Bond strengths of porcelain laminate veneers to tooth surfaces prepared with acid and Er,Cr:YSGG laser etching

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Statement of problem. The erbium, chromium: yttrium, scandium, gallium, garnet (Er,Cr:YSGG) hydrokinetic laser system has been successful in the ablation of dental tissues. It has been reported that this system is also useful for preparing tooth surfaces for adhesion, but results to date have been controversial.

Purpose. This in vitro study evaluated the bond strengths of porcelain laminate veneers to tooth surfaces after etching with acid and Er,Cr:YSGG laser conditioning.

Material and method. Forty extracted caries- and restoration-free human maxillary central incisors were used. The teeth were sectioned 2 mm below the cementoenamel junction. The crowns were embedded in autopolymerizing acrylic resin with the labial surfaces facing up. The labial surfaces were prepared with .05 mm reduction to receive porcelain veneers. The teeth were divided into 4 groups of 10 specimens. Thirty specimens received 1 of the following surface treatments before the bonding of IPS Empress 2 laminate veneers: (1) laser radiation from an Er,Cr:YSGG laser unit; (2) 37% orthophosphoric acid; and (3) 10% maleic acid. Ten specimens received no surface treatment and served as the control group. The veneers were bonded with dual-polymerizing resin, Variolink II. One microtensile specimen from each of the cervical and incisal thirds measuring 1.2 × 1.2 mm was prepared with a slow-speed diamond saw sectioning machine with a diamond-rim blade. These specimens were attached to opposing arms of the microtensile testing device with cyanoacrylate adhesive and fractured under tension at a crosshead speed of 1 mm/min, and the maximum load at fracture (Kg) was recorded. The data were analyzed with a 2-way analysis of variance and Tukey HSD tests (α=.05).

Results. No statistically significant differences were found among the bond strengths of veneers bonded to tooth surfaces etched with Er,Cr:YSGG laser (12.1 ± 4.4 MPa), 37% orthophosphoric acid (13 ± 6.5 MPa), and 10% maleic acid (10.6 ± 5.6 MPa). The control group demonstrated the lowest bond strength values in all test groups. Statistically significant differences were found between the bond strengths of cervical and incisal sections (P<.001).

Conclusion. In vitro microtensile bond strengths of porcelain laminate veneers bonded to tooth surfaces that were laser-etched showed results similar to orthophosphoric acid or maleic acid etched tooth surfaces. (J Prosthet Dent 2003;90:24-30.)

CLINICAL IMPLICATIONS
This in vitro study reported no difference in microtensile bond strengths of porcelain veneers bonded to tooth surfaces that were etched with an Er,Cr:YSGG laser, 37% orthophosphoric acid, or 10% maleic acid.

Patient demand for the treatment of unesthetic anterior teeth has grown. For many years the most predictable and durable esthetic correction of anterior teeth has been achieved by the preparation of complete crowns. However, this approach is undoubtedly the most invasive with the removal of substantial amounts of sound tooth substance with possible adverse effects on adjacent pulp and periodontal tissues.

Calamia described the clinical and laboratory procedures for bonding porcelain laminate veneers to acid etched enamel. The popularity of porcelain laminate veneers has increased since their introduction because tooth preparation is conservative and the restorations are esthetic. However, an in vitro study has described some disadvantages such as marginal adaptation and related bonding problems.

Traditionally, etching the enamel surface with orthophosphoric acid, a concept first proposed by Buonocore, has been commonly used to increase the bond strength between the composite and enamel. The technique of etching with orthophosphoric acid is used to create an irregular surface of enamel. This allows an increase in the prepared surface area available for the retention of the composite and an improvement in the marginal adaptation of laminate veneers. The retentive characteristics of acid-conditioned enamel surfaces depend on the type of acid, etching time, and chemical composition of enamel.
Three types of etching patterns have been described by Silverstone et al.\textsuperscript{10} after exposure of the enamel prisms to etching solutions: type I, preferential removal of prism core material, leaving the periphery intact; type II, preferential removal of periphery core material, leaving the prism core relatively unaffected; and type III, a more random etching pattern in which adjacent areas of the tooth surface correspond to types I and II, mixed with regions in which the pattern could not be related to prism structure. Morphologic information obtained by scanning electron microscopy indicated that the surface structure resulting from etching with 35\% orthophosphoric acid and 10\% maleic acid is similar.\textsuperscript{11,12}

