Lasers in Medical Science
https://doi.org/10.1007/s10103-017-2417-1

ORIGINAL ARTICLE

Comparative efficacy of Er,Cr:YSGG and Er:YAG lasers for etching of composite for orthodontic bracket bonding

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Received: 28 September 2017 / Accepted: 7 December 2017

Abstract

Several techniques have been proposed to obtain a durable bond, and the efficacy of these techniques is assessed by measuring parameters such as bond strength. Laser has provided a bond strength as high as that of acid etching in vitro and has simpler use with shorter clinical time compared to acid etching. This study aimed to compare the efficacy of Er:YAG and Er,Cr:YSGG lasers for etching and bonding of composite to orthodontic brackets. No previous study has evaluated the effect of these particular types of laser. A total of 70 composite blocks were randomly divided into five groups ($n = 14$): group 1, etching with phosphoric acid for 20 s; group 2, Er:YAG laser irradiation with 2 W power for 10 s; group 3, Er:YAG laser with 3 W power for 10 s; group 4, Er,Cr:YSGG laser with 2 W power for 10 s; group 5, Er,Cr:YSGG laser with 3 W power for 10 s. Metal brackets were then bonded to composites, and after 5000 thermal cycles, they were subjected to shear bond strength test in a universal testing machine after 24 h of water storage. One sample of each group was evaluated under a scanning electron microscope (SEM) to assess changes in composite surface after etching. The adhesive remnant index (ARI) was calculated under a stereomicroscope. Data were statistically analyzed. The mean and standard deviation of shear bond strength were 18.65 ± 3.36, 19.68 ± 5.34, 21.31 ± 4.03, 17.38 ± 6.94, and 16.45 ± 4.26 MPa in groups 1–5, respectively. The ARI scores showed that the bond failure mode in all groups was mainly mixed. The groups were not significantly different in terms of shear bond strength. Er:YAG and Er,Cr:YSGG lasers with the mentioned parameters yield optimal shear bond strength and can be used as an alternative to acid etching for bracket bond to composite.

Keywords Composite resins · Composite etching · Er,Cr:YSGG laser · Er:YAG laser · Shear bond strength · Orthodontic bracket bond

Introduction

Composite resins are among the commonly used dental restorative materials due to excellent properties such as conservative cavity preparation, optimal esthetics yielding excellent color match with natural teeth, and minimal clinical working time. Due to high prevalence of caries and significance of dental esthetics, use of composite resins has greatly increased. Growing number of orthodontic patients also necessitates finding a suitable method for orthodontic bracket bonding with minimal invasion to restored teeth and optimal bond strength. Chemical and mechanical methods available for this purpose include composite removal by bur, sandblasting, and air abrasion, which provide optimal bond strength; however, they compromise esthetics and may result in leakage of restorations [1–4].

Laser abrasion to enhance bond strength of orthodontic brackets is a minimally invasive technique. Erbium lasers have been used for this purpose and resulted in optimal bond strength to natural tooth structure and restorative materials such as composite resins [5, 6]. In orthodontics, laser can be used to modify the hard tissue. Depending on their level of energy, these photons can etch the surface to a depth of 10–20 μm [7, 8]. Laser etching is painless and has been suggested as an alternative to acid etching procedure due to time-

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Published online: 11 January 2018

consuming nature of acid etching, short shelf life of acids, and technical sensitivity.

The Er,Cr:YSGG and Er:YAG lasers are commonly used for laser etching. These lasers cause microexplosions inside the material and create craters. They cause evaporation of tissue fluids and hydroxyapatite crystals. These 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 [9]. These lasers are often compared based on the surface texture of materials after their irradiation as well as the amount of generated heat. The Er:YAG laser at wavelength of 2940 nm and Er,Cr:YSGG laser at wavelength of 2780 nm have a peak absorption in water [10, 11]. Both lasers have the same depth of etching (material removal); however, diameter of craters and the amount of ablated tissue with each pulse of Er:YAG laser are greater than those in Er,Cr:YSGG laser. However, the amount of generated heat is higher in use of Er,Cr:YSGG laser. Topcuoglu et al. in 2013 evaluated the effect of Er:YAG laser etching on bond strength of orthodontic brackets to enamel compared to phosphoric acid and showed that this laser was highly effective to enhance the bond strength accompanied by optimal abrasion under water coolant in the enamel [12].

