

# **Investigation of an Alternative Porcelain Bonding Technique**

by

**Tod M. Hardin**

OHSU School of Dentistry  
Department of Orthodontics

April 1996

Wu4  
H260  
1996

## Table of Contents

<b>Introduction</b>	<b>1</b>
<b>Literature Review</b>	<b>1</b>
<b>Methods and Materials</b>	<b>14</b>
<b>Results</b>	<b>21</b>
<b>Discussion</b>	<b>25</b>
<b>Summary and Conclusions</b>	<b>27</b>
<b>References</b>	<b>30</b>

DENTAL BRANCH  
OREGON HEALTH SCIENCES  
UNIVERSITY LIBRARY  
611 S.W. CAMPUS DRIVE  
PORTLAND, OREGON 97201

## Introduction

Direct bonding of orthodontic brackets to enamel has been widely accepted because of its ease, efficacy, and improved esthetics.<sup>1</sup> However, an increasing percentage of today's orthodontic population consists of adults who may need bonding to existing aesthetic restorations such as porcelain laminate veneers or metal-ceramic restorations. What remains to be seen is whether the aesthetic advantages and other benefits of direct bonding to enamel are possible for bonding to porcelain surfaces.

The conventional bonding system does not guarantee enough adhesion to porcelain to withstand orthodontic forces. For this reason silane couplers have become a cornerstone in the porcelain bonding regimen. They provide a bond to porcelain that is *chemical* in nature. The silane assisted bond between acrylic and porcelain has been tested and retested many times over the last 20 years and has yet to be perfected. The bond is either not strong enough to withstand orthodontic forces, or so strong that the porcelain restoration fractures upon debonding. With this in mind, it is my intent to evaluate a porcelain bonding technique utilized by a part-time instructor in the graduate orthodontic clinic at Oregon Health Sciences University. He claims his technique has been successful at achieving this elusive "middle ground."

## Literature Review

In 1955, Buonocore<sup>2</sup> realized that acid etching of enamel increases the bond strengths of acrylic materials to tooth structure. By applying 85% phosphoric acid to the enamel surface, he tremendously increased its surface area, thereby providing a means for increased mechanical

retention. Newman<sup>3</sup> found that water on the tooth surface gave a contact angle greater than 50 degrees, but when the tooth surface was treated with phosphoric acid a zero contact angle was produced. Essentially, acid etching changes the enamel surface from a low energy hydrophobic surface to a high energy hydrophilic surface, showing increased surface tension and wettability. Therefore, this wettable, micro-rough enamel is an ideal surface for adhesion of many different acrylics and composites. Bright<sup>4</sup> and Carstensen<sup>5</sup> later found that much weaker concentrations of phosphoric acid could produce this enamel surface.

When orthodontists first began bonding to porcelain, it quickly became apparent that methods used to bond to enamel were not applicable to bonding to ceramic. The need for increased mechanical retention and/or the existence of a chemical bond to porcelain arose. A major portion of this need was satisfied by utilizing silane couplers in ceramic bonding technique.

A silane coupler is able to assist in creating a chemical bond between inorganic mineral material and organic polymer.<sup>6</sup> An inactive silane is activated through a hydrolysis reaction with water, similar to that seen in figure 1. This activated silane, or silanol, is now capable of reacting with silanol groups existing on the porcelain surface, as well as with the organic carbon chains within the acrylic polymer. This bond formation is considered a condensation reaction.<sup>6</sup>

According to Plueddemann,<sup>7</sup> this chemical bond between the acrylic and porcelain is stable only if water is present, and if the environment in which the bond exists is completely rigid (fig. 2). While the acrylic polymerizes, water will assist in breaking and reforming the silane bonds.

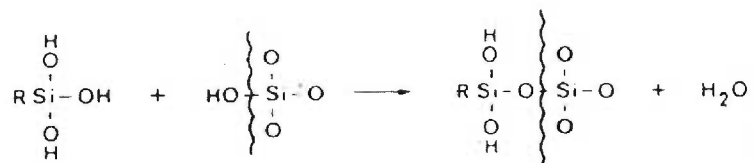
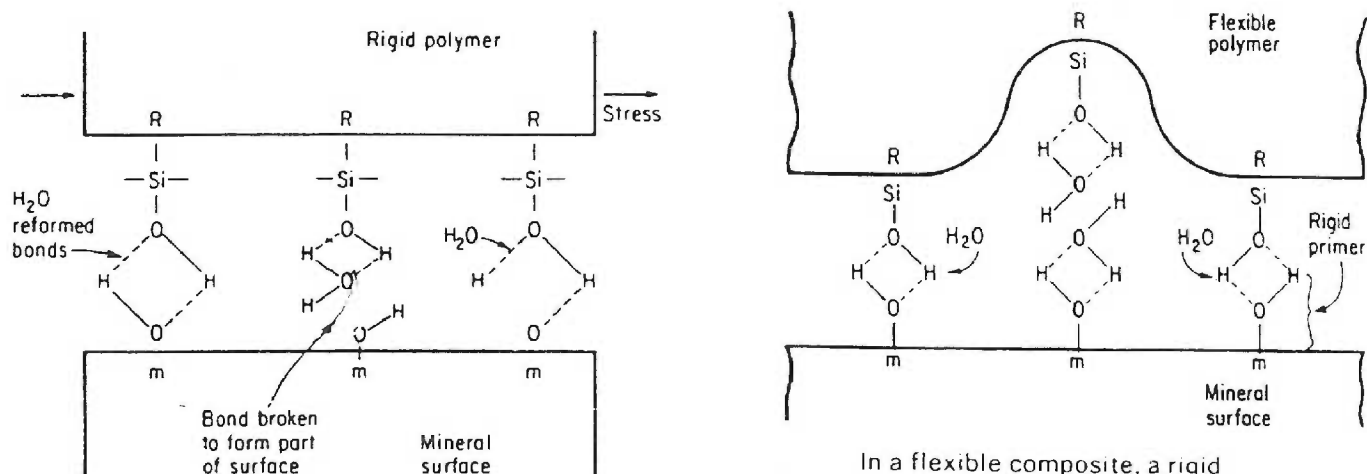


Figure 1 Activation of silane primer through hydrolysis reaction

This provides a necessary mechanism for relaxation of stresses created during polymerization shrinkage. If a non-rigid surface is present, silanol will retract from the surface as individual bonds are hydrolyzed and will no longer be available for new bond formation. Water will gradually interpose itself throughout the interface until adhesion is completely lost.



In rigid composite, water at surface of mineral reinforcement (e.g., glass fiber) reforms bonds in the silanol groups that were broken to bond the coupling agent to the mineral surface.

In a flexible composite, a rigid intermediate bond is necessary in order for coupling to occur. This primer reacts by the water mechanism with the silanol groups.

Figure 2

Silane couplers have been evaluated and utilized by the dental profession for nearly 20 years. Their original appeal to the practicing dentist was in the use of repairing fractured porcelain restorations. The most common silane coupler used in dentistry is termed gamma-Methacryloxypropyltrimethoxysilane (gamma-MPTS).<sup>6,9,10</sup> Other forms of coupling agents have been used, but have not shown bond strengths as high as gamma-MPTS.<sup>11</sup>

Newberg<sup>12</sup> looked at repairing dental porcelain with resin composite material and chemical bonding agents(silane). He used both active silane, and silane that had been stored for longer than the manufacturers recommendation. Porcelain surfaces were either roughened or left with the glaze intact. His results show that bonding with inactive silane, or no silane at all, produces very weak bond strengths. They also found that leaving the glazed porcelain surface unprepared created bonds too weak for clinical use. However, the use of active silane along with a roughened porcelain surface, showed composite bonds that were stronger than the cohesive strength of the porcelain.

