

The Effect of Porcelain Surface Conditioning on Bonding Orthodontic Brackets

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Abstract: The purpose of this study was to evaluate the effects of a new self-etching primer/adhesive used to enhance the shear strength of orthodontic brackets bonded to porcelain surfaces. Forty-five porcelain maxillary central incisor teeth were used in the study. The teeth were divided randomly into three groups: group I (control), the porcelain teeth were etched with 37% phosphoric acid followed by a sealant and the brackets were bonded with a composite adhesive; group II, the porcelain teeth were microetched and hydrofluoric acid and silane applied and metal brackets were then bonded with the composite adhesive; and group III, the porcelain teeth were etched with phosphoric acid and a self-etching primer/adhesive applied before bonding. Brackets precoated with the adhesive were used on all three groups of teeth. All teeth were stored for 24 hours at 37°C before debonding. The results of the analysis of variance ($F = 10.7$) indicated that there was a significant difference ($P = .001$) between the three groups. The mean shear bond strengths of conventional bonding using a 37% phosphoric acid and sealant was 4.4 ± 2.7 MPa, whereas that of microetching followed by the application of hydrofluoric acid and silane was 11.2 ± 4.7 MPa, and for the new self-etching primer/adhesive it was 10.3 ± 5.3 MPa. The last two groups had the highest bond strength values and were not significantly different from each other. (*Angle Orthod* 2005;75:858–864.)

Key Words: Porcelain; Surface preparation; Brackets; Shear bond strength

INTRODUCTION

With the increased number of adults seeking orthodontic treatment, clinicians often bond orthodontic brackets to teeth that have different types of restorations, including amalgam, gold, composite, and porcelain. One of the materials that particularly has presented problems to both the operative dentist as well as the orthodontist is porcelain surfaces. Whether the purpose is to repair a porcelain crown or to bond a

bracket to such a restoration, the difficulty that clinicians face in both situations is that the porcelain surface essentially is inert ie, it does not bond (adhere) readily to other materials. Therefore, a number of approaches have been attempted to alter the surface characteristics of porcelain or ceramic to provide sufficient bond strength to allow for the placement of orthodontic brackets.

The approaches suggested to improve bond strength to porcelain surfaces can be grouped into three broad categories, namely mechanical, chemical, or combination.

The purpose of mechanical alteration of the porcelain surface is to remove the glaze and roughen the surface to provide sufficient mechanical retention for the adhesive, allowing for the successful placement and retention of the orthodontic bracket. This alteration of the ceramic surface has been achieved by microetching (air abrasion or sandblasting),^{1–4} using a coarse diamond stone,^{5,6} or using sandpaper disks.^{2,6} Although the changes introduced by this approach have sufficiently increased the bond strength for orthodontic purposes, they also cause irreversible damage to the porcelain glaze.

Chemical alteration of the porcelain surface can be

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introduced by either etching the surface to increase the mechanical retention of the adhesive or by changing the porcelain surface affinity to the adhesive materials.

1. Hydrofluoric acid has been used successfully to etch the porcelain surface (glassy ceramics) and significantly increases the bond strength of orthodontic attachments.^{1-3,5,7-9} One of the disadvantages of this approach is that the ceramic surface loses its glaze and becomes difficult for the clinician to restore to its original luster. Phosphoric acid^{7,9} and acidulated phosphate fluoride⁶ have also been used to etch porcelain surfaces because they do not cause as much damage as hydrofluoric acid, but they were also found not to be as effective in providing adequate and consistent bond strength for orthodontic purposes.
2. Another approach used to enhance bond strength to porcelain surfaces is by changing the nature of the surface, using a coupling agent such as silane.^{1,7,10-15} The action of the silane coupler can be observed as performing two functions; the hydrolysable group of the coupler reacts with the inorganic dental porcelain whereas its organofunctional group reacts with the resin and enhances adhesion.¹⁵ Silanes are also known as adhesion promoters and function by adsorbing onto, and altering, the surface of a solid material (in this case porcelain), by either a chemical or physical process, to increase its interaction with other materials.¹⁴ The portion of the silane molecule that is not adsorbed presents a free surface that is wetted easily by adhesive materials.¹⁴ Investigators have found that the silane coupler actually forms a chemical bond with both the resin and the porcelain, thus forming a bridge between the two materials.^{14,15}