Berk et al. in 2008 compared conditioning by Er,Cr:YSGG laser with other conventional methods and concluded that this laser is efficient in 1.5–2 W power and yielded acceptable bond strength [13]. Since these lasers have yielded optimal bond strength as high as that obtained by acid etching as well as the minimally invasive nature of laser irradiation, this study aimed to assess the effect of two erbium lasers namely Er,Cr:YSGG and Er:YAG lasers on composite resin.

Materials and methods

In this in vitro, experimental study, 70 composite blocks (Filtek Z250, 3M ESPE, St. Paul, MN, USA) measuring 7 × 7 × 5 mm were fabricated and stored in distilled water. The composite blocks were made in two halves and each half was cured for 30 s. The upper half was used for etching and bracket bonding. Blocks were removed from the molds and were randomly assigned to five groups ($n = 14$).

Group 1: Composite blocks were ground by a diamond bur under water spray, etched with 37% phosphoric acid for 20 s, rinsed with 15 s, and dried for 15 s with gentle air spray.

Group 2: Composite blocks were irradiated with Er:YAG laser (Smart 2940 D Plus; Deka, Italy) with 2 W power, 100 mJ pulse energy, and 20 Hz frequency as VSP with pulse width of 230 μs under water and air spray.

Group 3: Composite blocks were irradiated with Er:YAG laser (Smart 2940 D Plus; Deka, Italy) with 3 W power, 150 mJ pulse energy, and 20 Hz frequency as VSP with pulse width of 230 μs under water and air spray.

Group 4: Composite blocks were irradiated with Er,Cr:YSGG laser (Water Lase iPlus, Biolase, USA) with 2 W power, 100 mJ pulse energy and 20 Hz frequency in H mode with pulse width of 60 microseconds under water and air spray.

Group 5: Composite blocks were irradiated with Er,Cr:YSGG laser (Water Lase iPlus, Biolase, USA) with 3 W power, 150 mJ pulse energy, and 20 Hz frequency in H mode with pulse width of 60 μs under water and air spray.

Bracket bond to composite surface

After composite surface preparation, one sample of each group was randomly selected for inspection under a scanning electron microscope (SEM). The remaining samples were used for bracket bonding. A thin layer of primer (Transbond XT, 3M ESPE, St. Paul, MN, USA) was applied on the surface by a microbrush so that it had a uniform thickness in all parts. Light curing was performed for 20 s. Next, Transbond XT adhesive was applied on bracket base (3M Unitek, CA, USA). Central incisor brackets (Dentaurum, Ultra trim, Ricketts Universal, Germany) were placed at the center of each block and pressed on the adhesive. Light curing was performed for 40 s. Excess resin was removed by an explorer and bracket stability was manually assessed. All samples bonded to brackets were incubated at 37 °C for 24 h in order to complete the setting process. After bracket bonding, samples were transferred to a thermocycler.

Thermocycling

All samples had to be stored in distilled water at 37 ± 2 °C in order to differentiate materials that are capable to tolerate moisture. Thus, bracket bonded blocks were stored in distilled water at 37 ± 2 °C for 24 h and were then subjected to thermocycling (TC300; Vafaei Industrial, Iran). All 65 samples were coded and subjected to 5000 thermal cycles between 5 and 55 °C with a dwell time of 20 s and a transfer time of 4 s. Thermocycling was performed to better simulate the clinical setting. After that, debonding was performed.

Table 1 Mean and standard deviation of bond strength in the five groups ($n = 13$)

Group	Minimum	Maximum	Mean	Std. deviation
Acid etching	13.213	24.327	18.65551	3.364794
Er:YAG 2 W	9.045	27.137	19.68896	5.340669
Er:YAG 3 W	14.480	26.839	21.31978	4.033061
Er,Cr:YSGG 2 W	7.976	31.175	17.38186	6.945291
Er,Cr:YSGG 3 W	7.976	22.831	16.45884	4.268961

Bracket debonding and measurement of shear bond strength

After thermocycling, samples were mounted in metal molds containing acrylic resin (Acropars, Tehran, Iran). After polymerization of acrylic resin, the samples were transferred to a universal testing machine (2050; Zwick Roell, Ulm, Germany) and subjected to shear load at a crosshead speed of 1 mm/min applied to the bracket-composite interface until debonding. Maximum load in Newtons was recorded and divided by the bracket base area (13.1 mm^2) to obtain shear bond strength in megapascals (MPa). The obtained values were recorded.

