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Comparison of the adhesive remnant index and shear bond strength of orthodontic brackets using acid etch versus Er:YAG laser treatments

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Abstract

Among the different methods of etching in orthodontic procedures, phosphoric acid etching is the most widely used method with the best bonding affinity, but it has its own drawbacks. To overcome these shortcomings new methods have been developed, among which laser-based approaches are of great importance due to ease of use and few side effects. In this study, the bonding strength of an Er:YAG laser was compared with those of acid etching and self-etching primers for the bonding of orthodontic brackets.

One hundred teeth were randomly divided into five groups to evaluate the properties of each different adhesive system: acid etching, self-etching, Er:YAG laser etching, Er:YAG laser etching + self-etching and Er:YAG laser etching + acid etching. Adhesive remnant index (ARI) scores and shear bond strength (SBS) data were analyzed using the Kruskal–Wallis test and ANOVA test, respectively.

The results of the ANOVA test implied that a significant difference exists between the mean SBS values of the study groups, where the acid-etched groups have the highest bond strengths. The results show that a statistically meaningful difference exists between the ARI scores of the groups.

The results of this study imply that acid etching is the best etching method with regards to bonding strength, but the Er:YAG laser has acceptable bonding strength.

Keywords: Er:YAG laser, orthodontic bracket, bonding strength

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Introduction

Etching is one of the most important steps of the bonding process in orthodontic procedures. Among the different methods of etching in orthodontic procedures, phosphoric acid etching is the most widely used method with the best outcomes. Despite these advantages, using an acid causes demineralization of the surface layer of the tooth and is the greatest disadvantage of this method (Gorelick *et al* 1982, Artun and Brobakken 1986). Because of this problem other methods have been developed for less invasive etching of teeth. Self-etching primers (SEPs) are one of these replacements that are in use for bonding procedures. Although SEPs have a shorter chair time and are much easier to use, they have their own drawbacks, including decreased bracket bond strength (Aljubouri *et al* 2003, Cehreli *et al* 2005, Romano *et al* 2005, Bishara *et al* 2006). The introduction of laser technologies for the purpose of etching has opened new windows in the field of dental treatment and tooth-related complications, including, but not limited to, orthodontic procedures. Among the different types of laser systems, Er:YAG laser etching has attracted most of the attention due to properties such as less chair time, balance of the calcium to phosphate ratio, induction of acid resistance and many other advantages. Based on these advantages, the Er:YAG laser has been used for the bonding of orthodontic brackets for years (Sagir *et al* 2013, Aglarci *et al* 2016, Akin *et al* 2016, Mirhashemi *et al* 2017). These specific characteristics of the Er:YAG laser suggest that it could be a replacement for other methods. There are numerous studies on the actual characteristics and suitability of different types of lasers for the purpose of etching in orthodontic procedures. Despite these efforts, the exact outcomes of using a laser for etching, with regards to its effects on the strength of the bonding between the brackets and the enamel, remains largely unresolved. Therefore, in this study we aim to compare the bonding strength of different etching methods, namely self-etching, acid etching, Er:YAG etching and combinations of these methods to understand the dynamics of bonding under these different conditions. Examination of the strength of this bonding, by measuring properties such as the adhesive remnant index (ARI) scores and shear bond strength (SBS) is the other aim of this study. Some studies have shown the effects of Er:YAG laser irradiation on both enamel demineralization and the bond strength of brackets (Lasmar *et al* 2012, Fornaini *et al* 2014). However, the outcomes of these investigations are, in most cases, paradoxical and inconclusive.

Materials and methods

One hundred teeth that had undergone trans-illumination testing and were proved to have intact enamel surfaces were entered into the study. Samples were stored in 0.2% thymol solution at room temperature. The solution was changed weekly to prevent bacterial growth. The teeth were randomly divided into five groups to evaluate the properties of each different adhesive system as follows.

Group 1: acid etching (phosphoric acid 37%, 3M Scotchbond).
Group 2: self-etching (3M, Unitek Transbond Plus).
Group 3: Er:YAG laser etching (25 mJ, 1.0 W).
Group 4: Er:YAG laser etching (25 mJ, 1.0 W) + self-etching (3M, Unitek Transbond Plus).
Group 5: Er:YAG laser etching (25 mJ, 1.0 W) + acid etching (phosphoric acid 37%, 3M Scotchbond).

Etching procedures

The buccal surfaces of the enamel teeth in group 1 were etched with 37% phosphoric acid (3M Scotchbond) for 15 s, then rinsed for 15 s, and dried thoroughly in moisture- and oil-free air to obtain an opaque white appearance. In group 2, the buccal surfaces of the enamel were etched with a self-etching kit (3M Unitek, Transbond™ Plus self-etching primer) for 3 s using manufacturer's guidelines. The buccal surfaces of the third group were etched using a 2940 nm Er:YAG laser (Pluser) for 10 s. The laser parameters were as follows: energy per pulse 25 mJ, and average output power of 1 W. Simultaneously, the teeth were washed to prevent overheating.

