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Original Article

Shear bond strength of orthodontic brackets after acid-etched and erbium-doped yttrium aluminum garnet laser-etched

Shiva Alavi[1], Reza Birang[2], Fatemeh Hajizadeh[3]

[1]Dental Materials Research Center and Department of Orthodontics, [2]Torabinejad Dental Research Center and Department of Periodontics, School of Dentistry, Isfahan University of Medical Sciences, Isfahan, [3]Department of Orthodontics, School of Dentistry, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

ABSTRACT

Background: Laser ablation has been suggested as an alternative method to acid etching; however, previous studies have obtained contrasting results. The purpose of this study was to compare the shear bond strength (SBS) and fracture mode of orthodontic brackets that are bonded to enamel etched with acid and erbium-doped yttrium aluminum garnet (Er:YAG) laser.

Materials and Methods: In this experimental *in vitro* study, buccal surfaces of 15 non-carious human premolars were divided into mesial and distal regions. Randomly, one of the regions was etched with 37% phosphoric acid for 15 s and another region irradiated with Er:YAG laser at 100 mJ energy and 20 Hz frequency for 20 s. Stainless steel brackets were then bonded using Transbond XT, following which all the samples were stored in distilled water for 24 h and then subjected to 500 thermal cycles. SBS was tested by a chisel edge, mounted on the crosshead of universal testing machine. After debonding, the teeth were examined under ×10 magnification and adhesive remnant index (ARI) score determined. SBS and ARI scores of the two groups were then compared using *t*-test and Mann-Whitney *U* test. Significant level was set at $P < 0.05$.

Results: The mean SBS of the laser group (16.61 ± 7.7 MPa) was not significantly different from that of the acid-etched group (18.86 ± 6.09 MPa) ($P = 0.41$). There was no significant difference in the ARI scores between two groups ($P = 0.08$). However, in the laser group, more adhesive remained on the brackets, which is not suitable for orthodontic purposes.

Conclusion: Laser etching at 100 mJ energy produced bond strength similar to acid etching. Therefore, Er:YAG laser may be an alternative method for conventional acid-etching.

Key Words: Bond strength, dental acid etching, erbium-doped yttrium aluminum garnet laser, orthodontic bracket

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Address for correspondence:
Dr. Fatemeh Hajizadeh, Department of Orthodontics, School of Dentistry, Ahvaz Jundishapur University of Medical Sciences, Golestan Street, Ahvaz 6135715775, Iran.
E-mail: Hajizadeh_fatemeh@yahoo.com

INTRODUCTION

Since the report of Buonocore in 1955, phosphoric acid etching has been a standard protocol to treat tooth enamel for bonding resins and orthodontic attachments.[1,2] However, decalcification is the one potential disadvantage, which leaves the enamel susceptible to caries attack, especially under orthodontic attachments.[3,4] Consequently, alternative methods that decrease the decalcification risk and provide clinically acceptable bonding strength have been sought. One of these methods is preparing the enamel by laser irradiation. In 1960s, after Maiman introduced the ruby laser, several types of laser have been applied in dentistry, such as carbon dioxide, neodymium-doped: yttrium aluminum garnet (Nd:YAG) and diode lasers.[5] The first-generation lasers were suitable for soft-tissue treatment, especially in periodontology.[6] When these lasers were used in dental hard-tissue, they resulted an inflammatory pulpal response.[7,8] Recently the

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development of mid-infrared lasers (erbium-doped yttrium aluminum garnet [Er:YAG] and erbium, chromium: yttrium, scandium, gallium, garnet [Er,Cr:YSGG]) allow ablation of both soft and hard-tissues with minimal thermal side-effects.[6,9]

The Er:YAG laser with a wavelength of 2940 nm can ablate enamel and dentin effectively, because its light is highly and efficiently absorbed by water and hydroxyapatite.[8]

It has been suggested that Er:YAG laser was able to decrease acid dissolution and increase fluoride uptake; thus, produce a surface, which is less susceptible to caries.[10-13]

The result of the studies in the past two decades on the application of laser etching for increasing bond strength of restorative material have been controversial. Some studies indicate that acid-etched teeth had significantly more bond strength than laser-etched teeth.[14-17]

On the other hand, others suggested that laser etching could result in bond strength comparable with[18-27] or even stronger than acid etching.[28,29]

These differences could be attributed to the various types of lasers or various irradiation parameters used, because the laser-hard tissue interaction is dependent on wavelength and irradiation energy.

