ORIGINAL ARTICLE

Laser etching of enamel for direct bonding with an Er,Cr:YSGG hydrokinetic laser system

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Irradiation of enamel with laser energy changes the physical and chemical characteristics of the enamel surface, and these alterations hold promise for the conditioning of enamel for bonding procedures. This laboratory study examined the influence of laser irradiation of enamel at 2 different power settings with an erbium, chromium: yttrium, scandium, gallium, garnet (Er,Cr:YSGG) hydrokinetic laser system (Millennium System, Biolase Technology, Inc; San Clemente, Calif) on the shear bond strength of orthodontic appliances and compared these with that of acid-etching. The prepared surfaces of 40 noncarious, intact, extracted premolars were exposed to laser energy: 20 teeth at 2-W setting (5.6 J/cm^2) and 20 teeth at 1-W setting (2.7 J/cm^2) of the commercial laser unit. Twenty teeth were etched with 37% orthophosphoric acid. Brackets were bonded with an orthodontic no-mix adhesive, and shear bond strength was determined with a universal testing machine. Data were analyzed with Kruskall-Wallis and Mann-Whitney U tests. Etched and restored surfaces of an acid-etched tooth and a 2-W laser-irradiated tooth were examined with scanning electron microscopy (SEM). Laser treatment under 2 W resulted in bond strengths of 7.11 $\pm$ 4.56 megapascals (MPa), which was not significantly different from that of acid etching (8.23 $\pm$ 2.30 MPa). Laser irradiation at 1 W resulted in bond strengths of 5.64 $\pm$ 3.19 MPa, which was significantly different from that of acid etching ($P <$ .05). However, large SD and coefficient of variation values of both laser groups made reliability of this method as an enamel conditioner questionable. Scanning electron microscopy studies of the restored irradiated surfaces showed good surface characteristics, whereas the lased surface was still more irregular than the restored acid-etched sample. Although laser devices are effectively used in some other areas of dentistry, enamel conditioning with an Er,Cr:YSGG laser cannot be considered a successful alternative to the conventional methods of increasing bond strengths to enamel. (Am J Orthod Dentofacial Orthop 2002;122: 649-56)

The first application of lasers in dentistry was reported in 1964.[1] These lasers were used to inhibit caries by increasing the resistance of enamel to demineralization.[1-3] Lasers were also demonstrated to vaporize and crater enamel surface with a high-energy beam.[4,5] Since then, attention has been focused on the treatment of soft and hard tissue lesions and desensitization of teeth.[6-8]

In recent years, there has been growing interest and advancement in the application of lasers for treating medical and dental maladies. Thus, different laser systems evolved for different needs. Commercially available dental laser systems can be used for curing and whitening, and for soft and hard tissue operations.[9]

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Orthodontic applications of laser treatment were based on the previous hard tissue studies with lasers. Laser irradiation, in particular, causes thermally induced changes on the enamel surface. It causes surface roughening and irregularity similar to that of acid etching to a depth of 10 to 20 μm, depending on the type of laser and the energy applied to the surface. In effect, the etching is through a process of continuous vaporization and microexplosions resulting from vaporization of water trapped in the hydroxyapatite matrix. The energy level basically depends on the photon energy.[10]

Laser etching is painless and does not involve vibration or heat, making it highly attractive for routine use. Furthermore, laser etching of enamel or dentin has been reported to yield a fractured and uneven surface and open dentin tubules, both apparently ideal for adhesion.[11] The surface produced by laser etching is also acid resistant: laser radiation of dental hard tissues modifies the calcium-to-phosphorus ratio, reduces the carbonate-to-phosphate ratio and water and organic component contents, and leads to the formation of more stable and less acid-soluble compounds, thus reducing susceptibility to acid attack and caries.[12,13] It has also been suggested that laser etching might create remineralization microspaces that trap free ions.[14] Thus, laser-induced caries resistance[2,14,15] would be of great importance in orthodontics.

