Effects of two erbium-doped yttrium aluminum garnet lasers and conventional treatments as composite surface abrasives on the shear bond strength of metal brackets bonded to composite resins

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ABSTRACT

Background: Bonding brackets to dental surfaces restored with composites are increasing. No studies to date have assessed the efficacy of laser irradiation in roughening of composite and the resulted shear bond strength (SBS) of the bonded bracket. We assessed, for the 1st time, the efficacy of two laser beams compared with conventional methods.

Materials and Methods: Sixty-five discs of light-cured composite resin were stored in deionized distilled water for 7 days. They were divided into five groups of 12 plus a group of five for scanning electron microscopy (SEM): Bur-abrasion followed by phosphoric acid etching (bur-PA), hydrofluoric acid conditioning (HF), sandblasting, 3 W and 2 W erbium-doped yttrium aluminum garnet laser irradiation for 12 s. After bracket bonding, specimens were water-stored (24 h) and thermocycled (500 cycles), respectively. SBS was tested at 0.5 mm/min crosshead speed. The adhesive remnant index (ARI) was scored under ×10 magnification. SEM was carried out as well. Data were analyzed using analysis of variance (ANOVA), Kruskal–Wallis, Tukey, Dunn, one-sample *t*-test/Wilcoxon tests, and Weibull analysis (α =0.05).

Results: The SBS values (megapascal) were bur-PA (11.07 ± 1.95), HF (19.70 ± 1.91), sandblasting (7.75 ± 1.10), laser 2 W (15.38 ± 1.38), and laser 3 W (20.74 ± 1.73) (compared to SBS = 6, all P = 0.000). These differed significantly (ANOVA P = 0.000) except HF versus 3 W laser (Tukey $P > 0.05$). ARI scores differed significantly (Kruskal–Wallis P = 0.000), with sandblasting and 2 W lasers having scores inclined to the higher end (safest debonding). Weibull analysis implied successful clinical outcome for all groups, except for sandblasting with borderline results.

Conclusion: Considering its high efficacy and the lack of adverse effects bound with other methods, the 3 W laser irradiation is recommended for clinical usage.

Key words: Bracket bonding, composite surface treatments, dental materials, direct composite veneer, erbium: Doped yttrium aluminum garnet laser, shear bond strength

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INTRODUCTION

A minimum of bond strength is necessary to allow the retention of brackets to dental surfaces. During bonding the brackets

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on the enamel surfaces, a properly cleansed and isolated enamel allows optimal bonding of brackets to the teeth using composite luting agents.[1-4] Due to their appropriate standards, direct composite resins are being increasingly utilized to fully or partially restore the labial or buccal surfaces of the teeth (e.g., as esthetic restorations). Hence, the rate of encountering such restorations in orthodontic treatments is increasing.[3,5,6] In such situations, orthodontists might be limited to bond the bracket onto a saliva-contaminated, polished, or an aged composite resin surface. A saliva-contaminated, polished, or aged composite restoration might have a compromised resin-to-resin bond strength and increase the failure rate.[1,3-5,7-9] This is because aging and water sorption might reduce the unsaturated double carbon = carbon bonds or remove the superficial layer of oxygen-inhibited nonpolymerized composite (which is necessary for proper resin-to-resin bond).[4,9-12] The prognosis of this link depends on multiple factors including old composite surface properties such as its smoothness or wettability as well as applied surface treatments.[12-16]

Various chemomechanical treatment techniques with varying results have been proposed to improve the compromised resin-to-resin bond strengths while repairing broken, aged, or stained composite restorations. These include irrigating, disk/bur abrading, sandblasting, etching, or silane/bonding agent application.[3,6,10-12,14,16] The studied surface treatments for improving repair bond strength of composite-to-composite are highly controversial:[12,17] Some researchers found promising effects of using hydrofluoric acid (HF)[15,18-20] roughening with a bur or sandblasting, while some researches failed to show a proper influence of all or some of these methods.[12,21,22]

