THE USE OF AN ADHESION PROMOTER IN THE
BONDING OF ORTHODONTIC BRACKETS

by
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of the requirements for the degree of Master of Science in Dentistry,
Thesis accepted by the faculty of the Department of Orthodontics, Indiana University School of Dentistry, in partial fulfillment of the requirements for the degree of Master of Science in Dentistry.

Chairman of the Committee

Date January 14, 1988
I would like to thank the members of my graduate committee for their help in preparation of this thesis. Gratitude is extended to Dr. LaForrest D. Garner for his encouragement in finishing the project. Special thanks go to Dr. Keith Moore, Dr. James Shanks and Professor Paul Barton for critical review of the manuscript.

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INTRODUCTION
The vast majority of orthodontists in the United States bond rather than band orthodontic brackets to anterior teeth. A 1979 survey of 2,000 orthodontists showed that 93 percent of them use bonding in their practice. There are many reasons for this, but the most commonly listed are:

1. Esthetics. Tooth-colored brackets, first in plastic and then in ceramics, are much more esthetic than anterior bands. Lingual orthodontics became a reality only after bonding of brackets emerged as everyday occurrences.

2. Separation of anterior teeth is eliminated, reducing the discomfort of the orthodontic "experience."

3. Interproximal areas are exposed for brushing and flossing. Also, decay under loose bands may go undetected over a protracted period, but when a bonded bracket breaks loose, it is apparent immediately in most cases. Bands tend to collect plaque along longer marginal surfaces than do smaller bonded brackets. This reduced plaque retention reduces gingival hyperplasia.

4. Interproximal space needed for bands is eliminated, and thus borderline extraction cases may be treated without extraction. (Interproximal reduction may also be accomplished at any time using bonded brackets.) This may explain why the extraction of bicuspid teeth has been reduced since bond-
ing has replaced banding. Prior to bonding, bands had to be removed and then recemented to correct tooth mass discrepancies.

5. Reduced chair time. Bonded brackets require only a fraction of the time to place bands.

6. Reduction of inventory. Whereas banding requires that 8 to 10 sizes per tooth be stocked, only one bond is needed per tooth. A banded system requires a band and bracket for each tooth, whereas bonds do not require a band. This reduces the cost.

7. Bonded brackets may be placed indirectly. This increases the accuracy of the strap up and thus reduces the number of wire bends. This speeds treatment and can reduce cost.

8. A bonded system does not require space closure when the brackets are removed, as is the case when bands are removed. This makes finishing easier and more predictable.

However advantageous bonding may be, certain requirements must be met for the process to be successful. Brackets must be relatively easy to place with a standardized technique. The bonding process must be compatible with oral soft and hard tissues. No permanent damage to enamel surfaces should occur, and no cytotoxic reaction should be produced by the banding medium. Microleakage must be prevented to insure that caries does not occur under the bracket and go undetected. Ideally, the accumulation of plaque and bacterial debris on marginal surfaces should be preventable. The process of bonding should provide a bond capable of withstanding mechanotherapy
loading as well as the forces of occlusion for a sufficient time to accomplish the desired tooth movement. And finally, when it is time to remove the brackets the bonds must break before tooth structure. This means that no fracturing of enamel can occur; the resin remnants must be removed and the enamel surface restored to a prebond condition. In addition, since rebonding would need to take place in a certain number of cases, cleaning of the enamel surface and repreparation for bonding should not remove excessive enamel. Working toward these requirements means that research in bracket design, tooth preparation and adhesive chemistry must come together to achieve the ideal bonding system.

This study was designed to determine if the use of a proprietary adhesion promoter would increase the bond strength of an orthodontic BIS-GMA direct bonding adhesive system to tooth enamel. Another purpose was to determine whether the traditional etch time of 60 seconds could be reduced while maintaining adequate bond strength. Such a reduction would result in less enamel damage when etching.
REVIEW OF LITERATURE
In 1955 Buonocore\textsuperscript{2} was the first to report that adhesion of resin could be increased substantially using a phosphoric acid etch. He was unsure as to how the acid etch caused an increase in adhesion, but his insight into the mechanics was very accurate. He reported:

The fact that we are using acids for our surface treatments lends heavy support to the idea that adhesion is due to a great increase in surface area and that the effect may be purely a physical phenomenon with other acids capable of producing the same results. In addition, the use of acids may increase the wettability of the surface allowing for more intimate contact between acrylic resin and enamel, thus favoring adhesion. Another possibility is that the use of acidic phosphate containing treatment material may, in addition to increasing surface area and wettability, allow for the absorption of highly polar phosphate groups on the enamel surface with the result that strong polar bonding to the acrylic may also result.

