Original Article

Influence of erbium: Yttrium-aluminum-garnet laser, potassium titanyl phosphate laser irradiation, and acid etch on microtensile bond strength of adhesives

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ABSTRACT

The aim of this study was to evaluate the microtensile bond strength (µTBS) of one layer or two-layer applications of single bond (SB) and prime & bond (PB) which prepared with erbium: Yttrium-aluminum-garnet (Er:YAG) laser, potassium titanyl phosphate (KTP) laser, and acid-etched dentin. Various surface pretreatments have been developed to have better adhesion to dentine. However, the effects of laser-etch and acid-etch on adhesion with various applications of bonding agents have not yet been achieved. Twenty-four human third molar teeth were used in this study. One-third of the teeth were removed; then the teeth divided into three groups and two subgroups randomly. After Er:YAG laser, KTP laser, and acid-etch applied to dentine, SB and PB applied one or two layer for the subgroups. Waiting in distilled water for 24 h, the teeth were sectioned to sticks and the sticks were stressed in tension until failure using a microtensile testing machine. The data were collected in SPSS for statically analysis with three-way ANOVA and independent sample *t*-tests at the confidence interval of 95%. The highest µTBS values were in Er:YAG laser and PB group in one-layer application. The Er:YAG laser can be useful to obtain high µTBS values. Applying a second consecutive coat of adhesive showed decreased µTBS values and KTP laser was not effective to obtain an increased µTBS values.

Key words: Adhesive, Erbium:Yttrium-Aluminum-Garnet Laser, Potassium Titanyl Phosphate Laser, Microtensile

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INTRODUCTION

Adhesion to dental hard tissues can be achieved by the use of bonding agents that promote a micromechanical interlock with both enamel and dentine. Bonding to dentin depends on the infiltration of synthetic adhesive monomers into a biological, collagen-rich substrate to form a hybrid layer. Nevertheless, dentine adhesives have brought about major changes in restorative procedures. The evolution of adhesive systems that has been designed to achieve the bond of the adhesive to the dental structure has improved the clinical performance of restorations because of better adaptation to cavity walls.[1,2] Consequently, there has been a decrease in microleakage and secondary caries. Most of the adhesive systems include an acid-etching procedure to provide better adhesion to dental substrate since it was intended for use in pretreatment of dental hard tissues. Acid-etching promotes increased bond strength to dental hard tissues, but acid-etching has some disadvantages like; making the dental substrate more prone to acid attacks, swallowing, aspiration, and burning of the tongues, increased dentin permeability increased diffusion coefficient, easy penetration of bacteria and this may cause to hypersensitive dentine.[3-6] The disadvantages of the acid-etching thought researchers that laser etching may be alternative to acid-etching.[5,7]

Laser appliances have brought indisputable benefits to modern dentistry.[8,9] They minimize the loss of healthy tissue and promote a great deal of comfort to patients.

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Laser procedure is normally well-tolerated, and there is reduced pain compared to that caused by the high-speed drill due to its noise and vibration.[10-12] To overcome the disadvantages of acid-etching, lasers could be considered an alternative device to prepare dentine and enamel for bonding procedures.[7] Furthermore, the use of laser devices may eliminate the need for the acid-etching procedure.[13-16] Several types of lasers such as neodymium: Yttrium-aluminum-garnet (Nd:YAG), erbium: Yttrium-aluminum-garnet (Er:YAG), and carbondioxide lasers are widely used in dentistry.[17]

The Er:YAG laser effectively ablates dental hard tissues with 2.94 μm wavelength and does not lead to irreversible alterations of the dental pulp or to significant thermal or structural damage in dental tissues.[18] The Er:YAG laser can increase fluoride uptake and decrease acid dissolution, thus creating a surface that is more resistant to acid attack and caries formation.[19]

A frequency-doubled Nd:YAG laser was introduced that is called the potassium titanyl phosphate (KTP) laser. The KTP laser is a solid-state laser designed to pass an Nd:YAG incident beam of 1064 μm through a KTP crystal to produce an intense visible green laser light of 532 nm. This process causes the 1064 μm wavelength to be shortened by half while doubling the beam's frequency.[17] The KTP laser has also been used for other dental applications, similar to the Nd:YAG laser.[20]

Adhesive systems are used to improve the durability of restorative materials. To improve the adhesion to dental hard tissues, three-step, two-step, and one-step adhesive systems are available.[21-24] Because they produce thin layers, the application of these adhesives in two layers instead of one has been widely recommended to improve clinical efficiency.[22,25,26]

Thus, the aim of this study was to evaluate the effects of the Er:YAG and the KTP laser etching on microtensile bond strength (μTBS) with two-layer adhesives applied to surfaces of two different bonding agents. The null hypothesis tested was that there were no differences between two lasers and two layers of adhesive applied on dentine's μTBS of two different bonding agents.

