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Review Article

Comparison of shear bond strength of rebonded stainless steel brackets with three different enamel surface conditioning methods

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ABSTRACT

Background: During the orthodontic bonding process, the need for repositioning or rebonding of orthodontic brackets on the enamel surface occurs frequently. The aim of this study is to compare the shear bond strength (SBS) in rebonding orthodontic stainless steel brackets with three different methods of enamel surface conditioning methods.

Materials and Methods: In this *in vitro* study, 80 human premolars that were extracted for orthodontic purposes were randomly divided into four groups and underwent orthodontic bonding procedure (N = 20). Except for the control group, three other groups underwent debonding and rebonding process in which after removing the remaining adhesive with tungsten-carbide bur, enamel surface conditioned by three different methods including re-etching with phosphoric acid, sandblasting + acid etching, and Erbium-doped Yttrium–Aluminum–Garnet laser. Then, the SBS of the bracket to the enamel surface was compared between different groups. Scanning Electron microscopy images were also obtained from a number of samples. Statistical analysis was performed by Kruskal–Wallis and Mann–Whitney tests.

Results: The highest SBS was observed in the primary bond (control group) with an average of 29,440 MPa. There was a significant difference between the studied groups ($P < 0.001$) and only the group that was re-etched with phosphoric acid had no significant difference with the control group ($P = 0.708$) $\propto =0.05$.

Conclusion: Rebonding of brackets using phosphoric acid for reconditioning of the enamel surface creates bond strength comparable to the primary bond. Other groups had significantly lower SBS than the control group.

Key Words: Dental air abrasion, dental bonding, dental debonding, orthodontic bracket, shear strength

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INTRODUCTION

The introduction of enamel etching by Buonocore and the direct bonding system by Newman have simplified the bracket bonding process.[1] The clinical success rate of fixed orthodontic bonded appliances depends on the bracket-adhesive-enamel surface.[2] It mainly depends on the mechanical retention of an adhesive

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within the irregularities created by the enamel etching process.[3] Failure of bond strength, either related to the patient or the orthodontist.[3]

Increasing the number of orthodontic therapeutic demands, such as bracket repositioning or accidental debonds, led clinicians to rebond brackets, which normally require surface preparation.[4] Enamel conditioning should provide sufficient shear bond strength (SBS) for brackets. Although there is no consensus on the optimum rate of SBS,[1] a review noted a range of 5.9–7.8 MPa.[5] This range was confirmed by some other studies.[6]

Importantly, bracket rebonding on the enamel with a history of debonding affects the strength of the rebond.[7] It can be attributed to the remaining adhesives on the enamel and thereby reducing the bond strength during rebond.[8,9] However, some studies reported similar rates of SBS for bond and rebond;[10] even some reported higher rates for rebond.[11,12] Hence, rebonding requires appropriate surface conditioning to remove remaining adhesive to achieve an acceptable level of SBS.[7] The recommended method for conditioning the enamel is the administration of phosphoric acid 35%–37% for 15 s after removing residual adhesive.[13] Recently, there have been efforts to achieve higher rebond strength using laser etching because some lasers can create irregular surface patterns comparable to that of acid etching without an increased risk of caries.[14,15] In addition, it can remove remaining adhesives from enamel.[16] Laser is painless with no need for local anesthesia and no heat damage or vibration.[3] Erbium-doped Yttrium–Aluminum–Garnet (Er:YAG) laser has the ability to remove hard dental tissues with minimal side effects.[17,18] Hence, it is an appropriate alternative to prepare the enamel surface.[18] Some studies reported comparable SBS of acid etching and ER:YAG laser etching.[3] However, some reported results were different.[19-22]

Air abrasion is another method to prepare the enamel surface, which should be performed by 50- μm aluminum oxide particles.[13] This method, which was first introduced by Black,[23] can enhance SBS by increasing the surface roughness and consequently bonding surface. In addition, it creates a reliable bond in cases where the enamel surface is damaged, such as hypomineralization.[24] Combining sandblasting and acid etching methods have synergetic effects.[25-27] However, some believe that these effects are not statistically significant.[28]

Few studies have compared different methods of enamel surface conditioning during the orthodontic bracket rebonding process. Therefore, this study aimed to compare the SBS in rebonding of orthodontic brackets using three different methods of enamel surface reconditioning.

MATERIALS AND METHODS

This study was performed on human premolar teeth extracted for orthodontic reasons. The study is approved by the School of Dentistry of the Isfahan University of Medical Sciences (code: 3400149). With the number of 20 samples in each group, there was a probability of 0.80 that a difference of d = 0.9 between the desired characteristics in groups showed significance at the level of 0.05. Initially, 80 human premolar teeth that met the inclusion criteria were included. The inclusion criteria were intact buccal surface (no caries, stain, abrasion and hypo/hyperminralized areas, and no deep grooves) and no cracks caused by tooth extraction. Then, the teeth were exposed to 0.1 thymol (weight/volume) and kept at room temperature for 24 h and after disinfection; the teeth were distilled in water and stored at room temperature until further experiments.