Wilmer Eames<sup>13</sup> performed a follow-up study evaluating two porcelain repair silanes. He soaked 27 composite-porcelain specimens in water at mouth temperature for over a year and found that retention increased appreciably. Mean bond strengths increased approximately 10% so that bonds created by both of the tested silanes were causing cohesive failure of the porcelain. Only one had shown this ability prior to the 1 year water storage (Fusion, George Taub Products). He also found that increased shelf life or lack of refrigeration of these repair systems was closely related with decreased bond strengths, which agrees with the

study done by Newberg<sup>12</sup>.

Highton<sup>14</sup> tested the efficacy of both a composite and an acrylic porcelain repair system that utilize a coupling agent, but with a slightly different approach than the previous two researches. Porcelain bars were fractured and then repaired using the two systems. He found that the acrylic repair system (using Fusion primer) was able to return 48% of the unrepaired porcelain strength, while the composite system (using Den-Mat porcelain repair) only returned 28%. He feels his results show that the acrylic repair systems are superior to the composite systems in terms of bond strength of repaired porcelain. However, he did not state the specific type of acrylic or composite he used .

Thomas,<sup>15</sup> also using porcelain bars, found that the three porcelain repair systems he looked at were not adequate for permanent repair of fractured porcelain. His research specifically looked at the effects of thermocycling on these composite-silane-porcelain repairs. The strongest repair was only 18% of the original shear strength of the unbroken porcelain.

From these last four reports it appears that silane couplers are not capable of adequately restoring fractured porcelain bars to their original strength. However, it is also apparent that a silane assisted bond between acrylic and porcelain has the potential to be stronger than the cohesive strength of the porcelain.

With the success the general dentist was having repairing fractured porcelain restorations with silane/acrylic materials, it was only a matter of time before the orthodontic profession started evaluating the silane bond of orthodontic brackets to porcelain teeth. Although many strides

have been made concerning this topic, research is still ongoing. It seems that each researcher has his or her own way of slightly varying experimental design so as to provide new insight into this bonding technique. Variables such as porcelain type, porcelain surface preparation, thermocycling, and length of time before debonding are just a few of the procedures that have been combined with silane couplers in order to evaluate this bond.

In 1979, Ghassemi-Tary<sup>16</sup> evaluated a silane/acrylic bond to porcelain fused to metal crowns. He concluded that roughening of the porcelain surface with sandpaper, in addition to using a silane coupler (Fusion), was required in order to produce bond strengths that would survive orthodontic forces. He did not evaluate the porcelain surface after debonding.

In 1980, Johnson<sup>17</sup> declared three major conclusions following his *in vitro* research evaluating bonding of orthodontic attachments to porcelain using a silane coupling agent. 1) Porcelain-silane-acrylic adhesive systems possess the necessary strength to withstand maximum orthodontic forces. 2) Prolonged exposure to heat, moisture, and severe temperature changes does not result in deterioration of the porcelain-silane- acrylic bond. 3) Stresses induced into the porcelain structure, because of the bonding process itself and thermal cycling, are not severe enough to produce damage to dental porcelain.

In 1984, Newman<sup>18</sup> found that resin bonded to porcelain denture teeth with the use of a silane coupler produced a significantly weaker bond than resin to acid-etched enamel. He thermocycled his samples prior to debonding.



Stokes<sup>19</sup> was the first to step away from using prefabricated porcelain denture teeth in his research. He evaluated the composite bond to feldspathic porcelain disks. He chose to use porcelain disks over porcelain denture teeth because he felt the porcelain in the denture teeth did not adequately represent the porcelain found in ceramic dental restorations. He noted that the dental silane primers he tested significantly increased bond strength to both glazed and roughened porcelain to the point of cohesive failure of the porcelain. This occurred less frequently in bonds to glazed porcelain. He advised orthodontists to have consent forms signed prior to bonding brackets to porcelain restorations.

In 1983 through 1985, Calamia<sup>20-22</sup> showed that etching with hydrofluoric acid, or using a silane coupler, alone do not produce as strong a bond to porcelain as using the two in combination. By etching porcelain for 2.5 minutes with hydrofluoric acid and applying a silane coupler, he achieved bond strengths around 20 Mpa. He also found that feldspathic type porcelains had almost twice the bond strengths of aluminous type porcelains, but had a much higher incidence of cohesive failure.

Dr. George Andreasen<sup>23</sup> evaluated bonding orthodontic brackets to porcelain utilizing non-prehydrolyzed and prehydrolyzed silane couplers. He states that in using non-prehydrolyzed silanes it is important to use the silane to wash the acid etch away rather than water. The phosphoric acid etchant activates the silane and hydrolyses it to interact with the porcelain surface. He does however, suggest that you rinse away the silane with water and dry the surface before bonding. He states that the prehydrolyzed primer is much more prone to losing its reactivity with long

shelf life and lack of refrigeration than is the non-prehydrolyzed.

In 1988, Eustaquio<sup>24</sup> evaluated the tensile strength of brackets bonded to porcelain-metal restorations, both glazed and unglazed, and the effectiveness of two polishing systems in restoring the porcelains to their original surface finishes. Five adhesive systems were looked at and all samples were thermocycled through 2500 cycles between 16 and 56 degrees C. The deglazed samples were prepared using a greenstone. He found that there was a significant difference in the bond strengths between the different adhesive systems, but there was not a significant difference between glazed and unglazed porcelain surfaces. System 1 (Ormco Corp.) in addition to Ormco porcelain primer provided the strongest bond (range=58-67 kg/cm<sup>2</sup>.) Upon debonding, he found the deglazed surfaces to be more vulnerable to porcelain fracture, and diamond polishing paste was more effective than polishing stones at restoring the porcelain surface to its original luster. He feels his results show that bonding to glazed porcelain is more preferable than bonding to deglazed.

Also in 1988, Kao<sup>36</sup> bonded stainless steel brackets to porcelain veneers varying the resin type, priming agent, surface preparation of the porcelain, and debonding time. The refinishing capacity of the porcelain surface after debonding was also assessed. Increasing the debond time, roughening of the porcelain surface, the use of a silane primer, and the use of a highly filled resin (Concise) all increased the shear debonding force. Porcelain fracture incidence went up considerably with the use of a silane coupler in combination with roughening of the porcelain surface (greenstone). Cleanup and refinishing of the porcelain after debonding was much easier to accomplish when the veneer surface had not been

roughened. Diamond polishing paste restored the roughened porcelain surface to a smooth, glazed-like appearance. However, if porcelain pieces had fractured away during debonding, the polished defects had undesirable contour and light reflection.

Smith<sup>25</sup> found that thermocycling did not significantly effect bond strengths of composite to porcelain. He also concluded that roughened porcelain could not be finished to original glaze following debonding. His results showed that if the right composite is chosen (ie. Concise) in combination with a silane coupling agent, clinically effective bond strengths can be achieved between composite and porcelain. He felt that aggressively preparing the porcelain surface should be avoided if at all possible, so that the likelihood of needing to replace the porcelain restoration will decrease. He mentioned that some of the new castable ceramic crowns rely totally on external staining, and that removal of this layer would mandate restoration replacement, even if the surface could regain its smoothness.

