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Original Article

Comparison of surface roughness of enamel and shear bond strength, between conventional acid etching and erbium, chromium-doped: Yttrium scandium-gallium-garnet laser etching – An *in vitro* study

S. Dilip[1], S. Srinivas[1], M. N. Mohammed Noufal[1], K. Ravi[1], R. Krishnaraj[1], Anila Charles[1]

[1]Department of Orthodontia, SRM Dental College, Chennai, Tamil Nadu, India

ABSTRACT

Background: The purpose of the study was to evaluate and to compare the shear bond strength (SBS), adhesive remnant index, and surface roughness of the samples bonded after etching with phosphoric acid and erbium, chromium-doped:Yttrium scandium-gallium-garnet (Er, Cr:YSGG) laser.

Materials and Methods: In the present analytical/descriptive study, 90 premolars extracted for orthodontic purposes were used, out of which 75 were randomly divided into five groups where five different methods were used to prepare the enamel for bonding; etching with 37% phosphoric acid for 15 s, irradiation with Er, Cr:YSGG laser at 1 watt for 10 s and 20 s, and irradiation with Er, Cr: YSGG laser at 1.5 watt for 10 s and 20 s. Following this, metal brackets were bonded with Transbond XT. Brackets were debonded 24 h, later and SBS were measured, and adhesive remnant index scores were measured. The remaining 15 teeth were used for surface evaluation of these five groups using three-dimensional optical profiler. The results of the SBS testing, adhesive remnant index) scores, and surface roughness values were analyzed by one-way analysis of variance and Tukey honestly significant difference tests with a significant level at 0.05.

Results: The difference in bond strength between the laser (1.5 W/20 s) and conventional acid etching was not statistically significant ($P > 0.05$). For acid etch tech, it was 10.48 Mpa and Laser etch at 1.5 W/20 s 10.46 Mpa bond strength attained by the other groups (1 W/10 Hz, 1 W/20 Hz, and 1.5 W/10 Hz) was significantly less than acid etched, and laser etched (1.5 W/20 Hz) groups with $P > 0.05$. The surface roughness was found to be similar between the laser- (1.5 W/20 s) and acid-etched groups ($P > 0.05$).

Conclusion: Irradiation with 1.5 W/20 s Er, Cr:YSGG laser produced bond strength comparable to acid etching.

Key Words: Bond strength, etching, laser

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Address for correspondence:
Dr. S. Dilip,
Department of Orthodontia, SRM Dental College, Ramapuram,
Chennai - 600 089,
Tamil Nadu, India.
E-mail: drsdilip@yahoo.com

INTRODUCTION

Phosphoric acid etching is a good method of preparing tooth enamel for bonding resins and orthodontics attachments. However, a potential disadvantage is the possibility of decalcification, which leaves the enamel susceptible to caries attack, especially under

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orthodontic attachments. A technique that produces clinically useful bond strength, without leaving the enamel susceptible to caries, would be advantageous.

There has been extensive research to find such alternative conditioning methods to overcome this main disadvantage of phosphoric acid etching. Some researchers have worked on conditioning enamel with polyacrylic acid, crystal growth conditioning, and pretreatment of the enamel surface with sandblast of aluminum oxide to reduce the enamel loss during etching.[1-3] However, these methods failed to achieve adequate bond strength to resist intraoral forces.[4]

One alternative to acid etching is laser etching. Various commercially available laser systems have been introduced for dental use erbium, chromium-doped: Yttrium scandium-gallium-garnet (Er. Cr: YSGG) laser, which uses a pulsed-beam system has been shown to be effective for soft-tissue surgery and for cutting enamel, dentine, and bone.[5,6] Enamel and dentin surfaces etched with Er. Cr: YSG lasers show micro irregularities and no smear layer. Kim *et al.* found that laser-etched enamel was more resistant to acid attack compared to phosphoric acid etching and this could be of great importance in orthodontics.[7] Since water spraying and air drying are not needed with laser etching, procedural errors can be reduced and time saved.

