Bond strength of aged composites found in brackets placed by an indirect technique

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One of the most popular techniques for the indirect bonding of orthodontic brackets was introduced by Thomas.[1] He used a permanent composite in place of a temporary adhesive to attach brackets to the patient's stone model. The "Thomas technique" creates an interface not present in most indirect or direct techniques, that is, the interface between an aged (set) composite and the sealant (Figure 1A).

This interface is a potential weak link. The age of the composite to which the sealant is applied could vary from hours to weeks depending upon the interval between bracket attachment to the stone cast and placement of brackets on the patient's teeth. Studies[2,3] of the repair of composites have shown that bond strengths are significantly reduced with an interface involving an aged composite. Despite the presence of a potentially weak interface there have been few laboratory investigations of brackets placed by the Thomas technique. An investigation which compared the shear bond strength of brackets attached by this technique and by a direct technique found no difference between the two methods if marginal voids were not present or if the voids resulting from the Thomas method were intentionally covered with sealant.[4] Nevertheless, two-thirds of the brackets attached with the Thomas technique had marginal defects which resulted in a 50% reduction in bond strength if the defects were not repaired with sealant. It should be noted that the age of the composite was not specified but appeared to have been relatively new as compared to the typical case encountered in clinical

Abstract

The "Thomas" indirect technique for bracket attachment produces an interface not present in direct techniques, that is, an aged composite-sealant interface. Our primary goal was to determine if a weakened interface was produced by a modified (sealant was mixed prior to placement of brackets) Thomas indirect technique when the composite was aged for 7 days. The enamel-bracket system was investigated in vitro by comparison of shear bond strengths for metal and ceramic brackets bonded to bovine teeth by a direct and indirect method. Nearly all specimens failed at the bracket-composite interface and, subsequently, no difference was found between specimens placed by direct or indirect methods. No evidence was found to suggest that an aged composite would predispose the enamel-bracket system to fail at the sealant-composite interface. The ceramic brackets used in this investigation had lower bond strengths then metal ones, but the breaking loads were similar.

Key Words

Ceramic and metal brackets • Shear bond strength • Interfacial fracture • Aged composite

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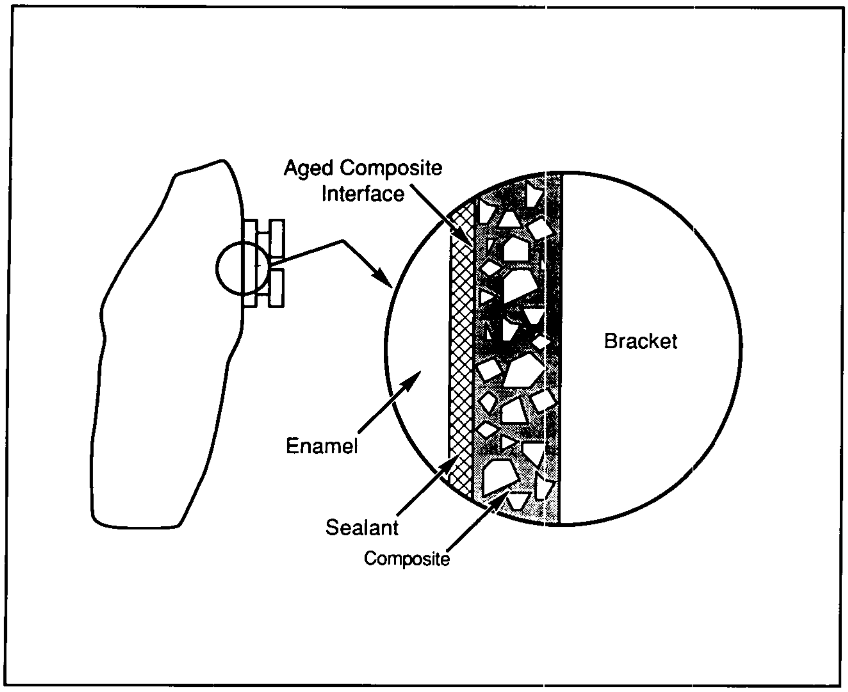

