A considerable number of orthodontic patients are adults, who have crown and bridge restorations fabricated from porcelain; therefore, orthodontists must develop a method that permits excellent bond strength of orthodontic attachment to porcelain. Application of a silane coupling agent is one of the methods used to enhance the bond strength to either glazed or roughened dental porcelains, and is now commonly used in clinical orthodontic practice. However, the bond strength achieved is still low, and long-term suc-
cess of this material is doubtful. Moreover, an in vitro study about the effect of long-term water storage on silane-treated resin/porcelain bonds revealed that the bond strength is substantially lower after 6 months.

The effect of surface preparation of porcelain on bond strength has been examined by many researchers. Smith et al evaluated shear bond strengths of orthodontic composite adhesives to treated porcelain surfaces compared with those to acid-etched enamel. They found that roughening the porcelain surface with silane treatment provided clinically acceptable bond strengths (8.1 to 8.6 MPa). Phoenix and Shen stated that surface treatments may enhance the wettability of porcelain surfaces and/or create microporosity that facilitates mechanical interlocking with low-viscosity resin.

Currently, air-abrasion technology has been examined as a potential application in dentistry. Researchers are now studying the use of air abrasive systems for mechanical etching, or modifying the surface of enamel, dentin, and restorative materials such as gold and porcelain. Zachrisson investigated the effect of variously treated porcelain surfaces on the tensile strength of orthodontic brackets bonded to feldspathic metal ceramic porcelain. The finding of this study demonstrated that sandblasted porcelain surfaces also treated with silane significantly increased the bond strength.

In recent years, advances in laser technology have greatly decreased its undesirable effects and made successful application of lasers in dentistry possible. In the past decade, there has been an innovation in utilizing the Nd:YAG laser to prepare enamel surfaces for direct bonding of orthodontic attachments. In addition, it has been used for roughening the porcelain surface before luting with a hybrid resin cement. Prior to Nd:YAG laser irradiation, a thin coat of the laser initiator material (black drawing ink, Camel, Bombay, India) was applied to the porcelain surface. Each specimen was exposed to the laser until the laser initiator material had completely disappeared (within 60 s) with a constant rate of 1.5 mm/s.

The purpose of this study is to evaluate shear bond strengths between feldspathic porcelain and mesh-backed orthodontic brackets after three different methods of preparing porcelain surfaces: intraoral sandblasting with 50-µm aluminum oxide particles, pulsed Nd:YAG laser etching, and 1 min of hydrofluoric acid etching. The surface morphology after preparation is examined with SEM.

MATERIALS AND METHODS

Specimen Preparation

Sixty-four porcelain-fused-to-metal specimens were fabricated with nonprecious metal. The square-shaped substructure cast with cross-shaped retentive projections for attachment of the acrylic resin block to mounting rings were fabricated by one dental technician. Prior to testing, they were stereomicroscopically inspected to rule out samples with surface defects or cracks. They were then stored in a clean, dry environment.

Surface Preparation of Porcelain

All specimens were rinsed with distilled water and ultrasonically treated in 70% ethanol for 5 min to eliminate potential organic deposits. Then they were polished and cleaned with pumice slurry, and washed and dried with oil-free compressed air. All specimens were randomly divided into four groups.

Group 1: Glazed porcelain with no surface preparation (control group)

Group 2: Intraoral sandblasting. Each specimen in this group was air abraded with aluminum oxide particles, grain size 50 µm (KCP 2000, American Dental Technologies, Troy, MI, USA) for 10 s. An area of approximately 20 mm² of the porcelain surface at the center of each specimen was subjected to the intraoral sandblaster until the selected porcelain surface appeared uniformly frosted. The pressure used was 689.5 KPa and the distance from the nozzle to porcelain surface was 10 mm.

Group 3: Nd:YAG laser. Each specimen in this group was treated with pulsed Nd:YAG laser (Twinlight Dental Laser Unit, Fotona, Ljubljana, Slovenia). The parameters were 150 mJ/pulse, 20 pps, with surface energy density of 375 J/cm² for 60 s as described by Hess. Prior to Nd:YAG laser irradiation, a thin coat of the laser initiator material (black drawing ink, Camel, Bombay, India) was applied to the porcelain surface with a nylon brush over an area of approximately 20 mm² and let stand for 1 min. Each specimen was exposed to the laser until the laser initiator material had completely disappeared (within 60 s) with a constant rate of 1.5 mm/s.

Group 4: Hydrofluoric acid treatment. Each specimen in this group was treated with 9.5% buffered hydrofluoric acid (Ultradent porcelain etch, South Jordan, Utah, USA) for 1 min according to the manufacturer’s instruction. The porcelain surface at the center of each specimen was coated with hydrofluoric acid using an Inspiral brush tip (Ultradent, South Jordan, UT, USA) over an area of approximately 20 mm², then rinsed with clean water for 30 s and dried with oil-free compressed air.
SEM Examination

One specimen was randomly selected from each group to be examined in terms of surface texture and surface characteristics. Each specimen was ultrasonically cleaned in distilled water, dried in a desiccator for 12 h, sputter coated with gold (sputter coater, SPI-module, West Chester, PA, USA), and the surface topography was examined with a scanning electron microscope (JEOL, Model JSM-5410LV, Tokyo, Japan) at an accelerating voltage of 20 KV.

