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Original Research Article

Comparison of Bond Strength of Orthodontic Bracket Etched by acid, Er: YAG Laser and Combined Treatment on Enamel Surface: An In Vitro Study

Dr. Mohamed Ramees M[1]*, Dr Sam Paul[2], Dr. Rahul VC Tiwari[3], Dr Heena Tiwari[4], Dr. Mithun Paul[5], Dr. Shalini Singh[6]

[1]MDS, Orthodontist, Consultant & Private Practitioner, Vijay Dental Clinic, Varkala, Trivandrum, Kerala, India
[2]Professor & HOD, Department of Orthodontics, Educare Institute of Dental Sciences, Chattiparamba, Malapuram, Kerala, India
[3]Consultant & Private Practitioner, OMFS, FOGS, Kondagaon, Chhattisgarh, India
[4]BDS, PGDHHM, Government Dental Surgeon, CHC Makdi, Kondagaon, Chhattisgarh, India
[5]MDS, Orthodontist, Neem Care Hospital, Mala, Kerala, India
[6]PG Student, Dept. of Conservative Dentistry and Endodontics, Vyas Dental College and Hospital, Jodhpur, Rajasthan, India

***Corresponding author:** Dr. Mohamed Ramees M
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Abstract

Phosphoric acid etching is the gold standard method of enamel preparation before application of bonding resins for orthodontic brackets. With the recent introduction of erbium-doped yttrium aluminum garnet (Er:YAG) laser in dentistry for the ablation of hard tissues, including enamel and dentin, laser enamel preparation has been proposed as an alternative to phosphoric acid etching. Hence this study was conducted to evaluate the shear bond strength of bracket bonded to teeth etched by Acid, Er:YAG laser. The aim of the study is to "Compare the bond strengths of orthodontic bracket etched by acid, Er: YAG laser, and combined treatment on the enamel surface." The objective of the study was to investigate methods that could obtain the maximal bond strength and to analyze the fracture mode of each method.
Keywords: Phosphoric acid, enamel, Er: YAG

INTRODUCTION

Brackets in fixed orthodontic treatment are used for transferring orthodontic forces to the teeth. Initially, orthodontic bands were used to attach the brackets to the tooth, and after welding brackets to bands, they were cemented to the tooth [1]. Buonocore introduced the acid-etch technique that was steadily used in various dental treatments [2]. Newman used the technique of direct bonding of orthodontic brackets which was considered as the first step in application of appliances with the enhancement of esthetic presentation [3]. This technique was developed rapidly as a result of its simplicity, efficacy and providing more esthetic qualities [4]. For achieving successful bonding, the bonding agent should penetrate to the enamel surface, have uncomplicated clinical use, dimensional stability and adequate bond strength [5]. The bond strength of orthodontic brackets should be adequate to not cause bonding failure and delay in treatment and it additionally ought to have adequate resistance against masticating forces and stresses from archwires [6]. Conversely, easy debonding of the brackets without any damage to the teeth needs sufficient and safe bond strength [7]. According to few stages for bonding of orthodontic brackets and related problems in the conventional system, other techniques such as application of self-etch primers or laser irradiation was suggested to simplify the bonding procedure [8]. The rationale of acid etching is to remove the smear layer left by the high-speed dental drill and produce an irregular surface by preferentially dissolving hydroxyapatite crystals on the outer surface. This topography can facilitate penetration of the fluid adhesive components into the irregularities. Once polymerization is complete, the adhesive is locked into the surface and contributes to micromechanical retention. If a laser can accomplish the aforementioned function of acid etching, and even produce a favorable surface for bonding to a restorative material, it may be a feasible alternative to acid etching. The ability of laser irradiation to remove the smear layer has been reported [9]. After being exposed to laser, enamel undergoes physical changes including melting and recrystallization, consequently forming numerous pores and small bubble-like inclusions [10]. This was resembling the type III etching pattern produced by orthophosphoric acid [11]. The recrystallization of dentin after laser exposure has also been demonstrated [13]. With the formation of a fungiform appearance, the microretention or possible chemical adhesion of a restorative material to tooth structure might be increased. Another study also showed that a laser could roughen the enamel surface [14]. Therefore, laser etching may be a feasible method of etching enamel. The Er:YAG laser with a wavelength of 2940 nm is highly absorbed by water and hydroxyapatite. It is the first approved laser tool applied to dental hard tissues in the United States, being effective in cutting enamel and dentin [15]. It was shown that Er:YAG laser-prepared dentin had improved bond strengths when compared with acid-etched groups [16]. However, the tensile strength of bracket-tooth bonds after preparation of the enamel surface by Er:YAG laser etching was inferior to that obtained after conventional acid etching [17]. Nonetheless, if the irradiation parameters can be advertently controlled, the subsurface fissuring that is unfavorable to adhesion may be avoided. There is paucity in literature that compares the bond strengths of orthodontic bracket etched by acid, Er: YAG laser, and combined treatment on the enamel surface. This study investigates methods that could obtain the maximal bond strength and analyzes the fracture mode of each method. Null hypothesis will be that there is no significant difference amongst the four groups.