Although the aforementioned techniques have been evaluated on the success of the repaired composite restorations, they are not assessed in the field of orthodontics, except in few studies.[6,11,23-25] This is critical: Studies on restoration repair are not generalizable to the bonding of orthodontic brackets to composite surfaces because of the differences in the configurations. For instance, a bonded bracket is composed of a resin-to-resin and a resin-to-metal interface, while repaired composite restorations have only a simple resin-to-resin interface. Moreover, luting cement used for bracket bonding always differ considerably in type and characteristics of the base composites, while this is not the case in restoration repair. Eventually, repaired restorations undergo direct masticatory shear and compressive forces, while luting cement exclusively undergo indirect shear-only forces exerted to the brackets.[11]

Apart from the above issues, it is noteworthy that to date, all methods were limited to chemomechanical techniques, and the effect of surface ablation using laser is assessed in none of the above-mentioned few orthodontic studies, and in only two studies on the repair of composite restorations (relevant to restorative dentistry).[26,27] Lasers play several key roles in orthodontics.[28-30] Different laser types including erbium-doped yttrium aluminum garnet (Er: YAG) are successfully used for conditioning the enamel before bracket bonding.[31,32] Recently, lasers have been shown effective for porcelain conditioning as well.[31] However, studies on the efficacy of lasers when roughening direct composites are lacking. Therefore, we sought to evaluate the effect of two lasers compared with chemical and mechanical approaches.

MATERIALS AND METHODS

Through this experimental *in vitro* study, 65 disks of composite resin (color A2, Unitek z100, 3M ESPE, USA) were used. The disks were 1.5 mm thin and 8 mm in diameter. They were molded using a rubber template open on both sides. After placing a translucent band under the mold, the first layer of composite (1 mm thin) was placed and light cured vertically for 40 s using a well-calibrated light-emitting diode unit with a probe of 8 mm diameter, and emitting 440 nm light at 400 mW/cm^2 (Mectron, Starlight Pro GAC, Italy). After placing the second composite layer, a glass slab was placed above the second layer to create a smooth surface. Then, it was light cured as stated above.

Sample Preparation

All specimens were stored in deionized distilled water for 7 days at room temperature and randomly assigned to five equal groups of 12 specimens each plus an extra specimen per group for scanning electron microscopy (SEM). The groups are described below:[3]

Group 1: Diamond bur abrading followed by phosphoric acid etching

Diamond burs with grit sizes 125–150 μm (863 Grit, Drendel and Zwelling, Berlin, Germany) rotating at high speed with constant water spray were used for surface roughening. The bur was moved on the composite surface thrice. A new bur was used after preparing every five disks. The surface was etched using 35% phosphoric acid (PA) for 20 s. The disk was rinsed with water for 1 min. Then, it was air-dried.[24]

Group 2: Hydrofluoric acid conditioning

Each disk was etched using 9.6% HF acid (Ultradent Etch, USA) for 2 min. The disk was rinsed with water for 1 min and was air-dried.

Group 3: Sandblasting

Disk surfaces were air-abraded at a pressure of 60 psi using a sandblasting device (Microblaster, Dento-Prep, Dental Microblaster, Denmark) with 50 μm particles of aluminum oxide for 10 s. The tip was positioned vertically (perpendicular to the specimen surface) and 5 mm away from the surface. Afterward, the specimens were rinsed 60 s with distilled water and air-dried.[33]

Group 4: Erbium-doped yttrium aluminum garnet Laser irradiation at 2 W

Surfaces were etched using laser irradiation. For this purpose, an Er: YAG laser (wavelength of 2940 nanometer, solid state source) (device type: Key laser 3+, KaVo Dental Corporation, Biberach, Germany) was used at 80 mJ/cm^2, 20 Hz for 12 s. These irradiation parameters of laser system were determined based on a pilot study. Average power output was 2 W, and the laser operated in pulse mode. The 2060 handpiece (KaVo Dental Corporation, Biberach, Germany) (by fiber tip diameter of 2 mm) of the system was used at a distance of 20 mm perpendicular to the composite disc surface in swiping movement to etch the surface.