Buonocore postulated that chemical bonding would be much more desirable than one that resulted only from mechanical retention. Unfortunately, there is no chemical bonding between enamel and resins. It is now generally considered that the phosphoric acid dissolves the organic portion of the enamel prism. The honeycomb pattern commonly seen in the scanning electron microscope photographs appears because the inorganic inner portion of the enamel prism is attacked by the phosphoric acid and dissolved while the organic outer perimeter of the enamel prism is not attacked. When resin is placed under pressure, it flows into these honeycomb areas. These resin tags produce mechanical interlocking of the resin to the enamel.

If true adhesion to the tooth were possible, then etching of the enamel would not be necessary; or at least could be reduced to a minimal amount necessary to reduce surface contamination.
Adhesion is produced when unlike molecules are brought into intimate contact with each other. It is very difficult for two solids to be placed in close enough proximity for the surfaces to adhere. This is because no matter how smooth the surfaces appear, at the molecular level where adhesion occurs the surfaces are rough. Contact of molecules occurs in such a small percentage of the total surface area that adhesion does not occur. Phillips\textsuperscript{3} has reported that adhesion does not occur when the surface molecules of the attracting substances are separated by distances greater than 0.0007 micron.

To overcome this difficulty, fluids are used that flow into the irregularities and fill the low spots. To produce adhesion in this manner, the liquid must flow easily over the entire surface and adhere to the solid. This is known as wetting. A classic example of this phenomenon is seen using glass slides. When brought together they exhibit little or no adhesion, but if a film of water is spread over the opposing surfaces, considerable adhesion is seen. The liquid film is known as the adhesive, and the surface it is applied to is known as the adherend.

According to Phillips,\textsuperscript{3} the energy at the surface of a solid is greater than in its interior due to unequal attraction of the outermost atoms. The greater this surface energy, the greater the capacity for adhesion. This is due to the relationship of surface energy and contact angle of the adhesive. The contact angle is a measure of wettability of the adhesive on the adherend. It is the angle formed by the adhesive and the adherend at their interface. The smaller the angle, the more the adhesive will spread over the surface of the adherend and vice versa.
Surfaces that have higher surface energy than the adhesive will achieve good wetting and good adhesion. Contamination of a surface with gases or films will reduce the surface energy and thus reduce wetting and adhesion. Phillips\(^3\) stated that a monolayer of water is sufficient to reduce the surface energy of the adherend and prevent wetting by the adhesive. Oxide films on metal surfaces also reduce the surface energy and inhibit the contact of an adhesive.

Buonocore\(^2\) learned of acid etching from its use in industry. Phosphoric acid was used to treat metal surfaces to obtain better adhesion of paints and resin coatings. The phosphoric acid was used to remove oxides and contaminants on the metal surfaces. He thought the same would apply to enamel surfaces, since the enamel surfaces have probably reacted with various ions, saliva, etc. Small imperfections in the surface were probably filled with a variety of extraneous materials, changing the superficial layer to one that was quite different from the underlying enamel. As a result, any receptivity to adhesion which the original tooth structure may have had for acrylic materials may have been lost. It was felt that an acid treatment of the enamel surface might render it more receptive to adhesion in the same manner as it does for metals.

Phillips\(^3\) has reported that a monolayer of water is always encountered on the enamel surface and even into cut tooth structure. He stated that the dental adhesive must displace this water or wet the surface better than the water that is already present in the tooth structure. It also must do this in a continuously aqueous environment. Enamel also contains varying amounts of fluoride which reduces surface energy even more.
Thus, enamel is a very hostile environment for adhesion to take place, and the search for a true enamel adhesive is a very difficult one.

**Bonding Resins**

Although originally intended to be used for pit and fissure sealants and restorative resins, acid etched bonding soon found its way into orthodontic bonding. In 1964 Newman\(^4\) published the first paper concerning the bonding of plastic orthodontic attachments to tooth enamel using the acid etch technique.

The original orthodontic bonding resin was methyl methacrylate. In 1962 Bowen\(^5\) patented a BIS-GMA resin (bisphenol A-glycidyl dimethacrylate). When the resin is filled with an inorganic filler it has proven to be stronger than methyl methacrylate resins filled or unfilled. This original resin, known as Bowen's resin or BIS-GMA, has completely dominated bonding resins, and most commercially available bonding resins are variations of the original. This material is also known as a composite resin, since it is a combination of a resin matrix and an inorganic filler. Numerous tests have been performed and most available resins have been found adequate for the purpose intended.\(^5,7\)

**Adhesion Promoters**

Until adhesion promoters were formulated, there was no chemical bonding between the tooth and the bonding resin, only mechanical interlocking of the resin with the inorganic tags left from the etching process. This process may allow microleakage of fluids at the tooth resin interface and does not bond as strongly as a chemical and mechanical bond would.
According to Ray,\textsuperscript{8} the expressions "adhesion promoter" and "coupling agent" were initially understood to refer to surface-active comonomer which, as the term suggests, is a concept applicable to the attempted chemical adhesion of plastic to tooth material.