Laser devices have been used in dentistry for soft tissue surgery, root end sealing and sterilization, and for altering enamel and dentin surfaces to increase resistance to decay or to facilitate the bonding of composites.\textsuperscript{13,14} Laser etching may be an alternative to acid etching of enamel and dentin. Laser etching is painless and does not involve either vibration or heat, making this treatment attractive.\textsuperscript{15} Furthermore, laser etching of enamel or dentin has been reported to yield an anfractuous surface (fractured and uneven) and open dentin tubules, both apparently ideal for adhesion.\textsuperscript{15} The surface produced by laser etching is also acid-resistant because laser radiation of dental hard tissues modifies the calcium-to-phosphorus ratio, reduces the carbonate-to-phosphate ratio, and leads to the formation of more stable and less acid-soluble compounds, thus reducing susceptibility to acid attack and caries.\textsuperscript{16}

The ability of erbium:yttrium aluminum garnet (Er:YAG) lasers to cut dental biocalcified tissue effectively has been demonstrated.\textsuperscript{15} Furthermore, the cutting efficacy is improved when the tooth surfaces are flooded with a water layer.\textsuperscript{15,17,18} The Er,Cr:YSGG pulsed-wave laser, when used with an air-water spray, has been shown to cut enamel, dentin, cementum, and bone efficiently and cleanly.\textsuperscript{19,20} The Er,Cr:YSGG laser produces microexplosions during tissue ablation, resulting in macroscopic and microscopic irregularities.\textsuperscript{21} The Er,Cr:YSGG laser initially causes vaporization of water and other hydrated organic components of the tissue.\textsuperscript{21} On vaporization, the internal pressure builds within the tissue until the explosive destruction of inorganic substance occurs before the melting point is reached.\textsuperscript{21}

The quality of the bond obtained by laser etching of enamel relates to the energy densities of the device.\textsuperscript{22} With low energy densities, the surface is largely unaffected by laser pulses and retention is poor. At intermediate exposures surface roughening occurs.\textsuperscript{22} At high energy densities, the enamel is fused and this thin layer of fused enamel becomes the weakest link in the chain of adhesion.\textsuperscript{22}

Laser-induced physical changes include melting and recrystallization with the formation of numerous pores and small, bubble-like inclusions. These profiles have been shown by some studies in CO\textsubscript{2} laser\textsuperscript{23} and Nd:YAG laser.\textsuperscript{24,25} In contrast, no melting or recrystallization was observed with Er,Cr:YSGG hydrokinetic system.\textsuperscript{19,26}

The purpose of this study was to determine the microtensile bond strengths of porcelain laminate veneers to acid-etched and Er,Cr:YSGG laser treated enamel, with an unetched group serving as the control. The enamel morphologic structure after laser etching and acid etching was also investigated with scanning electron microscopy (SEM). The hypothesis tested was that the microtensile bond strength obtained after Er,Cr:YSGG laser etching of enamel is similar to that obtained after acid etching.

**MATERIAL AND METHODS**

Forty extracted human maxillary central incisors with 10 mm anatomic crown length and 8 mm mesiodistal width were selected. Each tooth was free of dental caries and restoration. The teeth were cleaned and stored in saline solution at room temperature immediately after extraction.

The teeth were sectioned 2 mm below the cemento-enamel junction with a slow-speed diamond saw sectioning machine (Isomet; Buehler Ltd, Lake Bluff, Ill), and the crowns were embedded in autopolymerizing acrylic resin (Meliodent; Bayer Dental Ltd, Newbury, UK) with the labial surfaces facing up.

**Tooth preparation**

The facial surfaces of the teeth were prepared to accommodate veneers of equal thickness. A 0.5-mm facial reduction was performed with a chamfered cervical finish line and incisal bevel preparation. Self-limiting depth-cutting disks of 0.5 mm (834-51-021; Gebr. Brasseler, Lemgo, Germany) were used to define the
depth of the cuts, and then 1.4-mm chamfer diamond burs (6844-314-014; Gebr. Brasseler) were selected to refine the preparation. All tooth preparations were completed without sharp line angles (Fig 1).