Before bonding, teeth were mounted cylindrically by cold-cure acryl (AcroPars, Marlic Medical Co., Tehran, Iran), and polished using fluoride-free pumice powder for 10 s. Then, the teeth were randomly divided into four groups (n = 20): (1) control group; (2) re-etched using phosphoric acid 37%; (3) sandblasting + acid etching with phosphoric acid 37% group; and (4) etching using ER: YAG.

Initial bonding

Initially, all teeth were etched with phosphoric acid gel 37% for 30 s and then washed using water for 20 s, followed by drying for 20 s using oil-free airflow. At this stage, the adequacy of etching was evaluated by the frosted appearance on the enamel surface. Light cure primer was located on the teeth and its thickness was thinned by airflow with no oil as much as possible.

At this stage, the standard premolar stainless steel bracket with a 0.022-inch slot (Ortho Organizers Inc., California, USA), which light cure composite was placed on its base, was placed on the center of the anatomical crown of the tooth using bracket forceps (Tweezer) and pressure was applied on the bracket to minimize the thickness of the composite.

All mentioned materials, including acid etching, primer, and composite, were Master-Dent (Dentonics, USA) Light cure orthodontic adhesive. Then, the composite flashes were removed from the surface, and the composite was cured using visible light-curing unit (3M Unitek Ortholux LED Curing Light, US), with a power of 600 mW/cm^2 for 20 s (10 s of mesial and 10 s of distal surfaces). At this stage, the samples were placed in deionized water at 37°C in separate containers in an incubator (Behdad, Tehran, Iran) for 24 h. Furthermore, teeth were placed in Thermocycling Machine (Delta Tpo2, Nemo, Mashhad, Iran) to simulate the moisture and heat of the mouth environment (2000 cycles at 5°C–55°C with a dwell time of 30 s and transfer time of 10 s between baths).

Debonding

In the control group, brackets were removed by Universal Testing Machine (K–21046, Walter + Bai AG, Lohningen, Switzerland) at a blade speed of 1 mm/min and by measuring the initial values of SBS. To convert the values from Newton to MPa, the obtained number was divided into bracket base area (11.09 mm^2). Bracket Removing Plier (Dentaurum, Germany) was used to remove brackets in the three other groups. Then, the surface of the tooth was cleaned with a tungsten-carbide bur (Prima® Classic Orthodontic Debonding burs, UK) until no visible adhesive was remained under the dental unit light. At this stage, the teeth were rinsed and dried.

Rebonding

For all three groups, the rebonding protocol was similar to primary bonding, and the only variable was the enamel surface conditioning method. In the second group, preparation was done by phosphoric acid 37% according to the initial bonding protocol with a duration of 15 s (instead of 30 s in the initial bonding).[13] In the third group, enamel preparation was performed by aluminum oxide 50 µm (Danville Engineering Co, USA) for 10 s and then etched with phosphoric acid 37% following the same method. Then, the teeth were rinsed and dried. The distance from the tip of the sandblasting device to the sample was about 1 mm. In the fourth group, preparation was performed using Er: YAG (Fotona Fidelis Plus II® Combine laser equipment, Slovenia) with the following features:

- Very short pulse, 200 mJ energy, frequency of 10 Hz, duration of 30 s, a distance of 1 mm, water (70%), and air (90%).

Then, in all groups, new brackets were rebonded to the surface of the teeth with the same protocol, as described in the initial bonding section. Again, the samples were placed in an incubator for 24 h in deionized water at 37°C and subjected to a thermocycle. Noteworthy, moisture and heat were set similar to the oral environment, according to the previously described method. Then, the SBS test was performed similarly to the control group. During the SBS test, one sample from the first, second, and fourth groups was fractured. Furthermore, two samples from the third group were fractured. All fractured samples were excluded from the study. Scanning electron microscope (SEM, Carl Zeiss Leo 1430VP, UK) images were prepared from four samples to compare the conditioned surface.

Statistics

According to the Kolmogorov–Smirnov test, the data were not normally distributed (even after adjusting the data); hence, data analysis was administered using Kruskal–Wallis and Mann–Whitney test with the Bonferroni-adjusted method $\propto$ =0.05.

RESULTS

This study aimed to compare SBS in rebonded stainless steel brackets with three different methods of enamel surface conditioning. The mean and standard deviation of SBS (MPa) in the four study groups is provided in Table 1.