According to the controversial findings regarding the use of erbium lasers for enamel etching, the aim of this study is to evaluate the shear bond strength (SBS) between the acid etched enamel and laser irradiated enamel and to investigate the fracture mode of the bond.

MATERIALS AND METHODS

In this experimental *in vitro* study, 15 caries-free, intact human upper premolars extracted for orthodontic purposes in the Oral Surgery Department of Isfahan University of Medical Sciences were used. The teeth were cleaned of any soft-tissues covering the root surfaces.

Then, they were stored in Hanks balanced salt solution (Hank's Balanced Salt Solution [HBSS], Sigma-Aldrich, St. Louis, MO, USA) until they were ready to be used.[30,31] Antibiotics (penicillin ×100, Metronidazole ×100, Gentamycin ×100, Amphotericin ×100) with 1% volume ratio was added to HBSS to prevent bacterial and fungal growth.

The teeth were mounted in self-cure acrylic resin (Rapid Repair, Detrey Dentsply Ltd, Surrey, U.K) up to the cementoenamel junction. The buccal enamel surface was cleaned and polished with non-fluoridated pumice and rubber cup, then washed with an oil free air spray. The buccal enamel surfaces of the premolars were divided into mesial and distal regions with masking tape (approximately 1 mm width). One region was randomly etched with Er:YAG laser with a wavelength of 2940 nm (Fotona, Fidelis plus, Ljubljana, Slovenia).

Laser energy is delivered through a R14 handpiece with fiber optic system with 900 μm diameter [Figure 1]. It operates at 2 W power with 100 mJ energy output, 20 Hz of frequency and short pulse mode. The water and air setting were kept at 20%. Energy density and power density were calculated at 15.72 J/cm^2 and 31.45 W/cm^2, respectively. The beam was directed perpendicular to enamel at 1mm distance (contact mode) and was moved in a sweeping fashion by hand over an approximately 3 × 3 mm^2 during an exposure time of 20 s, which was enough to scan this area. The irradiated teeth were dried with an oil free air spray for 15 s.

The other region was etched with conventional 37% phosphoric acid gel (American orthodontics, Sheboygan, USA) for 15 s, then washed for 20 s and dried with an oil-free source for 20 s.

Bonding procedure

The frosty white appearance of enamel was visible in both regions for all specimens. Transbond XT primer (3M Unitek, Monrovia, CA, USA) was then applied to both etched surfaces; afterward an air jet was lightly applied to the enamel. Then, Transbond XT composite (3M Unitek, Monrovia, CA, USA) was applied onto the base of the two metal mandibular incisors brackets (American Orthodontic, Standard Edgewise .018, 380-0008, Sheboygan, USA). According to the manufacturer's

Figure 1: The R14 handpiece used in this study

instruction these brackets had a surface bonding area of 8.78 mm^2. The brackets were placed onto mesial and distal regions of the buccal tooth surface immediately and adjusted to final position and pressed firmly.

Excessive adhesives were removed from the periphery of the bracket base to keep the bond area of each tooth uniform and light-cured with a light-emitting diode (Starlight Pro, Mectron, Carasco, Italy) for 20 s (10 s from each proximal side). Then the masking tape was removed [Figure 2].

After storing the specimens in distilled water at 37°C for 24 h, they were thermocycled for a total of 500 cycles at 5-55°C with a dwell time of 30 s and a 10 s transfer time between baths, to simulate the heat and humidity conditions of the oral cavity.