Impression making and master die fabrication

Impressions of the 40 prepared teeth were made with polyvinylsiloxane impression material (Permagum; 3M ESPE AG, Seefeld, Germany). The impressions were poured with a vacuum-mixed polyurethane die material (Alpha Die MF; Schultz-Dental GmbH, Rosbach, Germany) according to the manufacturers’ instructions with respect to water/power ratio and mixing time. Dies were recovered from the impressions, and 2 layers of die spacer (Cement Spacer; Kerr Dental, Orange, Calif) were painted 0.5 mm short of the finish lines of the preparations.

Ceramic veneer fabrication

The veneers were waxed (Yeti Dental produkte; GmbH, Engen, Germany), sprued, and then pressed after investment. All procedures were performed with IPS Empress 2 materials (Ivoclar, Schaan, Liechtenstein), following the manufacturer’s recommendations. After divestment, the ceramic veneers were finished with diamond burs (863-204-016; Gebr. Brasseler) and glazed.

Surface treatment

The 40 prepared teeth were randomly assigned to 4 groups of 10 specimens (n = 10). Each of 3 groups was subjected to a different etching technique (Table I). Ten specimens received no surface treatment and served as the control group.

Table I. Materials used for surface conditioning

<table>
<thead>
<tr>
<th>Material Used</th>
<th>Time of etching</th>
<th>Brand</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>37% orthophosphoric acid</td>
<td>15 s</td>
<td>Bisco</td>
<td>Bisco Inc, Schaumburg, Ill</td>
</tr>
<tr>
<td>10% maleic acid</td>
<td>15 s</td>
<td>Scotchbond Multi-Purpose</td>
<td>3M, St. Paul, Minn</td>
</tr>
<tr>
<td>Er;Cr:YSGG hydrokinetic laser system</td>
<td>15 s</td>
<td>Millennium</td>
<td>Biolase Tech Inc, San Clemente, Calif</td>
</tr>
</tbody>
</table>

Laser treatment

An Er,Cr:YSGG hydrokinetic dental laser (Millennium; Biolase Technology, Inc., San Clemente, Calif) was used for laser etching. This hard- and soft-tissue laser creates laser-energized, atomized water droplets that act as cutting particles. Laser energy is delivered through a fiberoptic system to a sapphire tip terminal 6 mm long and 600 µm in diameter, bathed in an adjustable air and water vapor. It operates at a wavelength of 2.78 µm; pulse duration of 140 microseconds with a repetition rate of 20 Hz. Average power output can be varied from 0 to 6 W, depending on the tissue to be cut. The energy and power densities were (5.6 J/cm²) and (111 W/cm² at 2W), respectively, and were calculated by the manufacturer of the laser unit for the used power adjustment. The air and water spray of the hand-piece was adjusted to the “30” scale of the laser unit. The beam was aligned perpendicular to the enamel at 1 mm distance and was moved in a sweeping fashion by hand during an exposure period of 15 seconds over the entire area. The irradiated specimen was dried with an oil-free air source for 15 seconds.

Bonding ceramic veneers

The ceramic veneers were treated with fluoricid acid (Ceramic Etchant; Ceramco, Burlington, NJ) for 1 minute and neutralized (Ceramic Etchant Neutralizer; Ceramco) in accordance with the manufacturer’s instructions. Silane (Monobond S; Ivoclar) was first applied with a brush to the ceramic veneers for 60 seconds, and then a bonding agent (Heliobond; Ivoclar) was applied. After the teeth were etched, primer (Syntac Primer; Ivoclar) was applied to the tooth surface for 15 seconds, adhesive (Syntac Adhesive; Ivoclar) for 10 seconds, and then a bonding agent (Heliobond; Ivoclar) with a brush.

Cement (Variolink II; Vivadent, Ivoclar), comprising a combination of 25% Variolink yellow base, 25% Variolink white base, and 50% catalyst was hand-mixed following the manufacturer’s directions, and applied to both prepared teeth and the ceramic veneers. The ceramic veneers were placed on the prepared teeth with light finger pressure, and excess cement was removed with an explorer. Photo polymerization was performed with the light-polymerizing unit (Hilux 350; Express Dental Products, Toronto, Canada) at 350 mW/cm² (with a light tip to specimen distance of 0 mm) for 40 seconds for incisal, mesial, and distal surfaces.