Assessment of debonded samples to determine the adhesive remnant index

To determine the adhesive remnant index (ARI) score, samples were inspected under a stereomicroscope (Leica EZ4D) at × 10 magnification, and the impression of bracket on the samples and the amount of resin remnant on the bracket base were coded as follows:

1. All adhesive remaining on the substrate
2. More than 90% of adhesive remaining on the substrate
3. Between 10 and 90% of adhesive remaining on the substrate
4. Less than 10% of adhesive remaining on the substrate
5. No adhesive remaining on the substrate

Table 2 Frequency distribution of modes of failure in the five groups

Groups	Mixed failure	Cohesive failure	Adhesive failure
Phosphoric acid 37%	11	0	2
Er:YAG 2 W	13	0	0
Er:YAG 3 W	12	0	1
Er,Cr:YSGG 2 W	12	0	1
Er,Cr:YSGG 3 W	12	0	1

Table 3 Frequency of ARI scores on the composite surface

			ARI (code)		Total
			0	1	
Group	Acid etch	Count	2	11	13
		% within group	15.4%	84.6%	100.0%
	ErYAG2w	Count	0	13	13
		% within group	0.0%	100.0%	100.0%
	ErYAG3w	Count	1	12	13
		% within group	7.7%	92.3%	100.0%
	ErCrYSGG2w	Count	1	12	13
		% within group	7.7%	92.3%	100.0%
	ErCrYSGG3w	Count	1	12	13
		% within group	7.7%	92.3%	100.0%
Total		Count	5	60	65
		% within group	7.7%	92.3%	100.0%

Assessment of samples under a scanning electron microscope

One sample of each group was not bonded to brackets after preparation and instead was evaluated under a SEM. First, the surface of the sample was cleaned with ethanol, dried, and gold coated with 10–15 nm thickness by a coater. The surface of samples was inspected under a FE-SEM (HITACHIS-4160) with 5 nm accuracy and 30 kV at × 1000–2000 magnification under vacuum.

Statistical analysis

Data were analyzed using SPSS version 24. The mean, standard deviation, minimum and maximum were calculated and reported. The shear bond strength data were analyzed using one-way ANOVA. The ARI scores were analyzed using independent sample Kruskal-Wallis test.

Results

According to one-way ANOVA, no significant difference was noted in shear bond strength of the five groups ($P > 0.05$, Table 1). Table 2 shows the frequency of bond failure modes in the five groups. Assessment of the mode of failure revealed that bond failure was mainly mixed in groups 1–5. Table 3 shows the ARI scores, which were not significantly different among the five groups and confirmed the bond strength data as well ($P > 0.05$). The SEM results were presented in Figs. 1, 2, 3, 4, and 5.

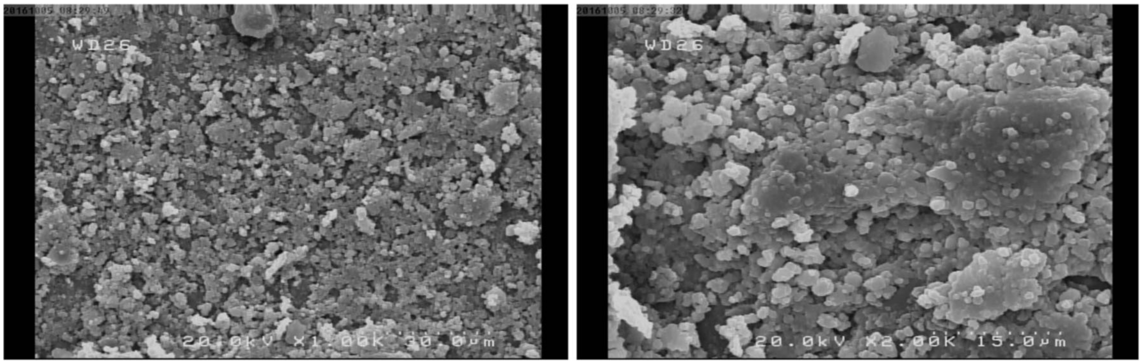

Fig. 1 Etched pattern of composite surface after etching with phosphoric acid

Discussion

Minimum bond strength for orthodontic brackets is 6–8 MPa, although some authors have reported that 2.86 MPa bond strength is also clinically acceptable [14–17]. Also, 5% of bracket bond failures occur due to 5.4 MPa loads and higher [17, 18]. Several factors affect the bond strength of orthodontic brackets to composite surface such as contamination, moisture, type of composite, adhesive resin viscosity, dimensions and design of bracket base, aging of composite in the oral cavity, storage conditions, and type of bond strength test used [14, 19]. Another important factor in this regard is type of surface treatment, which can be categorized into two groups of chemical and mechanical and can significantly affect the bond strength [14, 20]. Sobouti et al. used five preparation methods of composite surface for bond to bracket including diamond bur, hydrofluoric acid, sandblasting, and Er:YAG laser with 2 W and 3 W power [21].