Samples of the control group (29.440; 13.349.931 ± 48.19) and ER: YAG group (12.241; 3.6634.01 9.643±) presented the highest and lowest mean of SBS, respectively. There was a significant difference between the four study groups (P < 0.001), and the pair comparison differences are provided in Table 2.

As shown in Table 2, there was a significant difference between the sandblast + acid etching (p value

Table 1: The mean and standard deviation of shear bond strength, in study groups (MPa)

Group	*n*	Mean±SD	Minimum	Maximum
Control	19	29.440±9.931	13.34	48.19
Re-etching by phosphoric acid	19	22.666±12.284	6.21	38.91
Re-etching by sandblasting + acid etching	18	16.865±11.328	6.08	39.54
Re-etching by Er: YAG laser	19	12.241±9.643	3.66	34.01

Er: YAG: Erbium-doped yttrium-aluminum-garnet; SD: Standard deviation

(PV) = 0.035) and ER-YAG laser (PV < 0.001) groups and the control group. In addition, there was a significant difference between acid etching and ER-YAG laser (PV = 0.023) groups. There was no significant difference between the other groups. Scanning electron microscopy (SEM) images of samples are shown in Figure 1.

DISCUSSION

The bonding of brackets is the main component of the fixed orthodontic treatment.[1] However, not all appliances are successful, which leads to high costs for both patients and orthodontists.[2] Sufficient SBS is essential to maintain brackets on the enamel surface during orthodontic treatment.[29,30] Different values are reported as optimum for SBS[1], ranging from 5.9 to 7.8 MPa.[5,6] However, based on the findings of the present study, which was focused on the rebond process of orthodontic brackets, the mean SBS (12.24129.440 MPa) is different from the mentioned optimum value. Meanwhile, the reported optimum values are a minimum, and there is no consensus in this regard.[12,25,31] According to the findings, which compared four different groups, the highest level of SBS was in control group (29.440 MPa), followed by 22.666 MPa in re-etching by phosphoric acid group, 16.865 MPa in sandblast + acid etching group and 12.241 in the ER-YAG laser group.

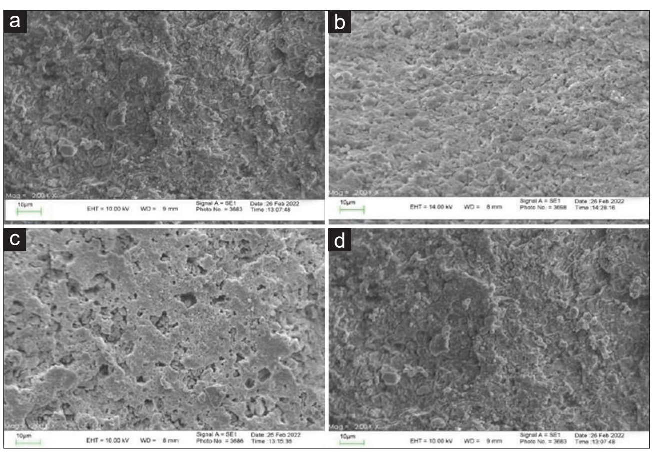

Figure 1: SEM images: (a) Primary etching with phosphoric. (b) Re-etching with phosphoric acid. (c) Re-etching with sandblasting + phosphoric acid. (d) Re-etching with Er:YAG laser. SEM: Scanning electron microscope; Er:YAG: Erbium-doped yttrium aluminum garnet.

As mentioned before, surface conditioning was performed using phosphoric acid in the first group, according to the standard protocol.[13] Although bond strength was lower in this group than in the control group, there was no significant difference between the two groups, which is in line with the standard protocol. The second group received sandblast + acid etching. The results indicated that sandblast had no effect on acid etching (i.e., increasing SBS) and showed no significant difference between combined administration of sandblasting and acid etching and the acid etching alone. However, SBS was significantly lower than in the control group. In an *in vitro* study, N Daratsianos noted that increased strength of the initial bond of metal brackets to enamel by sandblasting and acid etching is not always certain, and it does not seem to increase SBS.[32] In an *in vitro* and *in vivo* study that intended to compare two methods of preparing enamel to rebond orthodontic brackets (i.e., acid etching alone or combined usage of sandblasting + etching with aluminum oxide (with 90-µm particles), Dirie *et al.* reported that the SBS was higher in the group of combined methods than that of the primary bond and acid etching alone, based on the *in vitro* findings.[25]

This finding is in contrast with the present study in which the mean SBS in the sandblasting group and acid etching was significantly lower than in the control group. The difference can be attributed to methodological approaches, such as not simulating the oral environment using thermocycle and incubators or using larger aluminum oxide particles (90 µm) compared to the 50-µm particles used in the present study. In the *in vivo* section of that study, bond failure was significantly higher in the group that only received acid etching than the sandblast and acid etching group.