Silanization of the Specimens

All specimens in each group were cleaned with distilled water in an ultrasonic cleaner (Tru-Sweep, model-275 D, Crest Ultrasonics, NJ, USA) for 5 min and dried with oil-free compressed air for 10 s. Each specimen was treated with 37% phosphoric acid for 90 s, then Ormco porcelain primer (Ormco, Glendora, CA, USA) was applied. The specimens were left in situ for 60 s and the porcelain primer was reapplied for another 60 s. The specimen was then cleaned with water for 10 s and dried with oil-free compressed air for 10 s.

Direct Bonding Procedure

A thin film of System 1+ bonding resin (Ormco) was applied to the base of the stainless steel standard mesh-backed orthodontic bracket (Minidiamond, Ormco). Each bracket was placed at the center of the prepared porcelain specimen. To standardize the placement of each bracket, the samples were arranged on the surface of a surveyor table and the squared end of a chisel-shaped surveying rod was lowered with a seating pressure of 101.43 grams for direct bonding in a perpendicular direction for 60 s to make the thin film of adhesive resin. Excess resin was removed with an explorer. The specimens were let stand for 30 min before storage in distilled water at 37°C for 24 h in an incubator (Memmert model 400, Schwabach, Germany).

Shear Bond Strength Testing

Each specimen was mounted on a universal testing machine (Model 5566, Instron, Buckinghamshire, England). The shear load was applied with a monobevel chisel blade parallel to the porcelain/adhesive-resin interface. A crosshead speed of 0.5 mm/min was used until bond failure occurred. The shear force values at bond failure were recorded in kilonewtons (KN) and converted to megapascals (MPa).

Statistical Analysis

The SPSS program for Windows version 7.5 was used to calculate means and standard deviations of 24-h shear bond strengths for all four tested groups. The homogeneity of variances was tested with the Levene statistic. The data were then analyzed using one-way analysis of variance (ANOVA) for overall significance. The Scheffe multiple comparison test was used to identify which groups were significantly different at the 95% level of confidence.

RESULTS

The effects of the three different porcelain surface preparations on the shear bond strength between mesh-backed orthodontic brackets and feldspathic porcelain using System 1+ as an adhesive are demonstrated in Fig 1. The highest mean shear bond strength was observed in group 4, and the bond strength values decreased from group 2 to group 3 to group 1. The sites of bond failure were observed under a stereomicroscope at 10X magnification, showing that bond failure was mainly cohesive within adhesive material (Table 1).

Comparison of Shear Bond Strengths

The Levene test showed no statistically significant difference among variances of 24-h shear bond strength of all four tested groups (p > 0.05). One-way ANOVA showed a significant difference between the four groups (p < 0.05).

The Scheffe multiple comparison test, as shown in Table 2, revealed that there were statistically significant differences in the mean shear bond strength between the glazed porcelain (control) and the surface preparations. However, there was no statistically significant difference between the intraoral sandblasting, Nd:YAG laser, and hydrofluoric acid etching groups.
Table 1  Frequency distribution of bond failure site

<table>
<thead>
<tr>
<th>Surface Preparation</th>
<th>Site of bond failure</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Within porcelain</td>
<td>At adhesive/porcelain interface*</td>
<td>Within adhesive**</td>
<td>At bracket/adhesive interface***</td>
</tr>
<tr>
<td>No surface preparation</td>
<td>–</td>
<td>4 (26.7%)</td>
<td>8 (53.3%)</td>
<td>3 (20.0%)</td>
</tr>
<tr>
<td>Intraoral sandblasting</td>
<td>–</td>
<td>–</td>
<td>9 (60.0%)</td>
<td>6 (40.0%)</td>
</tr>
<tr>
<td>Nd:YAG laser etching</td>
<td>–</td>
<td>5 (33.3%)</td>
<td>5 (33.3%)</td>
<td>5 (33.3%)</td>
</tr>
<tr>
<td>HF acid etching</td>
<td>–</td>
<td>–</td>
<td>4 (26.7%)</td>
<td>11 (73.3%)</td>
</tr>
</tbody>
</table>

* 0% to 25% of the adhesive left on the porcelain.
** 25% to 75% of the adhesive left on the porcelain.
*** 75% to 100% of the adhesive left on the porcelain.

Fig 1 Bar graph shows the mean and standard deviation of 24-h shear bond strengths.