Figure 1A

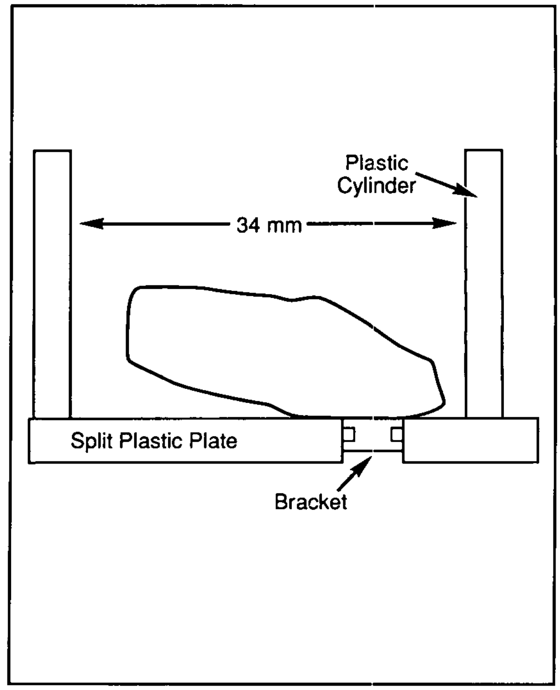

Figure 1B

Figure 1A-B
Schematic representation of specimens, which illustrates:

A. bracket bonded to bovine tooth with blowup of the various interfacial areas, and

B. tooth and bracket positioned in plastic cylinder for embedding.

situations. Possibly an older composite would produce a weaker interface.

A weakened interface could prove beneficial when using ceramic brackets if the interface did not reduce the bond strength too much. Ceramic brackets are noted for their high bond strengths and subsequent problems with debonding such as enamel and/or bracket fracture.[5,6,7,8,9] A controlled reduction in bond strength due to a weakened interface could simplify debonding procedures for ceramic brackets.

Evaluation of the Thomas technique is complicated by the number of variables which could potentially alter the bond strength of brackets. Foremost among these variables is the age of the composite when bonded to the tooth, which in this investigation, was set at 7 days. Another likely variable is the potential for incomplete curing resulting from not mixing the chemical cure sealant prior to placement of brackets. In the Thomas technique, brackets with attached aged composite are bonded to teeth with a chemical cure sealant; unfilled catalyst resin is applied to either the enamel or the composite surface while the universal resin is applied to the other surface. Mixing occurs when the two surfaces are brought together. To eliminate this potential variable, a "modified" Thomas technique was adopted where the chemical cure sealant was mixed prior to applying to both tooth and composite (bracket base). Finally, variations in composite and/or sealant film thickness can alter bond strength[10,11,12,13] and efforts were taken to minimize this potential variable.

The primary goal of this investigation was to determine if a weakened interface was produced by a "modified" (sealant was mixed prior to placement of brackets) Thomas technique when the composite was aged for 7 days.

Materials and methods

A conventional two-paste chemically cured composite/resin orthodontic bonding system (Concise, Dental Products/3M, St. Paul, Minn) was used in this investigation. The metal bracket (twin lower central incisor, Mini-mesh, Ormoco Corp., 1332 S. Lone Hill Ave., Glendora, Calif) had a woven foil mesh. The ceramic bracket (upper central incisor, Transcend, Unitek Corp., Monrovia, Calif) had a chemical surface treatment to increase bond strength. Since ceramic brackets are noted for their high bond strengths, it was assumed that when the enamel-sealant-composite-bracket system was tested for bond strength, failure might occur at the sealant-composite interface making these brackets useful for study of this interface.

Sixty bovine incisors, stored in water following extraction at a local slaughterhouse, were chosen as substitutes for human enamel due to their greater availability and larger size. A flat enamel surface was obtained by wet sanding the labial surface with progressively finer silicon-carbide abrasive papers (final grit 400). The 60 bovine incisors were randomly divided into four groups: 1) direct bonding with metal brackets, 2) indirect