Pakshir *et al.*[28] compared sandblasting (particle size was similar to the present study) and acid etching

Table 2: Inter-group comparison of the study groups

Group	Control	Re-etching by phosphoric acid	Sandblasting + etching acid
Re-etching by phosphoric acid	0.708		
Re-etching by sandblast + etching acid	0.035*	1	
Re-etching by Er-YAG laser	<0.001*	0.023*	0.602

*Level of significance=0.05. Er: YAG: Erbium-doped yttrium-aluminum-garnet with acid etching alone. They reported a mean of SBS in the group in which sandblasting was performed, higher than the other group. However, the difference was not statistically significant, indicating adding sandblast to the rebond process had no advantage. Noteworthy, they did not use a control group to compare the findings. In addition, they did not simulate the mouth environment (incubator and thermocycle).

A systematic review of *in vitro* studies[33] provided no evidence to support sandblasting before acid etching in bonding of orthodontic brackets in compare with the acid etching alone, which is consistent with the present study. The two final eligible studies were about bonding brackets on dental lingual surface.

Various factors can affect the SBS, including the type of debonding force, the speed of SBS machine blade, and the bracket type.[34] These factors may explain the observed difference in the finding of these studies.

The use of different lasers, particularly ER: YAG laser, in the orthodontic bonding process has been investigated by several studies. In this study, in the third group of rebonding, ER: YAG laser was used to prepare the enamel surface, and this group showed a significantly lower SBS in comparison with the control group (PV < 0.001).

Latić Hodžić *et al.* compared ER: YAG and acid etching during primary brackets bonding for enamel preparation. They used a wavelength of 2.94 µm and a pulse of 300 mJ for 10 s. They showed that the ER: YAG laser created an appropriate bond strength, which is an appropriate alternative for conventional acid etching.[35]

Sallam and Arnout compared surface conditioning during orthodontic bonding using conventional acid etching and ER: YAG laser. They showed that using this laser with a wavelength of 2.94 µm and frequency of 15 Hz for 20 s was an appropriate alternative to conventional acid etching and created acceptable SBS.[3]

Oshagh *et al.* conducted a study to compare the bond strength in bond and rebond of orthodontic brackets using acid etching and CO2 laser with a wavelength of 1.06 µm and frequency of 100 Hz for 0.2 ms.[12] Initially, two groups of human pre-molar teeth were prepared for initial bonding by two different methods of laser and acid etching. After debonding with the SBS machine and measuring the SBS of both groups, each group was divided into two subgroups, and a total of four subgroups underwent the rebonding process. During rebonding, enamel surface preparation in each subgroup was performed by either laser or acid etching method, and SBS was measured again.

Similar to the present study, the highest bond strength was obtained during the initial bond and for acid etching. In the rebonded groups, the SBS was higher in the two groups that received acid etching compared to the groups that received ER: YAG laser. However, in contrast to the present study, the observed difference was not statistically significant. This difference can be attributed to the different types of laser used (CO_2 laser) in their study and different parameters.

In previous studies, ER: YAG laser has not been used to prepare the enamel surface to rebond metal brackets, and it has only been used to prepare the enamel surface in the initial bonding. In line with their promising results, bracket rebond was performed using ER: YAG laser in this study. However, the results showed that the mean SBS in the third rebonding group (ER: YAG) was lower than in other groups and there was a significant difference between the control group and the acid etching group. However, due to differences in applied parameters, weather, the distance of laser irradiation from the enamel surface, and duration of radiation, it is not possible to make a certain conclusion regarding the poor efficiency of ER: YAG in preparing enamel surface for rebond of stainless steel brackets. Hence, further studies are needed to make a decisive conclusion, particularly in randomized clinical trials.

SEM images of samples that underwent surface morphology are provided in Figure 1. It seems that the order in morphological patterns is directly associated with the SBS of each group, as mentioned by Akhoundi *et al*.[4] However, more studies with appropriate design are needed to make a definitive conclusion.

Finally, it is necessary to mention some of our study's limitations. For instance, due to following an *in vitro* design, it was not possible to measure the increase in temperature of live pulp during applying of laser, or considerations regarding soft tissue during sandblasting, which are important clinical variables. Hence, future studies should focus on reducing the duration of these procedures or adjusting the correct ratios of laser power and amount of air/water to minimize these damages. In addition, for being able to generalize the results to the clinic, it is suggested that the mentioned criteria performed following well-designed randomized controlled trials with sufficient number, and in appropriate clinical conditions.

CONCLUSION

According to the findings of the present study, the usage of acid phosphoric as etchant to rebond of orthodontic metal brackets has the highest similarity to the control group (initial bond), and the use of sandblast + acid etch and ER: YAG laser for enamel conditioning during rebond process presented weaker efficiency than the usual method.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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