Original Article

Custom Base Preaging in Indirect Bonding

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Abstract: This in vitro evaluation analyzed the influence of custom base composite age on bond strength in indirect bonding. One hundred fifty permanent bovine mandibular incisors were randomly divided into 10 groups of 15 specimens each. Stainless steel brackets were bonded to the teeth using the Thomas indirect bonding technique using two different custom base composite-sealant combinations: (1) chemically cured Phase II® composite and chemically cured Custom I.Q.® sealant, and (2) light-cured Transbond XT® composite and chemically cured Sondhi Rapid Set® sealant. The composite custom bases were preaged for 24 hours and for seven, 15, 30, and 100 days. Shear bond strength tests for the two composite-sealant combinations showed no significant differences. Preaging of the custom base composite up to 30 days did not affect shear bond strength, and mean bond strength values exceeded 15 MPa in these groups. However, bond strength measurements for groups with a custom composite base aged for a longer interval (100 days) before sealant polymerization were significantly lower. On the basis of the results of this study, clinicians can safely use custom base composites aged up to 30 days when using the Thomas indirect bonding technique. (*Angle Orthod* 2004;74:106–111.)

INTRODUCTION

Royce Thomas developed an innovative indirect bonding technique in 1979.[1] This laboratory technique attaches brackets to a stone model with composite adhesive, which provides a customized base for each bracket. It probably is the most widely used indirect bonding technique today and established the foundation for contemporary indirect bonding.[2,3] Although Thomas[1] advocated the use of a chemically cured composite, recent publications have also described the use of thermally and light-cured composite adhesives for the construction of the custom bracket bases.[4–9] Only a thin layer of sealant is needed to bond the custom-based bracket to the tooth. In the original Thomas technique, a chemically cured sealant with two liquids was used: the catalyst resin was painted on the composite base, whereas a liquid universal resin was applied to the acid-etched enamel surface. A modification of this technique mixes the two components of the sealant before painting the sealant onto the bracket base and the enamel.[3,4,7,10] More recently, light-cured sealants have gained popularity.[9,11,12]

A custom base indirect bonding technique might be of particular interest when individualized setups are used to position the brackets. This is routinely done in lingual orthodontics because brackets are attached to very irregular and inconsistent lingual tooth surfaces. A thicker bracket base is often required, and custom base indirect bonding has overcome the problem of poor bracket base adaptation.[13,14] Furthermore, a thick composite layer will compensate for variations in labiolingual thickness of the teeth (eg, in peg-shaped maxillary lateral incisors), allowing their alignment with a preadjusted appliance.[14]

Unlike direct bonding techniques, the Thomas technique introduces an interface between a preaged custom composite base and a freshly polymerized sealant. Researchers have shown that once a resin composite is contaminated, polished, aged, or laboratory processed, the bond strength of fresh composite added to that surface drops considerably.[15–19] Ostensibly, this could produce a weakened interface when using the Thomas technique.[20] Restorative dentists have a keen interest in investigating bonding to aged composite because they repair faulty restorations. Researchers have described various adhesion mechanisms in composite repair. Chemical bonding relies on the chemical reaction of the resin with unreacted monomer groups on the surface of the substrate.[21,22] A final polymerization between the substrate and new resin occurs through unreacted carbon-carbon double bonds of the functional groups on the

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surface of the original polymer matrix.[23,24] The first 24 hours after polymerization offers the most reactive substrate for covalent bonding.[18] Dissimilar matrix formulae do not necessarily present an obstacle.[17,24] Mechanical adhesion will increase when the monomers of the new resin are able to dissolve the linear phases of the substrate and create an interpenetrating polymer network. The resin penetrates into the substrate and polymerizes to form molecular entanglements.[23] This type of bonding works best when the substrate contains no reactive functional groups or radicals on the bonding surface.[23] Researchers have advocated solvents, low-viscosity monomer resins, and unfilled intermediate resin layers to improve composite repair.[17,22,25–28]

The age of the bracket composite can vary from hours to weeks, depending on the interval between bracket attachment to the stone cast and its placement on the patient's teeth.[20] One report speculates that an older composite might produce a weaker bonding interface,[29] but little information exists regarding preaging of the custom base and its effect on indirect bonding strength. No published study has systematically evaluated the influence of the custom composite base age at the time of sealant polymerization in indirect bonding. Therefore, the aim of this study was to compare bond strengths in indirect bonding when using different time intervals to preage both light-cured and chemically cured custom base composites.