Adhesion promoters are absorbed onto the enamel surface so that interaction with the restorative resin by a chemical or physical process is facilitated, according to Jedrychowski et al.\textsuperscript{9}

Adhesion promoters have also been called tooth-restoration coupling agents by Chandler.\textsuperscript{10} It is apparent that a coupling agent that is capable of not only allowing the mechanical interlocking to take place, but also chemically links the tooth and the resin, would increase the adhesion of the resin to the tooth.

Adhesion promoters are not to be confused with sealers, such as that used in Concise (3M Company, St. Paul, MN) and several other restorative and orthodontic resins. Whereas the adhesion promoter chemically reacts with the enamel, the sealers are diluted non-filled BIS-BMA resins. Sealers mechanically interlock into the pores in the prepared enamel. They have a very low viscosity and a high penetration coefficient. Sealers thus flow into the pores more easily than a thick composite resin, with which they bond. Sealers do not chemically react with the enamel.

Various authors have tested several adhesion promoters of differing chemical composition, with mixed results. At present, the literature concerning adhesion promoters is very limited.

Ortiz et al.\textsuperscript{11} have shown an increase in adhesion to enamel and decreased marginal leakage with use of Simulate adhesion promoter
(Kerr Sybron, Detroit, MI). It is a butylacrylate-acrylic acid copolymer mixed with glycidyl methacrylate in an alcohol solution.

Jedrychowski et al.⁹ reported that the Simulate adhesion promoter bonds because the carboxylic acid groups promote absorption and adhesion to cationic surfaces such as hydroxyapatite.

Bowen and Misra¹² have shown that the NPG-GMA adhesion promoter increases enamel resin adhesion.

Bowen's N-phenylglycine glycidyl methacrylate (NPG-GMA) chelates with surface calcium in enamel and dentin and acts as a primer between hydroxyapatite and resin systems. A commercial product from S.S. White, Cervident uses this NPG-GMA system in an alcoholic solution.¹³ One end of the molecule contains an unsaturated linkage which, in theory, can copolymerise with Bowen's resin, while the other end features a moiety which, again in theory, may interact with surface Ca²⁺ ions in hydroxyapatite.⁸ If successful, this system would allow the direct adhesion of composites to enamel if the interfacial bonding were sufficiently strong, and the need for acid etching of enamel would be eliminated. Clinical trials using NPG-GMA also indicate some advantage in using this coupling agent.¹⁰

Fusayama et al.¹⁴ found that Clearfill (Kurray, Osaka, Japan) was superior to other resins tested because of its adhesion promoter effects. This product utilized a reaction product of 2-hydroxyethyl-methacrylate and phenyl phosphate-ester. Barkmeier¹³ indicated that there is some question as to the effect of long-term water contact with this product.

Farley et al.¹⁵ found that the adhesion of acrylic composite restorative materials to etched enamel increased when the enamel was
treated with vinyl benzyl phosphoric acid (VBPA), possibly due to bonding between calcium ions in the enamel and phosphonate groups in the vinyl benzyl phosphoric acid. VBPA, like Bowen's NPG-GMA, features an unsaturated linkage which might copolymerise with Bowen's resin, together with a phosphonate group which can interact with tooth material. Ray found the adhesive behavior observed with VBPA to be somewhat erratic, with the three-hour strength actually less than if the adhesion promoter had not been used.

A halophosphorus ester of BIS-GMA was also introduced in this country with purported bonding to enamel and dentin (Scotchbond 3M, Minneapolis, MN). The Scotchbond product has renewed interest in bonding material. Barkmeier reported that it is a two-part system. Resin A contains halophosphorus esters of BIS-GMA resin, diluent and benzoyl peroxide; Liquid B contains tertiary amine in alcohol and sulfinic acid salt.

**Acid Etching**

The next step in the bonding process to be investigated is tooth preparation. Various acids have been compared at various concentrations and times of etch. Etching is the production of surface irregularity caused by dissolution of the inorganic portion of the enamel prism. Buonocore compared 50 percent phosphomolybdate containing sodium tungstate and oxalic acid with 85 percent phosphoric acid. The phosphoric acid gave the best results, but he felt that other acids could be used to produce the same surface irregularity. Gwinnett, Newman, Retief, and Silverstone have tested
various acids. Phosphoric acid in concentrations from 30 to 50 percent seems to produce the best results when applied from 60 to 90 seconds.