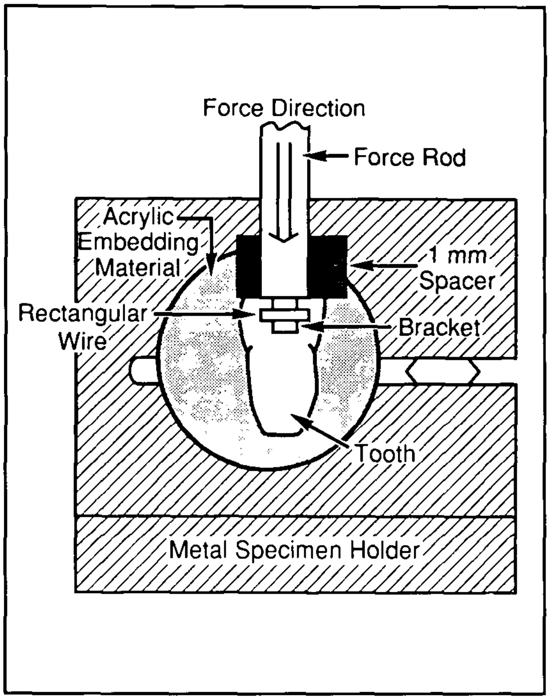

Figure 2A

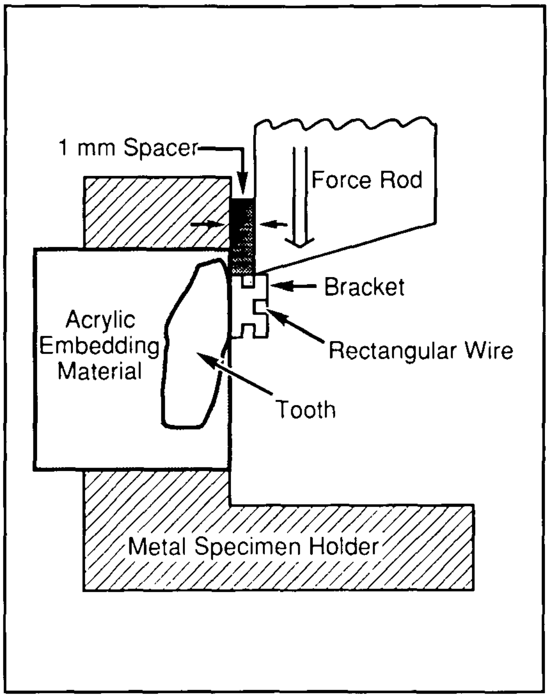

Figure 2B

Figure 2A-B
Schematic representation of embedded specimens mounted in testing jig, which illustrates:

A. Front view of specimens showing force rod and 1 mm spacer; and

B. Specimen and jig in cross-section.

bonding with metal brackets, 3) direct bonding with ceramic brackets, and 4) indirect bonding with ceramic brackets.

The manufacturer's instructions for direct bonding were followed, with two exceptions: the brackets were seated on the enamel surface with a constant force of 4.4 lb for 2 minutes and composite flash was removed before polymerization with a plastic explorer. Each specimen was bench cured for an additional 10 minutes before embedding (described below).

The indirect technique was performed as follows: 1) an alginate impression of each specimen was obtained and poured in stone (W/P ratio = 22/100, Super Die Stone, Whip Mix Corp., Louisville, Kentucky); 2) after setting and drying, the models were painted with a layer of separating agent (Al-cote, Dentsply/York Division, York, Penn) and allowed to dry; 3) the composite was mixed at a 1:1 ratio by volume and applied to the bracket base; 4) the bracket was placed on the model tooth surface with a constant 4.4 lb-force for 2 minutes; 5) composite flash was removed before polymerization with a plastic explorer; 6) margins were inspected for defects using a stereomicroscope; 7) an individual impression (Optosil, Unitek Corp., Monrovia, Calif) block was formed for each specimen by applying light body to the bracket and then the puffy body was applied using an acrylic tray made for the tooth; 8) the block with its embedded bracket was separated from the model by immersing in warm water and toothbrushing; 9) the impression blocks with embedded brackets were stored at room temperature for 7 days; 10) each tooth was etched and dried as described for direct bonding; 11) to ensure complete mixing, the sealant was mixed in a dappen dish at a 1:1 ratio and applied to both tooth surface and bracket base; 12) the impression block was placed over its corresponding tooth, held with light pressure for 2 minutes and removed after 10 minutes; and 13) bracket margins were examined for marginal defects with a stereomicroscope.