MATERIALS AND METHODS

Bonding procedure

One hundred fifty extracted bovine permanent mandibular incisors were obtained from a local slaughterhouse and stored in 0.5% chloramine solution before the experiment. Teeth were randomly assigned to 10 groups of 15 specimens. After cleaning with a brush and pumice-water slurry at slow speed, the teeth 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-inch slot stainless steel mesh base brackets (Mini Mono, order no. 0711-0103, 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. The dry model teeth were painted with diluted separating medium and allowed to dry for 24 hours. The bracket base was cleaned with alcohol. In groups P1 to P5, chemically cured Phase II® (Reliance Orthodontic Products, Itasca, Ill) adhesive was applied to the bracket to form the custom composite base. In groups T1 to T5, Transbond XT® adhesive (3M-Unitek, Monrovia, Calif) formed the custom bracket base, subsequent polymerization occurred by a halogen curing light (Polylux II, Kavo, Biberach, Germany) for two minutes. This extended curing interval achieved complete polymerization of the adhesive on the model. Transfer trays were made from vinyl polysiloxane impression material (Silagum AV-Putty soft, DMG, Hamburg, Germany). The specimens and their transfer trays were soaked in warm water for 30 minutes and were separated. The composite adhesive on the custom bracket base was cleaned by sandblasting with 50 μm aluminum oxide for three seconds. Before bonding the brackets to the teeth with sealant, the composite custom base was preaged in air at 73°F (23°C) for the following time intervals before bonding:

- Group P1, T1, 24 hours
- Group P2, T2, seven days
- Group P3, T3, 15 days
- Group P4, T4, 30 days
- Group P5, T5, 100 days

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. Groups P1 to P5 used Plastic Conditioner® (Reliance Orthodontic Products) before applying Custom I.Q.® (Reliance Orthodontic Products) sealant. Groups T1 to T5 used Sondhi Rapid Set® sealant (3M-Unitek, Monrovia, Calif). Both bonding materials are chemically cured sealants that consist of two separate liquids: one liquid is painted on the tooth and the other on the custom base of the bracket. All investigations followed the manufacturers' recommendations. After bonding completion, the transfer trays were removed, and the specimens were stored in distilled water.

Debonding procedure

Debonding was performed 24 hours after bonding of the sealant. The brackets were debonded with a Zwicki Z2.5 universal testing machine (Zwick, Ulm, Germany) at a cross-head speed of one mm/minute.[30,31] The plastic cylinders with the embedded teeth and the brackets were mounted on a joint and 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 fixed under the occlusal bracket wings to produce a shear-peel force parallel to the bracket base in an occlusogingival 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.[32]

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

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

Group	Base Composite	Sealant	Age of Custom Base	Mean (MPa)	SD (MPa)	Weibull Analysis: Weibull Modulus	Correlation Coefficient	Characteristic Bond Strength (MPa)	Shear Stress at 5% Probability of Failure (MPa)	Shear Stress at 10% Probability of Failure (MPa)
P1	Phase II	Custom I.Q.	24 h	15.18	4.27	2.84	0.969	20.33	7.14	9.20
P2	Phase II	Custom I.Q.	7 d	17.00	3.76	4.13	0.958	20.94	10.21	12.15
P3	Phase II	Custom I.Q.	15 d	16.74	2.42	5.40	0.931	19.75	11.39	13.02
P4	Phase II	Custom I.Q.	30 d	15.24	4.09	3.45	0.911	19.48	8.24	10.15
P5	Phase II	Custom I.Q.	100 d	12.17	4.60	2.16	0.983	17.49	4.41	6.16
T1	Transbond XT	Sondhi Rapid Set	24 h	18.02	3.37	4.74	0.979	21.66	11.58	13.48
T2	Transbond XT	Sondhi Rapid Set	7 d	16.65	4.55	2.75	0.953	22.53	7.65	9.94
T3	Transbond XT	Sondhi Rapid Set	15 d	15.90	5.27	1.24	0.835	30.53	2.78	4.97
T4	Transbond XT	Sondhi Rapid Set	30 d	16.69	4.18	3.25	0.981	21.61	8.67	10.82
T5	Transbond XT	Sondhi Rapid Set	100 d	11.72	4.46	1.38	0.909	20.52	2.39	4.02

3. All adhesive left on the tooth, with a distinct impression of the bracket mesh

ARI scores were assessed by the same operator.