Stokes<sup>26</sup> re-evaluated the porcelain bonding technique, and discovered that different silanes have different abilities to maintain adequate composite bond strengths to porcelain following six months of water storage. Fusion, a two-step silane, showed a significantly weaker bond after 6 months water storage than did Scotchprime(3M Co.), a pre-activated, one-step silane coupler.

In 1990, Winchester<sup>27</sup> tested four different silanating agents in bonding steel brackets to porcelain. Fusion provided the strongest shear and tensile bond strengths, but all provided adequate bond strength for clinical use. Therefore, he felt that roughening of the porcelain surface

does not appear to be necessary. He concluded that the prehydrolyzed silanes are more resistant to thermocycling breakdown than the non-prehydrolyzed. He also evaluated debonding techniques to help reduce porcelain fracture. Lift-Off pliers tended to reduce the risk of fracture, whereas shear debonding forces increased the risk of fracture. He also found that diamond polishing paste was the most effective at refinishing the porcelain surface after debonding.

In 1991, Dr. Raymond Lu<sup>28</sup> found that the use of hydrofluoric acid in combination with Scotchprime Ceramic Primer produced a bond of resin to porcelain that was stronger than the cohesive strength of the porcelain. He also discovered a difference in the efficacy of the porcelain primers he used. He felt that this was directly related to the degree of hydrolysis of the silane products. The higher the degree of hydrolysis, the better the bond the silane coupling agent provided.<sup>29</sup> He concluded that this was one of the major reasons why he was showing higher bond strengths with prehydrolysed versus non-prehydrolysed. The non-prehydrolysed must be activated with phosphoric acid before application, which introduces a higher likelihood of operator variability and incomplete hydrolysis. However, its shelf life is much longer than the prehydrolysed. Lu feels that if he would have used repeated applications of the non-prehydrolysed silane, as well as applying it with a scrubbing like motion, there would have been increased wetting of the porcelain surfaces and significantly higher bond strengths resulting.

In 1992, Hayakawa<sup>16</sup> evaluated the bond strengths of resin to porcelain utilizing different silane agents and different acid etching regimens. He found that if the silane agent reacted with OH groups on the

porcelain surface, forming siloxane bonds, hydrofluoric acid-etching is not needed to obtain strong adhesion between the composite and the porcelain. He also found that there was a much higher incidence of porcelain fracture when hydrofluoric acid was used as opposed to phosphoric acid. From his results, it appears that bond failures occurring near 20 MPa have a high incidence of porcelain cohesive failure.

In 1993, Suliman<sup>30</sup> prepared porcelain surfaces with either a diamond bur, sandblasting, hydrofluoric acid, or a combination of etching and diamond bur roughening. He found that although the combination treatment provided the greatest strength, it was not significantly greater than the other methods by themselves. A silane was used in each of the bonds, which ranged from 13-20 MPa.

In 1994, Ozden<sup>31</sup> evaluated the effect of surface treatments of porcelain on the shear bond strength of applied dual-cured cement. He also chose to thermocycle his samples between 6 and 60 degrees celsius for 100 cycles. The porcelain surface was either roughened with a diamond bur, etched with hydrofluoric acid, wetted with silane, or subjected to combinations of all three. He found that silane did increase all bond strengths regardless of the surface preparation. Roughening the porcelain surface, in combination with silane, had the strongest bond strength (11.59 MPa). Silane in combination with etching had about half this strength (5.69 MPa). The use of silane coupling agent together with etching and roughening with a diamond bur only consumed time; it did not improve the mean shear bond strength significantly.

Also in 1994, Whitlock<sup>32</sup> found that porcelain priming agents significantly increase the adhesive bond of composite to porcelain. He

evaluated premolar porcelain buttons following debonding and found that there were no cohesive failures of the porcelain, whether priming agent was used or not. However, this study used ceramic brackets instead of stainless steel, and debonded after only 10 minutes. It is likely that this was not enough time for full polymerization of the composite.<sup>33</sup>

In 1995, Major<sup>40</sup> conducted a study comparing the bond strengths of three types of adhesion promoters: Ormco Porcelain Primer (OR), All-Bond-2 (AB2) and Scotchprime Ceramic Primer (SP) with two orthodontic adhesives: Phase 2 (Reliance, Inc.) and Rely-a-bond (Reliance, Inc.). Utilizing different combinations of the above, he bonded 80 metal brackets to hydrated porcelain samples (porcelain type unknown). The porcelain surfaces were etched with 2.5% HF acid for 90 seconds prior to bonding. The samples were debonded 24 hours later. He found the debonding force of the samples that utilized the OR and SP primers were significantly stronger than those utilizing the AB2 system. Furthermore, Phase 2 resin resulted in higher bond strengths, but consequently increased the incidence of porcelain fracture on debonding.

Acidulated phosphate fluoride (APF) solution in contact with porcelain has been shown to create an irregular porcelain surface.<sup>34</sup> Barbosa<sup>35</sup> evaluated the *in vitro* bond strength to porcelain using various surface preparations as well as APF treatment. She found that a 1.23% APF solution applied to the porcelain surface for 5 minutes was unable to increase retention of orthodontic brackets. She did find that roughing of the porcelain surface with a diamond bur, in combination with a silane coupler, significantly increased retention. However, 77% of the bond failures were cohesive in nature, which is clinically unacceptable.

However, she concluded that combinations of sandpaper preparation, APF solutions, and silane treatment did not provide strong enough bonds for clinical use. Therefore, she feels that she demonstrated the need for more aggressive preparation of the porcelain surface to attain adequate bond strengths.

There are several conclusions that can be drawn from this review of the literature. First, preparing the porcelain in any way, whether it be with a diamond bur or hydrofluoric acid, causes a significant increase in the risk of porcelain fracture following debonding. Second, it appears that feldspathic porcelain is a more receptive bonding surface than aluminous porcelain. However, there is a greater incidence of cohesive failure of this type of porcelain. Third, thermocycling has produced dramatically different results depending on which study is being reviewed. Trying to predict and then reproduce the type of oral environment these bonds will be exposed to is an impossible task. In addition, there is no standardized regimen of thermocycling and thus comparing some of the results from research utilizing this procedure is like comparing apples with oranges. Fourth, questions raised by some of the researchers regarding the use of a non-prehydrolysed silane versus a prehydrolysed silane leave doubts as to which is the best to use. If both could be shown to be equally as effective, parameters such as storage capacity and ease of use could play importantly into a practicing orthodontist's decision to use one or the other.

Many authors claim that the use of hydrofluoric acid is needed to adequately bond to porcelain, but none reveal how dangerous it is to use. Moore<sup>37</sup> discusses the consequences of tissue contact with hydrofluoric

acid. The acid penetrates the skin, causing rapid destruction of underlying tissue. The dissociated hydrogen ion causes dehydration and corrosion of tissues. The caustic fluoride ion can induce liquefaction necrosis of soft tissue and destruction of the supporting bone. The severity of the burn is dependent upon the concentration of the acid and the duration of the exposure. Onset of symptoms can be as delayed as 24 hours for diluted acids and as fast as a couple minutes for concentrated acids. The pain associated with the burn can be quite intense. It has been suggested that the fluoride ion complexes with the calcium ion at the nerve ending, causing membrane potential imbalances and depolarization.

