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Comparison of Shear Bond Strength, Adhesive Remnant Index and Enamel Cracks in Bonding and Rebonding of Stainless Steel Brackets to Enamel Surface Conditioned with Er:YAG Laser versus Conventional Acid Etching

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A B S T R A C T

Objectives: The aim of the present study was to compare shear bond strength (SBS), adhesive remnant index and enamel cracks in bonding and rebonding of brackets to enamel, conditioned with erbium-doped yttrium aluminium garnet (Er:YAG) laser and conventional acid-etching.

Materials and Methods: Fifty-two bovine lower incisors were randomly divided into four groups consisting of group 1 (acid-conditioning in both bondings), group 2 (acid-conditioning in first and laser-conditioning in second bonding), group 3 (laser-conditioning in first- and acid-conditioning in second bonding), and group 4 (laser-conditioning in both bondings). After bracket placement, the samples were thermocycled and tested for SBS in both bonding procedures. Adhesive remnant index scores and enamel cracks were also determined. Tukey's test and one-way analysis of variance was used for statistical analysis (P<0.05).

Results: Mean SBS in the first bonding was 23.59MPa in groups 1 and 2, and 6.9MPa in groups 3 and 4. (P<0.001). The acid-etched teeth had a significantly lower SBS in rebonding, regardless of the reconditioning method (P<0.001). The SBS of the teeth conditioned with Er:YAG laser in the first bonding did not show significant changes in rebonding, although mean SBS was higher compared to the first bonding (P=0.675). Bonding most often failed at the enamel-adhesive interface and enamel cracks were observed in a few teeth.

Conclusion: The method of primary enamel preparation can affect SBS in rebonding. Based on our results, the mean SBS of Er:YAG-conditioned groups was clinically acceptable in bonding and rebonding, although it was lower compared to the acid-etched samples.
Keywords: Lasers; Orthodontics; Phosphoric Acids, Dental Etching

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INTRODUCTION

Direct bonding to enamel is one of the important aspects of restorative dentistry and orthodontics. Since a major part of success in this procedure is related to enamel preparation, knowledge of the enamel characteristics and basic principles of the etching process are crucial. In 1955, Buonocore [1] found that using 85% phosphoric acid solution, resulted in the adhesion of acrylic resins to enamel surface. However, widespread application of this method was postponed until the 1960s when Newman [2] introduced bonding of orthodontic brackets to enamel. Today, 37% phosphoric acid is one of the most common substances used for enamel etching. It has been suggested that 32% to 40% phosphoric acid conditioner is the best option to achieve a reasonable bonding to enamel [3].

On the other hand, the use of lasers in dentistry was first described in 1964 [4]. Lasers have different applications in orthodontics, including bracket debonding, improving the rate of tooth movement, removing adhesive remnants from the bracket base, and possibly preventing enamel demineralization [5]. Erbium-doped yttrium aluminium garnet (Er:YAG) laser, which was introduced in 1975, is emitted at a wavelength of 2940nm and precisely matches the maximum water absorption [6]. This laser seems to be effective in the removal of hard dental tissues such as enamel, with only minor side effects [6]. Therefore, it is used in dentistry for many purposes including caries removal and cavity preparation as well as bonding and debonding of brackets. In orthodontics this laser can be applied for enamel preparation and some studies have investigated its effects as a conditioner on shear bond strength (SBS). Hosseini et al [7] concluded that mean SBS obtained with Er:YAG laser (1W or 1.5W) was almost analogous to that of conventional etching. However, appropriate parameters are required for the application of this laser as a suitable replacement for surface conditioning. Gokcelik et al [8] reported similar results when comparing the use of Er:YAG laser, self-eching primers, and conventional etching. The findings of Lee et al [9] also corroborated these studies. In contrast, Martinez-Insuza et al [10] stated that adhesion to enamel following etching with Er:YAG laser was inferior to that obtained after conventional acid etching. They concluded that enamel prepared by Er:YAG laser can show extensive subsurface fissuring, which is unfavorable to adhesion.