Then, the teeth were air dried until a characteristic frosty opaque etched area was observed, similar to the acid-etched group. After the etching procedure, the brackets were bonded according to the following bonding procedures.

Bracket bonding

After the etching procedures, a thin layer of adhesive resin (Transbond XT, 3M, Unitek) was applied on the tooth surface using a brush. The brackets that were used were metal-based American orthodontic brackets with diameters of 4 $*$ 4 mm and 12 mm square cross section. The brackets were positioned centrally on the surfaces of the teeth and bonded using composite resin. Adhesives were cured using an LED light (Mectron) for 40 s.

Thermal cycling

For the purpose of simulation of the *in vivo* situation in the mouth cavity, after bracket bonding, the teeth were thermocycled between 5 °C and 55 °C for 500 cycles (20 s in 5 °C water and 20 s in 55 °C).

Bracket debonding

Debonding was performed using a universal testing machine with a cross head speed of 1 mm min^{-1}. The pressure was continued until bond failure. The amount of pressure was recorded in newtons, and for calculation of the SBS, the values of force were divided by the bracket base area, which in this case was 12 mm^2. The final value was reported in megapascals (mpa).

Statistical analysis

The data were analyzed using SPSS software (version 21.0; SPSS Inc, Chicago, IL). ANOVA and post-hoc multiple

Table 1. Mean SBS values of different groups in the study.

Groups	Count	Minimum	Maximum	Mean	Std. deviation
Acid phosphoric 37%	20	3.77	27.2	14.27	6.40
Self-etch	20	2.14	18.08	9.72	4.18
Er:YAG Laser	20	1.57	10.8	7.45	2.56
Self-etch + Er:YAG	20	4.06	10.1	8.29	1.42
Acid phosphoric 37% + Er:YAG	20	5.51	19.65	11.49	3.58

comparison tests were used to compare the SBS values of different samples among the groups. To analyze the ARI score levels the Kruskal–Wallis test was used. All tests were performed with a significance level of $p < 0.05$.

Results

SBS evaluation

The statistical characteristics of the SBS for all five groups of the study are summarized in table 1.

The results of the ANOVA test implied that a significant difference exists between the mean SBS values of the study groups ($P < 0.05$). Multiple comparisons were carried out between groups by means of the Tukey post-hoc test, which showed significantly higher SBS values for acid-etched groups compared to lasered groups (table 1).

ARI evaluation

The remaining adhesive on the teeth in each group was evaluated according to the modified ARI scores defined by Artun and Bergland in 1984 (Artun and Bergland 1984). The results of the ARI scores are presented in table 2. The results show that a statistically meaningful difference exists between the ARI scores of the groups.

Discussion

Over the last 30 years numerous studies have been carried out on the subject of techniques for the bonding of brackets to enamel. Various methods have been developed over the years, but in terms of bonding strength, acid etching is still considered as the gold standard method (Buonocore 1955, Keller and Hibst 1989, Yassaei *et al* 2014a). Despite its usefulness, acid etching is associated with many complications in practice; most notably it causes demineralization of enamel which can make the teeth prone to tooth decay, especially when air bubbles and saliva contamination disturb the resin penetrance and plaque accumulation adjacent to the brackets (Goldstein and Parkins 1995, Bevilacqua *et al* 2007).

There are some other options to phosphoric acid etching, namely the use of maleic and/or polyacrylic acids and sandblasting, but each of these has its own drawbacks. The most important of these drawbacks is weaker bond strength compared with phosphoric acid etching (Goldstein and Parkins 1995, Bevilacqua *et al* 2007). Recently, other methods have been introduced in the field of dentistry. One of these methods is the use of a laser beam and the creation of numerous bubble-shaped pores on the surface of the tooth enamel, which creates a rugged surface with open dentin tubules for binding and bracketing (Keller and Hibst 1989, Lee *et al* 2003). There are numerous advantages of using a laser instead of acid for etching; these advantages include, but are not limited to, alteration of the calcium to phosphorus ratio, reduction of water and organic content and a decreased risk of caries due to pyrophosphate formation. This latter case is of great importance for orthodontics (Sognnaes and Stern 1965, Keller and Hibst 1989, Oho and Morioka 1990). Self-etching is another method which has lower post treatment sensitivity than regular etching due to the presence of a substance called MDP-10. This method has a shear bond with lower strength in contrast to acid etching.

Our data show that, in general, the SBS values of bracket bonding are higher for acid etching compared with laser etching. It has been suggested that bond strengths ranging from 6 to 8 MPa can be considered as clinically acceptable bonding strengths (Gorler and Saygin 2017). Hence, we could consider the results of almost all of the methods in this study as acceptable for bonding purposes. Despite the presence of sufficient band strength in all the methods in this study, acid etching with a laser and the self-etching methods had similar bond strengths to the acid-etching method, while self-etching with lasers and laser-alone methods had less band power than lasers. Based on the present study, it seems that although the bond strength of self-etching is in a clinically acceptable range, it is lower than the ordinary acid-etching bond strength. Although self-etching had a lower bonding power in contrast to the acid-etching method, our results showed acceptable bonding power with this method, which is in agreement with the results from Ryan *et al* and Samir *et al*. Bishara *et al* suggested that although the strength of the self-etching bond was significantly lower than the acid-etch group, it could be clinically acceptable (Bishara *et al* 2006). Based on the present study, the bond strength obtained from the laser seems to be in the acceptable clinical range, but its strength is less than that of the acid-etching bond.

