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Bond Strengths of Orthodontic Bracket After Acid-Etched, Er:YAG Laser-Irradiated and Combined Treatment on Enamel Surface

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ABSTRACT

Laser ablation has been proposed as an alternative method to acid etching; however, previous studies have obtained contrasting results. The purpose of this study was to compare the bond strengths after acid etching, laser ablation, acid etching followed by laser ablation, and laser ablation followed by acid etching. Forty specimens were randomly assigned to one of the four groups. Two more specimens in each group did not undergo bond test and were prepared for observation with scanning electron microscope (SEM) after the four kinds of surface treatment. After the bond test, all specimens were inspected under the digital stereomicroscope and SEM to record the bond failure mode. Student's *t*-test results showed that the mean bond strength (13.0 ± 2.4 N) of the laser group was not significantly different from that of the acid-etched group (11.8 ± 1.8 N) ($P > .05$). However, this strength was significantly higher than that of the acid-etched then laser-ablated group (10.4 ± 1.4 N) or that of the laser-ablated then acid-etched group (9.1 ± 1.8 N). The failure modes occurred predominantly at the bracket-resin interface. Er:YAG laser ablation consumed less time compared with the acid-etching technique. Therefore, Er:YAG laser ablation can be an alternative tool to conventional acid etching.

KEY WORDS: Orthodontic bonding, Er:YAG laser ablated, Fracture mode.

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INTRODUCTION Return to TOC

The purpose of acid etching is to remove the smear layer left by the high-speed dental drill and create an irregular surface by preferentially dissolving hydroxyapatite crystals on the outer surface. This topography will facilitate penetration of the fluid adhesive components into the irregularities. After polymerization, the adhesive is locked into the surface and contributes to micromechanical retention. If a laser can achieve the above-mentioned function of acid etching, and even produce a favorable surface for bonding to a restorative material, it may be a viable alternative to acid etching.

The ability of laser irradiation to remove the smear layer has been reported.[1,2] After being exposed to laser, enamel underwent physical changes including melting and recrystallization, thus forming numerous pores and small bubblelike inclusions.[3–5] This was similar to the type III etching pattern produced by orthophosphoric acid.[6] The recrystallization of dentin after laser exposure has also been demonstrated.[7] With the formation of a fungiform appearance, the microretention or possible chemical adhesion of a restorative material to tooth structure might be increased. Another study also showed that a laser could roughen the enamel surface.[8] Therefore, laser etching may be a feasible method of etching enamel.

The results of previous studies on the application of laser etching for increasing bond strengths of restorative materials have been controversial. Investigation of enamel surface roughness showed that laser irradiation yielded a comparable[9] or smaller[10] amount of surface roughness than acid etching. With regard to bond strengths of restorative materials, some studies indicated that acid-etched teeth had significantly more bond strength than laser-etched teeth,[8,11–13] whereas others demonstrated that laser etching could result in bond strength comparable with[5,14–17] or even stronger than acid etching.[18,19] These variations could be attributed to the different types of lasers or different irradiation parameters used because the laser–hard tissue interaction is dependent on wavelength and irradiation energy.

The Er:YAG laser with a wavelength of 2940 nm is highly absorbed by water and hydroxyapatite. Being effective in cutting enamel and dentin, it is the first approved laser tool applied to dental hard tissues in the United States.[20,21] It was shown that Er:YAG laser-prepared dentin had improved bond strengths when compared with acid-etched groups.[22] However, the tensile strength of bracket-tooth bonds after preparation of the enamel surface by Er:YAG laser etching was inferior to that obtained after conventional acid etching.[23] Nonetheless, if the irradiation parameters can be advertently controlled, the subsurface fissuring that is unfavorable to adhesion can be avoided.

To date, there are no reported studies that compare the bond strengths of orthodontic bracket etched by acid, Er:YAG laser, and combined treatment on the enamel surface. This study investigates methods that could obtain the maximal bond strength and analyzes the fracture mode of each method.

MATERIALS AND METHODS Return to TOC

Specimen preparation

Extracted human premolars were used for this study. Crowns with caries, restoration, or fractures were discarded. Any remaining soft tissue was removed from the tooth surface with a dental scaler (Sonicflex 2000, KaVo Co, Biberbach, Germany). All teeth were stored in 4°C distilled water containing 0.2% thymol to inhibit microbial growth until use.