New products were introduced in the market, which were suggested as alternative bonding agents to porcelain surfaces including cyanoacrylates. Bishara et al¹⁶ reported that when bonding orthodontic brackets to porcelain surfaces, the use of a phosphoric acid etch with a cyanoacrylate adhesive produced significantly lower shear bond strength that was not clinically useful.¹⁶ In the same study, the authors also found that the use of a self-etch primer produced higher but less consistent shear bond strength and that the most reliable bonding procedure for bonding to porcelain surfaces was obtained with microetching together with the use of hydrofluoric acid and a silane coupler.¹⁶ Such a combination also produced the greatest damage to the porcelain surface.

Most recently, a new repair system was introduced, which combines the use of phosphoric acid with a self-etching adhesive that contains silane to enhance the

bond strength to porcelain. Given the convenience of eliminating the hazards associated with using hydrofluoric acid without a rubber dam during bonding orthodontic brackets, it would be of interest to determine whether this new system produces acceptable shear bond strengths. This would be particularly advantageous, if this could be accomplished without damaging the porcelain glaze caused by microetching or hydrofluoric acid before bonding.

The purpose of this study was to evaluate and compare the use of a new self-etching primer/adhesive that contains silane to enhance the bond strength of orthodontic brackets to porcelain surfaces.

MATERIALS AND METHODS

Teeth used

Forty-five porcelain maxillary central incisor teeth (Solorex Trubyte, Dentsply/York Division, York, Pa) were used in the study. Dental porcelain is a mixture of fine particles of quartz and feldspar. The feldspar is melted with heat to form a glassy phase and acts as a matrix for the quartz. The quartz provides strength and acts as a filler for the porcelain. The natural feldspars used in the manufacturing of dental porcelain are made of albite and orthoclase or microcline.¹⁵

Brackets used

Forty-five APC II stainless steel metal brackets pre-coated with the Transbond XT composite adhesive were used in this study. All brackets were identical ie, right maxillary central incisors, Victory Series (3M Unitek, Monrovia, Calif).

Bonding procedure

The pre-coated brackets were bonded to the teeth according to one of three protocols:

- Group I (Control): Fifteen teeth were etched with 37% phosphoric acid gel for 30 seconds, thoroughly washed, and dried. The sealant/primer was then applied to the porcelain surface, and the APC II-pre-coated brackets were placed on the teeth and light cured with a halogen light source for 20 seconds according to the manufacturer's instructions. This bonding protocol is identical to the one used clinically on human enamel.
- Group II: On 15 teeth, Porc-etch and Porcelain Conditioner (Reliance Orthodontic Products Inc, Itasca, Ill) was used. Before applying the conditioner, the teeth in this group were microetched (Microetcher II Intraoral Sandblaster, Danville Engineering, San Ramon, Calif) for five seconds using 50- μ m alumina particles at 0.23 MPa. This material is intended to

be used on glazed dental porcelain. The etchant that contains 9.5% hydrofluoric acid was then applied for three minutes to prepare the surface for the application of the conditioner. After thoroughly washing the etchant with water, the tooth was then dried. The conditioner, which contains silane, was applied liberally to the surface for one minute. The precoated bracket APC II was then placed on the tooth and light cured for 20 seconds.

- Group III: A new porcelain repair system, Clearfil Repair (Kuraray Dental, Okayama, Japan), was used in this study. This product is based on a two-step self-etching adhesive system, Clearfil SE Bond. A 35% phosphoric acid gel (K-Etchant Gel) is applied for five seconds, the primer (containing a phosphate monomer) is mixed with the porcelain bond activator (silane) and applied to the porcelain surface and air-dried. A layer of the bonding agent that contains phosphate and methacrylate monomers was then applied, thinned, and light cured for 20 seconds. The precoated APC II bracket was placed on the porcelain surface and light cured for 20 seconds.

During the bonding procedure, each bracket was subjected to a 300-g compressive force using a force gauge (Correx Co, Bern, Switzerland) for 10 seconds. Any excess bonding resin around the brackets was removed using a sharp scaler.