Group 5: Erbium-doped yttrium aluminum garnet laser irradiation at 3 W

The procedures explained for the Group 4 were repeated, however with the laser power set at 3 W.

Scanning Electron Microscopy

Five extra specimens were subjected to the SEM (Leo, Number 440, UK) at ×500–×2500 magnifications.

Bracket Bonding

A stainless-steel central bracket with an 18-inch slot (Dentaurum, Ispringen, Germany) was bonded to the etched surface of each resin disk, using a thin layer of adhesive primer (3M, Unitek, Monrovia, California, USA) was applied to treated composite surfaces. The adhesive resin (Transbond XT, 3M Unitek, Monrovia, California, USA) was applied to the bracket base, and the bracket seated on the surface of the restoration with a force of approximately 5 N. The excess adhesive resin was removed with an explorer before polymerization with a curing light.[24,25] The brackets were light cured (mectron) from mesial, distal, occlusal, and gingival sides (40 s/side).

Water Storage and Thermocycling

After 24 h storage in distilled water at the room temperature, all the specimens were thermocycled 500 times between 5°C and 55°C with a dwell time of 30 s between each cycle. To facilitate debonding, the samples were mounted in acrylic resin (Acropars, Iran) with the surfaces parallel to the debonding blade.[24,25]

Testing the Shear Bond Strength and Estimating the Adhesive Remnant Index

An even edge of a chisel-shaped steel rod attached to a universal testing machine (Zwick Roel, Germany) exerted the shear force at 0.5 mm/min crosshead speed. The force was aimed at the occlusal side of the bracket wings. The necessary force to debond each bracket was recorded and the debonding force was divided by the surface area size of bracket base (12.68 mm^2) to calculate the shear bond strength (SBS) in megapascal (MPa).[11,34]

Immediately, after debonding, the adhesive remnant index (ARI) was measured and recorded at ×10 magnification using a stereomicroscope (SZX9, Olympus, Japan). It had five scores: (1) All the adhesive resin remained on the disk surface. (2) More than 90% of the adhesive remained on the disk surface. (3) Between 90% and 10% of the adhesive remained. (4) Less than 10% of the adhesive remained; and (5) no adhesive remained on the surface.[11,29]

Statistical Analysis

Descriptive statistics and frequency distributions were calculated for SBS and ARI. The groups were normally distributed according to the Kolmogorov–Smirnov normality test. The findings regarding the SBS values were analyzed using a one-way analysis of variance (ANOVA) and the Tukey *post hoc* test. As well, using a one-sample *t*-test, each group mean SBS was compared with the SBS = 8 and 6 MPa, as an appropriate *in vitro* bond strength according to Reynolds, who suggested a 6–8 MPa bond as clinically acceptable.[35] Weibull analysis was conducted to estimate the probabilities of bond failure for each group. The ARI scores were analyzed using the Kruskal–Wallis, Dunn *post hoc*, and one-sample Wilcoxon signed-ranks tests comparing ARI scores with the median of the ARI range = 3. The level of significance was set at 0.05.

RESULTS

The best and worst SBS results belonged to the 3 W laser and air abrasion, respectively [Table 1]. The SBS values of all groups were significantly above the 8.0 MPa value, except the result of sandblasting which was insignificantly below 8.0 MPa [Table 1]. Compared to the value 6.0 MPa, all groups (including air abrasion) demonstrated significant results (all *t*-test $P = 0.000$). The comparison of the mean SBS values using one-way ANOVA showed a significant difference between the groups [$P = 0.0000$, Table 2 and Figure 1]. According to the Tukey *post hoc* test, only the difference between SBS values of groups HF and laser 3 W was not significant [Table 2].