All things considered, it is the intent of this study to show that a non-prehydrolysed silane(Ormco porcelain primer) can be as an effective coupler as a prehydrolysed silane(Scotchbond porcelain primer), when its method of application is changed from that recommended by the manufacturer, to that used by a part-time instructor in the graduate orthodontic clinic at Oregon Health Sciences University. This technique differs from Ormco's application instructions in that it eliminates the use of a water rinse following the Ormco silane primer application. Once the phosphoric acid is applied to the porcelain tooth, the bonding proceeds to completion without the introduction of water. This variation has proven effective in accomplishing adequate bond strengths, with a decrease incidence of porcelain failure upon debonding, in the private orthodontic practice of Dr. David May, a part-time instructor in the OHSU graduate orthodontic clinic. In addition to the silanes, a one-step acrylic bonding material, System 1 (Ormco), will be utilized in bonding to samples of glazed feldspathic porcelain. Bond strengths will be compared and the



porcelain surfaces will be examined by light microscope following removal of the bonded orthodontic brackets.

### Methods and Materials

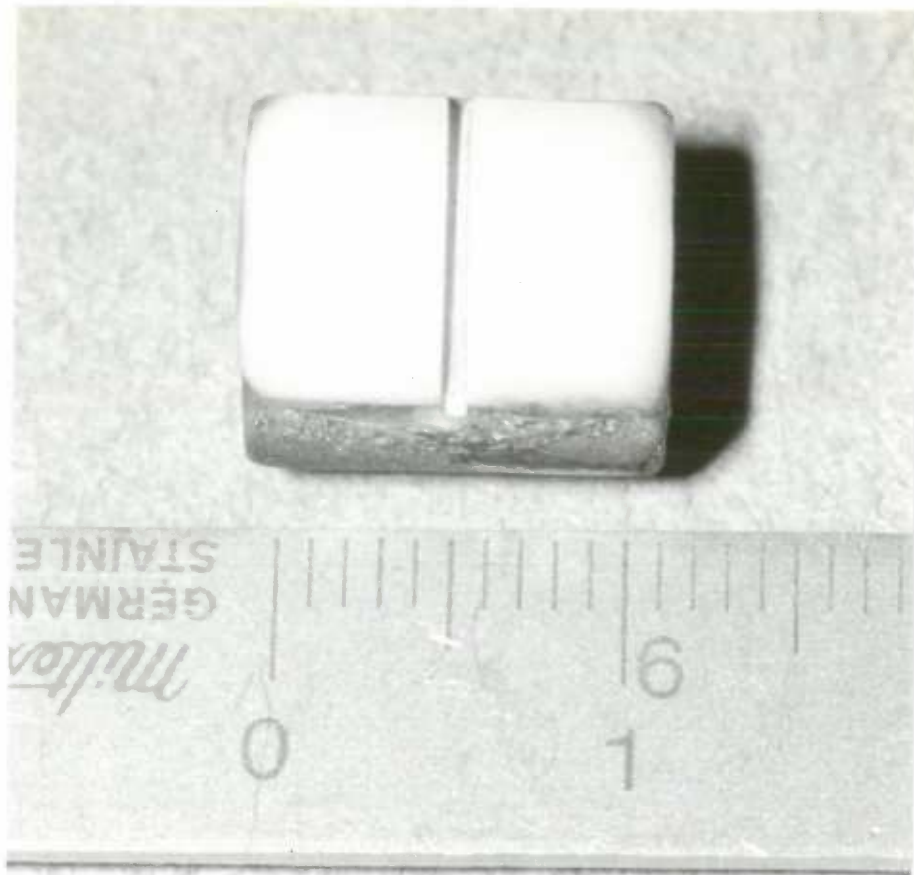
#### **Fabrication of Porcelain samples (Figure 3 and 4)**

Thirty ceramometal samples were constructed with the semiprecious metal UnitBond (Jensen Industries, Inc., North Haven, CT.), Jelenko Opaque Medium, and Jelenko Porcelain (Jelenko, Inc., Armonk, NY). The metal ingots were first sandblasted with 25 micrometer diameter aluminum oxide particles and then degassed at 1020 degrees C with an Ultra-Mat Unitek firing machine (Unitek Corp., Monrovia, CA). After cooling, a single layer of opaque was applied to the metals superior surface and fired at 930 degrees C under vacuum.

Next, the porcelain was stacked using a traditional condensation technique. Both body and enamel porcelain layers were vibrated to place



**Figure 3** Porcelain bonding sample



**Figure 4** Porcelain bonding sample showing size and two independent bonding surfaces and then blotted dry with facial tissue. Each of the two layers were fired independently at 900 degrees C under vacuum. The porcelain was then sanded flat with a fine grit abrasive lathe wheel to a uniform thickness of 1 to 2 mm. Using a thin abrasive disk on a mandrel, the center area of porcelain in each of the samples was removed to create two independent surfaces of porcelain of equal size. This provided two bondable porcelain sites on each sample, that when used, did not effect the porcelain surface adjacent to it. The samples were placed in an ultrasonic bath of distilled water for 10 minutes to remove any debris. Finally, the porcelain was glazed at 910 degrees C without vacuum.

### **Hydration of the Porcelain**

All thirty samples were submersed in distilled water, and kept at 37 degrees C for one week prior to bonding.

### **Bonding of Samples (Figures 5 through 9)**

The 60 bondable surfaces were divided into 3 groups such that 20 surfaces were bonded withOrmco Porcelain Primer (Ormco, Glendora, CA) using their recommended method of application, 20 surfaces were bonded with Ormco Porcelain Primer using an OHSU faculty members method of application, and 20 surfaces were bonded with Scotchbond Porcelain Primer (3M Dental Products, St. Paul, MN). As stated before, the Ormco Porcelain Primer is a non-prehydrolyzed silane coupler, and Scotchbond Porcelain Primer is a pre-hydrolyzed silane coupler. The adhesive system utilized in bonding the brackets in all three of the groups was System 1+ (Ormco, Glendora, CA). This is an acrylic, one-step adhesive material that was chosen due to its similarity to the adhesive system used by the OHSU faculty member.

The first 20 porcelain surfaces were prepared for bonding by applying a 35% phosphoric acid gel (Ultradent, South Jordan, UT) for 60 seconds, followed by removal of the etchant with the use of 2 to 3 mini-sponges (3M Dental Products, St. Paul, MN) saturated in Ormco Porcelain Primer. The saturated sponges are applied to the tooth while the etchant is still in place because it is the acidity of the etchant that activates the unhydrolyzed primer. The surface is then left undisturbed for 1 minute, rinsed for 20 seconds, and air dried. The second 20 porcelain surfaces were prepared exactly the same as the first 20 surfaces except that the

surfaces were not rinsed with water following the application of the primer. Finally, the last 20 surfaces were prepared for bonding utilizing the Scotchbond Porcelain Priming system. Scotchbond Porcelain Primer was applied to the back of the orthodontic bracket and then dried for 5 seconds. The 35% phosphoric etchant was applied to the porcelain surface for 15 seconds, rinsed for 15 seconds and then dried. Scotchbond Porcelain Primer was then applied to the porcelain and dried, followed by the application of Scotchbond Activator. After this was air dried, Scotchbond Multipurpose Primer was applied and dried for 5 seconds. Finally, Scotchbond Catalyst was painted on both the porcelain surface and the back of the bracket.