Er. Cr: YSGG laser irradiation might be a suitable technique to etch enamel for orthodontic bonding. Therefore, the purpose of the study was to compare the surface characteristics, shear bond strength (SBS), and adhesive remnant index (ARI) of the samples treated with conventional acid etching and Er, Cr: YSGG laser etching.

MATERIALS AND METHODS

In this the present analytical/descriptive study was performed on 90 premolars extracted for orthodontic purpose.

Criteria for selection of tooth:
- Teeth without enamel defects
- Teeth without morphological defect
- Teeth without decalcification
- Teeth that were not previously bonded
- No cracks caused by extraction forceps.

All teeth were stored in distilled water immediately after extraction, and the distilled water changed every week. These teeth were washed in water to remove any traces of blood. Teeth were cleaned off from adherent tissue tags and debris with ultrasonic scaler. The samples were stored in saline solution until ready for use.

Out of the total sample of 90 premolars, 15 premolars were used for surface roughness evaluation. The rest 75 premolars were used for SBS evaluation. The 15 premolars for surface evaluation were further divided into five groups of three teeth each, and the 75 premolars for SBS were randomly divided into five groups of 15 teeth in each group.

For surface roughness, the 15 premolars were divided into five groups of three teeth each
1. Phosphoric acid etching
2. Laser etching (1 W/10 s)
3. Laser etching (1 W/20 s)
4. Laser etching (1.5 W/10 s)
5. Laser etching (1.5 W/20 s).

For SBS, the 75 premolars were divided into five groups of 15 teeth each
1. Phosphoric acid etching
2. Laser etching (1 W/10 s)
3. Laser etching (1 W/20 s)
4. Laser etching (1.5 W/10 s)
5. Laser etching (1.5 W/20 s).

All these teeth were mounted vertical in self-cure acrylic resin block so that only the crown was exposed [Figure 1].

The buccal enamel surfaces of the teeth were pumiced, washed for 30s s, and dried for 10 s with a moisture-free air spray. All groups had 15 teeth for SBS and three teeth for surface roughness evaluation.

In Group 1, the buccal enamel surface was etched with 37% phosphoric acid for 15 s and rinsed with water and gentle air spray for 15 s and dried for another 15 s. The etched enamel showed a uniform dull, frosty appearance.

Er, Cr: YSGG laser [Figure 2] was used for etching the enamel surface with different power outputs.

The development of the Er: Yttrium -aluminum-garnet (Er: YAG) laser and more recently, the Er, Cr: YSGG laser permit ablation in both soft and hard tissues without any thermal side effects. These lasers can ablate enamel and dentin effectively because their light is highly and efficiently absorbed by both water and hydroxyapatite.

The Er, Cr: YSGG laser, which uses a pulsed-beam system, fiber delivery, and a sapphire tip bathed in a mixture of air and water vapor, has been shown to be effective for soft-tissue surgery and for cutting enamel, dentine, and bone. After Er, Cr: YSGG laser irradiation, the surface alteration of enamel and dentine shows microirregularities and the absence of a smear layer. This suggests that the Er, Cr: YSGG laser may etch enamel suitably for orthodontic purposes.

Surface roughness created by the five groups of pretreatment methods were evaluated and compared. This quantification of the roughness was performed by ultra precision bench top three dimensional (3D) optical profiler made by TAYLOR HOBSON Precision-TALYSURF CCI [Figure 3]. This uses a noncontact way of evaluating the surface roughness created on the surface of the enamel. The TalySurf CCI is an advanced 3D noncontact optical metrology tool used for advanced surface characterization. Three samples from each group were scanned under the 3D profiler, and the surface roughness parameters were received by noncontact method [Figure 4].

After etching, stainless steel premolar brackets (0.022 inch MBT 3M Gemini) were bonded. A thin, uniform coat of adhesive was applied to the etched surfaces. After the application of the bonding material (Transbond XT, 3M Unitek), the bracket was placed on the tooth surface, adjusted to its final position, and pressed firmly. Excessive sealant and adhesive were removed from the periphery of the bracket base to keep each bond area uniform. Each side of the tooth (mesial, distal, occlusal, and gingival) was light cured using curing light for 10 s, for 40 s. After that, specimens were stored in deionized water for 24 h before debonding.

