

Comparative Evaluation of Laser Etching and Acid Etching: An *in vitro* Study

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ABSTRACT

Introduction: Recent innovations in bonding propose laser ablation as an alternative method to acid etching.

Objectives: The objective of this study is to compare the effect of laser irradiation at medium-short pulse (MSP) mode, quantum-square pulse (QSP) mode, and acid etching on the shear bond strength (SBS) of orthodontic brackets to enamel.

Materials and methods: Forty-two premolars were allocated to three groups (14 each): (1) 37% phosphoric acid etching; (2) erbium-doped yttrium aluminum garnet (Er:YAG) laser etching with MSP mode; (3) Er:YAG laser etching with quantum-square pulse mode. Metallic brackets were bonded with Transbond XT. After photo polymerization, the SBS values were recorded with universal testing machine. Surface morphology was evaluated with scanning electron microscopy (SEM). The remaining adhesive was assessed using adhesive remnant index (ARI).

Results: Nonparametric test was used to analyze the statistical significance. A mean rank of 18.29 and 10.71 was obtained for QSP mode and acid etching with $p=0.015$, 18.14; and 10.86 for MSP mode and acid etching with $p=0.019$; and 14 and 15 for QSP mode and MSP mode with $p=0.748$. Statistically significant difference was found between laser and acid-etched group. The SEM scan showed MSP mode with regular and uniform surface, like acid-etched sample, whereas QSP samples had irregular and severely rough surface. The ARI indicates that failure sites are mainly at the enamel/adhesive interface in the acid-etched and MSP mode group and at the bracket base/adhesive interface in QSP mode group.

Conclusion: Laser etching in MSP mode is a successful alternative to acid etching, and provides a safer debonding of the brackets from the enamel surface without causing fractures.

Keywords: Acid etching, Bonding, Laser, Shear bond strength.

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INTRODUCTION

Enamel surface and bracket base should have bond strength that could withstand the mechanical and thermal effects present in the oral environment.¹ Brackets are bonded by altering the enamel surface. The process of conditioning the enamel surface is called acid etching.² Etching alters the enamel surface from low-energy hydrophobic surface to high-energy hydrophilic surface and also increases the surface area.³ 37% of phosphoric acid is used for etching and it has a high level of bracket bond strength.⁴ Demineralization of the most superficial layer occurs and makes the enamel surface more susceptible to long-term acid attack and caries, mainly around the orthodontic brackets and attachments.⁵

Maiman⁶ introduced four-ruby laser in 1960, and Stern and Sognnaes⁷ introduced the use of lasers in dentistry in 1964. Though many lasers are introduced, the erbium-doped yttrium aluminum garnet (Er:YAG) laser effectively alters the enamel and the dentin surfaces because of its 2.94 mm wavelength emission, which is coincident with the main absorption band of water and OH₂ groups in the hydroxyapatite.⁸ Absorbed laser is then converted to heat which boils the water present in the tooth, forming a high-pressure steam, and the explosive vaporization of water alters the smooth tooth surface and creates disorganized and microretentive morphology.⁴ Once enamel is exposed to laser, the enamel undergoes physical changes like melting and recrystallization, forming numerous pores and small bubbles, such as inclusions.⁹ The laser etching produces a surface which is resistant to carious attacks.¹⁰

Pulse duration of laser is used to modify enamel surfaces.¹¹ Variable square pulse technology allows active electronic control of laser pulse duration and amplitude. The pulse duration can be adjusted from 50 to 100, 300, 600 or 1000 μs. Due to high energy in shorter pulse, the energy loss with heat is less, which makes the ablation more effective, and thermal effect is not visible on the tissue surface.¹² This study aims at comparing the shear bond strength (SBS), enamel surface characteristics, and the adhesive remnant index (ARI) scores after etching the enamel surface with laser in quantum square pulse (QSP) mode, medium-short pulse (MSP) mode laser irradiation, and 37% phosphoric acid, followed by bonding.



MATERIALS AND METHODS

Forty-two human premolar teeth extracted for orthodontic treatment were collected, cleaned, and stored in normal saline at room temperature for a short period of time, which had intact enamel and no caries, cracks, restorations, or infections.