Statistical analysis

To calculate shear bond strength, the debonding forces (N) were converted into stress values (MPa) by taking into account the surface area of the bracket base. Bond strengths of the different groups were compared by two-way analysis of variance (ANOVA, $P < .05$) with the factors, namely, age of custom base composite (24 hours up to 100 days) and type of adhesive (Phase II® custom base composite–Custom I.Q.® sealant in groups P1–P5, Transbond XT® custom base composite–Sondhi Rapid Set® sealant in groups T1–T5). A Weibull analysis was performed: the Weibull modulus, characteristic bond strength, correlation coefficient, and the stress levels at 5% and 10% probability of failure were calculated. Kruskal-Wallis and Mann-Whitney nonparametric tests were used to determine whether there were any significant differences in the ordinal ARI values ($P < .05$).[33,34]

RESULTS

The mean shear bond strengths, standard deviations, and the parameters of the Weibull analysis (modulus, correlation coefficient, characteristic bond strength, and stress at 5% and 10% probability of failure) are given in Table 1. Figures 1 and 2 show the Weibull distribution plots of the probability of failure at a certain shear stress level for groups P1–P5 and T1–T5, respectively. A rather large variation of the Weibull modulus was found in the different groups, ranging from 5.40 in group P3 to 1.24 in group T3. Correlation coefficients for the Weibull analysis were higher than 0.9, with the exception of group T3 (0.835).

The analysis of variance indicated that there were no significant interaction effects of the two factors, namely, type of adhesive and age of the custom composite base ($F = 1.060$, $P = .379$). There were no significant differences in bond strength between the two adhesive combinations that were used ($F = 0.603$, $P = .439$). However, the age of the custom composite base was significantly different in the groups investigated ($F = 7.136$, $P < .001$). The post hoc Tukey test revealed that bond strength was significantly lower for brackets with a custom base that was aged for 100 days.

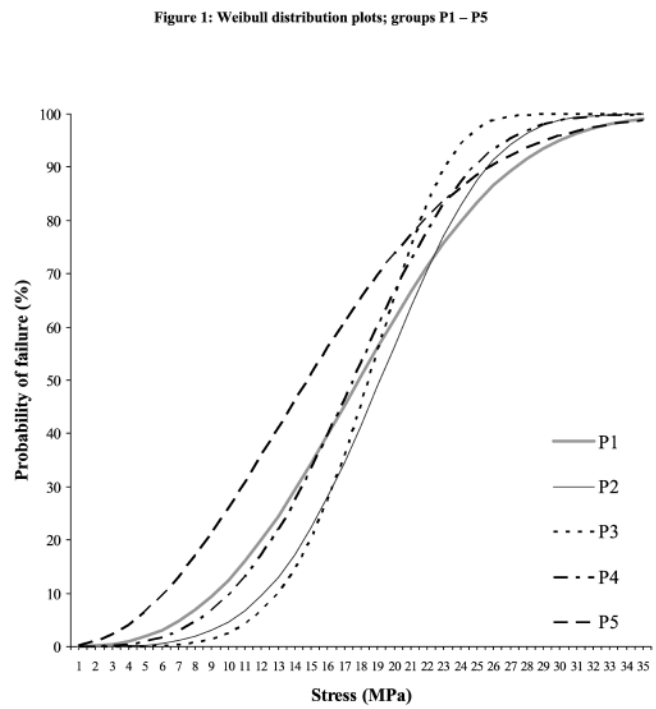

FIGURE 1. Weibull distribution plots. Groups P1–P5: Phase II® custom base adhesive, Custom I.Q.® sealant. Groups: P1, custom base adhesive aged for 24 hours; P2, custom base adhesive aged for seven days; P3, custom base adhesive aged for 15 days; P4, custom base adhesive aged for 30 days; P5, custom base adhesive aged for 100 days.

Means, standard deviations, and ranges of the ARI scores are given in Table 2. The Kruskal-Wallis test showed that