Debonding procedure

The universal testing machine, FIE-universal testing machine (UNITEK 94100), was used to test the SBS of each tooth [Figure 5]. The sample was mounted in lower arm of machine in such a way that the applied force was parallel to the tooth surface (gingivo occlusally).

A round stainless steel wire loop was threaded into an acrylic. The wire loop was passed through the wings of the bracket. The acrylic with the wire loop was fixed to the upper arm of Unitek universal testing machine at a cross head speed of 1 mm/min.

The force required to debond each bracket was registered in Newtons and converted into Megapascals as a ratio of Newton to surface area of the bracket base (MPa = N/mm^2).

Figure 1: Premolar teeth mounted on acrylic blocks.

Figure 2: Erbium, chromium-doped: Yttrium scandium- gallium -garnet laser unit.

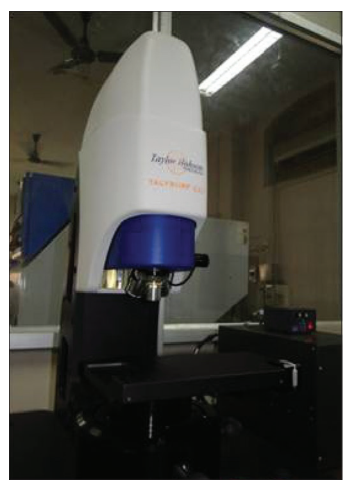

Figure 3: Three-dimensional optical profiler.

Adhesive remnant index

ARI score was determined to evaluate the site of debonding. The scoring was based on the following criteria:[8]

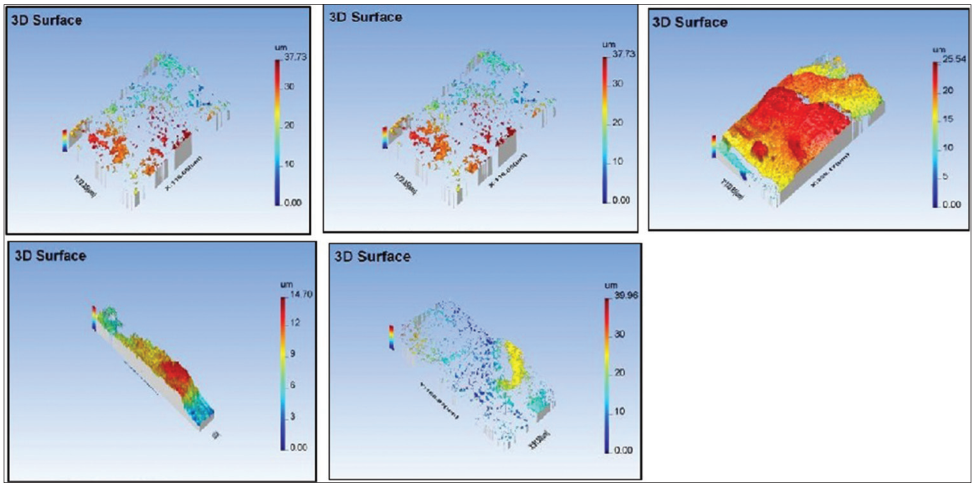

Figure 4: Surface analysis of treated enamel.

Figure 5: Instron universal testing machine.

1. Score 0 = No adhesive left on the toot
2. Score 1 = Less than half of the adhesive left on the tooth
3. Score 2 = added than half of the adhesive left on the tooth
4. Score 3 = All adhesive left on the tooth, with distinct impression of the bracket mesh.

Statistical analysis

Descriptive statistics including mean and standard deviations were calculated for each group [Table 1]. Multiple comparisons of SBSs and surface evaluation of the different groups were performed with the ANOVA test. A Tukey honest significant difference (HSD) test was then done to find the difference between each of the groups. The Chi-square test was used to evaluate differences in ARI scores between the groups. All statistical evaluations were made using statistical software (SPSS for Windows, version 10.00 SPSS, Chicago IL, USA).