Debonding procedure

The teeth were embedded in acrylic in phenolic rings (Buehler Ltd, Lake Bluff, Ill). A mounting jig was used to align the facial surface of the tooth to be perpendicular with the bottom of the mold. Each tooth was oriented with the testing device as a guide, so its labial surface was parallel to the force during the shear strength test. A steel rod with one flattened end attached to the crosshead of a Zwick test machine (Zwick GmbH & Co, Ulm, Germany). An occlusogingival load was applied to the bracket producing a shear force at the bracket-tooth interface. All brackets were debonded within half an hour from the time of initial bonding. A computer, connected electronically to the Zwick test machine, recorded the results of each test in megapascals. Shear bond strengths were measured at a crosshead speed of five mm/min.

Statistical analysis

Descriptive statistics including the mean, standard deviation, and minimum and maximum values were calculated for each of the three test groups. The analysis of variance was used to determine whether significant differences were present in the bond strength between the three groups. If significant differences

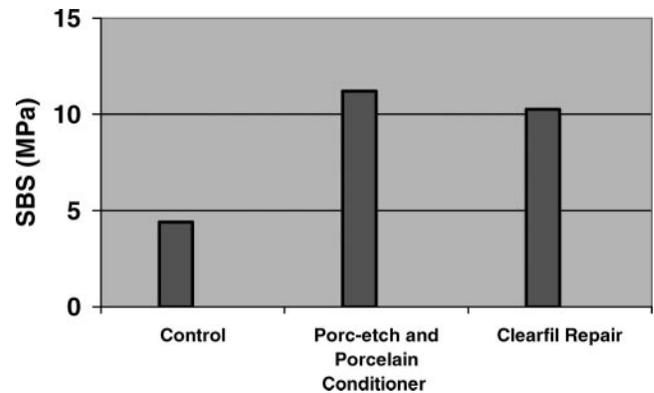


FIGURE 1. Histogram of the mean shear bond strength in megapascals comparing the three experimental groups tested.

were present, Tukey's posterior tests for harmonic mean sample size were used to determine which of the means were significantly different from each other. The frequency distribution of the shear bond strengths between the three bonding procedures tested were compared using the chi-square test at three force levels; <4.0 MPa, 4.0–6.0 MPa, and >6.0 MPa. Significance for all statistical tests was predetermined at $P \leq .05$.

Scanning electron microscopy

After debonding, representative samples of each of the three groups were examined under scanning electron microscopy (SEM) to assess the changes in the porcelain surfaces with the various bonding procedures. Any residual adhesive was first removed using a tungsten carbide finishing bur using slow speed and polished with Ceramist silicon points (Shofu, Menlo Park, Calif) before SEM examination. SEM photographs of the porcelain surfaces were taken at 100 \times and 1000 \times .

RESULTS

Comparison of the shear bond strength of the three groups tested

The results of the analysis of variance ($F = 10.7$) indicated the presence of significant differences in the shear bond strength between the three bonding procedures ($P < .001$). The Tukey's honestly significant difference posthoc test indicated that the mean shear bond strengths of the teeth prepared with Porc-etch and Porcelain Conditioner was 11.2 ± 4.7 MPa and for the teeth prepared with Clearfil Repair was 10.3 ± 5.3 MPa. These two groups were not different from each other but were both significantly stronger than the mean shear bond strength of the control group of 4.4 ± 2.7 MPa. The details of the comparisons are shown in Figure 1 and Table 1.

TABLE 1. Descriptive Statistics in Megapascals (MPa) and the Results of the Analysis of Variance Comparing the Shear Bond Strengths of the Three Porcelain Surface Preparations^a

Experimental Groups Tested	Mean	SD	Range	Tukey's HSD ^b
Group 1 (control): phosphoric acid and sealant	4.4	2.7	1.1–8.6	B
Group 2: microetching + hydrofluoric acid + silane	11.2	4.7	5.6–22.1	A
Group 3: phosphoric acid + self-etch primer + adhesive	10.3	5.3	1.6–19.5	A

F ratio = 10.7 *P* < .001

^a SD indicates standard deviation; HSD, honestly significant difference.

^b Groups with the same letters are not significantly different from each other.