The Weibull analysis indicated the higher probabilities of failure for the treatments with HF and 3 W laser, whereas

Figure 1: Box plots showing the shear bond strength (megapascal) of the studied groups. According to the Tukey *post hoc* test, except groups sandblasting and 3 W laser conditioning (which were rather similar), the shear bond strength of all other groups were significantly different from each other

Table 1: Descriptive statistics of shear bond strengths (MPa), and the results of the one-sample *t*-test

Treatment	Mean±SD	CV (%)	Minimum	Q1	Median	Q3	Maximum	95% CI	*P*
Bur-PA etch	11.07±1.95	17.62	7.80	9.65	10.65	12.83	14.50	9.83-12.31	0.0002
HF etch	19.70±1.91	9.67	16.80	18.15	19.50	21.73	22.20	18.49-20.91	0.0000
Sandblasting	7.75±1.10	14.23	5.80	6.93	7.95	8.58	9.20	7.05-8.45	0.4491
Laser 2W	15.38±1.38	8.97	13.00	14.55	15.25	16.53	18.10	14.51-16.26	0.0000
Laser 3W	20.74±1.73	8.34	18.40	19.00	20.75	22.48	23.00	19.64-21.84	0.0000

SD – Standard deviation; CV – Coefficient of variation; Q1 – 25th percentile; Q3 – 75th percentile; CI – Confidence interval for the mean; PA – Phosphoric acid; HF – Hydrofluoric

Table 2: The results of Tukey *post hoc* test comparing shear bond strength values as well as Dunn *post hoc* test comparing the adhesive remnant index scores

SBS of treatment A - B	SBS		ARI
	Mean difference	95% CI of difference	Difference in rank sum
Bur-PA - HF	−8.63***	−10.53-−6.737	16.7
Bur-PA - sandblasting	3.32***	1.420-5.213	−13.7
Bur-PA - laser 2W	−4.32***	−6.213-−2.420	0.542
Bur-PA - laser 3W	−9.68***	−11.57-−7.778	13.3
HF - sandblasting	11.95***	10.05-13.85	−30.4***
HF - laser 2W	4.32***	2.420-6.213	−16.2
HF - laser 3W	−1.04	−2.938-0.8551	−3.38
Sandblasting - laser 2W	−7.63***	−9.530-−5.737	14.3
Sandblasting - laser 3W	−12.99***	−14.89-−11.09	27.0***
Laser 2W - laser 3W	−5.36***	−7.255-−3.462	12.8

***$P<0.001$. SBS – Shear bond strength; ARI – Adhesive remnant index; CI – Confidence interval; Bur-PA – Bur-phosphoric acid; HF – Hydrofluoric

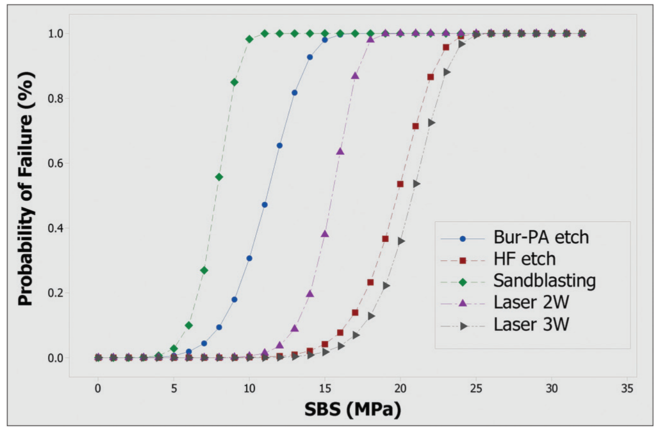

Figure 2: A visual illustration of Weibull moduli. A steeper slope indicates that the result is more reliable. A curve skewed to the right indicates that the probability of failure is lower for a given constant stress value

the most reliable results belonged to HF etching and sandblasting [Table 3 and Figure 2].

The Kruskal–Wallis test showed a significant difference between ARI scores of all groups [$P = 0.000$, Table 4]. The Dunn *post hoc* test indicated significant differences between the ARI scores of sandblasting with either of HF etching or 3 W laser groups [Table 2]. According to the Wilcoxon signed-ranks test, only the ARI scores of Groups 1 and 2 were significantly greater than ARI = 3 [Table 4].