Following the 10 minute bench cure, the bonded teeth were immediately embedded with autopolymerizing acrylic resin in 34 mm I.D. plastic tubes using a split polytetrafluoroethylene plate with a bracket size hole to orient the bracket (Figure 1C). After the acrylic had set, the split plate was removed. A piece of 0.0215 x 0.028 rectangular wire (Figure 2B) was inserted into the slot of each metal bracket to avoid wing distortion during testing. All specimens were stored for 24 hours in 37°C water.

Shear bond strength in 37±1°C distilled water[14] was determined with an Instron universal testing machine using a crosshead speed of 0.05 cm/min. A testing jig[14] (Figure 2) held the specimens so that the enamel surface was parallel to the direction of force application during the shear bond strength test. A 1 mm thick spacer was placed between the enamel surface and shear rod to ensure that the shear rod contacted the bracket of every specimen at the same location relative to the enamel surface (Figure 2). The metal brackets were engaged on

Table 1
Shear bond strength of metal and ceramic brackets

	Metal Bracket MPa		Ceramic Bracket MPa	
	Direct	Indirect	Direct	Indirect
N	15	15	15	15
Mean	11.7	11.8	8.3	8.6
SD	2.2	2.0	3.0	2.8
Range	6.4-14.0	8.2-14.5	4.3-12.2	4.6-15.0
ST*	[		]	
	[			]
		[	]	
		[		]

Significance test was evaluated by one-way analysis of variance with Sheffe multiple range test. Values connected by brackets are significantly different at $p < 0.05$.

the top wings while the ceramic brackets were turned sideways to avoid bracket wing fracture during testing.

Bond strengths were calculated as the breaking load divided by the area beneath the bracket base (metal area = 9.88 mm^2, ceramic area = 12.95 mm^2). The means and standard deviations were calculated for each group. One-way analysis of variance was used to test for significant differences. When there was not a Gaussian distribution for the data, a nonparametric test (Kruskal-Wallis) was applied to the data. Student's t-test was used for paired comparisons.

Fractured surfaces were examined with a stereomicroscope at 40x and when the different interfaces or materials were hard to identify a scanning electron microscope was used. Surfaces which appeared to be enamel-sealant interfaces were etched with acid so that the enamel etching patterns would be revealed if enamel was exposed.

Results

The statistical description of the shear bond strengths for each type of bracket (metal and ceramic) with direct and indirect bonding techniques are shown in Table I. Analysis of the data by a one-way analysis of variance with Scheffe procedure revealed no significant difference between brackets.

With respect to marginal defects, two of 15 metal brackets in the indirect bonding technique group showed marginal defects after removal of the composite resin flash from the stone model of the teeth. However, all specimens were free of defects after bonding to etched enamel, as determined with a stereomicroscope.

Fracture-path studies were performed to identify the weak phase or phases. Of the 60 specimens, 26 metal brackets and 27 ceramic brackets showed predominantly (greater than 50%) fracture at the bracket/composite interface, while 6 specimens failed mainly at the enamel/sealant interface, which was verified by acid etching of the tooth surface followed by examination with a stereomicroscope. One metal bracket specimen from the indirect bonding group had multiple fractures and a bond strength of 13.8 MPa. It showed evidence of fracture at the enamel-sealant interface, at the sealant-composite interface and at the composite-bracket interface.

Excluding five metal brackets with obvious defects and one fractured ceramic bracket, the specimens which failed predominantly at the bracket/composite interface were regrouped to compare the adhesive strength of the bracket-composite interface for the different brackets. Table 2 tabulates the statistical values and shows that ceramic brackets had lower bond strength and higher variation than metal brackets. Moreover, the bond strength difference between metal and ceramic brackets was significant (Student t-test, $p < 0.0001$).

Discussion

In this study, a modified Thomas bonding technique was evaluated using metal and ceramic brackets. The procedures of the Thomas technique were altered in order to insure complete curing of the sealant by prior mixing of sealant rather than relying upon placement of the brackets to mix the two components of the sealant.

