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Etching Enamel for Orthodontics with an Erbium, Chromium:Yttrium-Scandium-Gallium-Garnet Laser System

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ABSTRACT

Objective: To test the shear bond strength, surface characteristics, and fracture mode of brackets that are bonded to enamel etched with an erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser operated at different power outputs: 0.5 W, 1 W, and 2 W.

Materials and Methods: Human premolars that had been extracted for orthodontic purposes were used. Enamel was etched with an Er,Cr:YSGG laser system operated at one of three power outputs or with orthophosphoric acid.

Results: The shear bond strength associated with the 0.5-W laser irradiation was significantly less than the strengths obtained with the other irradiations. Both the 1-W and 2-W laser irradiations were capable of etching enamel in the same manner. This finding was confirmed by scanning electron microscopy examination. The evaluation of adhesive-remnant-index scores demonstrated no statistically significant difference in bond failure site among the groups, except for the 0.5-W laser–etched group. Generally, more adhesive was left on the enamel surface with laser irradiation than with acid etching.

Conclusion: The mean shear bond strength and enamel surface etching obtained with an Er,Cr: YSGG laser (operated at 1 W or 2 W for 15 seconds) is comparable to that obtained with acid etching.

KEY WORDS: Er,Cr:YSGG laser system, Laser irradiation, SEM examination, Shear bond strength.

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INTRODUCTION Return to TOC

Since the report of Buonocuore[1] in 1955, the standard protocol to remove the smear layer for successful bonding has been acid etching. The irregular enamel surface created by dissolving hydroxyapatite crystals permits penetration of the fluid adhesive components, and this penetration provides micromechanical retention. Acid etching of enamel appears to improve retention by selectively eroding certain hydroxyapatite formations and facilitating penetration by the development of resin tags.[2,3] Development of these micromechanical bonds contributes to long-term bonding strength.

The ability of laser irradiation to remove the smear layer has been reported.[4,5] After laser etching, physical changes such as melting and recrystallization occur in the enamel. Numerous pores and bubblelike inclusions appear, similar to those in the type III etching pattern produced by orthophosphoric acid, described by Silverstone et al.[2] Therefore, laser irradiation may be a feasible method to etch enamel surfaces.

After Maiman[6] introduced the four-ruby laser in 1960, several types of lasers, such as carbon dioxide (CO_2) and neodymium:yttrium-aluminum-garnet (Nd: YAG) lasers, have been used in dental practice. The first commercially available lasers were suitable for soft tissue treatments, especially in periodontics.[7]

However, when these lasers were applied to dental hard tissues, the result was major thermal damage, rendering these lasers unsuitable for hard tissue treatments. The development of the erbium:yttrium-aluminum-garnet (Er:YAG) laser and, more recently, the erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser permit ablation in both soft and hard tissues without any thermal side effects.[7,8] These lasers can ablate enamel and dentin effectively because their light is highly and efficiently absorbed by both water and hydroxyapatite.[8] Histological studies have revealed no pulpal inflammatory responses in dental hard tissue irradiated with the Er,Cr:YSGG laser.

The Er,Cr:YSGG laser, which uses a pulsed-beam system, fiber delivery, and a sapphire tip bathed in a mixture of air and water vapor, has been shown to be effective for soft tissue surgery and for cutting enamel, dentine and bone.[9,10] After Er,Cr:YSGG laser irradiation, the surface alteration of enamel and dentine shows microirregularities and the absence of a smear layer.[10] This suggests that the Er,Cr:YSGG laser may etch enamel suitably for orthodontic purposes. Therefore, the present study was conducted to test the shear bond strength, surface characteristics, and fracture mode of brackets bonded to enamel etched with an Er,Cr:YSGG laser operated at different power outputs.

MATERIALS AND METHODS Return to TOC

Sixty-seven human premolars that had been extracted for orthodontic purposes were used in this study. Crowns with caries, restorations, or fractures were discarded. Any remaining soft tissue was removed from tooth surfaces, and then the teeth were stored in distilled water. To prevent bacterial growth, the water was changed weekly.[11]

Sixty teeth were mounted horizontally in a self-curing acrylic resin so that at least 2 mm of the buccal enamel was exposed. The buccal enamel surfaces of the teeth were pumiced, washed for 30 seconds, and dried for 10 seconds. The 60 teeth were randomly assigned to one of four treatment groups. The remaining 7 teeth did not undergo the shear test but were prepared for scanning electron microscope (SEM) evaluation after different surface treatments. The four groups were as follows:

- Group A: Enamel etched with 37% orthophosphoric acid
- Group B: Enamel irradiated with the Er,Cr:YSGG laser at 0.5 W for 15 seconds
- Group C: Enamel irradiated with the Er,Cr:YSGG laser at 1 W for 15 seconds
- Group D: Enamel irradiated with the Er,Cr:YSGG laser at 2 W for 15 seconds