Bracket rebonding is a frequent procedure during orthodontic treatments. Sometimes, the bracket debonds accidentally, whereas intentional debonding is performed to reposition the bracket. There are several studies on the shear bond strength of brackets attached to re-etched enamel; however, there is no evidence regarding the use of Er:YAG laser instead of acid-etching during the first or second bonding procedures. The aim of the present study was to compare SBS, adhesive remnant index (ARI), and enamel cracks in bonding and rebonding of stainless steel brackets to enamel surfaces conditioned with Er:YAG laser or conventional acid-etching. We also attempted to determine whether the method of primary enamel preparation can affect secondary SBS.

MATERIALS AND METHODS

Fifty-two bovine lower incisors without any anatomical anomalies, caries, enamel cracks or fractures were selected. Prior to storage, the teeth were thoroughly cleaned under tap water, disinfected by immersion in 0.5% chloramine solution for 48 hours, and stored in distilled water at room temperature. Before bonding, the buccal surfaces of the samples were polished for 15s using a low-speed handpiece with rubber cup and pumice, and were washed for 10s. The rubber cup was changed following every 10 prophylaxis procedures. Afterward, the surfaces were dried thoroughly using moisture-free air spray for 10s. Next, the samples were randomly divided into four groups as follows:

Group 1: the teeth were conditioned with 37% phosphoric acid gel (3M Unitek, Monrovia, CA, USA) in the first and second bonding procedures (control group).

Group 2: the teeth were conditioned with phosphoric acid gel in the first bonding, and with Er:YAG laser (Doctor Smile, LAMBDA Scientifica S.p.A, Vicenza, Italy) in the second bonding.
Group 3: the teeth were conditioned with Er:YAG laser in the first bonding, and with phosphoric acid gel in the second bonding.
Group 4: the teeth were conditioned with Er:YAG laser in the first and second bonding procedures.
All samples in the first and second groups were etched with 37% phosphoric acid-etchant for 15s, rinsed for 10s, and thoroughly dried. In the third and fourth groups, the teeth were conditioned using Er:YAG laser with a power of 2W, energy of 200mJ, and frequency of 10Hz. The diameter of the laser tip was 800µm, and the laser was irradiated for 10s from a 2mm distance with 70% water and 90% air. Etching was repeated until the enamel surface showed a frosty, porous, and chalky appearance.
Next, the teeth were bonded in the midpoint of the anatomic crown to 52 lower incisor brackets (0.018-inch slot, Dentaurum, Ispringen, Germany) using Transbond™ XT primer (3M Unitek, Monrovia, CA, USA) and Transbond™ XT adhesive (3M Unitek, Monrovia, CA, USA), one of the most common adhesives applied in orthodontic studies. After adding a layer of the primer to the buccal surfaces of the teeth and thinning it using air-spray, the area was cured for 5s to prevent sagging of primer during bracket positioning. To make the debonding process easier, the excess composite was cleared before curing. Each surface was cured using a halogen light-emitting diode (LED)-curing device (LED.D Curing Light, Guilin Woodpecker, China) at a wavelength of 440-480nm for 40s (10s on each side). The light-curing device was placed in contact with bracket wings to maximize the curing depth. Consequently, all teeth were mounted using a self-curing acrylic resin with the aid of a 0.016×0.022-inch stainless steel wire to ensure they were perpendicular to the horizon. The samples were thermocycled (TC-300, Vafaei Industrial Factory, Tehran, Iran) using 1000 cycles in 5°C and 55°C water baths. Each cycle was performed for 20s with ten-second intervals. After thermocycling, the samples were stored in distilled water for 48h and were then placed in a universal testing machine (Zwick/Roell AG, Ulm, Germany) with a 1-kN load cell to measure SBS. The blade of the device was oriented in an occlusogingival direction and moved down-ward toward the tooth-bracket interface at a crosshead speed of 0.5mm/min. The loads were recorded in Newton (N) and were automatically converted to Megapascal (MPa) by a computer according to the bracket base area, precisely calculated using electronic gauges. After debonding, all brackets were placed in distilled water to assess the ARI under a stereomicroscope (Nikon, Tokyo, Japan) at ×10 magnification according to Artun and Bergland [11] as follows: score 0: no adhesive remnants on the tooth, score 1: less than 50% of adhesive remnants on the tooth, score 2: more than 50% of adhesive remnants on the tooth, and score 3: 100% of adhesive remnants on the tooth. Afterward, the remaining composite was removed from the teeth surfaces using a tungsten carbide finishing bur mounted on a low-speed handpiece until the enamel surface showed a smooth appearance under the light of the dental unit. The samples were prepared for the second conditioning and bonding, according to the abovementioned classification. New brackets were used for rebonding, and previous brackets were discarded. The samples were thermocycled, similar to the first bonding procedure. SBS and ARI scores were measured again after 48h of storage in distilled water. Enamel cracks were assessed after the first and second debonding procedures under a stereo-microscope at ×10 magnification.