Comparison of bond strengths between direct and indirect bonding techniques indicated no significant difference (Table 1). This result is in agreement with an earlier study[4] which used the same brand metal bracket and adhesive but had a younger composite (estimated by us to be 3-4 hours old before placement of brackets on the tooth). However, the mode of fracture was not the same as found here. Instead of fracture predominantly at the enamel-adhesive interface as shown in that study (72% of the indirect group and 56% of direct group), fracture occurred mainly at the composite-bracket interface (86.6% of both groups). A number of factors could explain the difference in mode of fracture found in our investigation as compared to the previous one.[4] The previous study used human maxillary premolars while our study used bovine teeth. Brackets have concave surfaces to fit human teeth; the bovine teeth in our study were ground flat. As a consequence, the film thickness was likely different in the two studies. This factor could lead to a thicker composite and thinner sealant phase in our study. Our study was, however, designed to give a consistent sealant-composite thickness by using a constant 4.4-lb force to place brackets against teeth in the direct technique, as well as a consistent composite thickness using a similar method to set the composite and bracket against the model teeth in the indirect method. Mixing of the sealant for the indirect technique could likely lead to a stronger enamel-sealant interface due to better curing of the sealant than in the earlier investigation[4]. Finally, our use of bovine teeth could be a factor. However, it has been shown that similar results have been obtained with bovine and human teeth.[12]

The data presented here do not suggest that the indirect bonding technique would provide easier clean-up after debonding because the mode of failure was primarily the same for both direct and indirect techniques (i.e. failure at the composite-bracket interface). However, they do suggest that a 7-day old composite surface will produce a sealant-composite interface with sufficient strength that this interface will not be the weak link for metal brackets placed by the indirect technique. Since this particular metal bracket design is noted for its good bond strength as compared to other types of metal brackets,[5] those ceramic brackets with exceptionally high bond strengths will likely not be clinically compromised if used with the modified double-sealant indirect technique used in this study.

The breaking loads for Mini-mesh metal brackets bonded with Concise has been reported to be 68.2±9.37 Kg for the direct group and 65.3±8.84 Kg for the indirect group.[4] The similarity between breaking loads for indirect versus direct groups is consistent with our results. In another study,[7] these same types of brackets were reported to have a shear bond strength of 12.1±4.6 MPa, which is consistent with values obtained in this investigation. The shear bond strengths of Transcend ceramic brackets bonded with Concise has been reported to be 18.4 ±5.4 MPa[7] and 12.4 ±3.2 MPa,[9] values considerably higher than our own. The ceramic brackets used here fractured primarily at the ceramic-composite interface giving results similar to another investigation,[9] which used the same types of brackets. Ceramic brackets generally break in other regions.[5,6,8,9] A possible explanation for the lower bond strengths of the type of ceramic bracket tested was that we used a 1-mm spacer, which would intensify the bending moment induced tensile stress for any given breaking load. Most researchers do not specify how far the load was applied from the enamel interface. One article showed a picture of the experimental arrangement which suggested that they tried to intensify the shear mode by loading the bracket as close to the enamel interface as possible.[9] We feel that using a 1-mm spacer results in a loading situation closer to what would occur in the mouth, where it would be very difficult to apply a pure shear load.

Table 2
Shear bond strength of metal and ceramic brackets fractured at the adhesive bracket interface

	Metal Bracket MPa	Ceramic Bracket MPa
N	21	26
Mean	12.6	8.9
SD	1.2	2.8
Range	9.8-14.5	4.6-14.9
ST*	[___ p<0.0001	___]

*Student's t-test

Another explanation for the low bond strength is that there was a batch variation in the uniformity of the ceramic brackets' silane coating. Quality control problems in the production process could partially explain why the new generation of Transcend brackets relies on mechanical rather than chemical retention. These new brackets would probably not give the same results as the ones tested here. Accidental surface contamination of the ceramic brackets at some stage from production to testing could have resulted in reduced bond strength. The distribution of bond strengths suggested that if contamination occurred, nearly all if not all of the brackets were affected.