An erbium, chromium, yttrium, scandium, gallium, garnet (Er,Cr:YSGG) hydrokinetic laser system was investigated in 1995 by Eversole and Rizoiu.[16] The same device was also evaluated for hard tissue preparation, soft tissue effects, osseous repair, and pulpal responses.[17-19] The device has been shown to create precise hard tissue cuts by virtue of laser energy interaction with water at the tissue interface, and it has therefore been termed a hydrokinetic system.[18] The hard tissue cutting effect of this system was also investigated by Lin et al.[20]

The purpose of the present study was to evaluate the effectiveness of the commercial Er,Cr:YSGG hydrokinetic dental laser system (Millennium System, Biolase Technology, Inc; San Clemente, Calif) at 2 different power settings in etching enamel for direct bonding of orthodontic appliances. Shear bond strength and the possibility of restoring the enamel surface to its original gloss after debonding were evaluated.

MATERIAL AND METHODS

Sixty noncarious human maxillary first premolars extracted with orthodontic indication were used in this study. Teeth with hypoplastic areas, cracks, or gross irregularities of the enamel structure were excluded. The teeth were stored in distilled water at 10° C after extraction, the oldest for nearly 3 months. The water was changed weekly to prevent bacterial growth.[10] The sample was randomly divided into 3 groups of 20 each. Each tooth was mounted vertically in a self-cure acrylic so that the crown was exposed. The buccal enamel surfaces of the teeth were pumiced, washed, and dried before the etching procedure.

Acid-etched group

A 37% orthophosphoric acid gel (Ivoclar-Vivadent; Schann, Liechtenstein) was used to etch 20 premolars for 30 seconds (group A). The teeth were then rinsed with water from a 3-in-1 syringe for 30 seconds and dried with an oil-free source for 20 seconds. For all teeth that were etched, the frosty white appearance of etched enamel was noticed.

Laser-etched group

An Er,Cr:YSGG hydrokinetic dental laser 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 600 μm in diameter, 6 mm long, and bathed in an adjustable air and water vapor. It operates at a wavelength of 2.78 μm and has a 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. Two different power settings were used in this study: 2 W for group B and 1 W for group C. Energy density and power densities were calculated by Biolase Technology Inc (San Clemente, Calif) (energy density, 5.6 J/cm^2, and power density, 111 W/cm^2 at 2 W; energy density, 2.7 J/cm^2, and power density, 55.6 W/cm^2 at 1 W). A small pilot study showed that subjecting enamel to laser energy at these settings resulted in a macroscopic etched-like surface, whereas higher power outputs resulted in visible cavitations. The air and water spray of the handpiece was adjusted to the "30" scale of the laser unit. The beam was aligned perpendicular to enamel at 1 mm distance and was moved in a sweeping fashion by hand over an approximately 4×4-mm area during an exposure time of 15 seconds, which was enough to scan this area. The irradiated sample was dried with an oil-free air source for 15 seconds.

Three additional premolars were conditioned with acid etching, 2-W laser, or 1-W laser for scanning electron microscopy (SEM) examination, but only the first 2 were examined under SEM.

Bonding procedure

Sixty stainless steel premolar brackets (Dentaurum, standard edgewise, 790-010; Pforzheim, Germany) with a base surface area of 10 mm^2(Development Orthodontics Department, Dentaurum) were used for this study. A thin coating of bonding agent (Express Dental Products; Toronto, Ontario, Canada) was applied on the prepared enamel surfaces and on the bracket bases with a brush. A chemically cured no-mix orthodontic bonding material (Express Dental Products, one-step orthodontic adhesive bonding system; Toronto, Ontario, Canada) was put on the bracket base, and the bracket was placed onto the enamel surface. A force of 300 g was applied to the brackets for 2 minutes with a force gauge (gauge, 006-013-00, Dentaurum) attached to a Parascop (Bego Bremer Goldschagerei Wihl.Herbst Gmbh & Co; Bremen, Germany), which was used to direct forces vertical to the bracket base.[21,22] Any excess resin was removed with a probe before the resin was polymerized. After 2 minutes of force application, the specimens were allowed to cure for an additional 10 minutes and then were immediately returned to the distilled water bath. The same operator (S.Ü.) performed the bonding of all the brackets. One macroscopically representative specimen from each of groups A, B, and C was not bonded and was stored for later SEM examination.

