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Testing the Shear Bond Strength of Orthodontic Brackets After Acid and Er: Yag Laser Etching

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ABSTRACT

This study compared the tensile strength of bracket-tooth bonds obtained after preparation of the enamel by conventional acid-etching, by Er:YAG laser etching , self-etching primer and combined treatments. Fifty five premolars were randomly divided to five groups. The teeth received five various treatments. Five specimens did not undergo bond test and were prepared for observation with scanning electron microscope (SEM) after surface treatment. The shear debonding test was performed at a crosshead speed of 5 mm/min. Failed brackets were examined by a stereomicroscope at 10x magnification to determine the bond failure interface using a modified adhesive remnant index (ARI). Mean SBS values and standard deviations for the groups were different, but no significant differences were observed in the SBS of all the groups' evaluated. All the methods of enamel conditioning tested in this study are potentially adequate for orthodontic bonding.

KEYWORDS bonding, Er:YAG laser, orthodontic brackets Subject: Medical Science

INTRODUCTION

The use of acid to increase microscopic roughness by selectively removing mineral crystals, to improve the micromechanical adhesion of composite restoratives, has become a standard procedure for enamel preparation since the report of Buonocuore[1–4]. Among the various proposed methods, the application of 37% phosphoric acid is the most widely accepted technique[3]. The advantage of etching with phosphoric acid is the high level of bracket bond strength achieved. On the other hand, the loss of mineral crystals, essentially the acid-protecting barrier, is inevitable. Because of this mineral loss, the acid-etched region may be vulnerable to successive acid attacks in the oral environment. Over the past decade, progress has been made in bonding enamel with a resin-modified glass ionomer adhesive system[5] and a self-etching primer (SEP) composite resin adhesive system[6,7]. An advantage of SEP is that they combine etching and priming in a single step, i.e. SEP contains acidic functional monomers that demineralize the tooth surface, while simultaneously improving the penetration of resin–monomer into the porous enamel substrate[8]. It has also been found that they reduce the amount of enamel lost during etching[9].

In spite of the fact that the acid-etching technique is a useful method, there is a need to simplify the technique to decrease the complexity and to improve the bonding procedure in an effort to maintain clinically useful bond strengths while minimizing the amount of enamel loss. Maiman[10] first reported the application of laser in medical treatment and after him Goldman et al.[11] explored the application of laser energy to hard dental tissues. The Er:YAG laser, with a wavelength of 2940 nm, is strongly absorbed by water and hydroxyapatite, as it was effective in cutting enamel and dentin, it was the first laser approved to treat dental tissues in the United States[12]. Laser etching of enamel or dentin has also been reported to yield a fractured and uneven surface with open dentinal tubules, both of which are ideal for adhesion[13]. The surface produced by laser ablation is also more resistant to carious attack compared to acid etched [14].

In the literature, the results of previous studies on the application of laser etching for increasing bond strengths of restorative materials have been controversial.

The aim of this in vitro study was to compare the shear bond strength (SBS) and adhesive remnant index (ARI) of orthodontic brackets bonded to enamel that has been conditioned with 37% phosphoric acid, self-etching primer, Er:YAG laser irradiation, or a combination of these.

MATERIALS AND METHODS

Sixty human premolars extracted for orthodontic reasons were used in this study. Only tooth with intact enamel surface, unexposed to chemical substances (i.e. hydrogen peroxide), without enamel hypoplasia, restorations, caries or defects were included.

The teeth were cleaned from any remaining soft tissue with a dental scaler (Piezon Master 700, EMS, Switzerland) and stored in 0.9% sodium-chloride solution at 4°C until the experiment. Prior to the experiment, the buccal enamel surfaces of the teeth were polished with a rubber cup and fluoride-free polishing paste (Vantal, Galenika, Serbia), rinsed with a water spray and dried with compressed air. The teeth were then randomly divided into five groups. One specimen from each group didn't undergo bond test and was prepared for scanning electron microscope (MIRA3 TeScan FEG-SEM) surface observation after different etching treatments. Waterproof one-mm-thick aluminum foil with a 4 x 4 mm hole was used to delineate the treatment areas for enamel conditioning.

