminated the earlier problems with indirect bonding: bond strength measurements were found to compare favorably with those of direct bonding.[4–6]

Most studies on indirect bonding have used bonding materials originally developed for direct bonding or for dental restorative purposes.[3–12] But several products have been introduced recently, specifically designed for indirect bonding procedures. In addition to chemically and light-cured composites for the fabrication of the custom base of the brackets in the laboratory, a fluoride-releasing composite adhesive has been presented, which is thermally cured in an oven, thus allowing for practically unlimited working time when placing the brackets.[13,14] In addition to light-cured sealants, different chemically cured sealants have been described that permit a marked reduction in chair time because of fast polymerization.[13–17] There is limited information available on bond strengths with these materials.

Advantages ascribed to the indirect bonding technique are decreased chair time, less patient discomfort, easier debonding, and improved ability to bond posterior

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teeth.[3,6,13,16,18] Because of placement of the bracket in the laboratory, the technique has been suggested to allow for more accurate bracket positioning.[3,11,16] Whereas Koo et al[19] found better bracket placement in bracket height for indirect bonding, the authors did not note a difference regarding angulation or mesiodistal bracket position between direct and indirect bonding techniques. Aguirre et al[20] demonstrated that neither direct nor indirect bonding techniques resulted in 100% accuracy of bracket positioning. Less than 10% of orthodontic practices in the United States use indirect bonding techniques.[21] One of the reasons for this is the difficulty in achieving consistent and predictable adhesion to the teeth.[12] The aim of this study was to measure bond strengths of indirect bonding techniques and adhesives with a custom base of the bracket. Different types of custom base composites (light-cured, chemically cured, thermally cured) were investigated in combination with chemically cured sealants.

MATERIALS AND METHODS

Bonding procedure

One hundred freshly extracted bovine permanent mandibular incisors were obtained from a local slaughterhouse and stored in 0.5% chloramine solution before the experiment. Previous studies have indicated that bovine enamel and human enamel have similar properties, and adhesive strength of bovine enamel is equal or slightly lower compared with human enamel.[22–25]

Teeth were randomly assigned to five groups of 20 specimens. After cleaning the teeth with a brush and a pumice/water slurry at slow speed, they were embedded in chemically cured dental acrylic (Palavit G, Heraeus Kulzer, Wehrheim, Germany) in plastic cylinders to allow for standardized and secure placement during testing. Maxillary central incisor 0.018″ slot stainless steel mesh base brackets (Mini Mono, order no. O711-0103, Forestadent, Pforzheim, Germany) were used throughout the study. The average surface area of the bracket base was 13.5 mm^2.

The indirect bonding technique was performed in the following manner: an alginate impression was obtained of each specimen and poured in orthodontic stone. On the dry casts, the teeth were painted with diluted separating medium and allowed to dry for 24 hours. The bracket bases were cleaned with alcohol. The bonding resin was placed on the bracket and—if necessary—worked into the mesh. For groups 1 and 2, Therma Cure® (Reliance Orthodontic Products, Itasca, Ill) adhesive was used. Group 3 was bonded with Transbond XT® adhesive (3M-Unitek, Monrovia, Calif). In group 4, Phase II® adhesive (Reliance Orthodontic Products, Itasca, Ill) was mixed according to the manufacturer's recommendations. The brackets were pressed firmly onto the model. Excess composite was removed with a scaler. The specimens in groups 1 and 2 were placed in a universal oven (Model No. 300, Memmert, Germany) at 250°F for 15 minutes to polymerize the Therma Cure® adhesive and were allowed to cool down after removal from the oven.[26] The temperature of the oven was checked with the built-in thermostat. In group 3, the adhesive was cured with a halogen curing light (Polylux II, Kavo, Biberach, Germany) for 2 minutes. This extended curing period was chosen to achieve complete polymerization of the adhesive on the plaster model.

After polymerization of the custom base adhesive, transfer trays were made from vinyl polysiloxane impression material (Silagum AV-Putty soft, DMG, Hamburg, Germany). After the transfer tray material had set, the specimens were soaked in warm water for 30 minutes. The transfer trays were removed from the plaster models, and sandblasting with 50-μm aluminum oxide cleaned the composite adhesive on the bracket base.