Twenty-four hours after bonding and complete preparation, the entire specimen was placed in a specially constructed automatic thermocycling apparatus.[23,24] The specimen was thermocycled between water baths held at 5° C and 55° C for 30-second cycles for a total of 500 cycles to imitate the heat and humidity conditions of the oral cavity.[21] The specimen was stored at room temperature in distilled water until the shear testing was performed a week later.

Debonding procedure

The embedded specimens were secured in a jig attached to the base plate of a universal testing machine (Model 500, Testometric; Lancashire, United Kingdom). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned so that the leading edge was aimed at the enamel-adhesive interface before being brought into contact at a crosshead speed of 0.5 mm/min. The force required to take off the brackets was measured in newtons, and the shear bond strength (1 MPa = 1 N/mm^2) was then calculated by dividing the force values by the bracket base area (10 mm^2).

One debonded specimen was randomly selected from each of the acid-etched and 2-W-irradiated groups. The enamel surfaces of these samples were cleaned with a tungsten-carbide bur, pumiced with a low-speed handpiece, and polished with polishing discs (281, 282, 283, 284, Hawe-Neos Dental; Bioggio, Switzerland) consecutively to finer grits to restore the labial plane to its original gloss. Two unbonded and 2 restored samples from the acid-etched and 2-W-irradiated groups were evaluated under a SEM (LEO 435 VP; Cambridge, United Kingdom). The 2 restored debonded samples were evaluated to learn whether the irradiated labial planes of the premolars could be restored to their original gloss after debonding. The teeth were mounted on specimen slubs with a vacuum-resistant adhesive and provided with a 200-Å coating of gold.

Residual adhesive

After debonding, the teeth and the brackets were examined under ×10 magnification. Any adhesive remaining after bracket removal was assessed according to the adhesive remnant index (ARI) and scored for the amount of resin adhering to the enamel surface.[25] The ARI scale has a range between 5 and 1, with 5 indicating no composite remaining on the enamel; 4, less than 10% of the composite remaining on the tooth surface; 3, more than 10% but less than 90% of the composite remaining on the tooth; 2, more than 90% of the composite remaining on the tooth; and 1, all composite remained on the tooth, as well as the impression of the bracket base. The ARI scores were also used as a more complex means of defining the site of bond failures among the enamel, the adhesive, and the bracket base.

Table I. Descriptive statistics and multiple comparisons for test groups

Treatment methods	*n*	*Range*	*Stress (MPa)* *Mean*	*SD*	*Acid*	*2-W laser*
Acid	20	5.32-13.00	8.23	2.3		
2-W laser	20	0.56-16.57	7.11	4.56	NS	
1-W laser	20	0.35-12.60	5.64	3.19	*	NS

*$P < .005$.
NS, not significant.

Statistical analysis

Descriptive statistics including the mean, SD, and minimum and maximum values were calculated for each of the 3 groups of teeth tested. Comparisons of means were made with Kruskall-Wallis and Mann-Whitney U tests. The chi-square test was also used to determine significant differences in the ARI scores between the different groups (SPSS for Windows, Release 7.5.1; Chicago, Ill). Significance for all statistical tests was predetermined at $P \leq .05$.