The enamel treatments for the groups were as follows:

- Group 1: 37% phosphoric acid gel (Kerr Corporation) + ConTec Prime (Dentaurum GmbH & Co. KG, Ispringen, Germany)
- Group 2: Beauty Ortho Bond (Shofu, Kyoto, Japan)
- Group 3: Er:YAG laser + ConTec Prime (Dentaurum GmbH & Co. KG, Ispringen, Germany)
- Group 4: Er:YAG laser + Beauty Ortho Bond (Shofu, Kyoto, Japan)
- Group 5: Er:YAG laser + 37% phosphoric acid gel (Kerr Corporation) + ConTec Prime (Dentaurum GmbH & Co. KG, Ispringen, Germany)

We used stainless steel orthodontic brackets for premolars (Discovery, Dentaurum, Roth 022, Inspringen, Germany), with the average bracket base area of 14.7 mm^2. The brackets were bonded to the buccal surfaces with ConTec LC adhesive (Dentaurum GmbH & Co. KG, Ispringen, Germany) according to the manufacturer's instructions.

For the acid-etching technique, we applied 37% phosphoric acid gel to the bonding area for 15 seconds. After rinsing with water spray, the enamel surface was dried with compressed air. The etched enamel showed a uniform dull, frosty appearance.

Self-etching primer application procedure

Beauty Ortho Bond was gently rubbed onto the bonding surface with the furnished disposable applicator and left undisturbed for approximately 3 seconds, followed by gentle air-drying and polymerization with a conventional halogen light source (Demetron LC, Kerr, USA) for 10 seconds.

Laser treatment

The enamel surfaces were irradiated with Er:Yag laser (AT Fidelis, Fotona, Slovenia) of a 2940 nm wave length, at 300 mJ/pulse, 10 Hz, 10 seconds. The surface was irradiated in a light contact mode using a 300 μm optical fiber with a contra-angle hand piece under water spray.

The enamel surface ached by acid or/and laser (Group I, III and V) was covered with a thin layer of ConTec Prime using a brush, gently air-dried and cured with a halogen light source for 20 seconds. ConTec LC adhesive paste was applied to the base of the bracket pad and the bracket was pressed firmly onto the tooth. Excess adhesive was removed from the periphery of the bracket base with a sponge. The adhesive was cured for 20 seconds from the mesial and distal sites.

Test procedure

After the bonding procedure all samples were stored in demineralized water at 37°C for 24 h. Before testing, the teeth were vertically placed into a custom-made mold made of acrylic resin, to ensure that the direction of force in relation to the bracket was the same for every specimen.

Samples were tested for the force at bond failure with an Universal Testing Machine (Instron 1332, Mass), retrofited by FastTrack 8800 Compact Digital Control Electronics, with the crosshead speed of 5 mm/min at 500N load cell, at the room temperature. Each tooth was oriented so that its facial surface was parallel to the direction of force during the Shear bond Strength (SBS) testing. The SBS values were calculated in megapascals (MPa) by dividing the force measured in newton (N) by the area of the bracket base (14.7 mm^2).

After debonding, the teeth and the brackets were examined under the 10 x magnification by an Olympus stereo microscope. The adhesive remained on the bracket was assessed according to a modified adhesive remnant index (ARI) Gokcelik et al.[15]. The ARI scale ranges from 0 to 5 (0= no adhesive left on the bracket; 1= less than 25% of the adhesive left on the bracket; 2= 25%-50% of the adhesive left on the bracket; 3= 50%-75% of the adhesive left on the bracket; 4= 75%-100% of the adhesive left on the bracket; 5= 100% of the adhesive left on the bracket).

Statistical analysis

Mean SBS values between the groups were compared with the One-way ANOVA. The ARI scores were analyzed with Kruskal-Wallis test.

RESULTS

Descriptive statistics are shown in Table 1. Table 1 about here According to One-way ANOVA test no statistically significant difference was found between the groups evaluated for the SBS test ($p = 0.433$). The frequency distribution of ARI scores for the five groups tested is shown in Chart 1. Chart 1 about here There was no statistically difference between the groups. Five specimens were prepared for scanning electron microscope (SEM) surface observation after different etching treatments.