MATERIALS AND METHODS

Twenty-four human primary molar teeth were used in this study. The teeth were stored in distilled water and used within 1-month. One-third of the teeth (from the coronal portion) were removed using an Isomet low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). A stereomicroscope was used to check for the absence of enamel and pulp tissue on the resultant substrate. Twenty-four teeth were divided into three groups and then into four subgroups randomly, therefore, two teeth were used for each group [Table 1].

Laser applications

The Er:YAG laser and the KTP laser were used in this study. The Er:YAG laser (Smart 2940D Plus, Deka Laser, Florence, Italy) was applied to dentine surface with noncontact mode. Laser energy was delivered with a wavelength of 2.94 μm, for 30 s at 100 mJ energy output, 1 W, 10 Hz frequency, and focal distance of 17 mm. The KTP Laser (Smartlite D, Deka, Calenzano Firenze, Italy) was applied to dentine surface with a wavelength of 532 nm, with a noncontact mode for 30 s at 1 W energy output with a pulsed mode (Ton: 10,Toff:50) and focal distance of 1 mm.

Acid-etching application

37% Phosphoric acid (FineEtch 37, Spident Co., Ltd, Korea) was applied for 30 s, rinsed for 20 s, and dried.

Bonding procedures

Two adhesives, prime and bond (PB) NT (Dentsply Detrey, Konstanz, Germany) and Adper single bond (SB) 2 (3M ESPE, St. Paul, MN, USA), were applied to surfaces according to the protocols of the manufacturer's instructions.

For PB one-layer application (PBX1); PB was applied to the surface, gently dried, and light-cured with a light-emitting diode curing light (Bluephase, Ivoclar Vivadent).

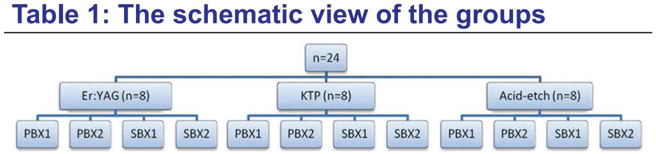
For PBX2, after following the same procedures, a second layer of PB was applied and light-cured in a similar manner.

For SB one-layer application (SBX1), SB was applied to the surface, gently dried, and light-cured.

For SBX2, after following the same procedures, a second layer of SB was applied and light-cured.

After applying adhesive, resin composite crowns (Tetric N-Ceram, Ivoclar Vivadent, Liechtenstein) were built up in 1 mm increments up to 5 mm. The teeth were stored in distilled water for 24 h.

Table 1: The schematic view of the groups



PB: Prime and Bond NT, SB: Adper single bond, One layer application: X1, Two layer applications: X2

At the end of 24 h, the teeth were longitudinally sectioned in both 'x' and 'y' directions with a slow-speed saw under water cooling to obtain bonded sticks with a cross-sectional area between 0.9 mm^2 and 1 mm^2. For each group, 16 sticks were obtained. The sticks were stored in distilled water for 24 h. Then the sticks (*n*:15) were fixed to the universal testing machine with cyanoacrylate adhesive plus an accelerator (Zapit, Dental Ventures of America, Corona, CA, USA). The specimens were stressed in tension until failure using a universal testing machine (LF Plus, LLOYD Instruments, Ametek, Inc., England) at a crosshead speed of 0.5 mm/min, and the μTBS was calculated and expressed in MPa. The remaining one stick was used for scanning electron micrograph (SEM) evaluation.

Statistical analysis

After recording the data, the results were subjected to statistical analysis using the software Statistical Packages for Social Sciences for Windows 15.0 (SPSS, Inc., Chicago, IL, USA). μTBS data were analyzed using three-way ANOVA, Tukey's *post-hoc*, and independent sample *t*-test.

RESULTS

When we compared the effects one by one, surface preparations, bonding agents and multiple coatings showed significantly differences ($P < 0.05$). In binary comparison, while surface preparation-bonding agents and surface preparation-coating relationship affected μTBS values ($P < 0.001$), the bonding agents-coating relationships had no effect on μTBS values ($P > 0.05$). In triple comparisons, surface pretreatments-bonding agent-coatings had no effect on μTBS values ($P > 0.05$) [Table 2].

According to Tukey's *Post-hoc* tests of surface preparations, there were no significant differences between the Er:YAG laser and acid-etching ($P > 0.05$), but KTP laser showed a significant decrease in binary comparison ($P < 0.05$) [Table 3].