Table 2  The comparison of 24-h shear bond strengths: results of the Scheffe multiple comparison test

<table>
<thead>
<tr>
<th>Surface preparation</th>
<th>No surface treatment</th>
<th>Intraoral sandblasting</th>
<th>Nd:YAG laser etching</th>
<th>Hydrofluoric acid etching</th>
</tr>
</thead>
<tbody>
<tr>
<td>No surface treatment</td>
<td>–</td>
<td>0.00**</td>
<td>0.003**</td>
<td>0.00**</td>
</tr>
<tr>
<td>Intraoral sandblasting</td>
<td>–</td>
<td>–</td>
<td>0.768</td>
<td>0.650</td>
</tr>
<tr>
<td>Nd:YAG laser etching</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.150</td>
</tr>
</tbody>
</table>

** α=0.01
SEM Examination

In group 1 (control), the SE micrograph of the glazed porcelain specimen with no surface preparation was extremely smooth, displaying no grooves or fissures (Fig 2). In group 2, the SE micrograph of the porcelain specimen after sandblasting was intricate and complex, with an angular appearance (Fig 3). In group 3, the SE micrograph of the Nd:YAG laser-prepared specimen indicated that the laser energy altered the smooth surface of feldspathic porcelain, creating homogeneous craters and pores with microcracks all over the surface (Fig 4). The SE micrograph of the group 4 specimen, etched for 1 min with hydrofluoric acid, showed that there was a complex, homogeneous pattern of numerous small channels all over the surface, resulting from dissolution of the continuous glass matrix. The irregularly shaped crystalline particles of porcelain appeared at the porcelain surface (Fig 5).

DISCUSSION

The results of this in vitro study indicated that surface preparation significantly increased the shear bond strength compared with the control group. This finding is in agreement with the previous studies by Smith et al and Kao et al, who found that roughening the porcelain surface together with the application of porcelain primers significantly increased bond strength. According to Cochran et al, shear bond strengths between 7 and 10 MPa or higher, with no porcelain frac-
ture on debonding, would be clinically acceptable. The use of a silane coupling agent alone as the control group in this study still achieved the minimum bond required. However, Thurmond et al.²⁴ proved that the use of the chemical agent without any physical alteration of the porcelain surface would not yield high bond strengths in long-term water storage.

Sandblasting followed by silanization produced the high shear bond strength of 12.41 MPa. This resulted from the additive effect of both mechanical and chemical adhesion. Sandblasting is considered to create mechanical retention.²⁵,²⁶ Wolf et al.²⁷ and Zachrisson et al.¹³ also showed a similar result; silane application to the sandblasted porcelain surface significantly increased the bond strength.

In the Nd:YAG laser-etched plus silane group, a significantly greater mean shear bond strength (11.71 MPa) was found than in the control group (9.08 MPa). The high bond strengths resulted from the additive effect of mechanical bonding from laser treatment and chemical bonding from the silane coupling agent. The use of Nd:YAG etching of porcelain required a laser-initiating material. The application of a laser-initiating material made it possible to create the specific laser-etched areas of porcelain surface. The uncoated surface of the porcelain remained unchanged when the beam was passed beyond the edge of the laser-initiating material. It has been shown that Nd:YAG laser works on a dark/light basis: the darker the material, the better the absorption.²² Thus, the use of laser-initiating material in this study enhanced the laser absorption into the porcelain surface.

The 9.5% hydrofluoric acid-etched group with silane yielded the highest mean shear bond strength (13.25 MPa), which was a result of the combination of mechanical and chemical bonding mechanisms. It was suggested that hydrofluoric acid etching would alter the feldspathic porcelain surface by creating microretention with undercuts. The results of this study were in agreement with Thurmond et al.²⁴ that 24-h shear bond strengths of the silanized, hydrofluoric acid-etched group were greater than the silanized, sandblasted group. However, their results were not statistically significantly different.

The differences in shear bond strength can be explained by the differences in microscopic surface texture among all tested groups. The glazed porcelain without surface preparation had no mechanical adhesion because the glazed surface did not permit resin tag formation. Therefore, the specimen in this group yielded the lowest shear bond strength. Sandblasted porcelain, which exhibited the roughest surface, slightly improved the shear bond strength compared to the controls. This may be due to the fact that despite the roughness from air abrasion with aluminum oxide particles, the method could not create microscopic undercuts sufficient for greatly improving bond strength. This finding was in agreement with Wood et al.’s study,²⁸ which stated that sandblasting creates surface irregularities without undercuts.

Hydrofluoric acid etching of feldspathic porcelain enabled an adequate resinous bond to be created to these materials.²⁷,²⁹ It was proved to be an effective procedure for enhancing and retaining bond integrity.³⁰ This result was in agreement with the findings of other studies.³¹-³³ They found that acid etching of porcelain yielded bond strengths that did not change as a function of water storage, unlike the use of silane alone.²⁴ These results suggested that surface topography was crucial in enhancing the bond strength. Surface roughening method and storage conditions interact strongly, and etched samples retained their strength after water storage.³⁰ However, the intraoral use of hydrofluoric acid poses certain dangers, and must be seen critically.³⁴,³⁵

The findings of this in vitro study have produced a database for the direct bonding technique of orthodontic attachments to porcelain surfaces. Further clinical research should be conducted to assess the bond integrity in an oral environment and to determine whether each type of surface preparation would be clinically successful in direct bonding.

**CONCLUSION**

Different approaches to bonding orthodontic brackets to a porcelain surface have been suggested. Both mechanical and chemical adhesion are considered to improve the bond strength. This study clearly indicates that different methods of porcelain surface preparation can produce micromechanical retention and increase the shear bond strength of orthodontic brackets to porcelain surfaces.

**REFERENCES**