RESULTS

Shear bond strengths

Descriptive statistics and results of multiple comparisons are shown in Table I and Figure 1. The acid-etched group (group A) yielded the highest mean debonding force (8.23 ± 2.30 MPa). This was followed by the 2-W laser-irradiated group B (7.11 ± 4.56 MPa) and the 1-W laser-irradiated group C (5.64 ± 3.19 MPa), respectively. A Kruskall-Wallis test showed that there were statistically significant differences among the 3 surface treatment methods with respect to bond strength ($P = .048$). A Mann-Whitney U test of couples revealed a significant difference only between the acid-etched and 1-W laser-etched group, whereas acid-etched and 2-W laser-etched couple and 1-W and 2-W laser-etched couple did not show a statistically significant difference.

Residual adhesive

The ARI was used to determine the bond failure location between different samples and etching groups. Table II lists the frequency of ARI scores for each

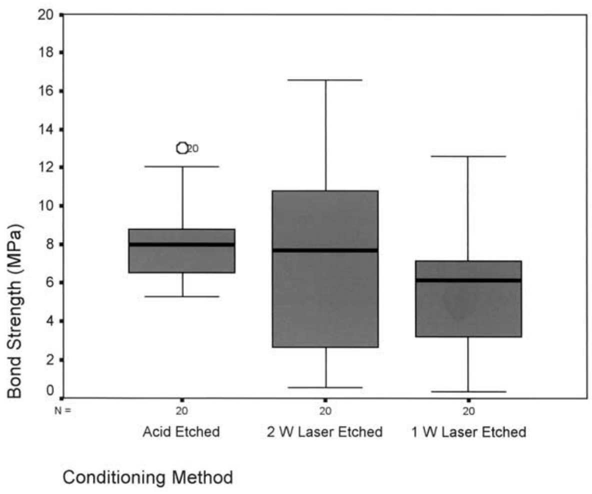

Fig 1. Mean values and SDs of shear bond strength determinations (in MPa) for 3 different pretreatments (n = 20).

etching group and the results of the chi-square test comparing the various groups.

The chi-square test comparing the ARI scores indicated significant differences between the various groups ($P < .001$). When the acid-etched group was dropped from the comparison, the remaining groups—the 2 laser-conditioning groups—showed no significant differences in the ARI scores ($P > .05$).

SEM examination

One macroscopically representative specimen from each of groups A and B was evaluated by SEM. SEM examination of group C was canceled after the testing procedure because the bond strength values achieved at this setting were below clinically acceptable levels. An untouched enamel specimen was also examined under SEM to allow us to make a visual comparison of the restored acid-etched and the 2-W laser-irradiated samples.

Surface characteristics of the acid-etched enamel seen in Figure 2 were in accordance with the type II etching pattern described by Silverstone et al.[26] Prism core material was preferentially removed, leaving the prism core relatively unaffected.

A surface that is laser irradiated at 2 W (Fig 3) resembles the type III etching pattern described by Silverstone et al[26]; it was characterized by a more random etching pattern in which adjacent areas of the tooth surface corresponding to types II and I were present. There were also regions in which the pattern could not be related to prism morphology. Cracks on the surface area were also visible on both directions.

The restored debonded surfaces of both the acid-etched (Fig 4) and the laser-etched sample (Fig 5) demonstrated surface structures smoother than the SEM-examined part of the intact enamel (Fig 6). However, the restored surface of the laser-etched sample showed a more irregular pattern than that of the restored acid-etched sample with tiny crack-like structures (Fig 5).

DISCUSSION

Many researchers have studied adhesion to enamel[27,28]; although different modalities have been tested,[29-31] phosphoric acid etching is probably the best method of bonding resins to enamel. A potential disadvantage of enamel acid etching is the demineralization of the most superficial layer, a matter of concern for orthodontists.[32-35] As a result of demineralization, the surface becomes more susceptible to long-term acid attack and caries, especially when resin impregnation is defective because of air bubbles or saliva contamination. These effects are particularly important because plaque tends to accumulate adjacent to the bonded orthodontic attachments. Maleic and polyacrylic acids have been used to control the enamel loss as alternatives to phosphoric acid.[22,36,37] The use of polyacrylic acid has resulted in reduced bond strength. Thus, laser-induced caries resistance would be of great importance in orthodontics.[2,14,15]