MATERIALS & METHODS

Specimen preparation

Sixty extracted human premolars were used for this in-vitro study. Crowns with caries, restoration, or fractures were discarded. Any remaining soft tissue was removed from the tooth surface with a dental scaler (Newtron P5 BLED, Acteon, North America). All teeth were stored in 48°C distilled water containing 0.2% thymol to inhibit microbial growth until use.

Fifteen specimens were indiscriminately allotted to each group. Two specimens in each group would not undergo bond test after different etching treatments. The enamel treatments of the groups were as follows:

- Group A: enamel etched with 37% phosphoric acid;
- Group B: enamel irradiated with Er:YAG laser at 300 mJ/ pulse, 10 pulses per second (pps), 10 seconds;
- Group C: enamel etched with 37% phosphoric acid and then irradiated with Er:YAG laser at 300 mJ/pulse, 10 pps, 10 seconds;
- Group D: enamel irradiated with Er:YAG laser at 300 mJ/ pulse, 10 pps, 10 seconds and then etched with 37% phosphoric acid.

Before the procedure was started, all the teeth were cleaned thoroughly by using rubber cup and fine-grit pumice, rinsed with water, and dried with an air spray. Waterproof 1mm-thick aluminum foil with a 3×4-mm hole was accustomed delineate the treatment areas for enamel conditioning.

Etching Procedure

For the acid-etching technique, 37% phosphoric acid solution was applied to the bonding surfaces with applicator brushes for 30 seconds, rinsed thoroughly with water spray, and dried the etched enamel with air using 3way-syring. The etched enamel showed a uniform, dull, frosty appearance.

Laser Treatment

The samples were irradiated with Er:YAG laser (Fidelius III, Fotona, Solvenia) of a wavelength of 2.94 mm at 300 mJ/pulse, 10 pps, 10 seconds. A pilot study was conducted on extracted teeth showed that this energy level produced a microscopically suitable etched pattern. The surface was irradiated manually in a light contact form using a 600-mm optic fiber with a contra-angle hand piece under water spray. After laser treatment, the surface of the enamel appeared frosty similar to that of the acid-etching technique.

Bonding Procedure

The etched surface produced by acid or laser was covered with a small amount of Transbond XT primer and orthodontic adhesive (3M unitek, US) with a brush. A thin, uniform coating covered the whole etched enamel. The Enlight adhesive was applied onto the base of the bracket pad (Dentaurum, Pforzheim Corp, Germany). With the adhesive applied, the bracket was then placed immediately onto the tooth surface, and was pressed firmly after adjusted to final position. Excessive sealant and adhesive were removed from the periphery of the bracket base to keep the bond area of each tooth uniform. According to the manufacturer's instruction, we used a conventional light-curing unit (Woodpecker, China) to shine on the mesial and distal edges of the bracket for 30 seconds each.