RESULTS

The ARI score of 3 was obtained in acid etching group for 80% of the samples. Group 5 (laser etching 1.5 W/20 s) showed ARI score of 3 in 66. Nearly 7% samples and ARI score of 2 in 33.3% samples. The other three groups (laser etching 1.5 W/10 s, 1 W/20 s, and 1 W/10 s) showed ARI scores of 2, 1 and 0 in 93.3%, 73.3%, and 80% of the samples, respectively. The difference between all the groups was highly significant and more amount of adhesive was left on acid etched followed by the 1.5 W/20s laser-etched group.

The difference between these two groups was not found to be statistically significant. All the other three groups showed average roughness which was less than the above two groups, the difference being statistically significant.

The statistical analysis of the values obtained for SBS showed that acid etching (Group 1) showed the highest bond strength (10.48 MPa) followed by laser etching at 1.5 W/20 Hz (10.46 MPa). The difference between these two groups was not statistically significant. This was followed by laser etching at 1.5 W/10 s (8.38 MPa), 1 W/20 s (6.89 MPa), and 1 W/10 s (4.79 MPa), respectively. The difference between these three groups and the other two groups (acid etching and laser etching for 1.5 W/20 s) was statistically significant [Tables 2 and 3].

DISCUSSION

Laser systems are more commonly used in dentistry in recent years. The first commercially available

Table 1: Descriptive statistical data for surface roughness

Descriptive								
Surface Characteristic								
	N	Mean	Std. deviation	Std. error	95% confidence interval for mean		Min µm	Max µm
					Lower bound	Upper bound		
Acid etching	3	0.49100	0.005000	0.002887	0.47858	0.50342	0.486	0.496
Laser etching (1W 10 sec)	3	0.15700	0.004000	0.002309	0.14706	0.16694	0.153	0.161
Laser etching (1W 20 sec)	3	0.22200	0.003000	0.001732	0.21455	0.22945	0.219	0.225
Laser etching (1.5W 10 sec)	3	0.22200	0.002000	0.001155	0.21703	0.22697	0.220	0.224
Laser etching (1.5W 20 sec)	3	0.48700	0.002646	0.001528	0.48043	0.49357	0.484	0.489
Total	15	0.31580	0.148463	0.038333	0.23358	0.39802	0.153	0.496

Table 2: Descriptive statistical data for shear bond strength (units-MPa)

Shear bond strength								
	N	Mean (MPa=N/mm^2)	Std. deviation	Std. error	95% confidence interval for mean		Min (MPa=N/mm^2)	Max (MPa=N/mm^2)
					Lower bound	Upper bound		
Acid etching	15	10.4847	1.16553	0.30094	9.8392	11.1301	9.17	12.69
Laser etching (1W 10 sec)	15	4.7967	1.35669	0.35029	4.0454	5.5480	2.13	6.77
Laser etching (1W 20 sec)	15	6.8940	1.38939	0.35874	6.1246	7.6634	4.15	8.91
Laser etching (1.5W 10 sec)	15	8.3800	1.10823	0.28614	7.7663	8.9937	5.11	9.69
Laser etching (1.5W 20 sec)	15	10.4633	0.73890	0.19078	10.0541	10.8725	8.91	11.67
Total	75	8.2037	2.47035	0.28525	7.6354	8.7721	2.13	12.69

Table 3: Analysis of variance testing for shear bond strength

Shear bond strength					
	Sum of squares	df	Mean square	*F*	Sig
Between Groups	354.945	4	88.736	64.268	0.000
Within Group	96.650	70	1.381		
Total	451.596	74			

lasers, such as carbon-dioxide and neodymium-doped: YAG, were suitable only for soft-tissue treatments, especially in periodontics. The main disadvantage for application on dental hard tissues was their thermal side effects. Er doped: YAG laser systems are capable of ablation in both soft and hard tissues without thermal side effects.[9-11] In orthodontics, lasers are mainly used for etching the enamel surface, curing, and debonding the brackets