Seven days after fabrication of the transfer trays the second part of the bonding procedure was performed[4]: The teeth were etched with 37% phosphoric acid gel (Ormco, Orange, Calif) for 30 seconds, rinsed thoroughly with water and air-water spray, and dried with compressed air for 20 seconds. The following indirect bonding sealants were applied according to the manufacturer's recommendations.

Groups 1 and 4: Maximum Cure® (Reliance Orthodontic Products, Itasca, Ill).

Group 2: Custom IQ® (Reliance Orthodontic Products, Itasca, Ill).

Group 3: Sondhi Rapid Set® (3M Unitek, Monrovia, Calif).

In groups 1, 2, and 4, Plastic Conditioner (Reliance Orthodontic Products, Itasca, Ill) was applied before bonding as suggested by the manufacturer. Group 5 served as a control group and was direct bonded using Transbond XT® adhesive according to the manufacturer's recommendations. The brackets were light-cured with a halogen light source (Polylux II, Kavo, Biberach, Germany) for 20 seconds (10 seconds from the mesial side and 10 seconds from the distal side of the bracket).

After bonding of the sealant was completed the transfer trays were removed. In case of bracket failure upon removal of the tray, the adhesive was removed from the tooth surface with a finishing bur and the custom base of the bracket was cleaned with a scaler and sandblasted. Then the bonding procedure was repeated. The specimens were stored in distilled water for 24 hours.

Debonding procedure

The brackets were debonded with a Zwicki Z2.5 universal testing machine (Zwick, Ulm, Germany) at a cross-head speed of one mm/min.[27] The embedded teeth and brackets were aligned in the testing apparatus to ensure consistency for the point of force application and direction of the debonding force for all specimens. A stainless steel wire loop (0.020 inch diameter) was engaged under the occlusal

TABLE 1. Shear Bond Strength (Mean, Standard Deviation) and Weibull Parameters[a]

Group	Adhesive	Mean (MPa)	SD (MPa)	Group Differences[b]	Weibull Modulus	Correlation Coefficient	Characteristic Bond Strength	Stress at 10% Probability of Failure (MPa)	Stress at 90% Probability of Failure (MPa)
1	Therma Cure/Maximum Cure	7.28	4.88	A	1.60	0.977	8.15	2.00	13.71
2	Therma Cure/Custom IQ	7.07	4.11	A	1.53	0.981	8.10	1.87	13.95
3	Transbond XT/Sondhi	14.99	2.85	B	6.06	0.948	16.13	11.13	18.51
4	Phase II/Maximum Cure	15.41	3.21	B	5.17	0.983	16.74	10.83	19.67
5	Transbond XT (Light cure)	13.88	2.33	B	6.83	0.919	14.85	10.68	16.78

[a] Groups with the same letters are not significantly different from each other (Tukey, $P < .05$).
[b] MPa indicates megapascals; SD, standard deviation.

bracket wings to produce a shear-peel force parallel to the bracket base in an occluso-gingival direction. The load at failure was recorded.

For each specimen the substrate surface was examined with an optical stereomicroscope (magnification 10×) and an adhesive remnant index (ARI) was determined:[28]

Adhesive remnant index

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 all adhesive left on the tooth, with distinct impression of the bracket mesh

The ARI score was assessed by the same operator.

Statistical analysis

To calculate shear bond strength, the debonding forces (N) were converted to stress values (MPa) by taking into account the surface area of the bracket base. Bond strengths of the different groups were compared by one-way ANOVA, with post hoc Tukey tests ($P < .05$). A Weibull analysis was performed: the Weibull modulus, characteristic bond strength, correlation coefficient, and the stress levels at 10% and 90% probability of failure were calculated. A Kruskal-Wallis nonparametric test was used to determine whether there were any significant differences in the ordinal ARI values ($P < .05$).