60 Ultratrim (Dentaurum, Pforzheim, Germany) lower incisor orthodontic brackets were then bonded to all 60 porcelain surfaces with System 1+ acrylic adhesive system, according to the manufacturer's recommendations. These brackets were chosen since the bracket base is relatively flat and is best suited to bond to the flat porcelain surface. The adhesive was applied to the back of the brackets and then they were seated to place using firm pressure. The excess resin was then removed with a scaler and after 10 minutes the samples were returned to the distilled water bath for 24 hours before shear testing.

### **Debonding of Samples (Figure 10)**

After 24 hours in the distilled water bath, each sample underwent shear testing with a calibrated Instron universal testing machine. The metal ingot base of each porcelain sample was placed in an Instron clamp and gripped with enough force so as to resist displacement during

debonding. The sample was then centered in the machine and a testing jig was attached to the inferior surface of the bracket wings so as to decrease the peeling moment. The arm of the Instron machine moved at a rate of .05 in/min. or 1.27mm/min.. Each sample was numbered so that evaluation of the porcelain surface as well as the bracket base could be accomplished under light microscope at a later time. The force applied to each bracket was recorded in pounds.



**Figure 5** Ormco Porcelain Primer (OPP) and Scotchprime Porcelain Primer (SPP)

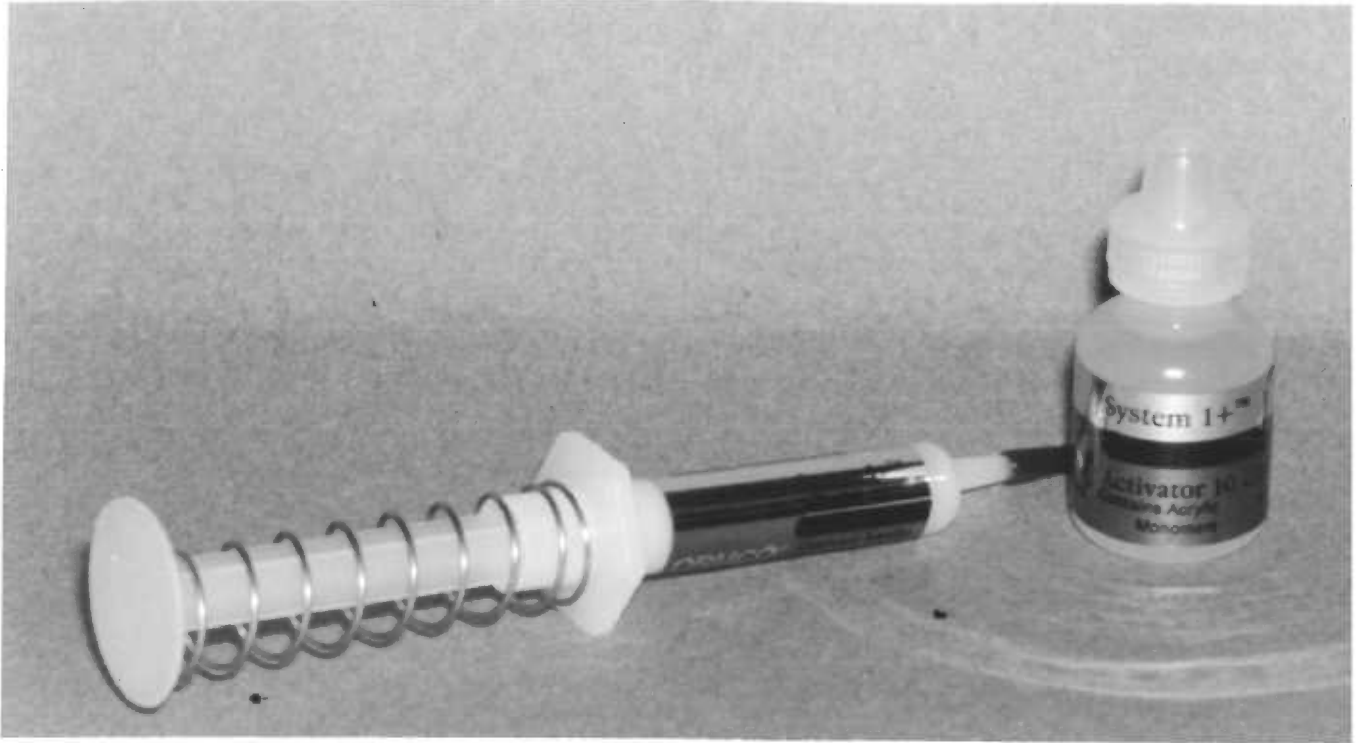


Figure 6 Ormco System 1+ bonding system



Figure 7 Other materials used in the Scotchbond Porcelain bonding technique



Figure 8 35% phosphoric acid gel



Figure 9 Bonded porcelain sample

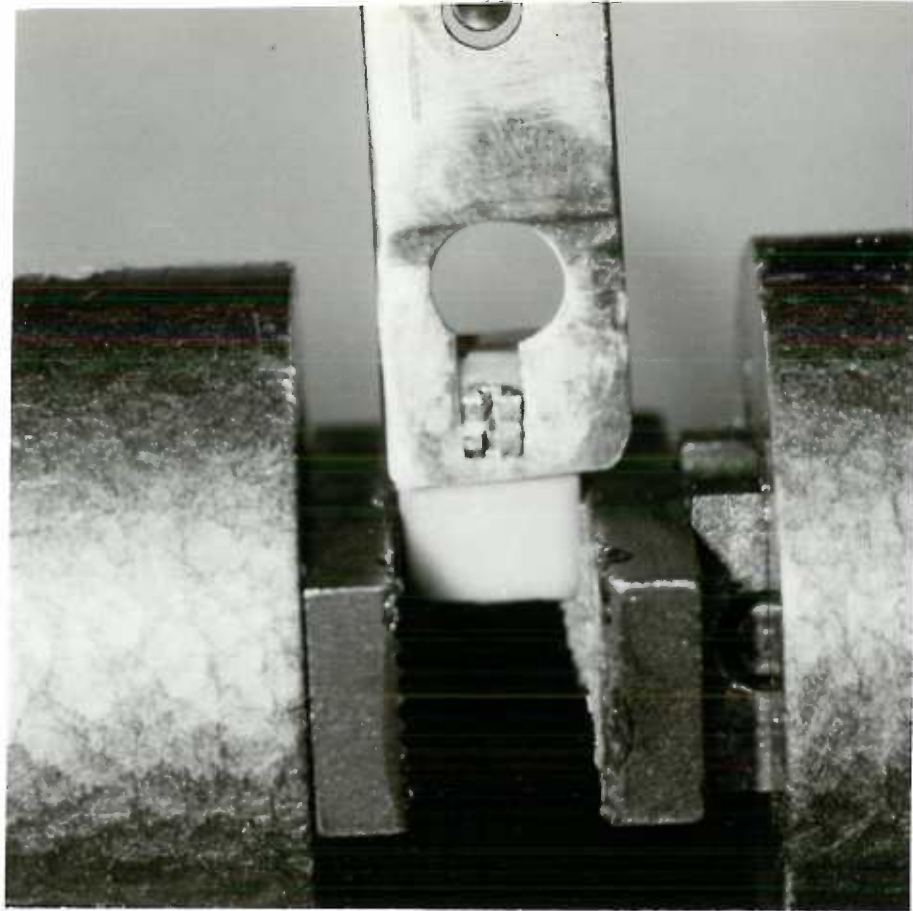


Figure 10 Sample being debonded in the Instron machine

## Results

### Shear Bond Strength

Knowing that the surface area of the orthodontic bracket bases was  $9.77\text{mm}^2$ , the force per unit area was, calculated in Mpa ( $\text{MN}/\text{m}^2$ ). Table I and figure 11 show the mean shear bond strength, range, standard deviations, and standard error of each of the bonding combinations. The mean shear bond strength of the Ormco Porcelain Primer with  $\text{H}_2\text{O}$  (OPPH20) was 15.42 Mpa (SD=5.46), and without  $\text{H}_2\text{O}$  (OPP) it was 3.81 Mpa (SD=2.77). Also, the mean shear bond strength of the Scotchbond Porcelain