TABLE 2. Frequency Distribution of the Shear Bond Strength Values in Megapascals (MPa) and the Results of the Chi-square (χ^2) Test Comparisons of the Three Porcelain Surface Preparations

Experimental Groups Tested	<4.0 MPa	4.0–6.0 MPa	>6.0 MPa
Group 1 (control): phosphoric acid and sealant	8	1	6
Group 2: microetching + hydrofluoric acid + silane	0	1	14
Group 3: phosphoric acid + self-etch primer + adhesive	3	0	12

$\chi^2 = 13.159$ *P* = .011

Frequency distribution of the shear bond strengths

The frequency distribution of the shear bond strengths of the three bonding techniques were compared using chi-square test. The results ($\chi^2 = 13.159$) indicated the presence of significant differences (*P* = .011) between the three groups (Table 2). The control group (conventional bonding) had the highest frequency of shear bond strength values of <4.0 MPa. On the other hand, the teeth that were microetched and had Porc-etch and Porcelain Conditioner applied as well as the teeth bonded with Clearfil Repair had the highest frequency of shear bond strength values of >6.0 MPa.

Scanning electron microscopy

In addition to shear bond testing, it is important to evaluate the quality of the porcelain surface after the removal of the residual adhesive and after polishing the surface. Using SEM, the results obtained from the shear bond testing can be explained further.

The intact, glazed porcelain surface can be seen in Figure 2a,b. The combined use of sandblasting, hydrofluoric acid-etch, and silane (Figure 3a,b) produced the roughest surface even after burnishing and polishing the porcelain surface. This explains why this group had the highest shear bond strength by the enhanced mechanical retention through the use of microetching and hydrofluoric acid. On the other hand, the use of phosphoric acid and a sealant with the composite adhesive (Figure 4a,b) resulted not only in little or no damage to the porcelain surface but also in a lesser ability for the adhesive to adhere mechanically to the surface. The use of Clearfil Repair that contains the self-etch primer/silane/adhesive (Figure 5a,b) resulted in much less damage to the porcelain surface while

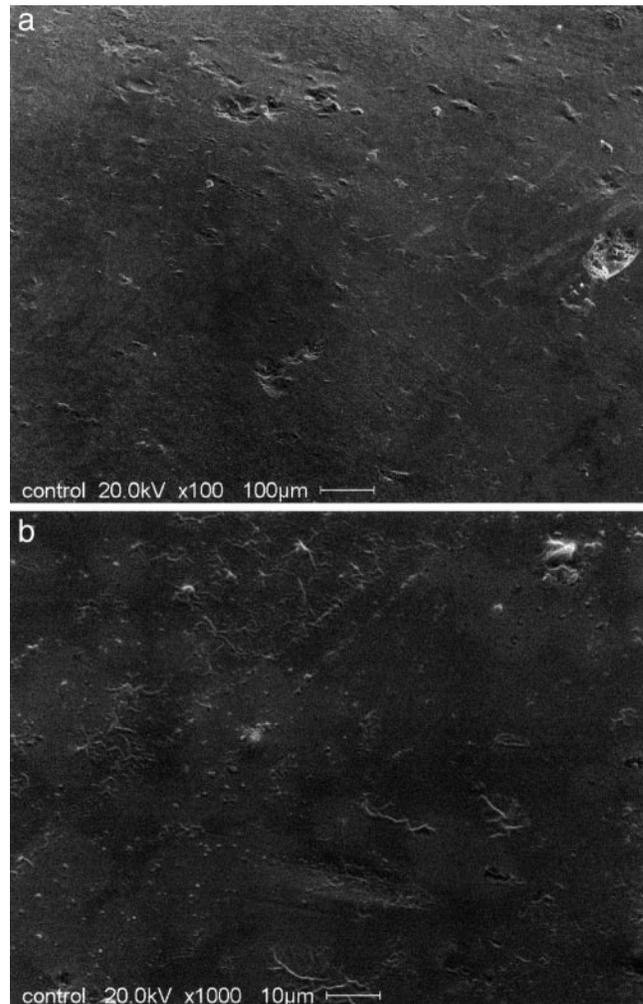


FIGURE 2. Scanning electron microscopy photographs of an intact, glazed porcelain surface at 100× (a) and 1000× (b). Note the smooth surface of the tooth.