Figure 1 shows the enamel surface after phosphoric acid etching treatment. Dissolution of hydroxyapatite by phosphoric acid produced tags and rough surface that afforded the mechanical lock for resin. Scanning electron microscopy of the enamel surface after self-etched primer is shown in Figure 2. After 300 mJ/pulse, 10 Hz and 10 seconds of Er:YAG laser irradiation (Fig. 3), rough irradiated surface with micro-cracks were found. Less regular, inhomogeneous ablated patterns, comparable with those of acid treatment, were also observed. Fig. 4 shows enamel surface after combination of Er:YAG laser irradiation and application of self-etching primer. After Er:YAG laser (300 mJ/pulse, 10 Hz, 10 seconds) followed by acid etching (Fig. 5), the enamel surface was similar to that of the acid group and revealed type I (preferential prism center etching) etching pattern, having a scaly appearance and circular depressions with a relatively flat-surface structure.

DISCUSSION

Because the main purpose of orthodontics is to preserve maximum tooth structure while treating malocclusions, this study was designed to determine whether laser systems can be used in orthodontics to obtain optimal bracket retention with minimal tooth structure destruction. Enamel etching with phosphoric acid is one of the most common and most effective ways to ensure mechanical lock of resin[1,16]. 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[17,18]. 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.[19] reported an increase in the calcium to phosphorus ratio achieved during laser irradiation, which leads to caries inhibition[20,21]. Therefore, laser irradiation might have an advantage over phosphoric acid in etching procedure for orthodontic bonding.

There are conflicting reports about the efficacy of lasers application for enamel etching. The investigation of enamel surface roughness showed that laser irradiation yielded a comparable[22] or smaller[23] surface roughness than those obtained by acid etching. Although some researchers have reported that the mean shear bond strength resulting from laser etching was lower than that from acid etching[19,24,25], others have reported more favorable results with laser irradiation[26-28]. These variations might be attributed to the different types of lasers or different irradiation parameters used, because the laser–hard tissue interaction is dependent on wavelength and irradiation energy.

In the present study, the highest bond strength was recorded in the group treated with self-etching bond (19.926MPa ±5.826MPa), followed by the group treated with the combination of laser irradiation and application of self-etching bond (18.584MPa ± 13.488MPa) and the group with combination of laser irradiation and acid etching (18.553MPa ±5.401MPa). As shown in Table 1, the combined treatment groups (groups 4 and 5) yielded similar bond strength values to those recorded in the laser-etched, acid etched and self-etched groups (groups 3, 1, and 2).

In our study, bracket failure occurred at the force between 13.48 and 19.92MPa. The mean bond strength value was found to be greater than the breaking strength of enamel, which is about 14MPa. These results suggested that clinically very good SBS can be achieved with all bonding methods.

There was not statistically significant difference between the bond strength values achieved with the Er:YAG laser irradiation and acid etching, which is in accordance with the findings of other studies[29,30]. In contrast to our results, Martinez et al.[25] demonstrated that bonding to Er:YAG-laser etched surfaces provided markedly weaker values than bonding to acid-etched surfaces.

There are contradictory findings with regard to the bond strength of brackets when the self-etching primers were used. Our results were similar to those reported by Gokcelik et al.[15], Hanning and Reinhart [31], Cal-Neto et al.[32], Arnold et al.[33] and Dorminey et al.[34]. In these studies, the SBS of orthodontic brackets after application of self-etching primers and conventional phosphoric acid did not differ significantly.

All combined methods we used can be considered as successful alternatives to the conventional methods. On the other hand, the use of laser irradiation or self-etching primer alone may be more practical in a clinical setting than combined methods. After acid etching, the demineralization of enamel and increased susceptibility to caries around the brackets could be considered complication of orthodontic treatment. Er:YAG laser irradiation might overcome this drawback and offer other benefits like shortening of clinical time needed for enamel preparation and reduced susceptibility to moisture during the etching procedure, while providing the bond strength similar to that of acid etching.