Statistical analysis:

One-way analysis of variance and Tukey's test were used for statistical analyses. The level of significance was set at 0.05.

RESULTS

Shear bond strength:

Table 1 shows the mean and standard deviation of SBS in the first and second bonding processes.

Table 1. Mean (M) and standard deviation (SD) of the shear bond strength (MPa) of both conditioning groups during the first and second bonding

First bonding	M(SD)	Second bonding	M(SD)
Acid	23.59(4.55)	**Acid**	16.18(2.66)
		Laser	9.49(4.66)
Laser	6.9(3.14)	**Acid**	8.43(5.5)
		Laser	9.29(4.83)

Because of the similar conditioning methods used in in groups 1 and 2 in the first bonding, their mean SBS was reported as a single group. Also, the means and standard deviations of the SBSs in the first bonding for groups 3 and 4 were reported together. In the first bonding, the mean SBS of the groups conditioned by acid-etching was significantly higher ($P<0.05$) than that of the groups prepared with Er:YAG laser (23.59MPa versus 6.9MPa). In the second bonding, the highest mean SBS was observed in the control group (16.17MPa). In the first bonding, 10 samples in the laser-conditioned groups showed SBS values lower than 5.8MPa, which were considered clinically unacceptable. Thirteen teeth showed similar unacceptable values in the second bonding process. This occurred only in the groups conditioned by laser in the first or second bonding procedures. All the teeth in the control group had an acceptable SBS in the first and second bondings. Table 2 shows the minimum and maximum SBS of the groups during the first and second bonding procedures.

Table 2. Maximum (max) and minimum (min) of shear bond strength (MPa) in all study groups in first and second bondings

Groups	First bonding		Second bonding	
	Max	Min	Max	Min
Acid➤Acid	33.18	16.03	19.60	9.83
Acid➤Laser	29.34	14.27	16.63	1.47
Laser➤Acid	12.03	3.50	20.16	3.21
Laser➤Laser	10.70	1.13	18.90	1.94

The minimum SBS of groups 1 and 2 in the first bonding was 14.27MPa. The results of t-test indicated that the teeth conditioned with phosphoric acid-etchant during the first bonding had a significantly lower SBS in the second bonding, regardless of the method used for reconditioning ($P<0.001$). On the other hand, when the samples were conditioned using laser during the first bonding, the SBS did not change significantly, irrespective of the method used for the second conditioning ($P=0.675$). Figure 1 shows SBS during bonding and rebonding.

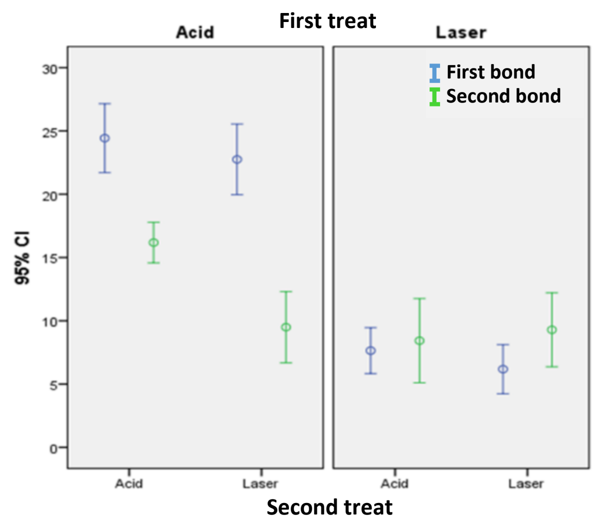

Fig. 1. Error bar showing 95% confidence interval of the mean for shear bond strength in the study groups. Comparisons can be made between the first and second bondings. First bond and second bond indicate shear bond strength after first and second treatments, respectively