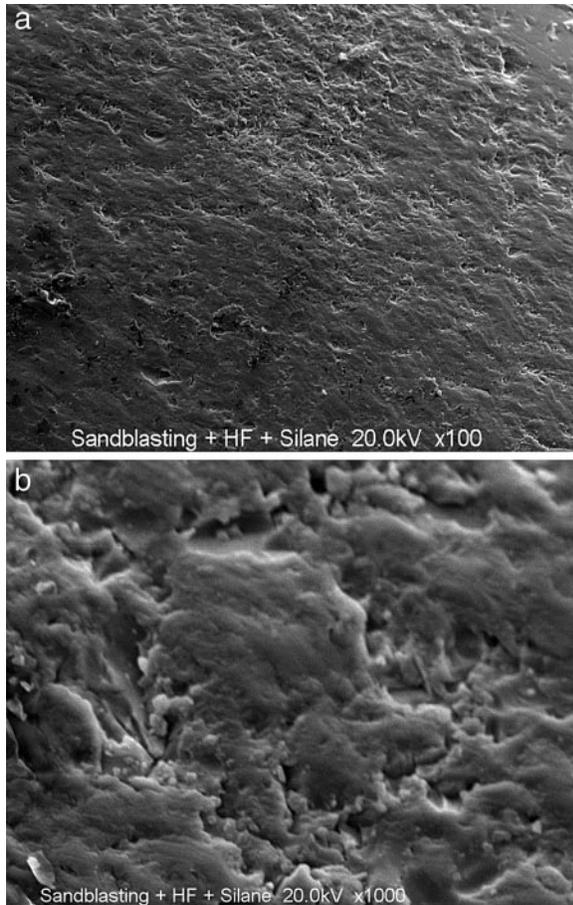


FIGURE 3. Scanning electron microscopy photographs of the porcelain surface at 100 \times (a) and 1000 \times (b) after microetching and the application of hydrofluoric acid and a silane coupler before bonding with a composite adhesive. Any residual adhesive was removed using a finishing bur and polished with Ceramist silicon points. Notice the relatively rough surface that not only facilitates mechanical retention of the adhesive but also causes irreversible porcelain surface changes.

maintaining reasonably high mean shear bond strength.

DISCUSSION

When bonding orthodontic brackets to porcelain surfaces, it is necessary to change the inert characteristics of the surface to achieve clinically acceptable bond strength. This alteration is accomplished by either increasing the roughness of the porcelain surface mechanically eg, by either microetching or the use of strong etchants such as hydrofluoric acid (or both), together with a silane coupling agent. Such procedures cause irreversible alteration to the glazed porcelain surface.

Andreasen and Stieg⁴ found that fracture of the porcelain itself was experienced during both tensile and shear testing when the silane coupling agents were

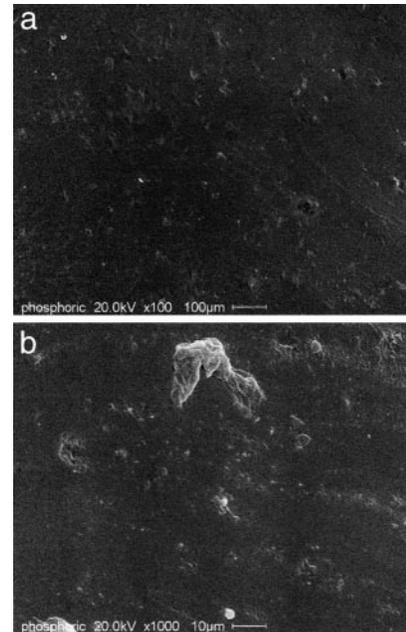


FIGURE 4. Scanning electron microscopy photographs of the porcelain surface at 100 \times (a) and 1000 \times (b) after phosphoric acid etch and bonding with a composite adhesive. Any residual adhesive was removed using a finishing bur and polished with Ceramist silicon points. Notice the relatively smooth surface except for some bur markings.

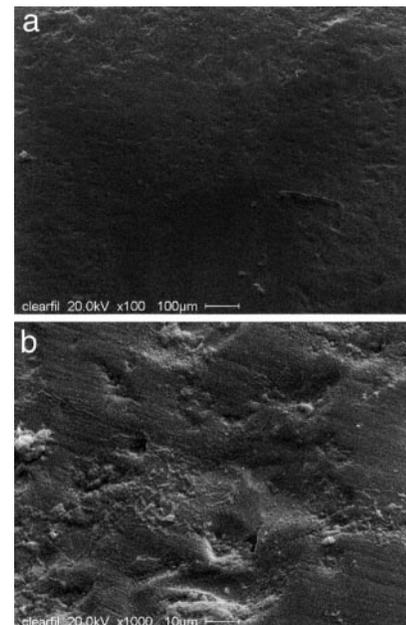


FIGURE 5. Scanning electron microscopy photographs of the porcelain surface at 100 \times (a) and 1000 \times (b) after applying Clearfil Repair. Any residual adhesive was removed using a finishing bur and polished with Ceramist silicon points. Notice the relatively smooth surface except for some bur markings.