Another method of enamel pretreatment, the air-abrasive technique (sandblasting), has also been described in the literature.[31,38,39] The enamel loss resulting from sandblasting at low pressure for a short time was found to be less than that associated with acid etching with 37% phosphoric acid; furthermore, the technique provided a quick method of conditioning and bonding teeth. However, the bond strengths achieved with sandblasting alone were not clinically acceptable.[40-42] In addition, the operator should be aware of the negative aspects of sandblasting with aluminum oxide in the mouth. Because an aerosol is generated, the operator should wear a mask and protective eyewear, and the patient should wear protective eyewear.[40]

Glass ionomer cements also have many favorable properties.[43] They are a reservoir of fluoride ions that protect against decalcification of the surrounding tooth structure, and the glass ionomer cement can easily be removed from the enamel. Resin-modified glass ionomer cements offer the same advantages and are less soluble and stronger than traditional glass ionomer cements. However, they require a pretreatment such as conditioning or priming. Moreover, resin composites have a significantly higher bond strength than resin-modified or conventional glass ionomer cements.[44-46]

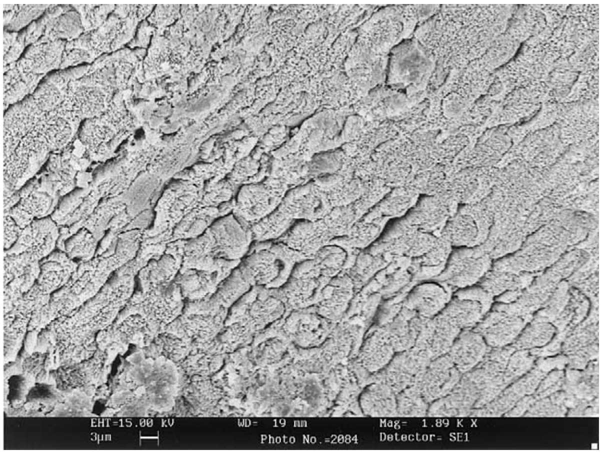

Fig 2. SEM examination of 37% orthophosphoric acid-etched enamel, group A (original magnification ×1890).

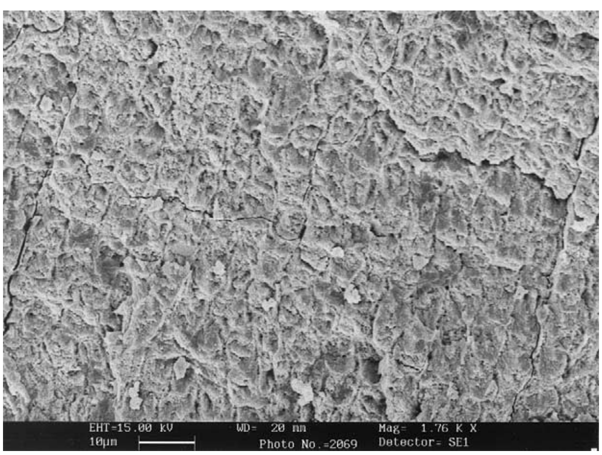

Fig 3. SEM examination of enamel surface etched with laser at 2-W output (original magnification ×1760).

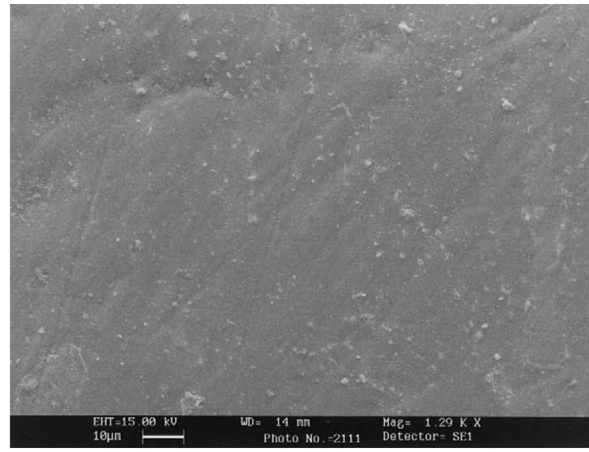

Fig 4. SEM examination of restored acid-etched enamel surface (original magnification ×1290).