During use or when debonding, ceramic brackets may fracture leaving a portion of the hard bracket to be removed by grinding. In some cases, the enamel fractures which is detrimental to the tooth. The Thomas indirect bonding technique coupled with ceramic brackets introduces a new interface that might become the site of failure, thereby making ceramic brackets more attractive. Unfortunately, the ceramic brackets tested failed at lower bond strengths than did the metal brackets, and thus this hypothesis could not be tested. From the standpoint of bracket removal, these particular ceramic brackets are likely to facilitate debonding. Their low bond strengths might lead to a high incidence of clinical debonding, but only clinical studies will answer this question. However, it should be noted that the average breaking load for ceramic brackets (116 N = 26 lbs, using data from Table 2) was only 6% less than that of metal brackets (124 N = 27.9 lbs).

Given the same bracket, most fractured specimens showed similar fractographs. On the tooth side of most (87%) metal bracket specimens, imprints of smooth metal mesh was evident. On the bracket side, the metal wires of the mesh were exposed but composite was embedded in the spaces between the wires, which is consistent with the view[5,10] that mechanical interlocking is the major source of retention between composite and metal brackets having metal mesh covering. It is likely that voids between composite and bracket mesh act as stress concentrators and become a critical factor for initiation of fracture. While it is very likely that interfacial voids/defects will weaken interfaces,[4,11,13] no evidence was found to suggest that voids were responsible for the low bond strength of the ceramic brackets used here. Most ceramic brackets revealed smooth surfaces without obvious defects on either fractured surface and no evidence (SEM and light microscope) of resin on the brackets.

One ceramic bracket broke from a wing through the base during preparation but all other brackets were intact after testing. Often a ceramic wing will fail before the composite during bond strength tests.[7] In order to obtain fracture through other phases or interfaces rather than fracture of the bracket, the bond strength tests were performed by applying force to the side of the ceramic bracket rather than directly to the bracket wings. Consequently, our finding of no fractured brackets during testing cannot be interpreted as indicating a low incidence of ceramic bracket failure in vivo.

The existence of marginal defects at bracket boundaries is undesirable due not only to their role in reducing retention but also to increased chances for decalcification of enamel at the bracket boundaries. With the procedures used here, no marginal defects were found on the bonded brackets prior to testing. Two of these experimental procedures are of clinical interest. First, only one tooth with a flat surface was used at a time in this investigation while a clinical situation will involve many teeth with natural surfaces. A slight mispositioning of the brackets with subsequent larger marginal gaps that would be harder to fill with resin is more likely in a clinical situation and, as a consequence, marginal gaps would be more likely. Second, a plastic explorer was used to remove the composite flash to avoid scratching the super die stone cast. A metal instrument would more likely scratch the cast leaving an indentation on the cast surface which would fill with impression material. This extra material would likely prevent proper seating of the bracket on the tooth, increasing chances for marginal defects. It seems likely that the use of plastic instruments for removal of unset composite flash would reduce the chances for marginal defects.

Attaching brackets by the Thomas indirect technique results in a complicated system involving many variables and three interfaces which maybe susceptible to failure *in vivo*. Two of these interfaces, resin-enamel and composite-bracket, have been widely investigated. Based on the results of investigations of the repair of composites,[2,3] problems with debonding at the resin-composite interface could be expected. Our results suggest that debonding at this interface is unlikely. However, subjecting specimens to a more severe environment (longer exposure to water and thermal cycling) could lead to failure at this interface during testing and suggests a potential problem with *in vivo* debonding.

It should be noted that the chemical sealant was mixed prior to bracket placement in order to insure proper curing of the sealant. While this step reduces the working time for bracket placement, the reduction should not hinder the clinician aided by a dental assistant. And as long as the brackets can be seated within the working time, the resin which penetrates the etched enamel will more likely be cured producing stronger tags and interfaces.

Conclusions

1. An aged (up to 7 days) composite surface, produced in the modified Thomas indirect technique, is not likely to compromise the bond strength of brackets attached by this technique.
2. No evidence was found to suggest that an aged composite would predispose the enamel-bracket system to fail at the sealant-composite interface.
3. All specimens were free of marginal defects after bonding to etched enamel as determined with a stereomicroscope.
4. The bond strengths of brackets placed by direct and indirect techniques are similar.
5. Fracture occurred primarily at the bracket-composite interface regardless of type of bracket (metal or ceramic) or method of bracket attachment (indirect vs. direct).
6. The ceramic brackets used in this investigation had lower bond strengths than metal brackets, but the breaking loads were similar.

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