RESULTS

The mean shear bond strengths, standard deviations, and the parameters of the Weibull analysis (modulus, correlation coefficient, characteristic bond strength, stress at 10% and 90% probability of failure) are given in Table 1. Figure 1 shows the Weibull distribution plots of the probability of failure at a certain shear stress level for the different groups.

The analysis of variance demonstrated that there were significant differences in shear bond strength between the groups investigated ($P < .001$, F = 27.224). The Tukey tests revealed that mean shear bond strengths for groups 1 and 2 were significantly lower than for groups 3, 4, and 5 (see Table 1).

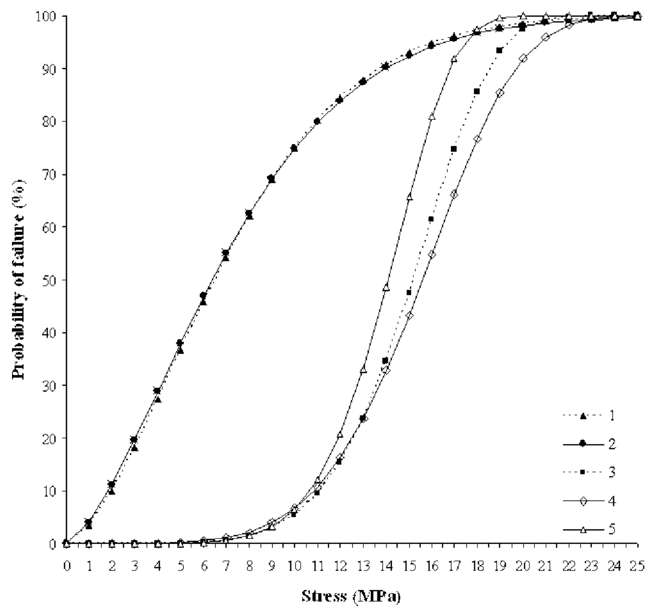

FIGURE 1. Weibull distribution plots. Groups: 1, Therma Cure/Maximum Cure; 2, Therma Cure/Custom IQ; 3, Transbond XT/Sondhi Rapid Set; 4, Phase II/Maximum Cure; 5, Transbond XT (Light cure).

Bracket failure was noted in groups 1 and 2, in two specimens each, after removal of the transfer tray. The bonding procedure was repeated in these specimens. No enamel fractures were found in any of the specimens. Means, standard deviations, and ranges of the ARI results are given in Table 2. The Kruskal-Wallis test indicated that there were significant differences between the groups ($\chi^2 = 15.13$, $P < .01$).

DISCUSSION

This study investigated bond strength for currently used adhesives and indirect bonding techniques on the basis of the Thomas technique, which means using a composite custom bracket base.[13–18,29,30]

The composite-sealant interface might present a weak

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

		ARI Scores						
Group	Adhesive	0	1	2	3	Mean	SD	Range
1	Therma Cure/Maximum Cure	—	1	19	—	1.95	0.22	1–2
2	Therma Cure/Custom IQ	—	1	19	—	1.95	0.22	1–2
3	Transbond XT/Sondhi	—	1	19	—	1.95	0.22	1–2
4	Phase II/Maximum Cure	—	8	12	—	1.60	0.50	1–2
5	Transbond XT (Light cure)	—	3	17	—	1.85	0.35	1–2

link in this indirect bonding technique because of the aged composite that is used, similar to reduced bond strengths found for the repair of composites.[5] Shiau et al[4,5] investigated bond strengths using a chemically cured composite which was seven days old when bonding of the sealant was performed. They concluded that no evidence was found to suggest that an aged composite would predispose the enamel-bracket system to fail at the sealant-composite interface. In the present study, the same period of seven days between polymerization of the composite and the sealant was chosen. Two indirect bonded groups demonstrated bond strengths comparable to the direct bonded control group, indicating that the aged composite-sealant link does not necessarily lead to lower bond strengths in indirect bonding techniques.