They concluded that Er:YAG with 3 W power provided the strongest bond (20.74 MPa) while in our study, 3 W Er:YAG yielded the highest bond strength (21.31 MPa) compared to other groups. Also, Sobouti et al. showed that laser etching with 2 W Er:YAG yielded 15.32 MPa bond strength, which was the highest after hydrofluoric acid group. Although we did not perform hydrofluoric acid etching, 2 W Er:YAG laser ranked second in terms of highest bond strength after 3 W Er:YAG laser, yielding a bond strength of 19.68 MPa [21]. Some studies suggest that sandblasting with alumina particles is suitable to obtain adequately high bond strength. However, in the study by Sobouti et al., this method yielded the lowest bond strength (7.75 MPa). The difference between this group and 2 W and 3 W Er:YAG laser in bond strength was statistically significant [14, 21–24].

Also, use of low concentrations of hydrofluoric acid for composite etching may be associated with chemical hazards; thus, it is not often used by dentists when there are safer alternatives [25]. However, the bond strength obtained in this method was optimal (19.70 MPa) and had a slight difference with the bond strength obtained by use of 3 W Er:YAG laser [21]. Controversial results have been reported for etching of composite surface with diamond burs [28, 29].

Studies show that use of laser is superior to other methods because it does not damage the superficial structure of tooth or dental pulp. In abrasion with diamond bur, these injuries are possible. Also, laser etching does not carry the risk of chemical contamination or tissue injury, which is possible in use of hydrofluoric acid in the process of etching. Also, laser etching results in very high bond strength, which does not result from sandblasting [26, 27]. Thus, laser can be used as an alternative to common methods since it does not damage the superficial or internal structures of teeth, has no toxicity, causes no tissue burns, provides optimal bond strength, and has short clinical