Teeth were randomly divided into three groups of 14 and root portion were embedded in color-coded phenolic rings using autopolymerizing polymethylmethacrylate, with the buccal surface parallel to the load direction under SBS testing. Before bonding, teeth were pumiced and rinsed.

In green group, the enamel surfaces were etched with 37% phosphoric acid gel for 20 seconds, rinsed with air/water spray for 15 seconds, and dried to a chalky-white appearance.

In orange group, the enamel surfaces were etched with an Er:YAG dental laser (Fig. 1, 2970-nm wavelength; LightWalker) for 15 seconds (120 mJ, 10 Hz, 1.2 W, water [50 mL/min]) in MSP mode.

In violet group, the enamel surfaces were etched with the same dental laser and same power settings, but in QSP mode.

In both laser-etching groups, the area to be bonded was scanned for 15 seconds with horizontal movements,

perpendicular to the enamel at a distance of 1 mm with a contact-type handpiece. The laser irradiation of enamel was performed manually with all protection precautions (Figs 2 and 3A to C).

Scanning electron microscope (SEM) photographs of one representative tooth from each group were taken to observe alterations in enamel surfaces. The surfaces of the enamel were evaluated according to the enamel damage index (EDI),¹³ which is a modification of surface roughness index described by Howell and Weekes.¹⁴

The EDI includes the following categories:

- Grade 0, smooth surface without scratches, and perikymata might be visible
- Grade I, acceptable surface, with fine scattered scratches
- Grade II, rough surface, with numerous coarse scratches or slight grooves visible
- Grade III, surface with coarse scratches, wide grooves, and enamel damage visible to the naked eye.

On the remaining 13 premolars in each group, 3M stainless steel brackets with an average bracket base surface area of 10.55 mm² were bonded to upper premolars using Transbond XT primer and adhesive (3M Unitek) according to the manufacturer's instructions. The adhesive was light cured on each proximal side for 10 seconds.



Fig. 1: 2970-nm wavelength; LightWalker machine



Fig. 2: The laser irradiation of enamel was performed manually, with all protection precautions



Figs 3A to C: Teeth divided into three groups and bonding done after etching



Fig. 4: Shear bond strength tested using universal testing machine

The SBS was tested using a universal testing machine operating at a speed of 0.5 mm/minute. The specimens were stressed in an occlusogingival direction under the occlusal wings of the bracket and parallel to the long axis of the tooth (Fig. 4). The values were obtained in Newton.

After debonding, the bracket bases and the enamel surfaces were examined under 25× magnification using a stereomicroscope to determine the amount of residual adhesive remaining on each tooth.

The ARI, ranging from 0 to 3, was used to assess the amount of adhesive left on the enamel surfaces.

- A score of 0 indicates no adhesive remained on the enamel surface.
- 1 indicates less than half of the adhesive remained on the tooth.
- 2 indicates more than half of the adhesive remained on the tooth.
- 3 indicates all adhesive remained on the tooth structure.¹⁵

Statistical Analysis

All the values were calculated as mean ranks and sum of ranks using Statistical Package for the Social Sciences software version. Mann–Whitney test was used to compare the difference among each groups.

RESULTS

The mean SBSs are summarized in Table 1. Nonparametric tests were used for analyzing the statistical significance between each group. Mann–Whitney test was used.

Statistically significant differences among the SBS values of the groups were seen. The QSP group produced the highest SBS values, followed by MSP group when compared with acid etching. Statistically significant

Table 1: Nonparametric tests were used for analyzing the statistical significance between each group. Mann–Whitney test was used

Groups	Mean rank	Sum of ranks	p-value
QSP	18.29	256	0.015
Acid etching	10.71	150	
MSP	18.14	254	0.019
Acid etching	10.86	152	
QSP	14	196	0.748
MSP	15	210	