used to increase the bond strength of orthodontic adhesives. The majority of these fractures were found in the shear sample group.⁴ Newman¹⁵ also reported that the strength of the bond between the resin and porcelain, attained with the use of a silane coupler, was sufficient to cause the fracture of porcelain. Such an occurrence is undesirable when associated with the removal of orthodontic brackets from porcelain crowns on restored teeth. Therefore, Newman¹⁵ suggested that when debonding orthodontic brackets from a porcelain surface, a ligature cutter be applied on the mesial and distal aspects of the bracket base and then twisted gently. Another approach used for bracket removal is by squeezing the mesial and distal bracket tie wings together, thus distorting the bracket. The residual composite can then be removed with a scaler or a slow speed finishing bur or both.

The present findings indicated that the weakest shear bond strengths were obtained when using phosphoric acid etch alone with the composite adhesive. Much stronger and consistent shear bond strength was obtained when the porcelain surface was microetched followed by the use of Porc-etch and Porcelain Conditioner, containing hydrofluoric acid and a silane coupling agent, before bonding the brackets. The new Clearfil repair self-etch primer/silane/adhesive combination had comparable mean shear bond strength (Table 1). On the other hand, the frequency distribution indicated a slightly higher frequency of shear bond strength values of <4.0 MPa with Clearfil Repair when compared with Porc-etch and Porcelain Conditioner, ie, having a slightly less consistent behavior (Table 2).

It should be emphasized that the differences between in vitro vs in vivo bond strengths need to be considered carefully, especially when bonding brackets to other restorative dental materials. Andreasen and Stieg⁴ indicated that the shear and tensile bond strengths of in vivo incisor and premolar enamel were significantly less than those of in vitro incisor and premolar enamel. They suggested that part of the in vivo increase in the rate of deterioration may be because of the mechanical and masticatory stresses placed on the bonds in the oral environment. They listed other factors, which may be of importance, including the moisture within the living tooth, flexing of the enamel during mastication, moisture contamination during bonding, as well as the thermal fluctuation in the oral cavity and the constant bathing of saliva. Andreasen and Stieg⁴ calculated that there was a decrease of approximately 17% to 22% in tensile strengths and 48% to 52% in shear strengths in vivo when compared with the in vitro bond strengths. They suggested that if this percent of in vivo decline is evident when bonding to porcelain surfaces, stronger bond strength would be

required for the efficient bonding of orthodontic brackets in the actual patient.

With this in mind, it seems that the clinician and the patient are better served by either using microetching, together with Porc-etch and Porcelain Conditioner or using the new Clearfil Repair for bonding brackets to porcelain surfaces. The major disadvantage with the first approach is the irreversible change in the porcelain glaze that occurs even after the surface is cleaned and polished. Such changes were observed to a much lesser extent when using the Clearfil Repair.

In addition to preservation of the porcelain surface glaze with Clearfil Repair by avoiding the need for surface roughening, not using hydrofluoric acid also reduces the hazard of a chemical burn to the gingival tissues. These are considerable advantages in orthodontics where time saving is very important and bonding procedures are done without the use of a rubber dam.

It should also be emphasized that the shear bond strength changes of Clearfil Repair as well as all the other systems need to be evaluated after long-term water storage and after thermocycling to validate the results of this study.

CONCLUSIONS

- The results indicated that the use of a phosphoric acid etch and sealant with a composite adhesive to bond orthodontic brackets to porcelain surfaces produced significantly low shear bond strength.
- The most reliable procedure for bonding orthodontic brackets to porcelain surfaces is through either microetching with the use of hydrofluoric acid and a silane coupler or the use of the Clearfil self-etch primer/silane/adhesive.
- Microetching and the use of hydrofluoric acid produce the greatest damage to the porcelain surface even after polishing when compared with the new self-etch/silane/adhesive combination.

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