When surface prepared with the Er:YAG laser, PBX1 showed significantly increased μTBS values ($P < 0.001$), as did the Er:YAG laser PBX2 ($P < 0.001$). PBX1 and PBX2 showed significantly increased μTBS values compared with SBX1 and SBX2 groups ($P < 0.001$).

According to SEM analysis, increased penetration depth could be seen when surface was etched with Er:YAG laser because of being a hard tissue laser [Figure 1].

When surface prepared with acid-etching, there were no significant differences SB and PB

In the KTP groups, PBX2 and SBX2 showed significantly decreased μTBS values compared with the Er:YAG laser and acid-etching ($P < 0.001$).

Altogether, one-layer application of two bonding agents showed higher bond strength compared to two-layer application.

DISCUSSION

Conventional dentin bonding protocols advocate the use of an acid to remove the smear layer, partially demineralize dentin and expose collagen fibers, in addition

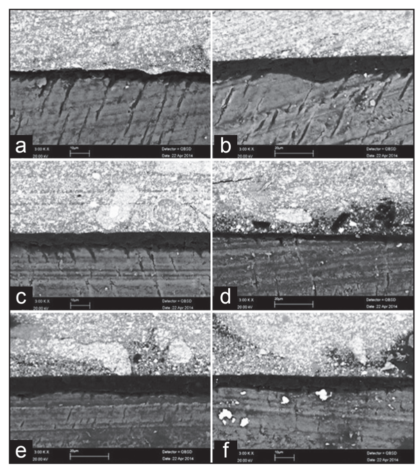


Figure 1: Scanning electron micrograph images of the groups (a) the image shows prime and bond (PB) application of erbium: Yttrium-aluminum-garnet (Er:YAG) laser surface (b) single bond (SB) application of Er:YAG laser surface (c) PB application of KTP laser surface (d) shows SB application of potassium titanyl phosphate laser surface (e) PB application of acid-etched surface (f) SB application of acid-etched surface

Table 2: Three-way ANOVA table for overall models

Source	Sum of squares	df	Mean square	F	P
Surface preparation	1908.39	2	954.19	13.41	0.000
Bonding agent	2030.38	1	2030.38	28.55	0.000
Coating	660.94	1	660.94	9.29	0.003
Surface preparation*bonding agent	1754.49	2	877.24	12.33	0.000
Surface preparation*coating	681.39	2	340.69	4.79	0.009
Bonding agent*coating	0.91	1	0.91	0.013	0.910
Surface preparation*bonding agent*coating	159.82	2	79.91	1.12	0.327

Table 3: Mean and SD

μTBS values(mPA)	Mean + SD (mPA)											
	KTP laser[b]				ER:YAG laser[a]				Acid etch[a]			
	PBX1	PBX2	SBX1	SBX2	PBX1A	PBX2	SBX1	SBX2	PBX1	PBX2	SBX1	SBX2
	20.04±8.73	11.93±5.03	16.90±10.68	6.41±2.12	31.17±15.22[A]	27.01±10.85[A]	13.39±5.14	14.24±7.06	19.32±8.95	20.52±5.52	20.52±5.52	18.23±8.11

[a,b]The surface differences, [b]Significant decrease when compared with a, [A]Significantly increased μTBS values, SD: Standard deviation, KTP: Potassium titanyl phosphate, Er:YAG erbium: Yttrium-aluminum-garnet, μTBS: Microtensile bond strength

to widening the lumen of dentinal tubules. Thus, the bonding agent is able to interact with dentin to form a hybrid layer. However, acid-etching may make dentin more permeable, and it may be not completely filled with adhesive. Therefore, alternative dentinal surface treatments like Er:YAG laser irradiation have been proposed, in order to achieve better bond strength results.[7,27]

Under the limitations of this study, the null hypotheses were rejected. There were significant differences between two lasers. The Er:YAG laser, which has a 2.94 μm wavelength, showed increased μTBS values when used with PB. The Er:YAG laser used with SB showed lower μTBS values, but they were not significantly different compared to those of the KTP laser.

Lasers are used in dentistry for different purposes, one of which is etching. According to some authors, the use of laser device can easily eliminate the need for the acid-etching procedure,[13-15] but to have a better adhesion to dental hard tissues, other authors recommend the use of the laser in combination with acid-etching.[7,9,16,28] In this study, the Er:YAG laser group showed better results than other groups. Increased μTBS values were in the Er:YAG lased group with bonded PB in one-or two-layer application. These results are understandable and may be explained by the high energy of the Er:YAG laser. The Er:YAG laser has a high absorption rate by water and can selectively remove hydroxyapatite crystals. When Er:YAG laser is applied to a surface, it creates irregular surfaces, without a smear layer and opened dental tubules that could improve retention of adhesive systems to dentinal substrate.[7,9,29-32] In this study, the Er:YAG laser showed the highest values in PBX1. According to intra-group comparison of the Er:YAG laser of either one- or two-layer application, the PB showed increased values to SB ($P < 0.05$).