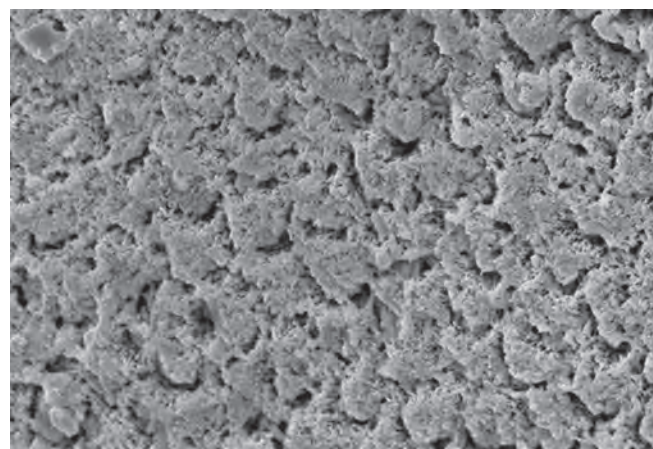


Fig. 5: Scanning electron microscope image of an enamel surface etched with 37% phosphoric acid

difference was found among the QSP and acid etching groups ($p=0.015$). The MSP and acid etching groups were statistically significant ($p=0.019$). The QSP and MSP groups had no significance ($p\text{-value}=0.748$).

Differences between the surface roughness of the acid-etched group and the laser groups were in accordance with images obtained from SEM; topographic irregularities were observed in all samples. The sample from the acid-etched group showed a rough surface, with numerous slight grooves visible. Both laser modes seemed to produce coarse scratches, wide grooves, and enamel damage visible to the naked eye.

Scanning electron microscope image of an enamel surface etched with 37% phosphoric acid is shown in Figure 5.

Scanning electron microscope image of an enamel surface etched with an MSP mode Er:YAG laser is shown in Figure 6.

Scanning electron microscope image of an enamel surface etched with a QSP mode Er:YAG laser is shown in Figure 7.

With regard to ARI scores, both MSP and QSP laser groups demonstrated that the composite was adhesive in nature to enamel, with more than 50% of adhesive remaining on enamel. In the acid-etched group, ARI scores are adhesive in nature, demonstrating less than 50% or no adhesive remaining on enamel.



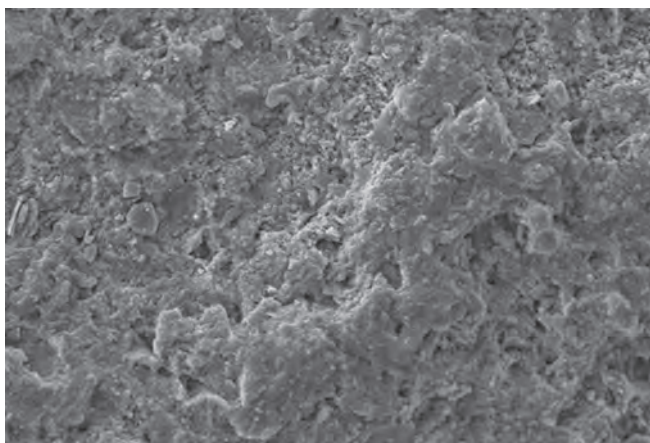


Fig. 6: Scanning electron microscope image of an enamel surface etched with an MSP mode Er:YAG laser

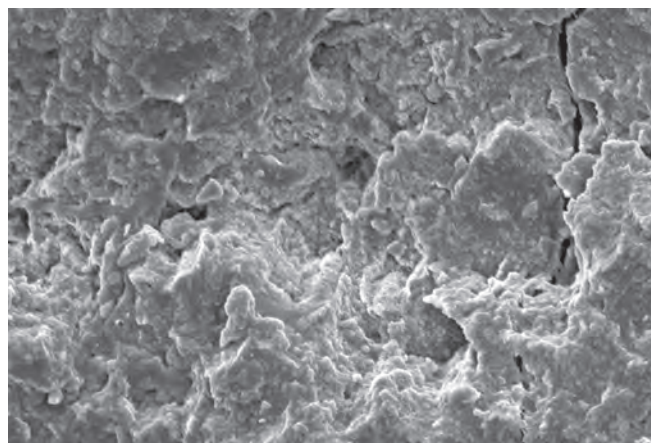


Fig. 7: Scanning electron microscope image of an enamel surface etched with a QSP mode Er:YAG laser