The SEM showed the bur-abraded and PA-etched surface as the smoothest and most homogenous surface followed by 2 W laser and air abrasion [Figure 3].

DISCUSSION

The minimum bond strength for orthodontic purposes is suggested to range between 6 and 8 MPa[6,35-37] although some authors found bounds as well as 2.86 MPa, clinically acceptable.[6,35] It is also suggested that a 5% probability of bracket failure should be at least 5.4 MPa.[37,38] Similar to another study,[37] almost all our groups provided SBS levels above this value except sandblasting which has slightly lower bond strength. This implies their proper application in the oral environment, of course taking the generalizability limitations of *in vitro* studies into account.[37,38] This indicates the adequacy of all techniques and is consistent with previous findings in this regard.[6,24,25,33] Several factors might affect the bond strength of orthodontic attachments to composite surfaces including contamination, moisture, composite type, viscosity of adhesive resin, the dimension and geometry of the bracket base, aging of the composite, storage conditions, and test method.[6,24] Another major factor in this regard is techniques of surface treatment, which to date involved chemical or mechanical approaches,[6,21] although our study showed that laser abrasion could be considered a new approach. In this study, etching with 3 W laser followed by sandblasting showed the most superior results in terms of SBS. Laser abrasion at 2 W power as well had proper results, being above the acceptable minimum values.

Since this is the first study of its kind on laser abrasion in orthodontic setups, we are limited to comparing our results with the two studies available on laser abrasion in composite repair in restorative dentistry. A study compared the effect of erbium- and chromium-doped yttrium scandium gallium garnet (Er, Cr: YSGG) laser with bur abrasion and sandblasting, and found it slightly superior to both of them (14.2 MPa compared to 10.6 and 13.8 MPa).[33] Another research compared the efficacy of three lasers Er, Cr: YSGG, neodymium-doped yttrium aluminum garnet, and CO_2 in repair bond strength of composites, and found proper results for all of them (ranging between 11.7 and 15.4 MPa).[26]

Etching with HF but not PA showed proper results in this setup. These results were comparable to the findings of other few studies.[23-25] This could be attributable to the methodological differences such as different brands or aging protocols applied. Abrasion with diamond burs in comparison with PA etching

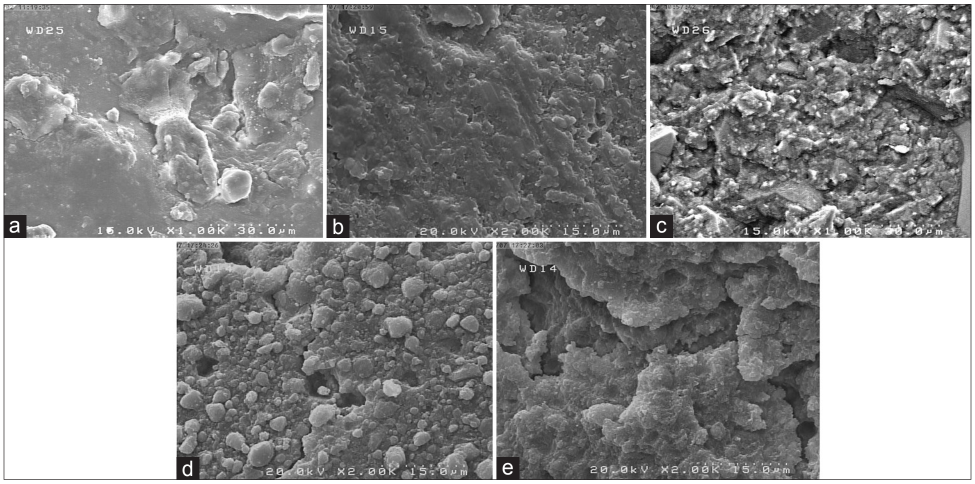

Figure 3: Scanning electron micrographs showing composite surfaces prepared by sandblasting (a), bur abrasion and phosphoric acid etching (b), hydrofluoric acid etching (c), 2 W laser (d), and 3 W laser (e)