Laser etchings were performed with an Er,Cr:YSGG laser system (Waterlase, Biolase Europe GmbH, Germany) emitting photons at a wavelength of 2780 nm. The laser was pulsed with a duration of 140 μm and a pulse repetition rate of 20 pulses per second (20 Hz) (Figure 1). In the present study, the wavelength was constant, and only the power output of the laser system was varied. Although the output power could be varied from 0–6 W, the three different power settings were used in this study were 0.5 W, 1 W, and 2 W. The air and water levels were 90% and 80%, respectively. The laser beam was perpendicular to the enamel at a 1-mm distance. To avoid unnecessary laser irradiation, an acrylic resin with a 4×4-mm hole was placed on the tooth surface.

For SEM (Jeol, JSM-5600, Tokyo, Japan), the 7 teeth were evaluated separately. One tooth was acid etched with orthophosphoric acid, and 6 were irradiated with the laser. A pilot study was conducted to determine a suitable etching time for Er,Cr:YSGG laser irradiation. We tried 15 seconds and 30 seconds as alternatives at the three power outputs and then observed the etched enamel with the SEM.

After all etchings were performed, stainless-steel standard edgewise premolar brackets (GAC, Central Islip, NY) were bonded to the teeth. These brackets had a surface bonding area of 12.6 mm.[2] A thin, uniform coating of adhesive agent was applied to the etched surface. After the bonding material (Transbond XT, 3M Unitek, Monrovia, Cal) was applied, the bracket was placed onto the tooth surface, adjusted to its final position, and pressed firmly into place. Excessive sealant and adhesive were removed from the periphery of the bracket base to keep each bonding area uniform. Light curing was performed for a total of 40 seconds by irradiating the mesial, distal, occlusal, and gingival aspects of the tooth for 10 seconds each.

After storing the specimens in water at 37°C for 24 hours, thermocycling for a total of 500 cycles at 5– 55°C with a dwell time of 30 seconds was performed. The shear bond test was accomplished with a chisel edge mounted on the crosshead of a testing machine (Instron Testometric M500–25, Testometric Company Ltd, Lancheire, Rochdale, UK). The edge was aimed at the bracket and enamel interface with a crosshead speed of 0.5 mm/sec, and the force decay was recorded in megapascals (MPa). The shear bond strength was calculated by dividing this force by the bracket base area.

After debonding the teeth, the brackets were examined under 10× magnification to evaluate the amount of resin remaining on the tooth. The adhesive remnant index (ARI) was used to describe the quantity of resin remaining on the tooth surfaces. The ARI scores ranged from 0–3 as follows: 0, no adhesive remained on the tooth; 1, less that half of the enamel bonding site was covered with adhesive; 2, more than half of the enamel bonding site was covered with adhesive; 3, the enamel bonding site was covered entirely with adhesive.

Statistical Analysis

Descriptive statistics, including the mean, standard deviation, and minimum and maximum values, were calculated for each group. Multiple comparisons of the shear bond strengths for the different etching types were performed with the ANOVA test. The chi-square test was used to evaluate differences in the ARI scores among groups. All statistical evaluations were made with a software program (SPSS for Windows, release 10.0.0, Chicago, Ill)

RESULTS Return to TOC

Shear Bond Strengths

Descriptive statistics for the comparison of shear bond strengths and ARI scores for the four groups are given in Tables 1–3. The acid-etched group yielded the highest mean shear bond strength (14.85 ± 2.59 MPa). The mean shear bond strengths for the 0.5-W, 1-W, and 2-W laser irradiations were 4.34 ± 3.16 MPa, 9.88 ± 4.43 MPa, and 11.14 ± 4.75 MPa, respectively. ANOVA analysis revealed a statistically significant difference between the 0.5-W laser–etched group and the acid-etched group ($P < .001$). No statistically significant difference was found between the 1-W and 2-W laser–etched groups and the acid-etched group.

SEM Examination

Figure 2 shows an enamel surface with the acid-etched pattern of orthophosphoric acid. A type III acid-etched pattern, with the regular rough surface and spaces described by Silverstone et al,[2] can be seen. The hydroxyapatite dissolved by phosphoric acid produced tags and rough surfaces that provided the mechanical lock for the resin.

Laser irradiation for 15 seconds and 30 seconds were investigated at the three outputs (0.5 W, 1 W, and 2 W). The 15 seconds of laser irradiation was enough for enamel etching (Figures 3–5). A 30-second irradiation was much more harmful to enamel, so 30 seconds was not used.