It is worth noting that various results have been obtained from the use of lasers in enamel etching, which can be explained by the types of lasers and their related parameters in studies.

Moreover, in concordance with the findings of others, (Corpas-Pastor *et al* 1997, Martinez-Insua *et al* 2000), the results of this study show that the mean SBS of the acid etching groups are higher than the laser-etching groups per se. This, however, is contrary to the findings of Visuri *et al* (1996).

The most probable explanation for such a pattern might be the fact that the patterns of laser etching, unlike those of acid etching, are not heterogeneous; therefore, they cannot

Table 2. The ARI scores of the samples.

Groups	Counts	ARI codes 0	1	2	Total
Acid Phosphoric 37%		17	1	2	20
	%within group	85.0%	5.0%	10.0%	100%
Self-etch		17	3	0	20
	%within group	85.0%	15.0%	0.0%	100%
Er:YAG laser		16	4	0	20
	%within group	80.0%	20.0%	0.0%	100%
Self-etch + Er:YAG		20	0	0	20
	%within group	100%	0.0%	0.0%	100%
Acid		10	7	3	20
Phosphoric 37% + Er:YAG	%within group	50.0%	35.0%	15.0%	100%
Total		80	15	2	20
	%within group	80.0%	15.0%	5.0%	100.0%

provide an effective surface for implantation of resin into the surface of the enamel. Others have proposed other explanations for this lower bonding strength, including enamel micro pores, cracks, craters and melted bubbles produced during the laser etching procedure (Ariyaratnam *et al* 1997), and also the power of the laser beam in use and superficial energy exerted by the laser (Drummond *et al* 2000).

The lower bonding strength of laser etching can be compensated by the fact that it makes the tooth surface resistant to attack from acid and needs a less-isolated field to obtain adequate bond strength. This is particularly important and helpful when high bonding strength is not necessarily important, for example, when using ceramic brackets. Debonding of ceramic brackets is difficult and is associated with a high risk of enamel fracture. This is especially important when chemical bonding of ceramic brackets with a silane coupling agent is provided (Lee 2005).

The results of this study of SBS with lasers and regular etching were not comparable with the results of Hosseini *et al* due to the 1.5 W laser and fewer samples in their study (Hosseini *et al* 2012). Yassei *et al* reported that although SBSs are higher with the acid-etching method, using an Er:YAG laser can provide acceptable strength for orthodontic treatment (Yassaei *et al* 2014b). These results were similar to ours. Contrary to the results of this research, Basaran *et al* concluded that the SBSs of the ordinary acid etching and laser are similar and comparable (Basaran *et al* 2007). They used an Er,Cr:YSGG laser, while we used an Er:YAG laser. This may be the reason for the different results. It seems that the use of various types of lasers is the main reason for this different outcome. In another study on 100 teeth, it was shown that all the groups had the potential for proper bonding (Gokcelik *et al* 2007). Self-etching and a laser had a similar SBS to acid etching. Finally, based on the results of this study, it seems that although the bond strength of the combination of the laser and acid-etching method is in the clinically acceptable range, it is lower than regular etching. Although the use of a laser with ordinary etching in some studies improved bond strength, it did not have a positive effect in this study. The probable cause of this event is different laser protocols.

In this study adhesive assessment was carried out according to the ARI introduced by Artun and Bergland (1984). The amounts of adhesive remnant can be evaluated with both qualitative and quantitative methods.

The results of the ARI scoring showed that bonding failures in the first four groups were mostly of the adhesive type, and in the last group the mixed bond failure was the predominant type of failure observed. There is no unified standard regarding the preferable site of bond failure. Some researchers believe that bond failure at the bracket– adhesive surface is better, because it reduces the risk of enamel fracture and crazing during the debonding procedure, especially for ceramic brackets (Yassaei *et al* 2014a). Others believed that bond failure at the enamel–adhesive interface was preferred since it left less residual adhesive remnants, and consequently shorter chair time was needed to remove them (Bishara and Trulove 1990). The results of Vijian *et al* were also similar to ours (Vijayan *et al* 2015). The evaluation of the etching pattern in the group with the combination of a laser and self-etching showed degradation. This also shows the accuracy of the results given the lower bond strength of this group than the acid-etching group.

Conclusion

It is concluded that all the methods of enamel preparation that were tested in this study are clinically suitable for orthodontic bracket bonding. Overall, the results of this study imply that acid etching is the best etching method with regards to bonding strength. Nevertheless, a combination of acid etching and Er:YAG laser etching can result in acceptable bonding strength with fewer drawbacks compared to the pure acid-etch approach.

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