Primer (SPP) was 13.58 (SD=6.68). It must be noted that two of the OPP bonds failed just prior to engaging them into the instron machine and were therefore assigned bond strengths of 0 Mpa.

An analysis of variance test was performed on the data using an  $\alpha=.05$ , and it was found that there was a statistically significant difference between the three groups. This was followed up with Scheffe tests showing that the OPPH2O and SPP are not different from each other, but that the OPP differs from each of them.

#### Site of Failure

Evaluation of the porcelain surfaces after removal of the orthodontic brackets showed a high percentage of porcelain fracture in the OPPH2O (80%) and SPP (60%) groups, with a less frequent occurrence in the OPP group (25%) (see fig 12). A chi square test was performed to see if failure was related to the group, and again it was found that the OPP group differed from the other two groups, but they did not differ from each other.

	OPPH2O Force	OPP Force	Scotch Force	OPPH2O MPa	OPP MPa	Scotch I
▶ Type:	Real	Real	Real	Real	Real	Real
▶ Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Ente
▶ Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuou:
▶ Format:	Free Format Fi...	Free Format Fi...	Free Format Fi...	Free Format Fi...	Free Format Fi...	Free Form
▶ Dec. Places:	2	2	2	2	2	2
Mean:	32.47	8.03	28.61	15.42	3.81	13.58
Std. Deviation:	11.50	5.83	13.03	5.46	2.77	6.18
Std. Error:	2.57	1.30	2.91	1.22	.62	1.38
Variance:	132.18	33.97	169.81	29.81	7.65	38.24
Coeff. of Variation:	.35	.73	.46	.35	.73	.46
Minimum:	8.30	0.00	3.50	3.94	0.00	1.66
Maximum:	52.00	17.60	50.00	24.67	8.35	23.73
Range:	43.70	17.60	46.50	20.73	8.35	22.07
Count:	20	20	20	20	20	20
Missing Cells:	0	0	0	0	0	0
Sum:	649.40	160.70	572.20	308.44	76.26	271.52
Sum of Squares:	23597.52	1936.63	19597.04	5323.07	436.14	4412.70