Specimen preparation

After cementation, specimens were stored in distilled water for 24 hours. Acrylic resin blocks were mounted in a slow-speed diamond saw sectioning machine (Isomet) with a diamond-rim blade. Two saw cuts were made parallel to the long axis of the tooth, and subsequently 4 saw cuts were made perpendicular to the long axis. This produced 2 I-shaped
specimens, 1 from the incisal portion, and the other from the cervical (Fig. 2, A). The porcelain bonded to the facial enamel surface was divided into an array of 1.2 × 1.2 × 5-mm beams (Fig. 2, B), with the top half consisting of porcelain and the bonding agent, and the bottom half consisting of enamel and dentin.28 Each specimen was tested individually.29

Cyanoacrylate adhesive (Zapit; Dental Ventures of America, Corona, Calif) was used to attach the microtensile specimens to opposing arms of the microtensile testing device (Harvard Apparatus Co. Inc., Dover, Mass). The mounting adhesive was applied sparingly to the edges of each specimen. The specimen was fractured under tension at a crosshead speed of 1 mm/min, and the maximum load at fracture (Kg) was recorded. Preparation of all specimens and completion of the testing were done by the same operator.

Fracture analysis

After the specimen was tested and removed from the testing apparatus, the fracture sites were observed with a stereomicroscope (SZTP; Olympus, Tokyo, Japan) at original magnification ×22 to identify the mode of failure. The fractured surface was classified according to 1 of 3 types: (1) adhesive failure between the bonding resin and the enamel/dentin; (2) cohesive failure in the bonding resin; and (3) cohesive failure in the enamel/dentin.

Statistical analysis

The ultimate stress (MPa) of the porcelain-enamel/dentin bonds were calculated as follows:30

\[
\text{Stress} = \frac{\text{Failure Load (Kg)}}{\text{Surface area (mm}^2\text{)}} \times 9.8
\]

The results of testing were entered into a spreadsheet (Excel; Microsoft, Seattle, Wash) for calculation of descriptive statistics. The obtained data were analyzed by 2-way analysis of variance and then Tukey HSD tests (SPSS/PC, Vers.10.0; SPSS, Chicago, Ill) for pairwise comparisons among groups (α=.05).

RESULTS

Microtensile bond strengths

The 2-way analysis of variance test indicated that tensile bond strength was significantly affected by position (cervical or incisal) \( P < .001 \) and treatment (acid or laser) \( P < .001 \), and there was no significant interaction between the 2 factors \( P > .05 \). Because there was no significant interaction, all data in each group were pooled. When the cervical and incisal data were pooled to investigate the effect of a particular surface treatment on bond strength, no statistically significant differences were found between the bond strength values of veneers bonded to 37% orthophosphoric acid (group B) and Er,Cr:YSGG laser-etched tooth surfaces (group A). Again, no statistically significant differences were found between the bond strengths of veneers bonded to 37% orthophosphoric (group B) and 10% maleic acid (group C) etched tooth surfaces. Statistically significant differences were found between the laser etched surfaces (group A) and the control (group D) \( P < .05 \). There were statistically significant differences between the orthophosphoric acid etched surfaces (group B) and the control (group D) \( P < .01 \). Additionally, no statistically significant differences were observed between laser etched and maleic acid etched tooth surfaces (Table II).

Mean bond strength values for different treatment groups were calculated together with standard deviations (Fig. 3). The mean bond strength of group B was higher than the laser-treated group (group A) in the incisal sections, but in the cervical sections group A was higher. The control group (group D) demonstrated the lowest bond strength values in all test groups (Table III).
Fracture patterns

In the laser-treated group (group A), most failures (17 of 20) were adhesive in nature at the bonding resin/enamel interface, and 2 specimens showed cohesive failure in the bonding resin. Only 1 specimen showed cohesive failure within the enamel. In the group etched with orthophosphoric acid (group B), most failures (19 of 20) were adhesive in nature at the bonding resin/enamel interface. One specimen showed cohesive failure within the enamel. The specimens in the group etched with maleic acid (group C) and in the control group (group D) showed adhesive fracture at the resin/enamel interface.