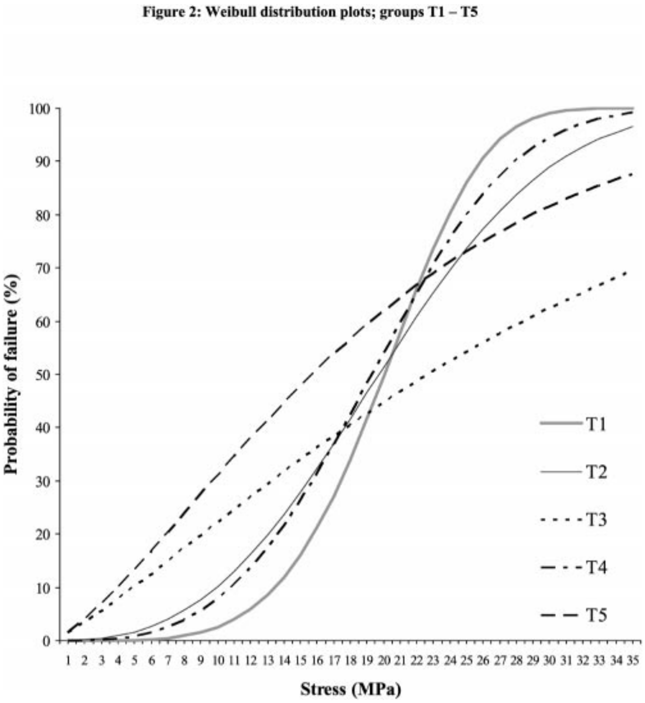

FIGURE 2. Weibull distribution plots. Groups T1–T5: Transbond XT® custom base adhesive, Sondhi Rapid Set® sealant. Groups: T1, custom base adhesive aged for 24 hours; T2, custom base adhesive aged for seven days; T3, custom base adhesive aged for 15 days; T4, custom base adhesive aged for 30 days; T5, custom base adhesive aged for 100 days.

there were no significant differences between the groups ($\chi^2 = 8.117$ and $P = .087$ for comparison of groups P1–P5, $\chi^2 = 3.700$ and $P = .448$ for comparison of groups T1–T5).

DISCUSSION

Although the use of a custom bracket base has been considered a ''further refinement'' in indirect bonding,[4] little information exists regarding the possible influence of custom base composite age at the time of bonding. Shiau et al[29] evaluated bond strength with seven-day-old composite surfaces and concluded that such a custom base would produce a sealant-composite interface with sufficient strength when used with indirect bonding. However, time spans longer than seven days frequently occur because indirect bonding procedures are oftentimes done by commercial laboratories and require additional time for shipping to the orthodontic office. Furthermore, individualized setups sometimes used in indirect bonding add to the laboratory time required. In this study, two commonly used base composite–sealant combinations were investigated: (1) the chemically cured base composite Phase II® and the chemically cured sealant Custom I.Q.®, and (2) the light-cured base composite Transbond XT® and the chemically cured sealant Sondhi Rapid Set®. Our results indicate that aging of the composite custom base for up to 30 days does not cause a reduction in shear bond strength. However, storage of the custom base for a longer time interval (100 days) before polymerization of the sealant had a detrimental effect on shear bond strength with both composites. The prolonged storage period resulted in mean bond strength values of 80.2% for Phase II® and of 65.0% for Transbond XT®, when compared with the 24 hour aged samples. On the basis of our results, bonding with sealants should occur within 30 days after polymerization of the custom base. The duration of time should accommodate indirect bonding laboratory procedures, shipment from a commercial laboratory, and ease of scheduling appointments.

The Thomas indirect bonding technique of this study used an unfilled sealant with low viscosity to bond to the composite custom base of the bracket. This method is comparable with the repair of a restorative resin material where unfilled or low-viscosity resins have been used.[17,22,26–28] An unfilled intermediate resin achieves better wetting of the substrate surface and to some degree dissolves and swells the polymer surface of the substrate.[28] Researchers report a wide range of interfacial bond strength from 25% to 100%

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

Group	Base Composite	Sealant	Age of Custom Base	ARI Scores 0	1	2	3	Median	Mean	SD	Range
P1	Phase II	Custom I.Q.	24 h	—	5	10	—	2.00	1.67	0.49	1–2
P2	Phase II	Custom I.Q.	7 d	—	6	9	—	2.00	1.60	0.51	1–2
P3	Phase II	Custom I.Q.	15 d	—	6	9	—	2.00	1.60	0.51	1–2
P4	Phase II	Custom I.Q.	30 d	—	7	8	—	2.00	1.53	0.52	1–2
P5	Phase II	Custom I.Q.	100 d	—	12	3	—	1.00	1.20	0.41	1–2
T1	Transbond XT	Sondhi Rapid Set	24 h	—	5	10	—	2.00	1.67	0.49	1–2
T2	Transbond XT	Sondhi Rapid Set	7 d	—	9	6	—	1.00	1.40	0.51	1–2
T3	Transbond XT	Sondhi Rapid Set	15 d	—	6	9	—	2.00	1.60	0.51	1–2
T4	Transbond XT	Sondhi Rapid Set	30 d	—	6	9	—	2.00	1.60	0.51	1–2
T5	Transbond XT	Sondhi Rapid Set	100 d	—	9	6	—	1.00	1.40	0.51	1–2