Table 1

Means and Standard Deviations for F/A

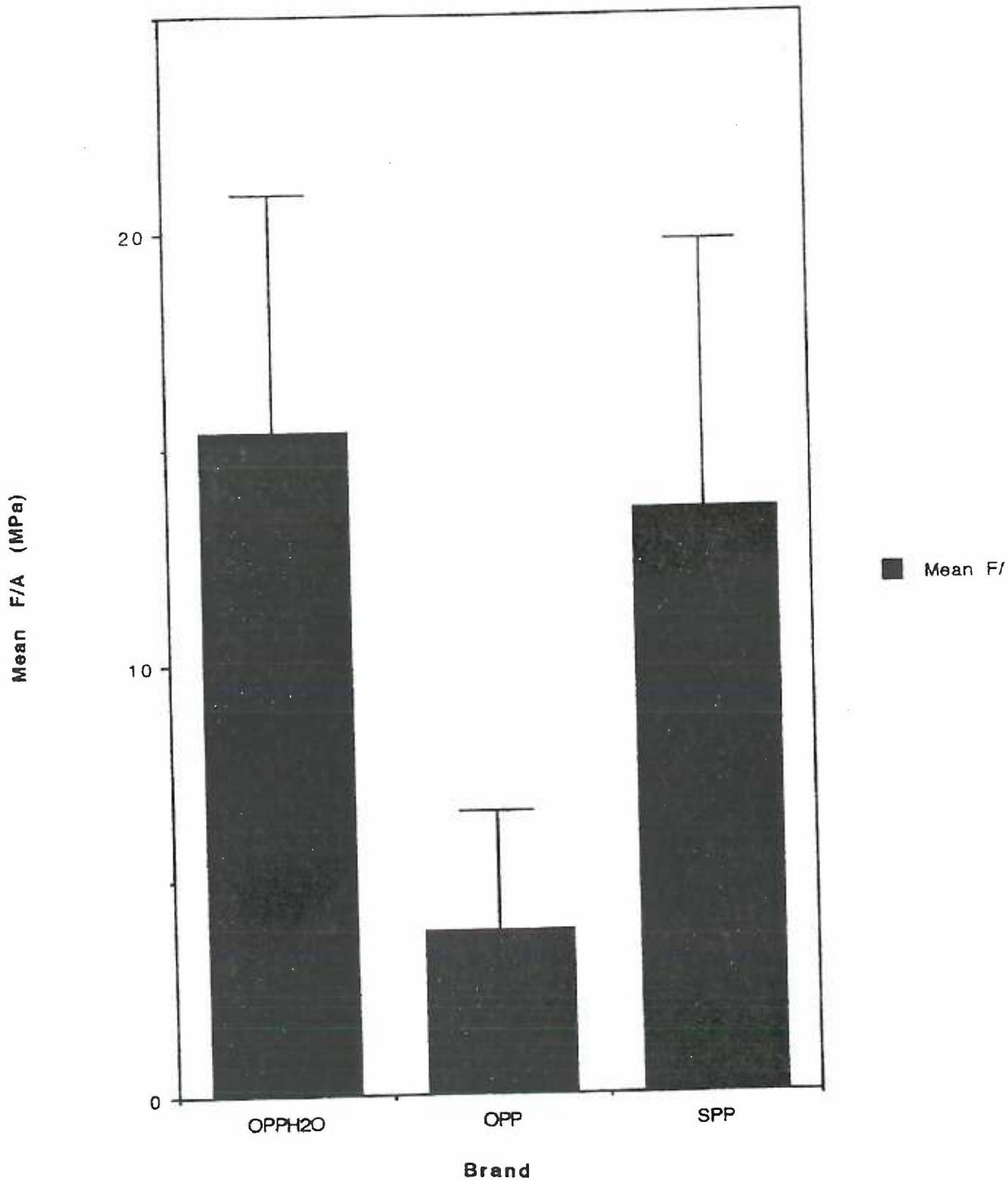


Figure 11

### Percentage of Failure by Brand

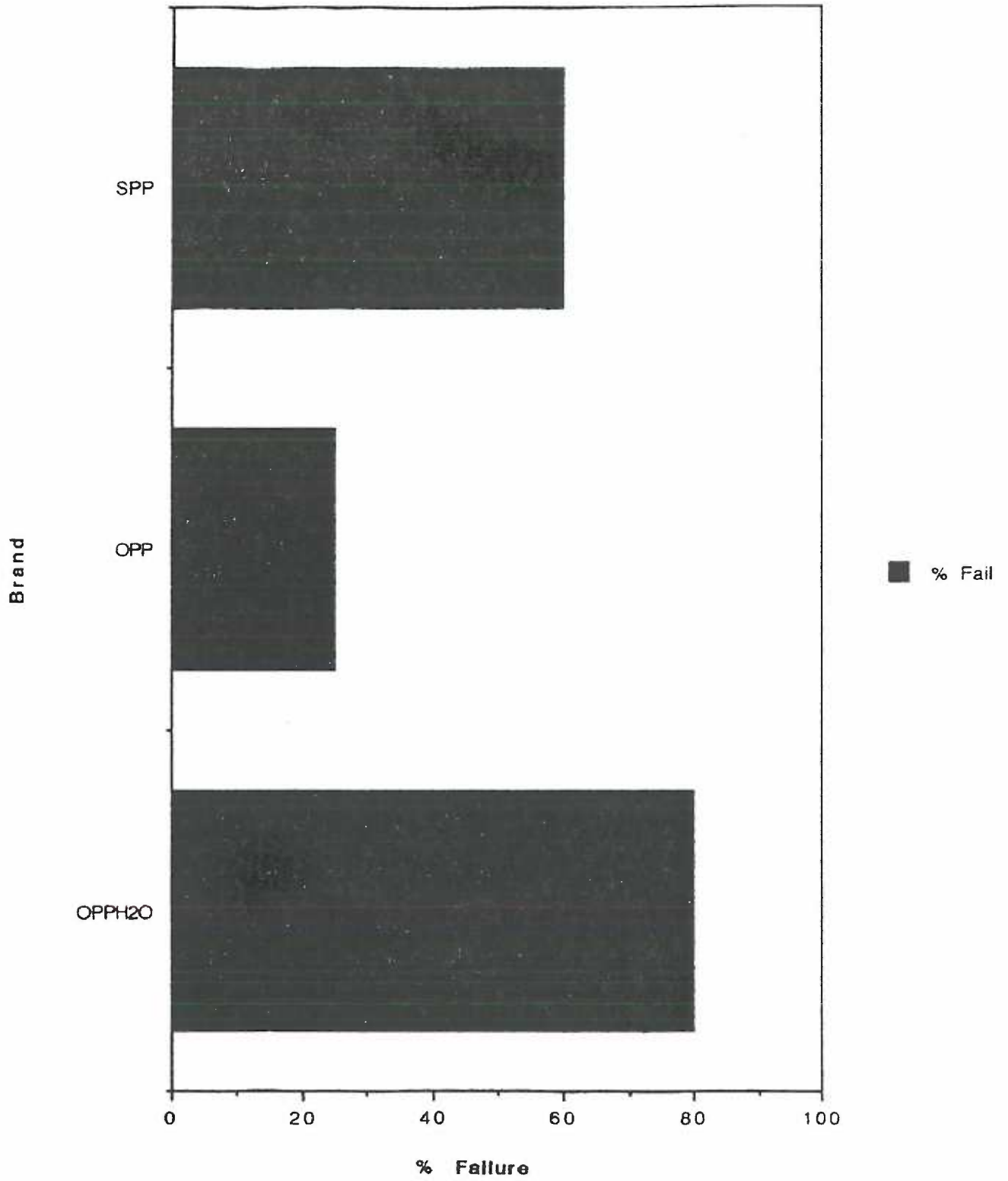


Figure 12 Percentage of porcelain fracture. Chi Square shows significant difference at  $p=.002$

## Discussion

Overall, organosilanes increase the bond strength of acrylic resin material to porcelain by performing two functions. On one hand, they provide a chemical link between the two materials, while on the other, the organic portion of the molecule increases the wettability of the porcelain surface, thereby providing a more intimate micro-mechanical bond.<sup>28</sup> However, the reliability of the organosilane assisted bond has been a concern of many previous studies in this area. While Andreasen<sup>23</sup> found that the prehydrolyzed silane (SPP) is easier to use, it generally has a shorter shelf life and is less stable in its container. Also, Stokes<sup>26</sup> found that the operator activated nonhydrolyzed silane (OPP) was associated with lower bond strengths at 6 months. In this day of advanced technology, along with manufacturers constantly improving their products to stay competitive, I feel there is no longer major differences between the two main types of silane couplers. The prehydrolyzed primers now have a shelf life of three years, non-refrigerated, and would be longer if a strict regimen for replacing the cap after use could be developed. The silane is not unstable, but the solvent in which it is dispersed easily evaporates. Also, more defined manufacturers instructions accompanying the nonhydrolyzed silane products tremendously reduces the risk of incorporating operator error. The results of this study suggest there is no significant difference between the mean bond strengths, standard deviations, and ranges between the two main types of porcelain priming agents (OPPH20 and SPP).

This study showed an unusually high occurrence of porcelain fracture within the OPPH20 and SPP groups, which agrees with many other

studies reporting that when a porcelain priming agent is used, it usually results in porcelain fracture upon debonding.<sup>23,38,39</sup> The raw data for these two groups suggests that any bond strengths over 9 Mpa usually resulted in porcelain failure. However, bond strengths as high as 17.5 Mpa occurred in the SPP group without porcelain failure, but were more the exception than the rule. An unusual result of this study was that the OPP group, which had very weak bond strengths, had porcelain failure occurring as low as 3.8 Mpa. Thus, not only did this bonding variation produce more unreliable bonds, it also caused porcelain failure to occur at a much lower debonding force.

The waterless technique utilized by by an OHSU faculty member did not seem to produce the results that were expected when this study commenced. This technique produced bonds to porcelain that were dramatically weaker than the other two methods. Possible explanations for why the results of this study do not support the porcelain bonding technique utilized by this instructor are as follows. First, although the Ormco Porcelain Primer utilized in this study is exactly the same as that utilized by the faculty member in his private practice, the two primers were produced roughly 10 years apart. I utilized Ormco primer from an unopened container sent straight from the manufacturer just prior to the commencement of this project, while the instructor's source is no less than 10 years old. Ormco states that they have not changed the components of this product since its original production. However, the possibility still remains that some kind of chemical reaction, breakdown, or contamination may have occurred to the faculty member's primer source that could make it more effective when water is not incorporated

into the application regimen.

Second, unlike this study, the instructor does not use distilled water in his porcelain bonding technique. The water supply in his office is badly contaminated with rust and other minerals originating from old pipes. This may explain why he gets improved bonding results when he does not use water in his bonding regimen. These types of contaminants in the water supply would have the potential to occupy silane binding sites that would normally be occupied by the inorganic material within the adhesive matrix. Thus, his bonds may be as weak as what this study reports, but still be stronger than what he encounters when utilizing his contaminated water source.

Finally, the potential remains that there could exist subtle differences in his bonding technique that only surface when he performs the procedure himself. Although every effort was made to execute his exact instructions regarding this technique, it is impossible to completely rule out operator error.