Test Procedure

After the brackets were bonded onto the teeth, a custom- made aligning device was used to mount the teeth vertically in custom- made aluminum cylinders (two cm in diameter) with plaster. A hole was prepared in an aligning device to fit exactly the aluminum cylinder. This would make the direction of force in relation to the bracket the same for every specimen. A wire loop on the aligning device hooked the bracket. Samples were tested for the force at bond failure with a Universal testing machine (LLOYD EZ-50) at a crosshead speed of one mm/min. The force and displacement to dislodge the bond between the bracket and enamel were recorded by the load cell, linear variable differential transformer (LVDT, Linear Ball Bearing Series, 65 mm, Half Bridge Model, RDP Electronics Inc., Pottstown, PA) and computer software (Merlin Software Suit, Instron Corp). To determine the fracture mode, we modified the method suggested by Oliver to evaluate debonded surfaces. The digital microscope calculated the area of adhesive remnant on the tooth, and an SEM observed the fracture site. If more than half of the resin remnant existed on the tooth, the bond failure site was at the bracket-resin interface. On the contrary, if less than half of the resin remnant existed on the tooth and the enamel surface was intact, then the bond failure site was at the resin-enamel site.

Analysis was done using SPSS version 20 (IBM SPSS Statistics Inc., Chicago, Illinois, USA) Windows software program. Descriptive statistics included computation of means and standard deviation. Analysis of variance (ANOVA) [for quantitative data within three groups] with post hoc Bonferroni test (to make more intra-groups comparison) were used for quantitative data comparison of all clinical indicators. Level of significance was set at P≤0.05.

STATISTICAL ANALYSIS

The results of the study were subjected to statistical analysis by applying following tests:

1) Mean

$$Mean = \overline{X} = \frac{\sum x}{n}$$

Where,
x – variable
n – sample size

2) Standard Déviation (S.D.)

$$S.D. = \sqrt{\frac{\sum(\overline{x} - x)^2}{n-1}}$$

$\overline{x}$ = being mean for variable x

3) Student's unpaired 't-test'

For comparing different variable in two groups. Formula for "t" is as follows:

$$t = \frac{I\overline{X_1} - \overline{X_2}I}{S.E.(\overline{X_1} - \overline{X_2})}$$

$$S.E.\overline{X_1} - \overline{X_2} = \sqrt{\frac{SD_1^2}{n_1} + \frac{SD_2^2}{n_2}}$$

Where S.E. $(\overline{X_1} - \overline{X_2})$ is standard error of difference between two sample means.

Here,
SD_1 = Standard deviation for the 1st group
SD_2 = Standard deviation for the 2nd group
n_1 = Sample size in 1st group
n_2 = Sample size in the 2nd group
$n_1 + n_2 - 2$ = Degrees of freedom

Bond Strength

Mean, standard deviation (SD), statistical significance (P value) is shown in Table-1 and Table-2. ANOVA and Post hoc Bonferroni test demonstrated that there was a highly significant difference noted between the conventionally etched (16.96±0.65 N), the laser conditioning group (22.1±0.64 N) and the combination of the acid etching and laser groups. Significant difference was reported in acid-etched then laser-ablated group (13.83±0.46 N) or that of the laser-ablated then acid-etched group (12.96±0.56 N) as seen in Graph-1 and Graph-2.