Forty-eight specimens were randomly assigned to one of the four groups. Two specimens in each group would not undergo bond test and would be prepared for scanning electron microscope (SEM) surface observation after different etching treatments. The enamel treatments of the groups were as follows:

- Group A: enamel etched with 37% phosphoric acid;
- Group B: enamel irradiated with Er:YAG laser at 300 mJ/pulse, 10 pulses per second (pps), 10 seconds;
- Group C: enamel etched with 37% phosphoric acid and then irradiated with Er:YAG laser at 300 mJ/pulse, 10 pps, 10 seconds;
- Group D: enamel irradiated with Er:YAG laser at 300 mJ/pulse, 10 pps, 10 seconds and then etched with 37% phosphoric acid.

Before the experiment, each tooth was cleaned thoroughly with a rubber cup and fine-grit pumice, rinsed with water, and dried with an air spray. Waterproof one-mm-thick aluminum foil with a 3 × 4-mm hole was used to delineate the treatment areas for enamel conditioning.

Etching procedure

For the acid-etching technique, we applied 37% phosphoric acid solution to the bonding surfaces with applicator sponges for 30 seconds, rinsed thoroughly with a forceful air-water spray, and dried the etched enamel with clean, dry air. The etched enamel showed a uniform, dull, frosty appearance.

Laser treatment

The samples were irradiated with Er:YAG laser (Opus TM 20, Lumenis Corp. Yokneam, Israel) of a wavelength of 2.94 μm at 300 mJ/pulse, 10 pps, 10 seconds. A previous pilot study on extracted teeth showed that this energy level produced a microscopically suitable etched pattern. The surface was irradiated manually in a light contact form using a 600-μm optic fiber with a contra-angle hand piece under water spray. After laser treatment, the surface appeared frosty like that of the acid-etching technique.

Bonding procedure

The surface etched by acid or laser was covered with a small amount of Ortho Solo sealant (Enlight, Ormco Corp, Glendora, Calif) with a brush. A thin, uniform coating covered the whole etched enamel. The Enlight adhesive paste was applied onto the base of the bracket pad (Dentaurum, Pforzheim Corp, Germany). With the adhesive applied, the bracket was placed onto the tooth surface immediately, adjusted to final position, and pressed firmly. Excessive sealant and adhesive were removed from the periphery of the bracket base to keep the bond area of each tooth uniform. According to the manufacturer's instruction, we used a conventional light-curing unit (Demetron Optilux 401, Danbury, Conn) to shine on the mesial and distal edges of the bracket for 30 seconds each.

Test procedure

After bonding the brackets to the teeth, we used a custom-made aligning device to mount them vertically in custom-made aluminum cylinders (two cm in diameter) with plaster. A hole in an aligning device (Figure 1) was prepared to fit exactly the aluminum cylinder. This would make the direction of force in relation to the bracket the same for every specimen. A wire loop on the aligning device hooked the bracket (Figure 1). Samples were tested for the force at bond failure with a Universal testing machine (Instron Corp, Canton, Mass) at a crosshead speed of one mm/min. The force and displacement to dislodge the bond between the bracket and enamel were recorded by the load cell, linear variable differential transformer (LVDT, Linear Ball Bearing Series, ±5 mm, Half Bridge Model, RDP Electronics Inc., Pottstown, PA) and computer software (Merlin Software Suit, Instron Corp). After the bond test, the debonded surfaces of all teeth were removed from the remaining tooth structure with a low-speed diamond-wafering blade (Isomet; 10.2 cm × 0.3 mm, arbor size 1/2 inch, series 15HC diamond; Buehler Ltd, Lake Bluff, Ill). The surface morphology was observed using the digital microscope (Leica MZ8, Heebrugg, Switzerland) at 8–25× magnification.

These coronal remnants were then prepared for observation with SEM by serial dehydration of graded ethanol solutions (50% to 100%) at 45-minute intervals. Finally, all specimens were mounted on aluminum stubs and sputter coated with gold. The specimens were then observed with SEM (TOPCON ABT-60, Topcon Corp. Tokyo, Japan) at accelerating voltage of 15 kV to examine the difference in surface quality among the phosphoric acid–etched, laser-irradiated, and etched and irradiated teeth.

To determine the fracture mode, we modified the method suggested by Oliver[24] to evaluate debonded surfaces. The digital microscope calculated the area of adhesive remnant on the tooth, and an SEM observed the fracture site. If more than half of the resin remnant existed on the tooth, the bond failure site was at the bracket-resin interface. On the contrary, if less than half of the resin remnant existed on the tooth and the enamel surface was intact, then the bond failure site was at the resin-enamel site.