Acid etching produces a dull chalky surface once the acid residues have been rinsed off and the tooth dried. The scanning electron microscope shows the honeycomb pattern of the enamel. This is due to dissolution of the inorganic portion of the enamel rod, which leaves the organic perimeter intact. Etching with acid removes the low energy organic film, increasing the wettability of the enamel and allowing the resin to flow into the etched surface area. This roughened surface allows for mechanical bonding when the resin cures. Resin manufacturers, using these research data, have recommended using 60-second etch times with 37 to 50 percent phosphoric acid.

Since the data were collected for this paper, other authors have suggested reducing acid concentration and etch time. A brief summary of these articles will follow.

Mardaja and Shannan used 37 percent phosphoric acid to etch for 15, 20, 30 and 60 seconds. They reported that 30-second etch time produced adequate bond strength, but 15 and 20 seconds did not.

Barkmeier et al. have varied etch time. They report no reduction in bond strength using etch times as short as 15 seconds. They also state:

The morphology of the enamel following etching for 15 and 60 seconds differed only in the amount of gross enamel loss. Comparing the control with the adjacent etch site it is clear that the 60-second etched surfaces have lost more enamel than the 15-second etch site. However, closer examination of the surfaces shows no morphological differences in the pattern or character of the etched enamel rods whether treated for 15 or 60 seconds.
Barkmeier et al.\textsuperscript{23} also tested reduced acid concentration and found satisfactory bonding with concentrations as low as five percent phosphoric acid for 15-second etch time. Bryant et al.\textsuperscript{24} reported similar data with both reduced etch time and acid concentration.

All of these studies used in vitro testing. Obviously, in a clinical situation it is not possible to control conditions as well as in a laboratory situation. There is a question as to whether these laboratory studies could be transferred to a clinical situation.

In a 1986 study Carstensen\textsuperscript{25} bonded 1,134 anterior teeth using 37 percent phosphoric acid. His etch time was 35 seconds. The mean treatment time was 15 months, and most of the patients were children, 11 to 15 years of age. Concise (3M Company, Minneapolis, MN) was the bonding agent, and the same operator bonded all teeth. The low failure rate was comparable to those in other studies: only 1.25 percent of the bonded brackets failed. Gorlich reported failure rates of 4 to 6.5 percent within a 12-month period, also using 37 percent phosphoric acid and 60 to 90-second etch times. Carstensen's study would seem to indicate that shorter etch times can be used successfully in a clinical situation.

The ability to reduce etch time and still maintain adequate bond strength is important for more than the minimal chair time involved in etching. Its most important improvement is in the reduced loss of enamel with shorter etch times. Diedrich\textsuperscript{26} found that a two-minute etch with 50 percent phosphoric acid provided optimum surface roughness. Silverstone,\textsuperscript{20} Brown and Way,\textsuperscript{27} and Fitzpatrick and Way\textsuperscript{28} reported that the loss of enamel using 30 to 50 percent phosphoric acid
was between 3-10 μm after one minute and 15 μm after two minutes. Diedrich⁶ found that resin penetration was 100 μm or more. This leaves resin tags deep in the enamel with the potential for fracturing pieces of enamel when removing resin at the time of bracket removal. Reducing the etch time then would be advisable to reduce the depth of tissue damage if it is possible to maintain adequate bond strength.
METHODS AND MATERIALS
The materials used in this study are shown in Table I. Simulate adhesion promoter (Kerr Sybron Corp., Detroit, MI) has been shown to produce reduced microleakage and increased bond strength of BIS-GMA type direct filling resins to tooth structure. The orthodontic adhesive used, MONO-LOK (Rocky Mountain Orthodontics, Denver, CO) is a silica filled BIS-GMA type system consisting of a base resin paste and a liquid primer (activator). The brackets used were ORMESH (Ormco Corporation, Glendora, CA) curved bicuspid brackets with 100 mesh size base. A total of 150 human bicuspid teeth which had been stored in water following extraction were selected for this study. Teeth were discarded if they were chipped, cracked, carious, decalcified or of unusual morphology. The crowns were separated from the roots, and the labial surface of each tooth was positioned parallel to a glass slide using Play-Doh as a support. After the tooth was surrounded with a mold made of silicone rubber, acrylic tray resin was poured into the mold to embed the tooth, while leaving the labial surface exposed. The embedded teeth were examined to insure that the labial surface was parallel to the top of the acrylic ring.

Bond failure in tension was tested using an Instron testing machine (Instron Corporation, Canton, MA). To insure that shear did not occur, each test was performed in a straight line vertical manner. It is important that the testing be done either in shear or in tension and not some combination, as this would produce quite variable
results. Testing in tension was preferred, as it was easier to produce pure tension than pure shear forces. This was accomplished by mounting the crowns in the acrylic block.