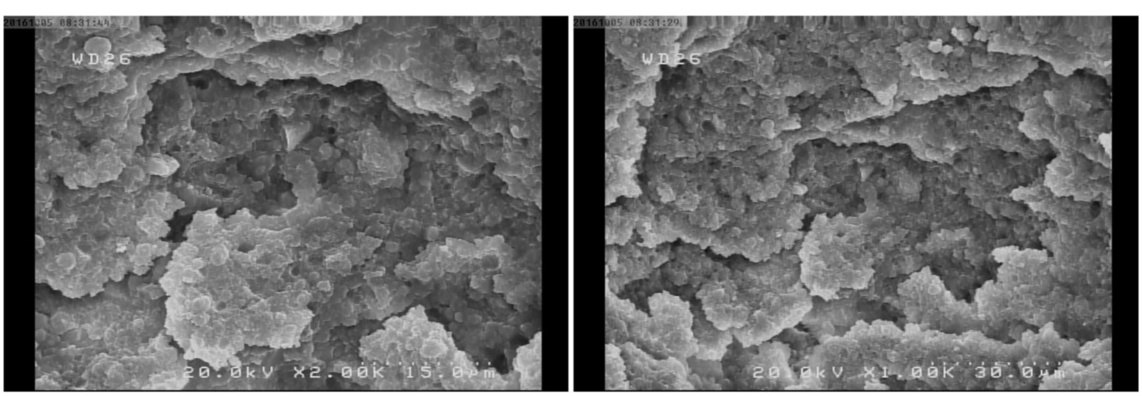

Fig. 2 Etched pattern of composite surface after etching with 2 W Er:YAG laser

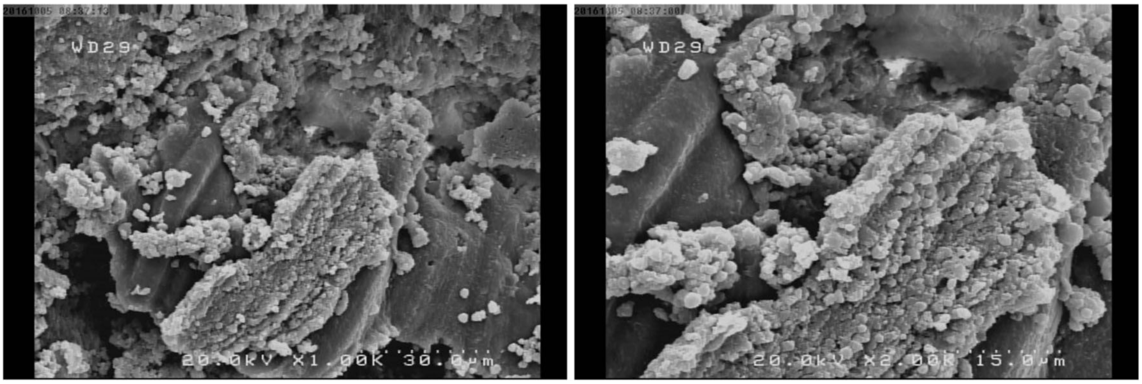

Fig. 3 Etched pattern of composite surface after etching with 3 W Er:YAG laser

use compared to 37% phosphoric acid etching. Thus, in general, use of laser etching is superior to other methods such as etching with 37% phosphoric acid, hydrofluoric acid, sandblasting, and diamond bur.

In our study, 2 W and 3 W Er:YAG laser showed higher bond strength than phosphoric acid group, but surfaces etched with Er,Cr:YSGG laser showed lower bond strength than the control group (37% phosphoric acid). Although assessing bond strength of five groups showed no significant difference, but it can be suggested that Er:YAG and Er,Cr:YSGG lasers can be used instead of 37% phosphoric acid to obtain a strong bond between bracket and composite. Er:YAG laser with 3 W power is specifically useful for this purpose and yielded the highest bond strength in our study.

Rossato et al. showed that Er:YAG laser with 200, 300, and 400 mJ energy and 10 Hz frequency can provide a strong bond between composite and adhesive resin such that Er:YAG laser etching is as efficient as bur abrasion and sandblasting [30]. In our study, Er:YAG laser etching was not significantly different from the control group, and optimal bond was achieved by use of this laser. Kimyai et al. reported that Er,Cr:YSGG laser can be as efficient as bur abrasion and sandblasting in composite to composite bond [31]. Hosseini et al. reported that the mean shear bond strength of orthodontic brackets bonded to enamel etched with 1 and 1.5W Er:YAG laser was similar to that in use of 37% phosphoric acid. It has been reported that morphological changes of enamel due to laser irradiation depend on the intensity of laser energy, duration of irradiation, distance between laser source and enamel surface, and flow rate of cooling water. In our study, composite was used instead of enamel but similar results were obtained and shear bond strength of orthodontic brackets bonded to composite blocks etched with Er:YAG laser was similar to those etched with 37% phosphoric acid [32]. Berk et al. showed that 2 W and 3 W Er,Cr:YSGG laser for etching and abrasion can provide a suitable bond. Similarly, in our study, 2 W and 3 W Er,Cr:YSGG laser yielded acceptable bond strength between orthodontic bracket and composite, and it was shown that laser etching can be used as an alternative to acid etching [33].

In our study, 92% of samples (60 out of 65) showed ARI scores of 4 and 5. Debonding was mainly of mixed type. In other words, failure occurred both at the composite-adhesive resin interface and within the adhesive resin. Clinically, this type of debonding is favorable because in this situation, there is no need to clean the enamel or composite from the remnants and thus, damage to enamel or composite during removal of bonding agent remnants decreases [34].