This study was designed to determine whether laser etching can be an alternative to conventional acid etching. Out of the total samples of 90 premolars, 15 premolars were used for surface roughness evaluation, three for each of the five groups of treated enamel. The remaining 75 premolars were randomly divided into five groups of 15 each and bonded with a conventional acid etching method using phosphoric acid etching and Er, Cr: YSGG laser systems at different power outputs and duration namely 1 W/10 s, 1 W/20 s, 1.5 W/10 s, and 1.5 W/20 s. Enamel etching pattern of phosphoric acid etching and laser were studied using a 3D profiler. The Instron Universal Testing Machine (UNITEK) was used to test the SBS of each tooth followed by the assessment of ARS index according to the criteria put forward by Reynolds.[8]

The Er, Cr: YSGG laser used in the present study has an average power output that can vary from 0 to 6 W. For cutting enamel, high irradiation outputs from 2.5 to 6 W can be used.[12,13] In a previous study by Basaran *et al.*,[14] three power outputs were used (0.5, 1, and 2 W). However, the 0.5 W setting resulted in inadequate bond strength. The usage of different power outputs causes different effects. Ozer *et al.* compared Er, Cr: YSGG laser irradiation at 0.75 and 1.5 W with phosphoric acid etching and self-etching primer (SEP) for orthodontic bonding. They stated that varying power outputs of laser irradiation made different etching patterns: 0.75 W laser irradiation had lower SBS, whereas 1.5 W power output showed comparable SBSs with phosphoric acid and SEP.[12] In the present study, 1 W and 1.5 W were used because these were the minimum power outputs which could produce acceptable bond strength.

The study by Basaran *et al.*[14] used 15 s for laser etching. However, in this study, both 10 and 20 s were used to evaluate the effect of time on the surface characteristics and the SBS. Acid-etching times can vary from 15 to 60 s.

Surface roughness evaluation

A quantitative measurement of surface roughness was obtained using a noncontact 3D optical profiler. The highest surface roughness was obtained for acid etching (0.491 μm) followed by laser etching at 1.5 W/10 s (0.487 μm). The other three groups showed surface roughness values of 0.157 μm (1 W/10 s), 0.222 μm (1 W/20 s), and 0.222 μm (1.5 W/10 s), respectively. The statistical analysis, ANOVA, and Tukey HSD tests showed that the acid etching and laser etching at 1.5 W/20 Hz have statistically significant higher surface roughness when compared to the other three groups.

The results of this study were in concordance with the study done by Ozer *et al*., who evaluated the surface characteristics of enamel etched with phosphoric acid, SEP, 0.75 W, and 1.5 W Er, Cr: YSGG laser using scanning electron microscope. They found that enamel etched with 1.5 W Er, Cr: YSGG laser had similar surface roughness to acid-etched enamel.[12]

Shear bond strength evaluation

SBS was evaluated for the conventional acid etch group, and the laser etch groups with different power outputs and duration. The mean SBS of conventional acid etch was found to be 10.48 Mpa and was the highest. This was followed by the laser etch (1.5 W/20 Hz) group with a value of 10.46 Mpa. The other three laser-etched groups showed lower SBS values of 4.79Mpa (1W/10 s), 6.89Mpa (1 W/20 s), and 8.38 (1.5 W/10 s), respectively. The difference between acid etching and 1.5 W/20 Hz laser etching was not statistically significant.