SBS testing

The shear bond test was accomplished with a chisel edge, mounted on the crosshead of a Universal Testing Machine (Walter + Bai AG, Löhningen, Switzerland). The edge was aimed at the bracket-enamel interface with a crosshead speed of 1 mm/min and the debonding forces were recorded for each specimen in Newtons and then converted to megapascals. SBS was calculated by dividing this force into the bracket base area.

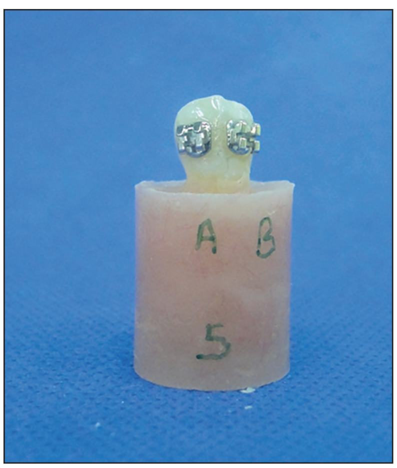

Figure 2: One of the samples which, the right side was etched by 37% phosphoric acid and the left side etched by erbium-doped yttrium aluminum garnet laser

The shear bond test was performed by a technician who was blinded about the preparation procedures undertaken for the groups.

Failure mode

The debonded buccal surface of each tooth was evaluated under ×10 magnification and the adhesive remnant index (ARI) was quantified according to the criteria established by Artun and Bergland,[32] i.e., 0 = no adhesive left on tooth, 1 = less than half of the adhesive left on tooth, 2 = more than half of the adhesive left on tooth, 3 = all the adhesive left on tooth.

Statistical analysis

SBS means were analyzed statistically by Student's *t*-test. Mann-Whitney *U* test was used for assessing the ARI scores. Significant level was set at $P < 0.05$. Statistical comparisons were performed with software Statistical Package for the Social Sciences for windows (version 19.0, Chicago, IL, USA).

RESULTS

Descriptive statistics for the comparison of SBS for the two groups are given in Table 1.

The acid-etched group had higher SBS means (18.86 ± 6.09 MPa) than laser-etched group (16.61 ± 7.70 Mpa), but no significant difference was found between both groups ($P = 0.41$).

The location of the fracture for each group was evaluated with the ARI index [Table 2]. Three possible types of fractures may be observed: Cohesive fracture (within the body of the composite), adhesive fracture (at the composite-bracket base or enamel-composite interface) and mixed fracture.[33]

In the acid-etched group, 40% of fractures were located at the bracket-adhesive interface (ARI 3), 20% at enamel-adhesive interface (ARI 0) and 40% were mixed fractures (ARI 1 and 2). In the laser etched

Table 1: Descriptive statistics of shear bond strength (in MPa) for the phosphoric acid and laser etching groups

Group	*n*	Mean (SD)	Standard error	95% CI for mean		Min	Max	*P* value
				Lower bound	Upper bound			*t*-test
Acid etching	15	18.86 (6.09)	1.83	14.93	22.79	8.54	30.16	0.41*
Laser etching	15	16.61 (7.70)	1.99	12.34	20.88	5.01	28.13	

*No statistically significant difference. SD: Standard deviation; CI: Confidence interval

Table 2: Residual adhesive rating according to ARI for laser-etched and acid-etched groups

Value	Criterion	Interpretation	Acid etching frequency (%)	Laser etching frequency (%)	*P* value Mann-Whitney *U* test
ARI 0	No adhesive left on the tooth	Adhesive fracture at composite-enamel interface	3 (20)	7 (47)	0.08*
ARI 1	Less than half of the adhesive left on the tooth	Mixed fracture	2 (13)	4 (27)	
ARI 2	More than half of the adhesive left on the tooth	Mixed fracture	4 (27)	2 (13)	
ARI 3	All adhesive left on the tooth	Adhesive fracture at bracket-composite interface	6 (40)	2 (13)	

*No statistically significant difference. ARI: Adhesive remnant index

group, 47% of bond failures were located at the enamel-adhesive interface (ARI 0), 13% at bracket-adhesive interface (ARI 3) and 40% were mixed fractures (ARI 1 and 2). No cohesive failures within the body of the resin and no enamel tooth fractures were found.