Table-1: Inter-group comparison, Mean±SD, significance value. Lasing showed superior bond strength to acid etching

Table 1	Mean	Std. Deviation	Minimum	Maximum	P value
phosphoric acid	16.96	0.65	16.00	18.20	<0.001 (S)
laser	22.1	0.64	21.10	23.00	
Phosphoric acid + laser	13.83	0.46	13.00	14.60	
laser + Phosphoric acid	12.96	0.56	12.10	13.80	

Table-2: Inter-group comparison of bond strength values. Lasing is superior to acid etching and there is statistical difference between the groups

Table 2		Mean differences	P value
phosphoric acid	laser	-5.14	<0.001 (S)
	Phosphoric acid + laser	3.12	<0.001 (S)
	laser + Phosphoric acid	4.00	<0.001 (S)
laser	phosphoric acid	5.14	<0.001 (S)
	Phosphoric acid + laser	8.26	<0.001 (S)
	laser + Phosphoric acid	9.14	<0.001 (S)
Phosphoric acid + laser	phosphoric acid	-3.12	<0.001 (S)
	laser	-8.26	<0.001 (S)
	laser + Phosphoric acid	0.87	<0.001 (S)
laser + Phosphoric acid	phosphoric acid	-4.0	<0.001 (S)
	laser	-9.14	<0.001 (S)
	Phosphoric acid + laser	-0.87	<0.001 (S)