Once the teeth were mounted in the acrylic blocks, the Play-Doh was washed away with tap water and a soft bristle toothbrush, and excess resin was removed with a laboratory bur. Teeth with hypocalcification, fractures, or heavy stain were discarded, as were improperly mounted teeth. After screening for defects, the specimens were stored in tap water until bonding.

The teeth were then randomly divided into two main groups:

1. Bonded with the adhesion promoter
2. Bonded without the adhesion promoter

Each main group was subdivided into three smaller groups, with 60-second, 30-second, and 15-second etching times. The sample size was 25 randomly selected teeth per group, as this was the largest sample that could be thermocycled in a uniform batch.

Groups were identified as follows:

<table>
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<th>Etch Time</th>
<th>Without Promoter (A)</th>
<th>With Promoter (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 sec.</td>
<td>Group 1A</td>
<td>Group 1B</td>
</tr>
<tr>
<td>30 sec.</td>
<td>Group 2A</td>
<td>Group 2B</td>
</tr>
<tr>
<td>15 sec.</td>
<td>Group 3A</td>
<td>Group 3B</td>
</tr>
</tbody>
</table>

The 25 teeth in each subgroup were air dried using a chip blower. This eliminated the possibility of oil contamination from an air compressor. The samples were pumiced for 10 seconds with flour of pumice with a bristle brush in a straight handpiece at slow speed. Each tooth was then rinsed with tap water to remove all pumice and again dried with a chip blower. Using a stop watch for precise timing,
each tooth was etched according to its timing group. The acid used was a 37 percent phosphoric acid supplied by Rocky Mountain Orthodontics for use with MONO-LOK bonding resin. The acid was applied with a small sponge and cotton forceps. Care was taken to prevent damage to the etched surface in applying the acid. The sponge was dabbed and not wiped over the surface.

After the completion of etching, each sample was rinsed for 20 seconds under running tap water to remove debris and neutralize the acid. Then the tooth resin block was dried with the chip blower. The brackets were degreased in a beaker of ethyl alcohol in an ultrasonic cleaner for 12 minutes and then air dried with a chip blower. They were handled only with cotton forceps to avoid contamination. The primer (an amine initiator) was painted on the enamel surface of each tooth as well as the mesh surface of the bracket. The resin paste was placed on the bracket, and the bracket was placed in the approximate position. Firm pressure was used in seating and aligning the brackets. This pressure caused a mixing of the resin system, and polymerization started. Excess resin that escaped from under the bracket was removed with a scaler, with care being taken not to touch the bracket (Figure 1). Samples that did not have good adaptation of the bracket base to the tooth were not used.

The samples were allowed to cure for 10 minutes in air and placed in a 37° water bath for 24 hours. They were then thermocycled to approximate normal oral conditions (Figure 2). The cycling temperature range was 40°C (15-55°) in water. Each of the 2500 cycles lasted two minutes.
After cycling, the samples were again stored in water at 37°C. One week from the date of bonding, the samples were tested in tension until bond failure occurred. The testing apparatus consisted of the Instron testing machine (Instron Corporation, Canton, MA) and a gim-baled device that insured testing in tension (Figure 3). This device was produced from orthodontic wire soldered so as to produce hooks to secure the bracket on the occlusal and gingival tie wings. These wires were soldered to a common heavy gauge wire that delivered the force in a straight line to the bracket (Figure 4). This insured that testing was in tension and not some combination of tension and shear. Bond strength was recorded in kilograms. Crosshead speed of the Instron machine was .05 in/min.

The three groups that received the adhesion promoter were treated in the same manner, except that the adhesion promoter was introduced between the etched tooth and the adhesive. The Simulate promoter was a butylacrylate-acrylic acid copolymer mixed with glycidyl meth-acrylate in an alcohol solution. When the tooth was etched and dried, the adhesion promoter was painted on with a small sponge. The material had low viscosity and was highly volatile. The manufacturer's instructions called for keeping the tooth wet with the adhesion promoter for 20 seconds. This required several applications due to the high volatility. Once the 20-second time period was over, the resin primer was painted on the tooth and bracket, and resin paste was placed on the bracket. The bracket was then seated with firm pressure using cotton forceps. The excess resin was removed, and resin was air cured for 10 minutes. After being stored for 24 hours
in a 37°C water bath, the samples were thermocycled 2500 times from 15-55°C, stored for one week in 37°C water, and tested until bond failure occurred.