Scanning electron microscopy

SEM photographs of 37% orthophosphoric acid, 10% maleic acid, and Er,Cr:YSGG hydrokinetic laser-treated enamel are shown in Figure 4. The enamel surface etched with 2 acid solutions and a laser system showed different results according to Silverstone’s etching patterns. The 37% orthophosphoric acid removed the periphery core material but left the prism core relatively unaffected (type II), producing a very rough enamel surface. The 10% maleic acid treatment resulted in preferential removal of prism core material and left the periphery intact (type I). Er,Cr:YSGG hydrokinetic laser-treated enamel showed a more random etching pattern in which adjacent areas of tooth surface correspond to types I and II, mixed with regions where the pattern could not be related to prism structure. There was no recrystallization or melting observed.

DISCUSSION

The results obtained support the research hypothesis of an expected similar adhesive force after laser treatment. This result is in accordance with the study of Usumez et al. in which they compared these methods for bonding orthodontic brackets to enamel surfaces. On the other hand, the results of this study disagree with the results from other studies. These differences may be related to the different type of laser used, duration of exposure, and energy applied to the surface.

This study also compared the microtensile bond strengths of specimens in the 10% maleic acid and 37% orthophosphoric acid etched groups. The results have indicated that there were no significant differences in microtensile bond strengths between the 2 groups. The results of this study are in agreement with the works of Goes et al. and Hermans and Vrijhoef. For microtensile testing, the tensile bond strength is dependent on the area of the bonded surface. In this study, failures occurred mostly at the bonding resin/enamel interface and did not involve the enamel or ceramic except for the 2 specimens which showed cohesive
failure within the enamel. Microtensile testing should more closely approximate clinical applications. How-
however, microcracks and other defects can possibly occur during the production of specimens with a slow-speed diamond saw sectioning machine, which may cause pre-
mature failure of the bond. Therefore the specimens must be prepared carefully.29

Laser-treated enamel demonstrated strong bonding to the porcelain laminate veneers. The highest microten-
sile bond strength was achieved with 37% orthophosphoric acid for the incisal sections while the highest mean bond strength was achieved with laser treatment for the cervical sections. It is believed that these differ-
ences are due to exposure of the dentin layer in the cervical portions of specimen because of decreased thickness of enamel in this region. Visuri et al15 sug-
gested that the greater presence of peritubular dentin, which has a greater mineral content than intertubular
dentin, may result in better bonding to the dentin. In their study they obtained higher shear bond strength of composite when it was bonded to Er:YAG laser-pre-
pared dentin compared with acid-etched dentin. An-
other difference between acid etchant and laser actions related to dentin is their effect on the structure of dentin
tubules. When an acid etchant is applied, the peritubular
dentin is preferentially etched, resulting in funnel-
shaped openings to the tubules. This structure may con-
tribute with polymerization shrinkage to pull the tags away from the walls. Laser irradiation produces no demi-
neralization of peritubular dentin and the dentinal tu-
bules remain open with no widening.21 This effect may have contributed to microtensile bond strengths of cer-
vical sections where dentinal exposures were present. Sources for the large deviations found in this study in-
clude variations in enamel structure, storage effects, age,
condition of individual teeth, variations in enamel
depth, and nonhomogenous laser treatment of surfaces.

CONCLUSIONS
Within the limitations of this study, 37% orthophos-
phoric acid (13.0 MPa) – and 10% maleic acid (10.6
MPa) – treated enamel surfaces showed statistically simi-
lar bond strength values. Porcelain laminate veneers
demonstrated the highest bond strengths to 37% or-
thophosphoric acid-etched (13.0 MPa) and Er,Cr:YSGG
hydrokinetic laser system-conditioned tooth surfaces
(12.1 MPa). The differences were not statistically different.

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Copyright © 2003 by The Editorial Council of The Journal of Prosthetic Dentistry.
0022-3913/2003/$30.00 + 0
doi:10.1016/S0022-3913(03)00235-X