RESULTS Return to TOC

Bond strengths

The forces at bond failure of the different etching methods are shown in Table 1. Student's *t*-test demonstrated that laser ablation could yield a force (13.0 ± 2.4 N) similar to that of the acid-etched group (11.8 ± 1.8 N). Moreover, this strength was significantly higher than that of the acid-etched then laser-ablated group (10.4 ± 1.4 N) or that of the laser-ablated then acid-etched group (9.1 ± 1.8 N). The values of groups C and D were not significantly different.

Fracture mode

Table 2 shows the failure sites in the four groups. Most of the specimens of the four groups had adhesive failures at the bracket-resin interface. In other words, attached resin on the enamel surface could be seen in most of the specimens. No cohesive failures within the resin and no enamel fractures were found. The laser-treated group had more adhesive failures at the enamel-resin interface.

SEM examination of surface treatment

Figure 2 shows the enamel surface after phosphoric acid treatment. This morphology revealed type III etched pattern with mixed prism centers and prism periphery etching.[25] Dissolution of hydroxyapatite by phosphoric acid produced tags and rough surface that afforded the mechanical lock for resin. After 300 mJ/pulse, 10 pps, and 10 seconds of Er:YAG laser irradiation (Figure 3), rough irradiated surface with microcracks were found. Less regular, inhomogeneous ablated patterns, comparable with those of acid treatment, were also observed.

When the enamel surface was acid etched and then Er:YAG laser treatment (300 mJ/pulse, 10 pps, 10 seconds) (Figure 4), two kinds of morphological changes could be found. One was the honeycomb-like appearance induced by acid etching (arrowhead). The other was the laser-ablated surface (arrow) accompanied by the appearance of microcracks. After Er:YAG laser (300 mJ/pulse, 10 pps, 10 seconds) and then acid treatment (Figure 5), the enamel surface was similar to that of the acid group and revealed type I (preferential prism center etching) etching pattern, having a scaly appearance and circular depressions with a relatively flat-surface structure.

DISCUSSION Return to TOC

In this study, the laser-treated group attained bond strength similar to that of the acid-etched group (Table 1) and even greater than those of the combined treatment groups. The SEM photomicrograph of the laser-ablated group (Figure 3) at energy of 300 mJ/pulse, 10 pps, 10 seconds showed an uneven, irregular surface with occasional microcracks to enhance retention. This surface roughness might be comparable with the acid-etched surfaces (Figure 2). After acid etching and then Er:YAG laser irradiation (Figure 4), the surface showed a mixed type of structure. Er:YAG laser ablated some of the acid-etched surface; thus, the honeycomb-like appearance could not be found. Wavelike ablated residue could be seen instead of the acid-induced area.

If Er:YAG laser irradiation was done first followed by acid etching (Figure 5), the portions and structures of the laser-affected area would be dissolved by acid and would demonstrate a pattern similar to that of the acid-etched group. The acid-etched effect would be lessened and a more flattened surface would appear.

Most of the specimens had bond failure sites at the bracket-resin interface (Table 2). This indicated that these four kinds of treatment could give good surface wetting. The laser group had more failure rate at the enamel-resin interface. We suspected that this was because of uneven and inhomogeneous surface produced by laser irradiation that contained many stress concentration sites. However, debonding is a process of crack formation, propagation, and subsequent bond failure. It is also related to the wetting ability and surface energy. The combination of these factors would not necessarily cause the laser-treated group to have weaker bond strength.

The bond strength of acid etching and Nd:YAG or CO_2 laser irradiation has been compared. Either laser ablation could achieve strength comparable with acid etching[5,14,15,17] or laser irradiation would decrease the bond strength as reported previously.[11,13,26,27] The decrease in laser irradiation was attributed to a reduced surface roughness[10] or laser-induced lower surface energy,[12] melted bubbles, craters, cracking, and micropores of the enamel.[8] These melted and resolidified enamel might contain by-products (α-tricalcium phosphate or β-tricalcium phosphate) of phase transformation like those of laser-irradiated dentin.[28,29]

Although the CO_2 laser is also highly absorbed by hydroxyapatite, the enamel surface often showed cracks and melted texture after CO_2 laser irradiation.[10] These adverse effects would reduce the bond strength. On the other hand, Er:YAG laser has been approved as an effective tool for hard tissue ablation. Our results were different from those of a previous study,[23] which showed inferior adhesion to enamel after Er:YAG laser irradiation when compared with that obtained by acid etching. We considered the choice of irradiation parameters the main reason. In our study, we determined the energy settings according to the SEM observation of the pilot study. Therefore, the unfavorable condition like extensive subsurface fissuring reported by Martinez-Insua et al[23] was not seen in this experiment.