[a] 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.

in composite resin repair.[24,27] The age of the resin composite seems to influence this reduction in adhesion. Because the number of unreacted monomer groups decreases during polymerization, the possibility for primary bonding to those groups also declines.[16] On the basis of the evaluation of composite specimens that were stored between one and 360 days, Söderholm and Roberts[35] speculated that the main bonding mechanism during composite repair is mechanical retention. Both Söderholm and Roberts[35] and Mitsaki-Matsou et al[26] found a decrease in bond strength with aging of the composite. This is similar to the results of this study where storage up to 30 days resulted in higher bond strength than a longer storage of 100 days. The reason for the decrease in bond strength after long-term storage remains unclear. One difference between the repair of composites in restorative dentistry and the preaged composite used in indirect bonding is that custom base composites are stored dry before bonding, whereas the restorative composites for repair have been subjected to an intraoral environment. The hydrolysis of the material and temperature changes may affect material properties in composite repair but not in indirect bonding.

Zachrisson and Brobakken[36] discovered earlier that in direct bonding, the bonding adhesive constantly filled the entire contact surface. Hocevar and Vincent[37] reported on the detrimental effect of voids on bond strength in indirect bonding: they found a 50% mean reduction in bond strength in specimens with unfilled voids when compared with specimens free of voids or those with voids that were sealed. Hocevar and Vincent[37] used a modified restorative composite two-paste system diluted with unfilled resin (Concise®, 3M-Unitek, Monrovia, Calif). Both the sealants used in this study were designed primarily for indirect bonding purposes. One of the sealants (Sondhi Rapid Set®) has been advocated both to fill in possible voids in the custom base and to correct imperfections in the fit of the custom base against the enamel through its silica filler.[2] Mean bond strength measurements exceeded 15 MPa in all groups with custom base composite aged for 30 days or less. No significant differences in bond strength occurred between the groups with the chemically cured and the light-cured base composite. Although clinicians cannot rule out voids in custom bases or sealants, both indirect bonding adhesive systems used in this study enable the clinician to bond brackets with sufficient strength.

Weibull distribution analysis has proven useful for evaluating the fracture behavior of materials and components used in engineering, where experimentally observed variations are often attributed to the presence of faults, defects, or porosities.[38] Weibull analysis may prove more appropriate for evaluating the fracture behavior and reliability of adhesives than the calculation of means and standard deviations.[38–40] Nkenke et al[41] and Britton et al[42] pointed out that researchers should not presume a normal distribution of bond strength values: Nkenke et al[41] believe deviations in bond strength due to clinical bonding errors can only decrease the values. Probability calculations enable investigators to place in context the clinical significance of in vitro shear bond strengths.[43] The Weibull function takes into account the weaker values in the distribution, which have clinical importance. This type of analysis allows the prediction of bond failures at low forces from resin systems with high mean bond strengths.[38,44] In this study, the Weibull parameters illustrated in Figures 1 and 2 demonstrate a considerable probability of failure at low stresses for groups P5, T3, and T5. This indicates that preaging the composite base for 100 days might jeopardize the bond. The Weibull analysis for group T3 calls for cautious interpretation because this group had the lowest correlation coefficient (0.835). The calculation of the correlation coefficient by regression analysis indicates how well the data fit the Weibull equation. Therefore, the Weibull analysis may not adequately resemble the distribution of bond strength values in group T3. Furthermore, the lowest Weibull modulus (1.24) was calculated for group T3. This indicates a wide variation of the results, a factor also reflected in the largest standard deviation value in this group. One of the drawbacks of the Weibull analysis is that large samples may be needed to ensure meaningful results.[38,39] McCabe and Walls[38] pointed out that when groups of 10 specimens are used, one or two abnormal results may give a misleading impression. The sample size of 15 specimens per group in this study seems appropriate for bond strength testing in general. However, a larger sample size might have been beneficial for application of the Weibull analysis.

CONCLUSIONS

Aging of the custom base composite for up to 30 days did not adversely affect bond strength, and aging of the composite for 100 days resulted in significantly lower bond strength both for Phase II®–Custom I.Q.® and for Transbond XT®–Sondhi Rapid Set® base composite-sealant combinations. Weibull analysis confirmed this assessment and indicated considerable risk for bond failure at clinically relevant levels of stress with base composite aged for 100 days.

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