The force necessary to produce fracture was recorded automatically and graphed by the Instron testing machine. The location of fracture was observed and recorded for each sample. For each sample group minimum, maximum and mean fracture force was calculated. The groups were compared for significant statistical differences between times of etch, and to determine if there was a significant difference when the adhesion promoter was used. A two-way analysis of variance was used for all these comparisons.
Table II and Figure 5 indicate for each group the force required to fracture the bonds. Bartlet's test for homogeneity of variance showed that variances were homogeneous, even though there were large differences between high and low tensile bond strengths within groups. One possible reason for those differences could be voids produced in the polymerization of the resin. Voids in the resin would reduce bond strength.

Tensile testing resulted in fracture of the resin at the bracket-resin interface for all but two samples. These two showed cohesive bond failure. This would indicate that the bond strength of the resin to the tooth is stronger, even at short etch times, than the resin-bracket bond. Statistical analysis of the data showed no significant difference ($P > .05$) for any group due to etch time (Table III). A statistical comparison of all control groups with all adhesion promoter groups showed a significant increase in bond strength with use of the adhesion promoter ($P \leq .05$).

However, since all but two of the test samples failed at the bracket and not the tooth interface, the statistically significant difference has no practical meaning. It appears that tests of orthodontic bonding resins must use some method of testing that does not involve brackets, since the area of failure always was in the bracket.

Figure 6A shows the appearance of the bracket after testing, and Figure 6B shows the corresponding tooth with the imprint of the
bracket in the retained resin. Even though there was a statistical
difference between groups when the adhesion promoter was used, the
author is at a loss to explain this due to the mode of fracture.
It also could not be shown that the adhesion promoter was helpful
when etch time was varied. This was due to equal bond strength at
all etch times.

All samples had at least 20 percent of the resin remaining on
the tooth after bond failure, and most showed 60 to 90 percent of
the resin remaining. Many samples had 100 percent resin retained
on the tooth. Not one sample showed complete resin fracture from
the tooth. In the samples that showed cohesive failure, 100 percent
of the tooth surface was covered with resin. Sample size varied due
to several factors. Some teeth had the entire facial surfaces removed
in testing. This was probably due to partial fracturing that occurred
when the tooth was extracted. Once the testing force was applied,
the entire tooth failed. These specimens were not counted. One group
had only 19 good samples. This was the 15-second etch time with no
adhesion promoter. Samples incorrectly mounted were discarded,
leaving a shortfall of six samples in this group. The percentage
of variations for this group was the same as the 60-second etch time
with adhesion promoter group, and the standard deviation was less
than the 60-second group. It was decided to use this group of 19,
since the data were similar to those of the other groups tested.
Also, the location of fracture was recorded to be at the resin-bracket
interface, but the percentage of resin remaining on the tooth and
bracket was not recorded due to operator error.
The morphology of the enamel following etching for 15, 30 and 60 seconds differed only in the amount of gross enamel loss (Figures 7A and 7B). These findings are the same as reported by Barkmeier et al.22
FIGURE 1. Bicuspid specimen mounted in acrylic block with bracket bonded to enamel surfaces.
FIGURE 2. Thermocycling apparatus.
FIGURE 3. Stress-breaking member suspended from upper member of Instron testing machine. Bonded specimen in position for tensile test.
FIGURE 4. Wire apparatus in position under bracket wings of bonded bracket.
FIGURE 5. Tension bond strength of adhesive.
FIGURE 5
TENSION BOND STRENGTH OF ADHESIVE

KILOGRAMS

WITH PROMOTER

WTHOUT PROMOTER

TIME (seconds)
FIGURE 6A. Scanning electron micrographs of debonded tooth surface. (Original magnification x30)

FIGURE 6B. Scanning electron micrographs of debonded bracket surface. (Original magnification x30)
FIGURE 7A. Scanning electron photomicrograph of etched enamel, 15, 30 and 60-second etch times. (Original magnification x500)

FIGURE 7B. Scanning electron photomicrograph of etched enamel, 15, 30 and 60-second etch times. (Original magnification x1500)
<table>
<thead>
<tr>
<th>Materials</th>
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<td>MONO-LOK Resin Bonding System</td>
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<td>Denver, CO</td>
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<td>Ormesh Bicuspid Brackets</td>
<td>Ormco Corp.</td>
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<td>Instron Corp.</td>
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<td>Canton, MA</td>
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</table>
**TABLE II**

Tension Bond Strength of Adhesive

**MONO-LOK Orthodontic Adhesive Group A Alone**

<table>
<thead>
<tr>
<th>GROUP</th>
<th>SECONDS</th>
<th>MINIMUM FRACTURE FORCE</th>
<th>MAXIMUM FRACTURE FORCE</th>
<th>MEAN FORCE</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A N=19</td>
<td>15</td>
<td>6.0 kg.</td>
<td>18.5 kg.</td>
<td>11.6 kg.</td>
<td>3.1</td>
</tr>
<tr>
<td>2A N=23</td>
<td>30</td>
<td>6.0 kg.</td>
<td>17.0 kg.</td>
<td>11.6 kg.</td>
<td>2.8</td>
</tr>
<tr>
<td>3A N=21</td>
<td>60</td>
<td>7.5 kg.</td>
<td>18.5 kg.</td>
<td>12.1 kg.</td>
<td>3.2</td>
</tr>
<tr>
<td>N=63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MONO-LOK Orthodontic Adhesive Group B + Adhesion Promoter**