The Mann-Whitney *U* test showed no significant differences ($P = 0.08$) between two groups according to the ARI evaluation.

DISCUSSION

In the present study, the laser-etched group had similar loading strengths with the acid-etched group ($P = 0.41$).

Maijer and Smith reported that 8 Mpa of bonding strength is adequate for orthodontic brackets.[34] Therefore, bond forces range in both group were within acceptable limit and laser etching at these setting seems acceptable for clinical use.

These results agree with the findings of Basaran *et al.*,[23,24] Jamenis *et al.*[22] and Ozer *et al.*[26] On the other hand, our results are not in agreement with those of Uşümez *et al.*[17] Von Fraunhofer *et al.*,[14] Martínez-Insua *et al.*[35] and Corpas-Pastor *et al.*[16] These controversies could be due to different tooth structures, type of laser and different laser setting such as power output, wavelength, emission mode, contact or non-contact mode, irradiation time, water cooling and irradiation distance.

The ARI values indicated no significant difference in the bond failure site among the two groups. Although in the laser group more adhesive remained on the brackets, which is not suitable for orthodontic purposes. These findings agree with those of previous studies.[22,24,29] This could be an advantage or disadvantage. Less chair time would be needed with less adhesive left on the enamel after debonding, but some authors state that bond failure at the bracket-adhesive interface or within the adhesive is more acceptable (safe) than failure at the adhesive-enamel interface, because enamel fracture and cracking have been reported at bracket debonding, especially with ceramic brackets.[36]

The ability of Er:YAG laser to ablate dental hard tissue is ascribed to its 2940 nm wavelength, which is coincident with the absorption band of water and hydroxyapatite of enamel. The irradiation is highly absorbed by the water molecules in the enamel, causing sudden heating and water evaporation. Consequence is high stream pressure that leads to the micro-explosions with ejection of tissue particles, which are characteristic of the ablation process and determine the micro-crater like appearance of lased surface. The majority of irradiation is consumed in the ablation process and leaving very little residual energy for adverse thermal interactions with the pulp tissue and peripheral soft- and hard-tissues.[10,23]

Moreover, Er:YAG laser can be applied in wet conditions and the clinician has more control of the area to be etched. Although, gel acids are more stable than liquid acids, there is always a shift of gel acid on the enamel surface.

Often, laser etching leaves the tooth with a rough surface, so time saved with laser etching might be used performing additional polishing after debonding.

Furthermore, laser radiation can lead to the micro-crack formation in the enamel surface, which acts as starting points for fracture, acid attack and demineralization. Consequently, the possible positive effect of erbium laser irradiation in preventing enamel demineralization around the brackets is reduced or eliminated.[37]

In this study, the irradiation was performed manually in order to simulate the clinical condition.[12,38] To ensure identical conditions for both groups, the buccal surface of each sample was divided into mesial and distal regions using a masking tape then; one region was etched with acid and the other with laser. Every sample was thermocycled for 500 cycles to simulate oral conditions.

The results show that laser etching procedure produce clinically acceptable bond strengths, but this was an *in vitro* study and the result may be different when the procedures are performed on the patients. Further investigation to evaluate structure and mechanical properties of the enamel after bonding with laser is suggested.

CONCLUSION

According to the results of this study, the mean bond strength and bond failure mode of 37% phosphoric acid-etched group and Er:YAG laser-etched group were not significantly different. Therefore, Er:YAG laser may be an alternative method for conventional acid-etching.

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