Discussion

The null hypothesis stating that there is no significant difference between the four groups: Phosphoric acid, Laser, Phosphoric acid+laser and Laser+phosphoric acid has been rejected. In orthodontic practice, a minimum of bond strength between the enamel surface and bracket base is essential for the retention of brackets to dental surfaces and bracket base must be enough to withstand the mechanical and thermal effects of the oral environment. Bonding of brackets is based on alteration of the enamel surface, and the standard protocol for this procedure is an acid etching [18]. The bonding between the bracket and the enamel is based on mechanical interlocking of the adhesive into the micro-porosities of the enamel surface. Therefore, surface conditioning is essential to increase bond strength to enamel. Phosphoric acid etching has been using as standard practice and 30% to 50% phosphoric acid gel, applied for 30 to 60 seconds, is commonly used to remove smear layer for successful bonding and presented as the gold standard method of enamel preparation. Enamel etching modifies the tooth surface from being of low-energy and hydrophobic to being of high-energy and hydrophilic, increasing the surface area for bonding [19]. Innovations in technology as well as the advancement of dental materials for the conditioning of enamel offer several options for orthodontic brackets bonding to the clinician. The most common conditioning technique used in bonding procedures is the use of phosphoric acid as etchant, whereas it is the method that has proved to be the most effective in terms of shear bond strength. However, acidetching has been associated with decalcification and a greater degree of enamel loss [20]. Er:YAG lasers are one of the most popular among laser etching. This laser causes microexplosions inside the material and creates craters. They cause evaporation of tissue fluids and Hydroxyapatite crystals. Er:YAG lasers with a moderate level of energy create a strong bond and do not cause melting or changing the orientation of crystalline structure of enamel in contrast to Nd:YAG and CO2 lasers [21]. The bond strength of orthodontic brackets should be adequate to not produce bonding failure and hindrance in treatment and it also should have sufficient resistance against masticatory forces and stresses from archwires [22]. Conversely, easy debonding of the brackets without any damage to the teeth requires sufficient and safe bond strength [23]. According to few stages for bonding of orthodontic brackets and related problems in the conventional system, other techniques such as application of self-etchprimers or laser irradiation have been suggested to simplify the bonding procedure. Laser etching using erbium laser can be performed with two different wavelengths (2940 and 2780 nm) [24]. This technique has several advantages such as no vibration or heat at the time of irradiation and producing a surface which is acid resistant by altering the calcium to phosphor ratio and formation of less soluble compounds. These characteristics make the erbium family more popular in orthodontics.[25] In this present study, Group B that is laser-treated group attained maximum bond strength which was greater than the conventionally etched (Group A) and groups where combined treatment was done (Group C and Group D). Size of the bonding area is a critical factor for the assessment of the bond strength; hence it is of prime important to control this area. In the present study, the excessive adhesive and resin outsidethe bracket was removed. The placement of aluminum foil also had significance in carefully controlling the etched and irradiated areas, which would help in the reduction of the variations and allow uniform bonding area [24]. The shear bond strength (SBS) of orthodontic brackets should be high enough to prevent bonding failure and should offer adequate resistance against chewing forces and stresses from arch wires. The SBS between the bracket and enamel surface depends on three factors: the design of the bracket base, the adhesive material or bonding resin itself, and the preparation of the tooth surface. Although outcome of acid etching results in high bond strength, its great negative element is the potential for caries formation. Acid etching eliminates and demineralizes the most superficial layer of enamel and makes the teeth more sensitive to long-term acid attacks [23]. Lee S B *et al.*, proposed laser ablation as an alternative method to acid etching. The in-vitro study compared the bond strengths after acid etching, laser ablation, acid etching followed by laser ablation, and laser ablation followed by acid etching. Forty specimens were arbitrarily allocated to one of the four groups. Two more specimens in each group did not undergo bond test and were arranged for observation with scanning electron microscope (SEM) after the four types of surface treatment. After the bond test, all specimens were investigated under the digital stereomicroscope and SEM to document the bond failure mode. The results demonstrated that the mean bond strength of Er:YAG laser ablation was not entirely different from that of acid etching, but considerably greater than those of combined treatments. The failure modes occurred principally at the bracket-resin interface. Compared with the acid-etching technique Er:YAG laser ablation consumed less time. Therefore it was concluded that the Er:YAG laser ablation can be an alternative tool to conventional acid etching. This was in accordance with the results of the current study. Raji H S *et al.*, in an in-vitro study investigated the shear bond strength of teeth prepared for bonding with Er-YAG laser etching and compared them with phosphoric acid etching. The shear bond strength of bonded brackets with the Transbond XT adhesive system was measured with the Zwick testing machine. It was concluded from the results that laser etching at 150 and 100 mj was sufficient for bond strength and presented better results as compared to phosphoric acid [24]. Various studies are not in agreement with our current study. Rosalia C B *et al.*, in this study evaluated the shear bond strength, the adhesive remnant index scores, and etch surface of teeth prepared for orthodontic bracket bonding with self-etching primer and Er:YAG laser conditioning [25]. The results of this study suggest that Er:YAG laser irradiation could not be an option for enamel conditioning. Brauchli M L *et al*., evaluated the impact of an Er:YAG laser and CO2 laser on bond strength and enamel surface structure [26]. As the results were obtained it was concluded that conventional acid etching showed superior bond strength in comparison with both the laser conditioning methods. Of concern were the fissures observed in the enamel surface treated with the Er:YAG laser. According to MF Lasmar, enamel etching for brackets is usually done with phosphoric acid. Er:YAG lasers have been recently used for this purpose with conflicting results. Hence the effects of lasers on tooth demineralization and the effects of different combinations of laser treatments and bonding agents were evaluated [27]. The tensile bond strength of metallic and ceramic brackets using TransbondXT and Fuji OrthoLC were also tested, using acid etching, laser treatment or a combination of both. It was suggested that the demineralization promoted by laser was lower than the one produced with acid. Laser treatment produced lower tensile stress strength than acid, but still enough to produce clinically efficient retention. The combination of laser and acid produced the best retention results. In our study, bond strength was better with the combination of laser and acid as compared to the acid etching alone. With all the thorough research and studies by various authors it can be concluded that the Er:YAG laser can be an alternative tool to conventional acid etching. Further detailed clinical studies and research is required to draw the conclusion as it is a controversial subject whether acid etching is superior as compared to Er:YAG lasers or vice-versa.

Conclusion

Within the limitations of our study, it was reported that the mean bond strength of Er:YAG laser (Group A) ablation was statistically different from that of acid etching (Group B) (P <).05), as well as those of combined treatments (Group C and Group D)(P<0.05). The Er:YAG laser performed better and showed high bond strength as compared to other groups, hence Er:YAG laser can be an alternative tool to conventional acid etching.

Null hypothesis stating that there will be no significant difference between the groups is rejected and it has been reported that lasing was superior in etching the surface for bonding brackets as compared to acid etching and the combination of lasing and acid etching.

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