<table>
<thead>
<tr>
<th>GROUP</th>
<th>SECONDS</th>
<th>MINIMUM FRACTURE FORCE</th>
<th>MAXIMUM FRACTURE FORCE</th>
<th>MEAN FORCE</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1B N=25</td>
<td>15</td>
<td>6.5 kg.</td>
<td>20.0 kg.</td>
<td>12.9 kg.</td>
<td>3.2</td>
</tr>
<tr>
<td>2B N=24</td>
<td>30</td>
<td>8.0 kg.</td>
<td>18.5 kg.</td>
<td>12.8 kg.</td>
<td>2.9</td>
</tr>
<tr>
<td>3B N=24</td>
<td>60</td>
<td>6.5 kg.</td>
<td>18.0 kg.</td>
<td>13.3 kg.</td>
<td>3.0</td>
</tr>
<tr>
<td>N=73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Out of 136 samples tested, all but two failed at the resin-bracket interface. Both of these samples exhibited cohesive failure.
TABLE III
Analysis of Variance Procedure

CLASS LEVEL INFORMATION

<table>
<thead>
<tr>
<th>CLASS</th>
<th>LEVELS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Period</td>
<td>3</td>
<td>15, 30, and 60 Seconds</td>
</tr>
<tr>
<td>Materials</td>
<td>2</td>
<td>Control/Adhesion Promoter</td>
</tr>
</tbody>
</table>

NUMBER OF OBSERVATIONS IN DATA SET = 236  ALPHA = 0.05

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SUM OF SQUARES</th>
<th>MEAN SQUARE</th>
<th>F</th>
<th>CRITICAL VALUE</th>
<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Period</td>
<td>2</td>
<td>12.94</td>
<td>6.47</td>
<td>0.71</td>
<td>3.07</td>
<td>Non-significant</td>
</tr>
<tr>
<td>Adhesion Promoter/Control</td>
<td>1</td>
<td>62.58</td>
<td>62.58</td>
<td>6.86</td>
<td>3.92</td>
<td>Significant</td>
</tr>
<tr>
<td>Time Period/Adhesion Promoter</td>
<td>2</td>
<td>0.16</td>
<td>0.08</td>
<td>0.01</td>
<td>3.07</td>
<td>Non-significant</td>
</tr>
<tr>
<td>Within or Error</td>
<td>130</td>
<td>1186.47</td>
<td>9.13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The results of this study were analyzed according to the questions examined: (1) Did the adhesion promoter help the bonding process? (2) Did reducing the etch time from 60 seconds to 30 and 15 seconds reduce the bond strength at the tooth-resin interface?

Although the comparison of adhesion promoter data against the control data showed a statistically significant increase in bond strength, the results are inconclusive since all but two samples failed at the bracket-resin interface, and not at the tooth-resin interface where the adhesion promoter has its effect.

In the original testing of this material, Ortiz et al. used a loop of wire embedded into the resin when testing the adhesion promoter. In their testing the adhesion promoter did increase bond strength and reduce marginal leakage. It would seem to follow that using the adhesion promoter with orthodontic brackets would increase bond strength, even though it could not be proven.

Application of this highly volatile material would help to control moisture contamination, which is a problem in a clinical situation. Reduction of microleakage under the bonding resin would also appear to help prevent decay and staining under bonded brackets, but that was not tested in the present experiment.

With regard to the second question considered in this study, it could not be shown that reducing the etch time even to 15 seconds
reduced the bond strength to the tooth. This, coupled with no occurrences of tooth-resin bond failure, would support the contention that etching times can be substantially reduced. As longer etch times produce longer resin tags and deeper enamel defects, more damage is done to the tooth, and it is more difficult to clean up after debonding. Therefore, reducing etch times should save time and tooth enamel.

The third point to be noted here is that orthodontic bonding resins should not be tested using brackets, as they appear to be the weak link. A more retentive design should be developed to bond better both mechanically and, if possible, chemically. However, if the bracket bond is the weak link, then from a clinical point of view, improved bonding at the enamel is meaningless. Maybe further research should be directed towards systems which chemically bond to metal such as Kulzer's Silicoater or the 4-meta type adhesion promoters.
SUMMARY AND CONCLUSIONS
The purpose of this study was to determine (1) whether the use of a proprietary adhesion promoter would increase the bond strength of an orthodontic BIS-GMA direct bonding adhesive system to tooth enamel, and (2) whether the use of such a promoter would allow a decrease in the traditional etch time of 60 seconds, while maintaining adequate bond strength. Such a reduction would result in less damage to the tooth.