Basaran *et al*. reported that the mean SBS and enamel surface etching obtained with an Er, Cr: YSGG laser (operated at 1W or 2W for 15 s) was comparable to that obtained with acid etching.[14] In another study by Ozer *et al*., almost similar bond strength was achieved with acid etching and laser irradiation at 1.5W indicating that the mean bond strengths in this study were similar to these studies.[12]

Acid-etching results in chemical changes that may modify the organic matter and decalcify the inorganic component. As a result of this demineralization, enamel becomes more susceptible to caries attack, which is induced by plaque accumulation around the bonded orthodontic attachments.[15] Laser etching of enamel creates microcracks that are ideal for resin penetration. Hossain *et al*. reported an increase in the calcium to phosphorus ratio achieved during laser irradiation, which leads to caries inhibition.[16] Therefore, laser irradiation might have an advantage as an etchant for orthodontic bonding. Laser etching can also save chairside time because of the lesser number of steps required and this maybe an important factor from a clinical point of view.[17]

The findings obtained from this study were also in agreement with von Fraunhofer *et al*., who reported that adequate bond strength of laser etching was obtained only with higher power output.[18]

Although the mean bond strength of the three laser groups 1 W/10 Hz, 1 W/20 Hz, and 1.5 W/10 Hz showed a statistically significant difference from the other two groups, the bond strength was in the acceptable range as suggested by Reynolds,[8] Maijer and Smith.[19]

High adhesive strength between bracket and tooth are an essential factor in any treatment concept, also increased bond strength is always necessary in certain clinical situations. Frequent debonding can lead to prolonged treatment time and patient burn out.

The SBS values also correlated with the surface roughness values wherein, those groups which had a higher surface roughness value had a correspondingly higher SBS value. This indicates that increased surface roughness translates to a better micromechanical bond.

Adhesive remnant index

In this study, the adhesive remnant index was carried out as given by Reynolds in 1975.[8] The samples were graded from 0 to 3, where 0 indicates no adhesive left on the tooth and 3 indicates all adhesive left on the tooth, with distinct impression of bracket mesh. The mean of ARI scores for acid-etched and laser-etched (1.5 W/20 Hz) groups ranged from score 2–3 indicating that the bond between the enamel surface and adhesive was much stronger than that between the adhesive and the bracket base. This could be either an advantage or disadvantage. Less chair time is needed with less adhesive left on the enamel after debonding, but it might cause enamel fracture while debonding.

The Chi-square test showed that difference between all the groups were highly significant statistically, but more amount of adhesive (score 3) was left on acid etched and 1.5 W/20 Hz laser-etched groups. This result correlates with a study done by Ozer *et al*. in 2008. It was found that laser etching at higher output showed more amount of adhesive left on the tooth surface.[12]

In recent years, orthodontists deal with an ever-increasing number of adolescents and young adults who lack the seriousness of proper maintenance of fixed appliance in comparison with adults; the necessity for increasing the bond strength for such patients is beneficial. In case of lingual orthodontics, bracket breakage and rebonding are a tedious and laborious process. Thus, in all such cases, acceptable level of bond strength will be comfortable for both clinician and patient.

At that same time, there are some clinical situations such as bonding of ceramic brackets which frequently cause enamel fracture because of high SBS. In these cases, a lower power output and duration of laser etching may bring down the SBS values to acceptable levels, thereby preventing enamel damage during debonding and facilitate easier clean up. This versatility of lasers where the power output and duration can be altered to suit the clinical situation can also be an advantage.

To inculcate lasers in the armamentarium, the clinician should have a comprehensive understanding of the principles and fundamentals of laser and its helpful abilities. The numerous advantages of Er, Cr: YSGG laser, make it a viable alternative to conventional acid etching. The main disadvantage is the capital expenditure the clinician has to spend for Er, Cr: YSGG lasers, but this type of lasers can be used for vast variety of procedures in all fields of dentistry, thereby giving a better cost/benefit ratio.

Further *in vivo* studies using a split-mouth design comparing conventional acid etching and laser etching should be conducted to know its effect on a clinical setting. In addition, future *in vivo* studies can concentrate on the caries resistance of laser-etched enamel.

CONCLUSION

Overall, from this study it can be concluded that laser etching at 1.5W/20Hz achieved similar surface roughness and shear bond strength compared to conventional acid etching and could be a viable alternative for surface preparation of enamel. Lower power outputs can be used in those clinical situations which demand lesser bond strength

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Conflicts of interest
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