DISCUSSION

In our study, we evaluated the effects of phosphoric acid etching, MSP mode and QSP mode laser irradiation on surface roughness characteristics of enamel, SBS values of brackets, and ARI scores. In our study QSP group produced the highest SBS values, followed by MSP group when compared with acid etching. Etching enamel with phosphoric acid is used commonly to create resin tags on enamel surface.¹⁶ The process of acid etching is effective for bonding, but it leads to demineralization of the enamel surface, an undesirable effect, because acid is the main cause of dental caries during orthodontic treatment. With the introduction of lasers in dentistry, their effects on the surface treatment of enamel have been investigated, and laser ablation became an alternative to acid etching.¹⁷ Laser irradiation produces an amount of surface roughness comparable¹⁸ or similar¹⁹ to acid etching. Er:YAG laser conditioning is proved to be effective for hard-tissue ablation without any thermal side effects.^{20,21} Er:YAG laser-treated enamel is resistant to acid attack when compared with phosphoric acid-etched enamel according to Kim et al.⁴ Studies have shown that the SBS of Er:YAG laser-conditioned surfaces is variable.²²⁻²⁶ The Er:YAG laser ablation is the result of an explosive vaporization of water within the tooth. Light of this wavelength is also absorbed well by enamel.²⁷⁻²⁹ Enamel is composed of 85% mineral by volume and the remaining 15% consists of free water along with equal amounts of protein and lipid.³⁰ The absorbed laser energy is converted to heat which boils the water abruptly and the boiled water forms high-pressure steam which leads to ablation process when the pressure exceeds the ultimate strength of the tooth. During the process of ablation, water evaporates explosively with tooth particles and the ablated materials and their successive recoil force creates craters on the enamel surface. The irradiated enamel surface becomes a flaky structure with an irregularly serrated and microfissured enamel

morphology. In few studies, Er:YAG laser was reported to interact well with dental hard tissue and to promote increased SBS in comparison with acid etching.^{22,23} On the contrary, higher bond strength following acid etching was reported in other studies.²⁴ Er:YAG pulse duration and pulse energy play a decisive role related to laser ablation ability and the surface conditioning for adhesion.³¹ In order to reduce thermal deposition and scattering effects for surface modification, Er:YAG laser pulses must be of short duration and low pulse energy. However, Er:YAG lasers are inefficient while in short duration, low-pulse-energy regime.³²

In our study, the SEM scans showed that acid-etched sample had a regular and uniform rough surface, whereas both of the laser samples had irregular and severely rough surfaces. The QSP sample had deeper grooves than did the MSP sample. However, the SEM evaluations were made from a single specimen of each group, which provides only a limited visualization of surface morphology.

The ARI scores showed that debonding sites are mainly at the enamel/adhesive interface in the acid-etched group, causing minimal risk of enamel fractures. Few authors suggested that bond failure within the adhesive or at the bracket/adhesive interface is more advantageous than failure at the enamel/adhesive interface, because it might lead to enamel fracture while debonding.³³ On the contrary, the time required for removing adhesives from the enamel depends largely on the amount of remnant adhesive³⁴ and, accordingly, the fewer adhesive remnants reduces the operator time. Although the failure sites are in the enamel/adhesive interface, more adhesive was present on the enamel surface in both laser irradiation groups, suggesting a safer debonding, which is in accordance with the results of Usümez et al.²⁵

From our study Er:YAG laser can be used for acid etching since it has comparable and higher SBS when

compared with acid etching. More studies have to be carried out to evaluate the effect of different Er:YAG laser settings on the adhesive interface morphology and the alterations of enamel. The SEM study showed that successful alteration of the enamel surface can be done with the use of laser etching. However, clinical studies are required to verify clinical success.

CONCLUSION

- Laser etching is a successful alternative to acid etching.
- The MSP mode of Er:YAG laser can be used efficiently without much of damage to the enamel surface, when compared to QSP according to the SEM results.
- Laser etching provides a safer debonding of the brackets from the enamel surface without causing fractures.

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