Different levels of Er:YAG laser energy were used by researchers, but most of them required that increased energy levels of Er:YAG laser energy cause the heating of dental structures, microcracks, and melting.[33,34] For these reasons, we preferred to use the Er:YAG laser with for 30 s at 100 mJ energy output, 1W, 10 Hz frequency.

According to the Tukey *post-hoc* test, there were no statistical differences between the Er:YAG laser and acid-etching ($P > 0.05$). However, between the Er:YAG laser, acid-etching, and the KTP laser, significant differences were found ($P < 0.05$). The KTP laser had shown low μTBS values compared to the Er:YAG laser and acid-etching. There was a significant decrease in the values of two-layer application both in SB and PB groups. This result might be related to the low wavelength features of this laser. Possibly, the 532 μm wavelength of this laser does not provide a sufficiently etched surface. Another reason for the decreased values may be the effects of the laser on the smear layer. Tewfik *et al.*[35] found the laser did not modify the permeability of the smear layer-covered dentine, although SEM examination revealed modifications to the surface of the smear layer with no subsequent effects on the underlying dentine. Schoop *et al.*[36] found that the KTP laser obviously causes melting and recrystallization of the surface, thus partly obliterating the dentinal tubules. This may influence the penetration of adhesive to dentinal substrate. Akin *et al.*[37] found that the KTP laser is not effective in obtaining an increased μTBS values when they used KTP laser on silicone-based soft denture liners. We are in agreement with these authors that the KTP laser is not effective in obtaining increased μTBS values.

Acid-etching is commonly used to provide increased adhesion to dental hard tissues. Acid-etching provides homogeneous, uniform microporosities that lead increased adhesion to dental hard tissues. In this study, no significant differences were found in either one- or two-layer application of SB or one- or two-layer application of PB in acid-etched surfaces.

In the PBX1 group, the mean μTBS values were 23.51 MPa, and the order of the MPa values was Er:YAG>KTP>acid-etching, respectively. In PBX2 group, the mean values were 19.82 MPa, and the best MPa values were Er:YAG>acid-etching>KTP. These results also agree with the previous studies.[13-15] that the acid-etching procedure can be discarded when used with PB. In the SBX1 group, the mean μTBS values were 16.94 MPa, and the best MPa values were acid-etching >KTP>Er:YAG. In the SBX2 group, the same values were 12.94 MPa, and the order of MPa values were acid-etching >Er:YAG>KTP. SB used with acid-etching showed better results than SB used with the Er:YAG laser. Burnett *et al.*[38] found increased bond strength values when the Er:YAG used with SB, but in this study, increased bond strength was only obtained when the Er:YAG was used with PB.

The high MPa values were seen with PB. The result of this study was in accordance with Jiang *et al.*[39] and Delfino *et al.*[40] that PB showed higher μTBS values in Er:YAG lased surfaces. This result likely depends on the composition of these materials. PB contains dipentaerythritol pentaacrylate monophosphate (PENTA), an acidic phosphonated monomer, that could interact with the calcium ions left on the dentine surface or even in the underlying dentine.[41] NT contains urethane dimethacrylate (UDMA) and PENTA instead of hydroxyethylmethacrylate (HEMA). It was reported that mixtures of UDMA and HEMA in acetone have a high potential to be effective enamel/dentine adhesives. It is not clear if the PENTA contained in this system is less effective than HEMA for adhesive resin bonding to the demineralized dentine.[42] Acetone, a volatile solvent in the adhesive system can remove all residual moisture from the etched enamel carrying resin monomers into close adaptation with the surface.[43] and this may affect the diffusion of adhesive into dentine tubules which may increase the bond strength.

The authors[25,26,44] suggested that two-layer application of these adhesives would be beneficial, but in this study, μTBS values decreased in two-layer applications. There are different opinions about multiple-layer applications, but according to our results (unpublished data), multiple applications vary from the restorative materials, adhesives, and techniques used in the study.

The total μTBS values of multiple applications of SB and PB showed a decrease, meaning that two-layer applications cannot improve μTBS values.

CONCLUSIONS

Within the limitations of this study, there were significant differences between the Er:YAG laser and the KTP laser. The Er:YAG laser could be useful to obtain high μTBS values, but KTP laser was not effective to obtain an increased μTBS values. Applying a second consecutive coat of adhesive showed decreased μTBS values.

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