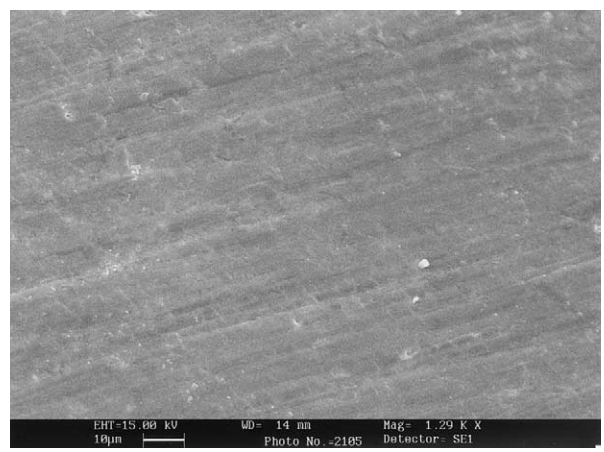

Fig 5. SEM examination of restored 2-W laser-etched enamel surface (original magnification ×1290).

Table II. Residual adhesive ratings according to ARI for 3 different etching procedures

Group	*ARI 1*	*ARI 2*	*ARI 3*	*ARI 4*	*ARI 5*	*Chi-square test*	*Chi-square test (acid group dropped)*
Acid	12	3	3	–	2	38.887	0.847
2-W laser	–	2	1	3	14	$P<.001$	$P>.05$
1-W laser	–	1	2	4	13		

The good results recorded by Silverman et al[47] in a clinical study of a resin-modified glass ionomer cement have been attributed to the bracket design by Hogervorst et al,[40] who studied adhesion and enamel loss and reported good results with a resin-modified glass ionomer cement but suggested enamel pretreatment with phosphoric acid.

The results of this study indicate that bond strengths achieved with the Er,Cr:YSGG hydrokinetic laser system at 1-W power setting were statistically different

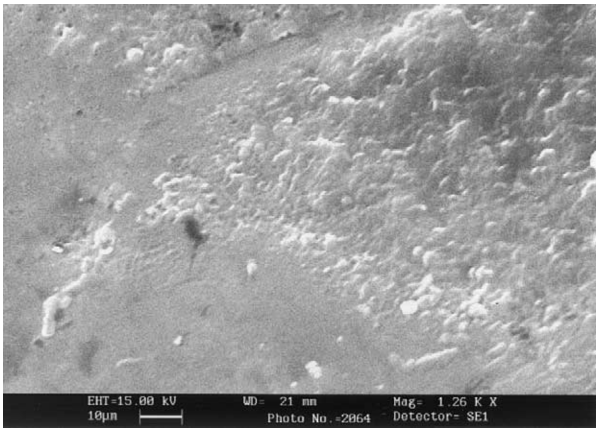

Fig 6. SEM examination of intact enamel surface (original magnification ×1260).