To accomplish these goals, 150 bicuspid teeth were mounted in a testing jig, and orthodontic brackets were bonded according to their testing group. The teeth were divided into two main groups:

1. Bonded with the adhesion promoter
2. Bonded without the adhesion promoter

Each main group was subdivided into three smaller groups, with 60-second, 30-second, and 15-second etching times. The sample size was 25 per group, as this was the largest sample that could be thermocycled in a uniform batch.

Groups were identified as follows:

<table>
<thead>
<tr>
<th>Etch Time</th>
<th>Without Promoter (A)</th>
<th>With Promoter (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 sec.</td>
<td>Group 1A</td>
<td>Group 1B</td>
</tr>
<tr>
<td>30 sec.</td>
<td>Group 2A</td>
<td>Group 2B</td>
</tr>
<tr>
<td>15 sec.</td>
<td>Group 3A</td>
<td>Group 3B</td>
</tr>
</tbody>
</table>

The samples were then tested in tension using an Instron testing machine. The location and force required to produce bond failure were recorded. Only two samples of the 136 samples tested had bond failure other than at the resin-bracket interface. These two fractures were cohesive in nature.
When groups were compared using a two-way analysis of variance, there were no significant differences in bond strength between 15, 30, and 60-second etch times. When the use of an adhesion promoter was compared with the control groups, a statistically significant difference was noted. However, this result has no practical meaning, since all but two samples failed at the resin-bracket interface. No reason can be cited for an increase of bond strength other than random circumstance.

This study, along with several others, indicates that etch times can be reduced from the traditional 60-second etch time and still maintain adequate bond strength. The adhesion promoter has been shown by other means to increase bond strength. However, this study failed to prove that the adhesion promoter increased the bonding strength when tested with orthodontic brackets.

Bracket debonding in a clinical setting is often observed to occur at the resin-tooth interface. This may indicate an inability to control the quality of the etched tooth surface to the extent that was possible in this in vitro study. These results would suggest the need of an in vivo experiment to determine the efficiency of an adhesion promoter under realistic clinical conditions, which are often less than ideal.

Finally, the failure of the resin at the bracket mesh level would suggest that improved designs should be developed for retaining the resin to the bracket. True chemical adhesion of resin to tooth and resin to bracket would allow the effective stress bearing area of the resin to be increased and could eliminate the stress risers intro-
duced by current designs which depend on mechanical retention. Plastic brackets do bond chemically with the resin, but have various other shortcomings. Ceramic brackets under development by most orthodontic companies may offer chemical bonding without the shortcomings of plastic.

Many resin manufacturers continue to recommend 60-second etch times in their directions for use. This study and several others listed here would indicate that this practice is no longer necessary.


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Professional Organizations

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North Central Dental Society, Vice President, 1987
Indiana Dental Association
American Dental Association
American Association of Orthodontists
This study was designed to determine whether the use of a proprietary adhesion promoter would increase the bond strength of an orthodontic BIS-GMA direct bonding adhesive system to tooth enamel. Another purpose was to determine whether use of the promoter would allow a decrease in the traditional etch time of 60 seconds, while maintaining adequate bond strength. Such a reduction would result in less damage to the tooth.

A total of 150 bicuspid teeth were mounted in a testing jig, and orthodontic brackets were bonded according to their testing group. The teeth were divided into two groups, one group bonded with the adhesion promoter and one without. Each group was subdivided into three subgroups of 25 samples each, with etching times of 60, 30, and 15 seconds. After bonding, the samples were stored in water at 37°C
24 hours before being thermocycled 2500 cycles. Thermocycling range was 15-55°C. The samples were then returned to the 37°C storage until testing.

One week after bonding the samples were tested in tension using an Instron testing machine. The location and force required to produce bond failure were recorded. Only two samples of the 136 samples tested had bond failure other than at the resin-bracket interface. These two fractures were cohesive in nature.

All groups were compared using a two-way analysis of variance. There was no significant difference in bond strength between 15, 30 and 60-second etch times. This study indicates that etch times can be reduced from the traditional 60-second etch time and still maintain adequate bond strength.

Many resin manufacturers continue to recommend 60-second etch times in their directions for use. The findings of this study indicate that this practice is no longer necessary.

The adhesion promoter has been shown by other means to increase bond strength. However, this study failed to prove that the adhesion promoter increases the bonding strength when tested with orthodontic brackets, since all but two samples failed at the resin-bracket interface.