Table 3: The Weibull analysis of the treatments

Treatment	Weibull modulus	R^2	Stress for different probabilities of failure (MPa)				
			$\sigma_{0.05}$	$\sigma_{0.10}$	$\sigma_{0.90}$	$\sigma_{0.95}$	$\sigma_{0.99}$
Bur-PA etch	5.86	0.958	7.15	8.09	13.69	14.32	15.41
HF etch	10.09	0.970	15.30	16.40	22.30	22.90	23.90
Sandblasting	7.15	0.970	5.43	6.01	9.25	9.60	10.20
Laser 2W	11.50	0.933	12.35	13.15	17.20	17.60	18.27
Laser 3W	11.17	0.949	16.48	17.58	23.17	23.72	24.65

R^2, correlation coefficient; $\sigma_{0.05}$, $\sigma_{0.10}$, $\sigma_{0.90}$, $\sigma_{0.95}$, and $\sigma_{0.99}$, stress levels at 5%, 10%, 90%, 95%, and 99% debond probabilities, respectively. Bur-PA – Bur-phosphoric acid; HF – Hydrofluoric

Table 4: Frequency distributions of adhesive remnant index scores across the groups (%), and the results of the one-sample Wilcoxon test comparing with the adhesive remnant index value=3

Treatments	1	2	3	4	5	*P*
Bur-PA etch	1	3	4	3	1	1.0
HF etch	6	4	1	1	0	0.0070
Sandblasting	0	1	2	4	5	0.0120
Laser 2W	2	0	7	3	0	0.7825
Laser 3W	5	2	5	0	0	0.0177

ARI scores: All the adhesive resin remained on the disk surface; More than 90% of the adhesive remained on the disk surface; Between 90% and 10% of the adhesive remained; <10% of the adhesive remained; No adhesive remained on the surface. ARI – Adhesive remnant index; Bur-PA – Bur-phosphoric acid; HF – Hydrofluoric

might be successful because of the increased mechanical interlocking (as potentially the most influential factor) and the formation of deep craters and streaks.[6,24,39] Other studies have suggested sandblasting with alumina particles as a proper method to regain proper bond strengths.[6,40-42]

Nevertheless, from a clinical point of view, HF conditioning and sandblasting might not be as safe and convenient as surface abrasion with diamond burs, and thus are being shunned globally,[12,17,43,44] although some authors consider air abrasion as a safer method than utilizing burs or stones, since they consider it more uniform and less aggressive.[6,45] Even low concentrations of HF might be a hazardous chemical, which is ill-advised for clinical practice.[25] Moreover, diamond burs have shown contradictory and highly variable results in preparing composite surfaces[12,13,16,17,21,46] with some studies in orthodontic setup suggesting it as the most effective method (about 10 and 18.5 MPa).[23,25] Therefore, considering the safety and efficacy of the treatments, it seems that laser abrasion might be a proper substitute: It can produce appropriate bond strengths while being safe at the same time, since it is frequently used in clinics and does not show pulpal temperature rises above high-speed handpieces.[31,47]

CONCLUSIONS

The 3 W Er: YAG laser was the most effective approach for abrading aged composite restorations before attempting to bond metal brackets to composite surfaces. Due to its uniform abrasion results (unlike bur abrasion), its safety of use (unlike HF application and sandblasting), and the very good bond strength it provides, it is recommended for abrading the aged composite surfaces before bonding brackets to them. Future studies should evaluate its effect *in vivo*.

The only drawback of 3 W Er: YAG laser as a composite abrasive (compared to the alternative but weaker method of bur abrasion) is the cost of the laser device, which will hopefully reduce as the technology advances. Moreover, a laser device can have multiple usages and might not be used only for composite abrasion. Its multiple uses might justify its expenses.

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Conflicts of Interest

There are no conflicts of interest.

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