### **Summary and Conclusions**

This study showed that two of the leading silane couplers (OPPH<sub>2</sub>O and SPP) are consistently effective in establishing a clinically acceptable bond between an acrylic orthodontic adhesive and a glazed porcelain surface. In fact, these bonds were strong enough to surpass the cohesive strength of the porcelain. No porcelain surface preparation was needed to achieve this high of a bond strength. Both preactivated and non-preactivated silanes were represented in this study, and no significant difference in bond strengths between the two could be discovered. The

Ormco Porcelain Primer was an easier material to use because there were less steps involved in its application, it took less time to apply, and there were fewer bottles of necessary solutions that could potentially become contaminated. Unfortunately, both materials caused a number of porcelain fractures upon debonding (OPPH2O slightly greater than SPP, but not significant).

The alternative technique of omitting the recommended water rinse when utilizing the Ormco Porcelain Primer did not produce a clinically adequate bond to porcelain. As Reynolds<sup>41</sup> reported, 6 to 8 MPa is the minimal shear bond strength that is required to withstand normal orthodontic forces, so OPP's mean of 3.81 MPa was not sufficient.

These results suggest that the elusive "middle ground" of porcelain bonding has still not been discovered. With this in mind, I feel that it is important to reiterate the statement made by Dr. A. N. Stokes following his porcelain bonding research; "Orthodontists need to have consent forms signed prior to bonding brackets to porcelain restorations." The technology is now available for orthodontists to adequately bond brackets to glazed porcelain with some reliability. However, this study, and others like it, have not been able to show a debonding technique that predictably preserves the architecture and polish of the bonded porcelain restoration.

## References

1. Gorelick C., Bonding/ the State of the Art. A National Survey. J Clin Orthod 1979; 13: 39-53
2. Buonocore MG., A Simple Method of Increasing the Adhesion of Acrylic Filling Materials to Enamel Surfaces. J Dent Res 1955; 38: 849-53
3. Newman GV. And Facq JM., The Effects of Adhesive Systems on Tooth Surfaces. AJO 1971; 59; 67-75
4. Bright DS. And Shannon IL., Effect of Phosphoric Acid Gel on Tensile Strength of Direct Bonded Orthodontic Brackets. Int J Orthod 1980; 18: 7-13
5. Carstensen W., Direct Bonding with Reduced Acid Etchant Concentrations. J Clin Orthod 1993; 27: 23-24
6. Vanherle, Guide, and Smith, Dennis C., Posterior Composite Resin Dental Restorative Materials, Minnesota Mining and Mfg. Co., 1985, p.146
7. Plueddemann EP., Water is Key to New Theory on Resin-to-Fiber Bonding. Modern Plastics 1970; 92-98
8. Newburg R. And Pameijer CH., Composite Resins Bonded to Porcelain with Silane Solution. JADA 1978; 96: 288-91
9. Chen TM. And Brauer GM., Solvent Effects on Bonding Organo-silane to Silica Surfaces. J Dent Res 1982; 61(12): 1439-1443
10. Soderholm JM. And Shang SW., Molecular Orientation of Silane at the Surface of Colloidal Silica. J Dent Res 1993; 72(6): 1050-1054
11. Rosenstiel SF., Titanates and Zircoaluminates as Coupling Agents for Dental Cements. Inter J Prosth 1993; 6: 298-302
12. Newburg R., Composite Resins Bonded to Porcelain with Silane Solution. JADA 1978; 96: 288-91



13. Eames WB., Porcelain Repairs: Retention After One Year. Oper Dent 1979; 4: 75-77
14. Highton RM., Effectiveness of Porcelain Repair Systems. J Prosth Dent 1979; 42: 292-294.
15. Nowlin TP., Evaluation of the Bonding of Three Porcelain Repair Systems. J Prosth Dent 1981; 46: 516-518
16. Hayakawa T., The Influence of Surface Conditions and Silane Agents on the Bond of Resin to Dental Porcelain. Dent Mater 1992; 8: 238-240
17. Johnson RG., A New Method for Direct Bonding Orthodontic Attachments to Porcelain Teeth Using a Silane Coupling Agent: An In Vitro Evaluation. AJO 1980; 78: 233-34
18. Newman SM., Direct Bonding of Orthodontic Brackets to Esthetic Restorative Materials Using a Silane. AJO 1984; 86: 503-506
19. Stokes AN., Surface Preparation for Bonding to Porcelain and Gold. Aust Ortho J 1986; 9: 321-23
20. Calamia JR., Effect of Coupling Agents on Bond Strength of Etched Porcelain. J Dent Res 1984; 63: 179
21. Calamia JR., Shear Bond Strength of Etched Porcelains. J Dent Res 1985: 296
22. Calamia JR., Etched Porcelain facial Veneers: A New Treatment Modality Based on Scientific and Clinical Evidence. NY J Dent 1983; 53: 255-59
23. Andreasen GF., Bonding and Debonding Brackets to Porcelain and Gold. AJO 1988; 93: 341-45
24. Eustaquio R., Comparative Tensile Strengths of Brackets Bonded to Porcelain with Orthodontic Adhesive and Porcelain Repair Systems. AJO 1988; 94: 421-25

25. Smith GA., Orthodontic Bonding to Porcelain--Bond Strength and Refinishing. AJO 1988; 94: 245-52
26. Stokes AN., Effect of 6-Month Water Storage on Silane-treated Resin/Porcelain Bonds. J Dent 1988; 16: 294-296
27. Winchester L., Direct Orthodontic Bonding to Porcelain: An In Vitro Study. Brit J Ortho 1991; 18: 299-308
28. Lu R., An Investigation of the Composite Resin/Porcelain Interface. Aust Dent J 1992; 37: 12-19
29. Culler SR., Investigations of Silane Priming Solutions to Repair Fractured Porcelain Crowns. J Dent Res 1986; 65: 191
30. Suliman AA., Effects of Surface Treatment and Bonding Agents on Bond Strength of Composite Resin to Porcelain. J Prosth Dent 1993; 70: 118-20
31. Osden AN., Effect of Surface Treatments of Porcelain on the Shear Bond Strength of Applied Dual-cured Cement. J Prosth Dent 1994; 72: 85-88
32. Whitlock BO., Shear Strength of Ceramic Brackets Bonded to Porcelain. AJO 1994; 106: 358-64
33. Ferracane JL., Correlation Between Hardness and Degree of Conversion During the Setting Reaction of Unfilled Dental Restorative Resins. Dent Mater 1985; 1: 11-14
34. Wunderlich RC., The In Vitro Effect to Topical Fluorides on Dental Porcelain. J Dent Res 1985; 64: 296
35. Barbosa VLT., Direct Bonding to Porcelain. AJO 1995; 107: 159-64
36. Kao EC., Direct Bonding of Orthodontic Brackets to Porcelain veneer Laminates. AJO 1988; 94: 458-68

37. Moore PA., Hydrofluoric Acid Burns. *J Prosth Dent* 1982; 47: 338-39
38. Wood DP., Bonding to Porcelain and Gold. *AJO* 1986; 89: 194-205
39. Sorensen JA., Shear Bond Strength of Composite Resin to Porcelain. *Int. J. Prosthodont* 1991; 4: 17-23
40. Major, PW., 24-Hour Shear Bond Strength of Metal Orthodontic Brackets Bonded to Porcelain Using Various Adhesion Promoters. *AJO* 1995; 108: 322-329
41. Reynolds, IR., A Review of Direct Bonding. *Br J Orthod* 1975; 2: 171-178