A 2-W laser irradiation produced a type III acid-etching pattern (Figure 6) similar to that produced by acid etching, whereas a 1-W laser irradiation produced a more preferred type I etching pattern (Figure 7). A honeycomb-like appearance was seen with a 1-W laser irradiation. The laser-ablated surfaces were accompanied by the appearance of microcracks that aid the penetration of resin. No significant enamel surface etching was obtained by a 0.5-W laser irradiation (Figure 8).

ARI Scores

The ARI scores for the four groups are listed in Table 3. The ARI scores indicate the site of bond failure for the acid-etched and laser-etched groups.

The chi-square test revealed statistically significant differences among the four groups ($P = .023$). When the 0.5-W laser–etched group was dropped from the comparison, the remaining groups showed no statistically significant differences ($P = .661$).

DISCUSSION Return to TOC

Laser systems are used more commonly in dentistry in recent years. Because the main purpose of orthodontics is to preserve maximum tooth structure while treating anomalies, this study was designed to determine whether laser systems can be used in orthodontics with minimal tooth structure destruction and optimal bracket retention. The SEM evaluation helped us to inspect the amount of destruction on the etched enamel surfaces.

The Er,Cr:YSGG laser used in the present study creates laser-energized, atomized water droplets that act as cutting particles[9]. This laser system creates precise hard-tissue cuts by virtue of the laser energy interacting with water at the tissue interface, called a hydrokinetic system. With this system, not only is the temperature suppressed, but cutting efficiency is increased.[9] Laser energy is delivered through a fiber optic system to a sapphire-tipped terminal. The average power output can vary from 0–6 W. For cutting enamel, high irradiation outputs from 2.5–6 W can be used.[12] However, lower power outputs that would probably etch enamel (0.5 W, 1 W, and 2 W) were used in the present study.

In the present study, the laser wavelength was constant (2780 nm). The laser power outputs were varied because the main purpose of the present study was to determine the shear bond strengths and surface characteristics of brackets bonded to enamel etched with a Er,Cr:YSGG laser operated at different power outputs. The usage of different power outputs causes different effects.

The handpiece of the Er,Cr:YSGG laser system is light and useful. Ease of handling aids in the use of this apparatus and prevents unnecessary etching of the enamel. Nevertheless, even when using liquid acid etchants, there is always a shift of acid on the enamel surface. Gel acids are useful in etching the correct place and amount of enamel surface.

Both 15 seconds and 30 seconds of laser-etching time were evaluated in the present study. A laser-etching time of 15 seconds was preferred because 30 seconds of laser irradiation was not useful, as shown by SEM examination. Acid-etching times can vary from 15–60 seconds. However, because reports have noted no significant differences between acid-etching times, 15 seconds of acid etching was performed. Although the total etching times were not recorded in the present study, laser etching may save time because, unlike acid etching, it eliminates washing the enamel surface after etching. The time required for washing a tooth varies from 15–30 seconds, so the total time needed for a full-mouth bonding could be decreased by 300–600 seconds. The 5 to 10 minutes of chair time saved by immediate placement of the bracket on a laser-etched tooth is an important finding of the present study. Still, there is a need for studies to determine the real chair time.

Phosphoric acid is one of the best methods to bond resins to enamel.[1,13] A potential disadvantage of enamel etching is the complete removal of the smear layer and exposure of dentinal tubules. Acid etching results in chemical changes that may modify the organic matter and decalcify the inorganic component.[14,15] As a result of this demineralization, enamel becomes more susceptible to caries attack, which is induced by plaque accumulation around the bonded orthodontic attachments. Hossain et al[12] reported an increase in the calcium to phosphorus ratio achieved during laser irradiation, which leads to caries inhibition.[16,17] Therefore, laser irradiation might have an advantage as an etchant for orthodontic bonding. In previous studies[7–9], cutting of enamel and dentine with laser systems was established. In the present study, the use of the recently introduced Er,Cr:YSGG laser to etch enamel for orthodontic purposes was studied.

In the present study, the laser-etched enamel surfaces (except for the 0.5-W laser–etched group) had bond strengths comparable with those of the acid-etched group. These three groups (1-W laser–etched, 2-W laser–etched, and acid-etched) were within acceptable limits. Maijer and Smith[18] demonstrated that 8 MPa of bonding strength is adequate for orthodontic purposes. Lower shear bond strengths were obtained with the 0.5 W of laser irradiation.

In the literature, there are conflicting reports about the use of lasers for enamel etching. Although some researchers have reported that the mean shear bond strength resulting from laser etching is lower than that from acid etching,[11,19,20] others have reported more favorable results with laser irradiation.[12,21,22] In the present study, we found the highest bond strength in the acid-etched group (14.85 MPa ± 4.59 MPa), followed by the 2-W laser–etched group (11.14 MPa ± 4.75 MPa) and the 1-W laser–etched group (9.88 MPa ± 4.43 MPa). These three etching modalities were clinically acceptable. However, etching with a laser system uses a motion controlled by the hand. This motion perhaps caused uneven etching patterns, which may have lead to the higher standard deviations of shear bond strengths in the laser-etched groups. This is a problem that must be overcome.