One of the orthodontist's primary concerns is to return the enamel surface to as near its original state as possible after the debonding and clean-up process[35].

After debonding, the sites of failure within the bracket-adhesive-enamel complex can occur within the bracket, between the bracket and the adhesive, within the adhesive, and between the tooth surface and the adhesive[36]. A modified ARI index has been developed to quantify the amount of adhesive that remains on the bracket after a bracket base debond[37]. In our study, scores 4 and 5 were more frequent in groups I and III. These results showed that in the laser-irradiated and acid-etched group (I and III, respectively), less adhesive was left on the enamel than in groups II, IV and V. This fact can be advantageous for clinicians when removing the adhesive after debonding brackets with minimal effort to clean up the residues[38].

CONCLUSION

All the methods of enamel conditioning tested in this study are potentially adequate for orthodontic bonding according to the SBS values. The advantages of laser application might not be in greater bond strength values, but in more convenient clinical application and the better preservation of enamel integrity after debonding of orthodontic brackets.

Table 1. Descriptive statistics of the Shear Bond Strength

Group	I	II	III	IV	V
Mean	16.259	19.926	13.105	18.584	18.553
Median	15.578	22.177	10.544	19.184	18.844
Std Error	2.240	1.757	3.144	4.067	1.629
Std Dev.	7.429	5.826	10.426	13.488	5.401
Lower 95%CL	11.268	16.012	6.100	9.523	14.924
Upper 95%CL	21.249	23.840	20.109	27.645	22.181
Minimum	6.054	9.796	4.014	1.973	8.707
Maximum	29.728	25.578	34.762	41.633	26.395
Count	11.000	11.000	11.000	11.000	11.000
Analysis of Variance					
Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	316.781	4	79.195	0.968	0.433
Error	4089.404	50	81.788		
Total	4406.185	54			

Chart 1.