Because the bond strength is related to the size of the bonding area, it is important to control this area.[30] In this study, we removed the excessive adhesive and resin outside the bracket. The aluminum foil also carefully controlled the etched and irradiated areas. This would reduce the variations and allow uniform bonding area.

We designed a special apparatus for testing the bond strength (Figure 1). The force exerted by the Instron was transmitted by a lever arm; thus, the force read by the load cell was not equal to the force exerted on the bracket. Although the direction of force was perpendicular to the bracket, we could not calculate the bond strength using the “force/area” formula and call it tensile bond strength. Nonetheless, every specimen was tested in the same manner, and it was still meaningful to compare the forces among the four groups.

After acid etching the enamel, demineralization and susceptibility to caries around brackets are complications of orthodontic treatment. Er:YAG laser ablation might overcome this drawback and offer other benefits like reduction in clinical time, a reduced susceptibility to moisture during etching, and bond strength similar to that of acid etching.

CONCLUSIONS Return to TOC

The mean bond strength of Er:YAG laser ablation was not much different from that of acid etching ($P > .05$), but significantly larger than those of combined treatments ($P < .05$). The failure modes occurred predominantly at the bracket-resin interface. The Er:YAG laser can be an alternative tool to conventional acid etching.

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TABLES Return to TOC

TABLE 1. Forces at Bond Failure of Different Surface Treatments

	Forces at Bond Failure (N)*
Acid etched	11.8 ± 1.8 (10)[a]
Laser ablated	13.0 ± 2.4 (10)
Acid etched then laser ablated	10.4 ± 1.4 (10)
Laser ablated then acid etched	9.1 ± 1.8 (10)

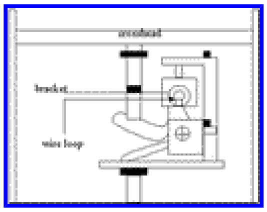
[a] Values are means ± standard deviation (number of specimens).
* $P < .05$.

TABLE 2. Bond Failure Site of Different Surface Treatments

	Bracket-Resin Interface	Within Resin	Resin-Enamel Interface
Acid etched	9[a]	0	1
Laser ablated	7	0	3
Acid etched then laser ablated	10	0	0
Laser ablated then acid etched	9	0	1

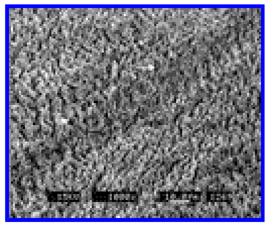
[a] Values are number of specimens.

FIGURES Return to TOC



Click on thumbnail for full-sized image.

FIGURE 1. The apparatus for testing bond strength



Click on thumbnail for full-sized image.

FIGURE 2. Photomicrograph of the enamel surface after acid treatment. This morphology shows type III etching pattern with regular rough surface and spaces after dissolution of hydroxyapatite (arrow)

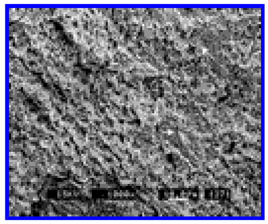


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FIGURE 3. Photomicrograph of the enamel surface after Er:YAG laser irradiation (300 mJ/pulse, 10 pps, 10 seconds). It also shows a rough irradiated surface and an irregular ablated pattern when compared with that of acid treatment. Microcracks could be seen on the treated surface (arrow)

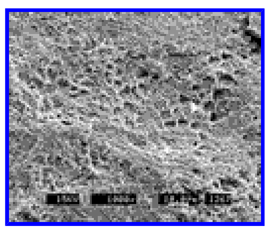

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FIGURE 4. Photomicrograph of the enamel surface after acid and then Er:YAG laser treatment (300 mJ/pulse, 10 pps, 10 seconds). Etched residue (arrowhead) and laser-irradiated surface (arrow) could be found together with the appearance of microcracks

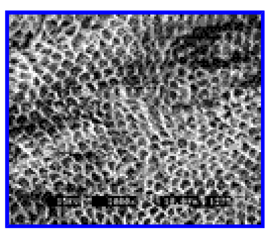

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FIGURE 5. Photomicrograph of the enamel surface after Er:YAG laser (300 mJ/pulse, 10 pps, 10 seconds) and then acid treatment. It was similar to that of the acid group with honeycomb-like appearance and more flattened surface

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