Adhesive remnant index:

The ARI scores of all groups are illustrated in Table 3. In the acid-etched samples, 17 specimens (8 from group 1, and 9 from group 2) had an ARI score of 0, while 8 teeth (4 from group 1, and 4 from group 2) demonstrated a score of 1, and only one tooth in group 1 had an ARI score of 3 in the first bonding. In groups 3 and 4, a total of 23 teeth showed an ARI score of 1, and only three samples demonstrated a score of 2 at this stage.

No specimen showed scores 3 or 4 during the first bonding process, indicating that after

Table 3. Adhesive remnant index (ARI) scores of the study groups in the first bonding (N=13)

Study Groups	ARI 0	1	2	3
Acid➤Acid	8.11	4.2	1.0	0.0
Acid➤Laser	9.13	4.0	0.0	0.0
Laser➤Acid	11.13	2.0	0.0	0.0
Laser➤Laser	12.13	1.0	0.0	0.0

bracket debonding in all groups, no adhesive (or only a small amount) remained on the enamel surface. All the samples had an ARI score of 1 in rebonding, except for two samples in the control group. Figure 2 shows adhesive remnants on the bracket base, bonded to the reconditioned enamel of a sample from group 3.

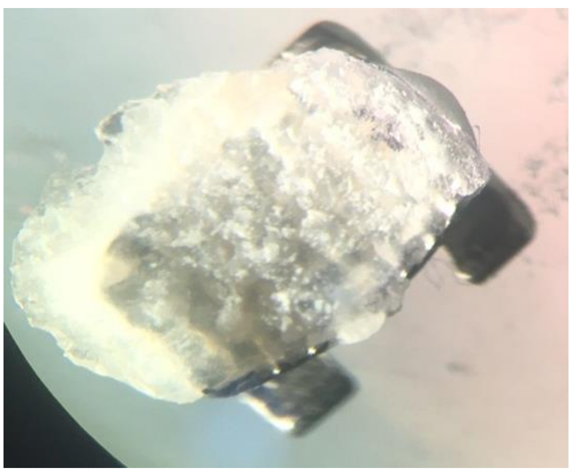

Fig. 2. Adhesive remnants on a bracket base bonded to the reconditioned enamel of a sample from group 3

Enamel Cracks:

Only four teeth from the acid-etched groups showed enamel cracks after the first debonding. One sample had two enamel cracks, while the others showed only one crack. These teeth were marked to be distinguishable during rebonding. Photographs of the four cracked teeth were taken under a stereomicroscope after the first and second debonding processes to ensure no new cracks had developed. After the second debonding, only two samples from group 3 showed new small cracks (Figure 3).

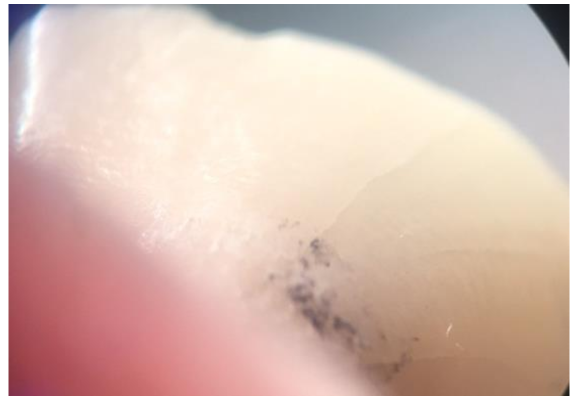

Fig. 3. Enamel cracks in a sample from group 3 after the second debonding

All the cracks were clinically invisible and no enamel tearing was seen in the groups despite the high SBS of the acid-etched samples in the first bonding process.