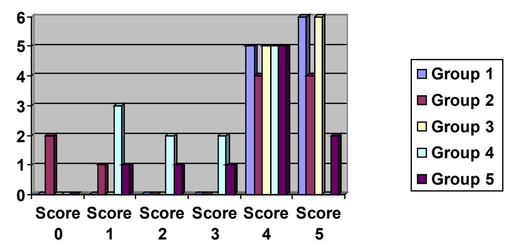


Figure 1. SEM of enamel treated with 37% phosphoric acid

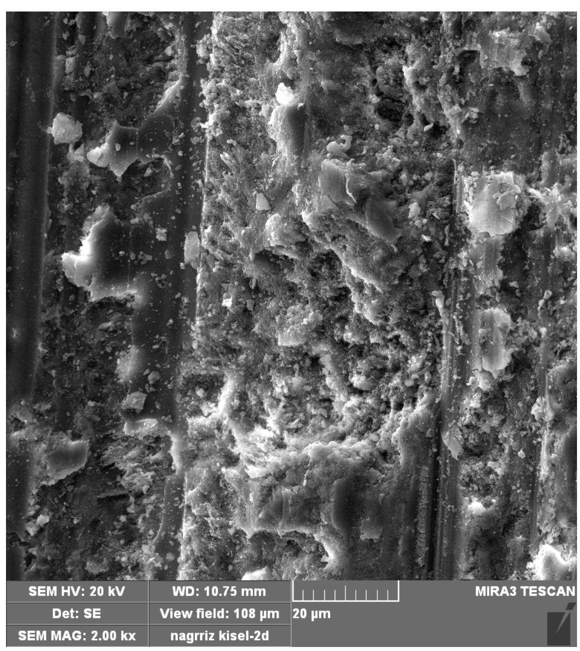


Figure 2. SEM of enamel treated with self-etching primer

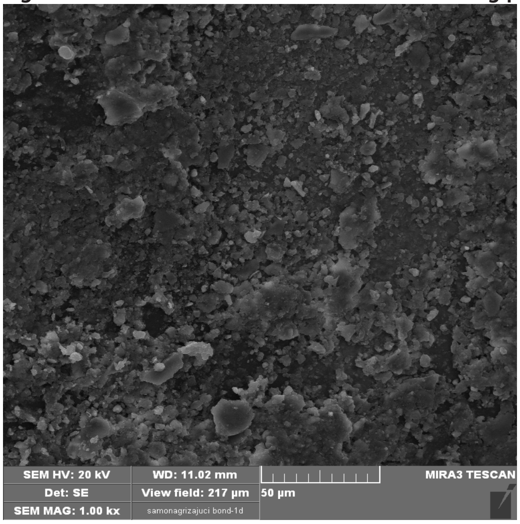


Figure 3. SEM of enamel treated with Er: YAG laser irradiation

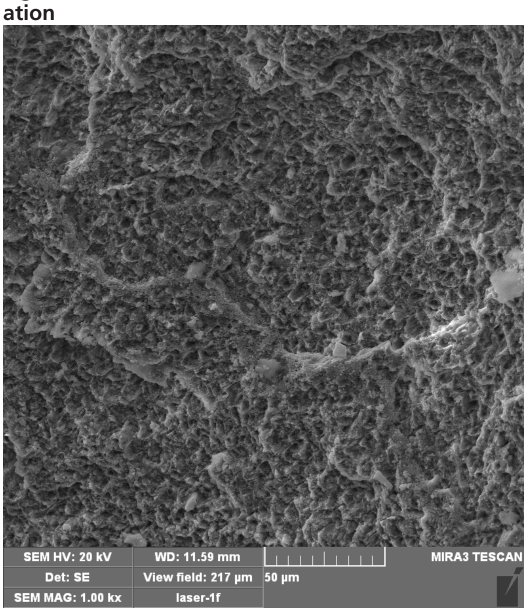


Figure 4. SEM of enamel treated with laser and self-etching primer

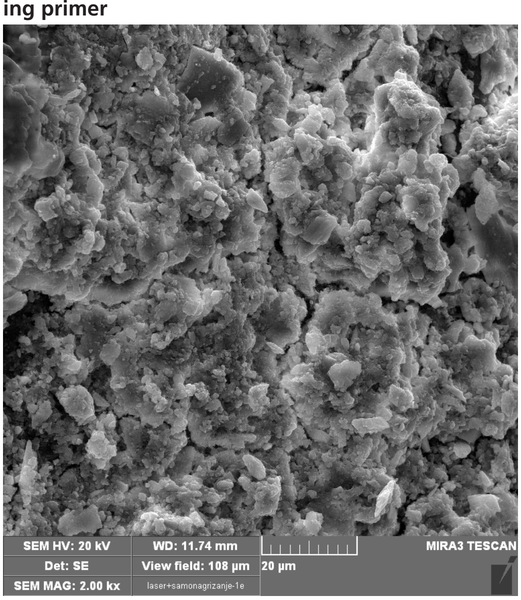
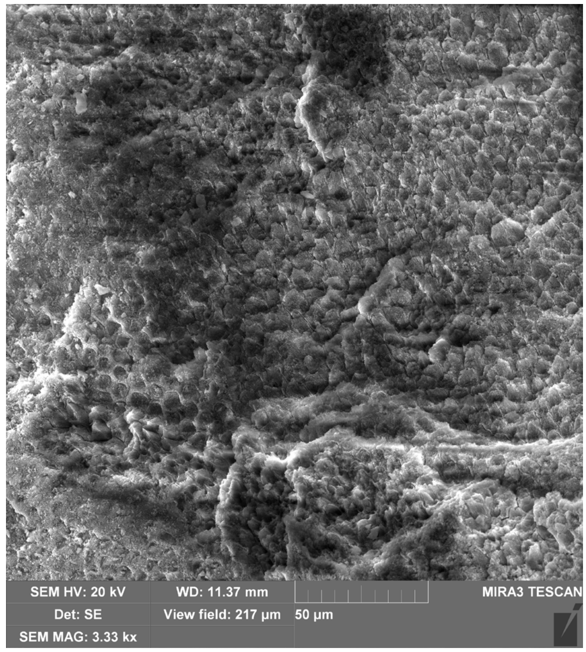


Figure 5. SEM of the enamel surface after Er:YAG laser irradiation (300 mJ/pulse, 10 Hz, 10 seconds) followed by acid application.



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