from those of acid etching. On the other hand, notwithstanding that the 2-W laser-irradiated group yielded statistically similar bond strength values to those of acid etching, the means of both laser groups were lower than that of the acid-etched sample. Moreover, the high range of SDs seen in both laser groups and the high coefficients of variation (64% and 57%), far above the clinically acceptable levels of 20% to 30%, make questionable the reliability and predictability of the laser-etching method. During treatment, orthodontic attachments are subjected to tensile, shear, and torsion forces. Maijer and Smith[37] found a bond strength of 8 MPa to be adequate for orthodontic brackets. According to Reynolds,[48] adequate bond forces range from 6 to 8 MPa. Also, because more than half of the bond strength values remained below these values in both laser groups, laser etching at these settings seems unacceptable for clinical use. These results agree with the findings of von Fraunhofer et al,[10] Roberts-Harry,[49] Corpas-Pastor et al,[50] and Martinez-Insua et al.[51] On the other hand, our results are opposite to those of Visuri et al[11] and Walsh et al,[52] probably because they used different power outputs of laser devices and different tooth structures. It is clear that the bond obtained by laser etching of enamel relates to the nature of the altered surface. When individual bond values are evaluated, relatively high and low values can be seen in both laser groups, whereas the acid-etch values remain in a narrower range. This difference is probably the result of the hand-controlled sweeping motion of the laser beam during the conditioning; the motion might cause a weakly standardized etching pattern throughout the irradiated area. Further research and investigation to define a standardized, optimal etching procedure with the Er,Cr:YSGG hydrokinetic laser system might help to solve this problem.

The 15-second laser etching time used in this study was determined on the basis of the small pilot study and was shorter than that required for acid etching. The minimum time required for acid etching is 15 seconds, followed by 15 to 30 seconds of washing and 5 to 10 seconds of drying the etched surface (ie, a total time of 30 to 45 seconds). If laser etching and drying could be performed in 20 to 25 seconds, allowing immediate placement of a bracket, there would be a savings of 10 to 20 seconds per tooth and a savings of 3.5 to 7 minutes for a full-mouth bonding. Still more time could be saved if etching and fast resin curing could be combined in the same laser unit. Moreover, this laser can be used in wet conditions and the water-cooled system does not cause any untoward thermal effects on the tooth pulp.[19]

We found etching of the enamel surface with the hydrokinetic system to be practical. The handpiece was light and versatile, and there was no need for an initiator such as ink on the enamel surface, as was required for the previous dental laser systems. Moreover, the clinician has more control of the area to be etched with the laser system. Although gel acids are more stable than liquid acids, there is always a shift of acid on the enamel surface. Nevertheless, these putative advantages of laser etching might be outweighed by the reduced bond strength values, unpredictable results, relatively irregular surfaces despite restoration after debonding, and capital expenditure associated with current laser units. Additional clinical work might be necessary to restore the laser-etched enamel surface to its original gloss after debonding; this could negate the chair time gained during the etching procedure. However, these SEM evaluations were made on the basis of qualitative descriptions of different types of enamel surfaces of single specimens from each group and should be considered with caution. A quantitative evaluation of larger samples by means of profilometry or atomic force microscopy is suggested for further bond strength studies.

The results of the ARI scores clearly indicate that failure sites were mainly at the enamel-adhesive interface in both laser irradiation groups. ARI scores of 4 and 5 might suggest that less adhesive left on the enamel surface results in less time spent cleaning the teeth after debonding.[53] However, some authors state that bond failure at the bracket-adhesive interface or within the adhesive is more desirable (safer) than failure at the adhesive-enamel interface because enamel fracture and crazing have been reported at bracket debonding, especially with ceramic brackets.[54] The preferred site of failure is controversial and should be determined.

CONCLUSIONS

The aim of this study was to compare the acid-etch technique with laser enamel etching at 2 different power settings. The results of the study indicate that etching of enamel surface with an Er,Cr:YSGG hydrokinetic laser system yielded statistically similar but lower and less predictable bond strengths than did acid etching with 37% orthophosphoric acid for 30 seconds. On the other hand, laser etching was found to be more practical and faster than conventional acid etching. Laser-induced caries resistance would also be of great importance in orthodontics. Furthermore, lasers might save some clinical time; however, time savings are not yet great enough to justify the capital expenditure necessary to acquire laser units, and the time saved might be spent performing additional clinical work after debonding. Further investigation to define a standardized, optimal etching procedure with the Er,Cr: YSGG hydrokinetic laser system and to evaluate enamel structure after debonding is suggested.

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