The SEM evaluation of the acid-etched group and 2-W laser–etched group revealed a similar etching pattern, which is described by Silverstone et al.[2] The shear bond strengths of these two groups were more similar to each other than to that of 1-W laser-etched group. The shear bond strength of the 1-W laser– etched group was lower but still acceptable.

The evaluation of ARI scores demonstrated no statistically significant difference in bond failure sites among the groups, except for the 0.5-W laser–etched group. However, generally, more adhesive was left on the enamel surface with laser irradiation. This finding, which was in accordance with that of a previous study,[21] could be considered an advantage or a disadvantage. Less chair time is needed with less adhesive left on enamel after debonding, but it may cause enamel fracture while debonding, especially with ceramic brackets.

CONCLUSION Return to TOC

- The mean shear bond strength and enamel surface etching obtained with Er,Cr:YSGG laser (operated at 1 W or 2 W for 15 seconds) is comparable to that obtained with acid etching.

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TABLES Return to TOC

Table 1. Descriptive Statistics for Acid Etching and Laser Etchings with 0.5, 1, and 2 Watt power outputs for 15 Seconds

Group[a]	n	Mean	SD	SE	Maximum (MPa)	Minimum (MPa)	F	*P*
A	15	14.85	2.59	1.53	20.33	8.42	7.483	$<.001$
B	15	4.34	3.16	1.72	10.8	1.79		
C	15	9.88	4.43	1.47	15.47	6.62		
D	15	11.14	4.75	1.58	17.57	7.59		
Total	60	10.85	5.32	.62	20.33	1.79		

[a] A indicates acid etching; B, 0.50 Watt etching; C, 1 Watt etching; D, 2 Watt etching.

Table 2. Multiple Comparisons for Laser Etchings at 0.5-W, 1-W, and 2-W Power Output for 15 Seconds and for Acid Etching

	Laser Etching			
	0.5 W	1 W	2 W	Acid Etching
Laser etching				
0.5 W		ns	ns	***
1 W			ns	ns
2 W				ns
Acid etching				

*** $P < .001$; ns, not significant.

Table 3. Residual Adhesive Ratings According to the Adhesive Residue Index for the Different Etching Procedures

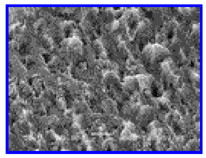
	Adhesive Residue Index[a]					
Etching Group	0	1	2	3	Chi-Square Test	Chi-Square Test[b]
Acid	2	7	4	2	19.329, $P < .05$	4.116, $P > .05$
0.5-W Laser	9	4	1	1		
1-W Laser	2	3	8	2		
2-W Laser	2	3	7	3		

[a] ARI: 0 indicates no adhesive remained on the tooth; 1, less than half of the enamel bonding site was covered with adhesive; 2, more than half of the enamel bonding site was covered with adhesive; 3, the enamel bonding site was covered entirely with adhesive.
[b] Test does not include 0.5-W laser group.

FIGURES Return to TOC

Click on thumbnail for full-sized image.

Figure 1. The laser system used in the study



Click on thumbnail for full-sized image.

Figure 2. The acid-etched enamel surface

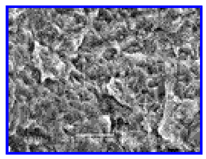


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Figure 3. Enamel surface after 2 W of Er,Cr:YSGG laser irradiation for 30 seconds

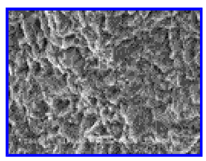

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Figure 4. Enamel surface after 1 W of Er,Cr:YSGG laser irradiation for 30 seconds

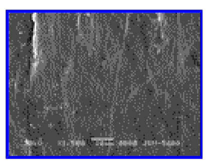

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Figure 5. Enamel surface after 0.5 W Er,Cr:YSGG laser irradiation for 30 seconds

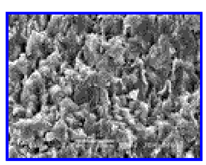

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Figure 6. Enamel surface after 2 W Er,Cr:YSGG laser irradiation for 15 seconds

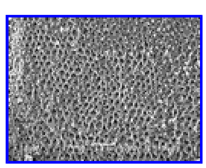

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Figure 7. Enamel surface after 1 W of Er,Cr:YSGG laser irradiation for 15 seconds

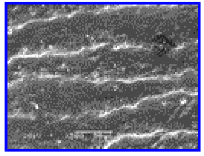

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Figure 8. Enamel surface after 0.5 W of Er,Cr:YSGG laser irradiation for 15 seconds

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