DISCUSSION

In the present study we compared SBS and ARI values of teeth conditioned with phosphoric acid versus Er:YAG laser in bonding and rebonding processes, to find the effects of primary conditioning on secondary bond strength. It was concluded that the SBS of the acid-conditioned groups was higher than the clinically acceptable range [12-14]. These high amounts of bond strength may be harmful, since they can lead to tooth-structure damage and formation of enamel-cracks during debonding, as observed in the teeth from our acid-etched samples. The mean SBS for the laser-conditioned groups was clinically acceptable, although it was significantly lower than that of the control group. In comparison to the laser-conditioned groups, the teeth treated with phosphoric acid in the first bonding, showed a significant reduction in their secondary SBS. In is noteworthy that the minimum SBS of groups 1 and 2 in the first bonding was the maximum clinically acceptable amount of bond strength [13,14] and the mean SBS of the second bonding was acceptable in all study groups [12]. The mean primary SBS of the laser-conditioned samples was lower than the secondary SBS. In the laser-conditioned-groups, some samples had an SBS lower than the minimum acceptable range in the first or second bonding, which is not surprising. Sometimes, a bracket might detach even before the patient leaves the office because of poor isolation or inferior enamel characteristics. Nevertheless, as these low SBS values were only observed in the laser-treated samples, this could also be attributed to the lower enamel-conditioning power of laser, compared to acid-etching. It is possible that fewer porosities are formed on the enamel surface, when using laser. The results of several articles have confirmed that Er:YAG laser can be an appropriate alternative to acid-etching [15-20] although some authors have rejected this hypothesis [10,20-22]. It has been reported that the SBS of brackets to enamel conditioned with Er:YAG laser using two different powers (1 and 1.5W) was similar and higher than that in acid-etched samples [7]. Oshagh et al [23] compared the SBS of orthodontic brackets to human enamel between CO2-laser and conventional acid-etching conditioning methods in bonding and rebonding. They found that in the groups in which the primary preparation was performed by an acid-etchant, the secondary preparation did not show significant differences between the two methods, and the secondary SBS was lower than the first bonding. However, the secondary preparation using acid-etchant, provided a higher bond strength. In groups where laser was used for primary preparation, the secondary treatment did not show significant differences in SBS, but higher bond strength was observed when acid-etchant was used in the secondary preparation [23]. This is in contrast to the results obtained in the present study. More adhesive remnants were detected on the tooth surface in the acid-etched groups. The authors postulated that the reduced SBS of the acid-etched groups in rebonding was related to the residual adhesives on the enamel surface, whereas the lower levels of SBS in the lased groups during the second bonding could be the result of burning properties of the laser. Phosphoric acid is effective in resolving hydroxyapatite crystals rather than adhesive remnants, while the burning features of lasers can be responsible for the elimination of residual adhesives on the tooth surface [23]. Finally, they stated that enamel preparation by acid, either primary or secondary, provides a sufficient bond strength for brackets, whereas enamel preparation by laser in the first and second bonding procedures results in SBS values lower than the minimum acceptable bond strength [23].

In the current investigation, the ARI scores were not significantly different among the studied groups; which was similar to results reported by Hosseini et al [7]. In contrast, Gokcelik et al [8] found higher ARI scores in the Er:YAG-lased samples than the acid-etched specimens. Oshagh et al [23] stated that there were more adhesive remnants on the enamel surface of the teeth prepared by acid-etching compared to laser-etching.

CONCLUSION

The method used for primary enamel preparation can affect the SBS in rebonding. In contrast to the laser-conditioned groups, the samples prepared by acid-etching in the first bonding had significantly lower SBS values in rebonding, regardless of the method used for enamel reconditioning. The mean SBS of the laser-conditioned groups was clinically acceptable, although it was significantly lower than that of the control group. Some brackets showed an unacceptable SBS to the lased enamel during bonding and rebonding. The ARI scores were not different between the two conditioning methods. Bonding most often failed at the enamel-adhesive interface. The teeth that showed enamel cracks either in bonding or rebonding, were from the groups which used acid-etching in the first or second bondings, respectively. This can indicate higher SBS in acid-etched enamel. No enamel tearing was observed after the first or second debonding.

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CONFLICT OF INTEREST STATEMENT

None declared.

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