The experimental design of the present study using one tray for each tooth allows for an ideal adaptation of the custom base to the tooth surface. Generally, when indirect bonding is used in orthodontic practice, trays are formed for bonding multiple teeth, eg, one tray is used for each quadrant to be bonded. In a clinical setting, incorrect placement of a tray for multiple teeth may result in larger sealant film thickness and a decrease of the bond strength.

The original Thomas technique, group 3, showed bond strengths comparable to the direct bonded group 5 and the modified Thomas technique, group 4. Although the bond strength in the modified Thomas technique group 2 was significantly lower than in groups 3, 4, and 5, it was comparable to original Thomas technique group 1, which used the same composite for the custom bracket base. Although the lower bond strengths in groups 1 and 2 may be because of the bracket base composite, the results of our study show that the use of the original Thomas technique does not cause lower bond strengths compared with the modified Thomas technique or direct bonding procedures.

In the present study, groups 1 and 2 showed mean bond strength measurements of 7.28 and 7.07 MPa, respectively. Reynolds[31] had suggested that minimum bond strength of 5.9–7.8 MPa is sufficient for orthodontic bonding purposes. Therefore, the mean bond strength measured for these two groups might be considered adequate. But for the interpretation of the results of bond strength measurements, mean values are of limited use for the clinician.[32] A survival analysis, eg, Weibull analysis, may be more appropriate to indicate the clinical performance because it outlines the probability of failure at a certain force level.[33] The graph of the Weibull analysis (Figure 1) shows considerable chance of bond failure for groups 1 and 2 when shear stress approaches the abovementioned level of 5.9–7.8 MPa. The fact that both groups with the thermally cured composite exhibited lower bond strengths suggests that the reason for this is related to the custom base composite. Two different temperatures and intervals have been recommended for curing the thermally cured composite Therma Cure used in these two groups. Sinha et al[13] used a temperature setting of 325F for 20 minutes on the basis of the manufacturer's recommendation at that time. Gange[26] stated that the composite would fully polymerize when exposed to a temperature of 250F for 15 minutes. We tried to follow this more recent recommendation as closely as possible. Our oven was preheated to 250F, and on opening the oven for placement of the models with the attached brackets, the temperature of the oven dropped slightly. The models were kept in the oven for 15 minutes after the temperature of 250F was reached again, and they were removed promptly thereafter.

In a clinical study on 30 consecutive patients, Miles[30] compared bracket failures using indirect bonding techniques with light-cured and thermally cured composites. He found more bond failures with the thermally cured material only for bonding plastic brackets (Spirit MB, Ormco, Orange, Calif) but not for metal brackets. His conclusions were that the heat during curing affected the base of the bracket or the difference in thermal expansion between bracket and base may have caused distortion of the base or microcracks in the custom base. But these findings do not explain the lower bond strengths in the present study when bonding metal brackets with the material.

The differences in ARI scores between the groups investigated were statistically significant. The lowest mean ARI score of 1.6 was found for group 4 (Phase II, Maximum Cure) vs the highest ARI scored of 1.95 in groups 1–3. This indicates that less adhesive was left on the tooth in group 4. In general, the failure site of metal brackets has been identified as the adhesive-base interface and, when bond strengths are high, failure will more often occur at the enamel-adhesive interface.[34,35] This tendency was found in our study as well, where group 4 had the lowest mean ARI score and showed the highest average shear bond strength (15.41 MPa). But this shear stress measurement was only slightly higher than in groups 3 (14.99 MPa) and

5 (13.88 MPa) and not significantly different from these two groups. Although ARI differences were statistically significant, the clinical relevance of this finding might be limited because of the rather small difference in the means.

CONCLUSIONS

- The bond strength of the light-cured composite/chemically cured sealant group 3 and the chemically cured composite and sealant group 4 compared favorably with the direct bonded light-cured group 5. The probability of bracket failure at clinically relevant shear stress levels was low for groups 3, 4, and 5.
- Indirect bonding with a thermally cured custom base (groups 1 and 2) showed significantly lower bond strength than groups 3, 4, and 5.
- Both the original (group 3) and the modified (group 4) Thomas technique were able to achieve bond strengths comparable to direct bonding techniques.

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