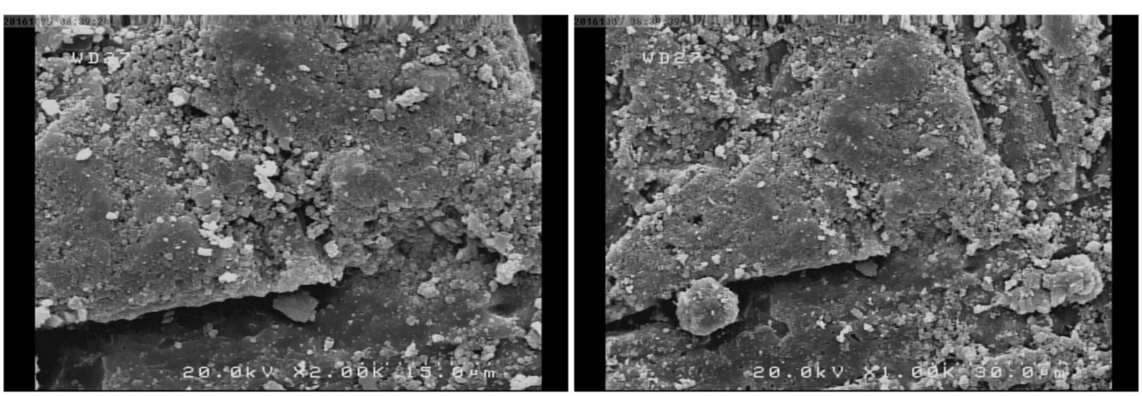

Fig. 4 Etched pattern of composite surface after etching with 2 W Er,Cr:YSGG laser

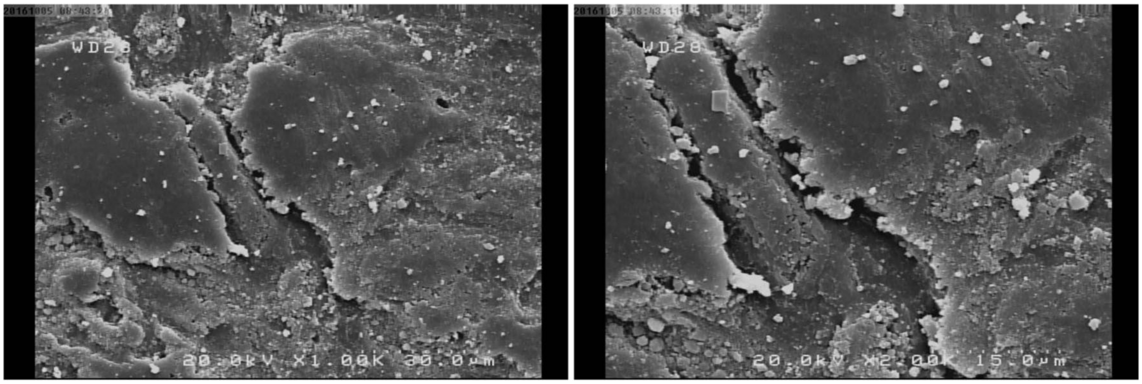

Fig. 5 Etched pattern of composite surface after etching with 3 W Er,Cr:YSGG laser

In the clinical setting, the frequency of this failure mode would be higher because optimal etching cannot be performed due to no control over moisture, temperature, time, or patient movements [35]. Moreover, structural pattern of bracket base is such that debonding at the resin-bracket interface is uncommon [36].

In contrast to our findings, Lee et al. evaluated bonded orthodontic brackets and showed that in acid etched and Er:YAG laser etched samples, failure mainly occurred at the resin-bracket interface [37]. Such a controversy in the results may be due to difference in debonding test since Lee et al. applied tensile load while we performed shear test. Valleta et al. found that debonding under tensile load more commonly occurs at the resin-bracket interface while it more commonly occurs at the resin-tooth interface under shear load [38]. Also, our study showed that ARI scores were not significantly different in the five groups.

Our study had an in vitro design. In vitro studies have limitations in simulation of clinical setting. Loads applied to brackets in vitro are different from loads in the oral environment. Thus, generalization of results to the clinical setting must be done with caution. In the oral environment, brackets are under a combination of shear, tensile, and torsional loads. Moreover, a variety of stresses is present in the oral environment such as thermal alterations, moisture, acidity, and microbial plaque, which are hard to simulate in vitro [35].

Conclusion

Comparison of Er,Cr:YSGG and Er:YAG laser etching showed that the bond strength provided by 2 W and 3 W Er:YAG laser was higher than that created by 2 W and 3 W Er,Cr:YSGg laser. In our study, Er,Cr:YSGG and Er:YAG laser etching yielded optimal bond strength values comparable to that of acid etching, and this technique can be suggested as an alternative to acid etching. The ARI score on the composite surface showed that debonding mainly occurred at the resin-composite interface. Also, our study showed that bond strength resulted from laser etching was equal or slightly higher than that of conventional acid etching.

Acknowledgements The authors would like to thank the Laser Research Center of Dentistry, Dentistry Research Institute, Tehran University of Medical Sciences.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study has been approved by the ethical committee of Tehran University of Medical Sciences.

Informed consent This study was in vitro.

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