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Effect of Er:YAG Laser Irradiation with Various Power Levels on Shear Bond Strength of Repair to Aged Nanofilled Composite Resin

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ABSTRACT

Objectives: The increasing applications of composite resins and the need for correction of defects developed over time call for strategies to increase the bond strength of new repair composite resin to old (aged) composite resin. Thus, this study aimed to assess the effect of erbium-doped yttrium aluminum garnet (Er:YAG) laser irradiation with various power levels on shear bond strength (SBS) of repair to aged nanofilled composite resin.

Materials and Methods: Thermocycled disc-shaped (4.0×7.0mm) nanofilled composite resin specimens were randomly assigned to 4 groups (n=15): bur abrasion and 35% phosphoric acid (control group), irradiation of 1 W Er:YAG laser, irradiation of 2W Er:YAG laser, and irradiation of 4.5W Er:YAG laser. The SBS was measured after the application of repair composite and thermocycling. Specimens were observed under a stereomicroscope to determine the mode of failure. Atomic force microscopy (AFM) was used to assess the surface topography. Data were analyzed with one-way ANOVA, Games-Howell, and Fisher's exact tests ($\alpha=0.05$).

Results: The mean SBS in the 1W and 2W laser groups was significantly lower than that in the 4.5W laser and control groups ($P<0.05$). The difference in SBS of the 1W and 2W laser ($P=0.999$), and the 4.5W laser and control ($P=0.999$) groups was not significant.

Conclusion: Er:YAG laser irradiation with 4.5W power yielded a SBS comparable to that of the control group and significantly higher than that of the 1W and 2W laser groups.

Keywords: Dental Restoration Repair; Composite Resins; Dentistry, Operative; Lasers, Solid-State; In Vitro Techniques

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INTRODUCTION

In the recent years, the clinical applications of composite resins have greatly increased due to optimal esthetics, cost-effectiveness, improved mechanical properties, and advances in bonding and curing systems [1-3]. Although the new composite resins have significantly improved wear resistance and color stability, polymerization shrinkage of about 1.5% to 3% leading to microleakage, subsequent marginal discoloration, pulpal irritation, recurrent caries, and reduced durability is still problematic [1-7]. Thus, irrespective of the structural differences of composite resins, most of them experience defects sometime after their application in the oral cavity, making the replacement or repair of composite restorations necessary [1,4].

Since differentiation of bonded composite resin and the underlying tooth structure is sometimes challenging, replacement of composite restorations may increase the risk of pulp exposure due to unnecessary cavity extension to the sound tooth structure [4,8]. In spite of that, repairing defective composite restorations is a more conservative approach than their replacement and can lower the risk of damage to the tooth structure and dental pulp [4,9,10]. Thus, reparability is a favorable characteristic of composite resins, which can be assessed by evaluating the bond strength of repaired composite restorations [11,12].

Chemical bonds, depending on the presence of an oxygen-rich superficial layer containing carbon-carbon double bonds, mediate the adhesion of a new layer of composite resin to the superficial aged layer, as well as micromechanical interlocking [13-14]. Since the amount of available carbon groups is low in aged composite resins [9], chemical bonding is not highly reliable, and the increased surface roughness of the aged composite resin determines the success of bonding by enhancing the interlocking mechanism and improved coverage of the aged composite with unfilled resin [8]. Therefore, several methods such as plasma application, bur abrasion, acid etching, air-borne particle abrasion, and laser irradiation are used to alter the surface topography of the existing composite restoration [4,15,16]. Atomic force microscopy (AFM) and scanning electron microscopy are commonly used for assessment of surface topography with several advantages such as enabling direct observation of surfaces with high resolution in different environments [17].

Several studies have attempted to find the most effective surface treatment for this purpose, but no consensus has reached on this topic so far [4,10,18]. Ahmadizenouz et al. [4] assessed the effects of air abrasion, erbium-doped yttrium aluminum garnet (Er:YAG) laser irradiation with an output power of 1.5 W, etching with 35% phosphoric acid after bur abrasion, and applying 9% hydrofluoric acid, and concluded that all the tested methods similarly enhanced the shear bond strength (SBS) of nanofilled composite repairs. Barcellos et al. [10] reported lower bond strength of repair composite to aged layer after Er:YAG laser irradiation, compared with grinding by a diamond bur and applying conventional adhesive. However, some others reported equal efficacy of Er:YAG laser irradiation and diamond bur abrasion for enhancement of bond strength [18], and higher satisfaction of patients with the use of laser, compared with bur abrasion [19].

It should be noted that the micromorphology of laser-irradiated surfaces depends on the chemical composition and structural properties of composite resins in addition to various exposure parameters of Er:YAG laser [20,21]. Accordingly, Duran et al. [8] suggested assessment of the effects of various Er:YAG laser parameters on different types of composite resins to create a guideline. The effects of different parameters of Er:YAG laser on repair bond strength of microhybrid [8,22] and nanohybrid [23,24] composite resins have been previously studied. Due to their superior compressive strength [25] and reduced polymerization shrinkage while providing strength [26] and high polishability [27], nanofilled composite resins can be used for restoration of both anterior and posterior teeth with direct and indirect methods [27,28]. Several studies have compared the effects of Er:YAG laser irradiation on repair bond strength of nanofilled composite resins with other surface treatments [4,10,29]. However, to the best of the authors' knowledge, the impact of different power levels of Er:YAG laser on repair bond strength of these resins has not been previously studied. Thus, the purpose of this experimental study was to evaluate the change in SBS between the repair nanofilled composite resin and aged layer after irradiation of Er:YAG laser with various power levels. The null hypothesis of the study was that no significant difference would be found in SBS between the repair nanofilled composite resin and aged layer after irradiation of Er:YAG laser with various power levels.

MATERIALS AND METHODS

In this in vitro experimental study, 60 disc-shaped specimens with 7mm diameter and 4 mm height were fabricated from the A2 shade of a nanofilled composite resin (Filtek Z350 A2E; 3M ESPE, St. Paul, MN, USA) in prefabricated plexiglass molds. Composite resin increments with 2mm thickness were applied and packed incrementally in the molds. To obtain a smooth surface, a Mylar strip (KerrHawe SA, Bioggo, Switzerland) was placed over the second layer applied. After curing the top surface of each increment individually for 20 seconds by using a curing unit (Bluedent LED Smart, D & A Electronics, Plovdiv, Bulgaria) as recommended by the manufacturer, the mold was reversed and the bottom surface was similarly cured. Light curing was performed vertical to the specimen surface from 1mm distance in a continuous mode with 1300mW/cm^2 light intensity. After curing of 5 specimens, the light intensity was checked by a radiometer (DigiRate LM-100, Monitex Industrial Co., New Taipei, Taiwan). After removal of specimens from the molds following their polymerization, they were cured for another 40 seconds to ensure complete uniform polymerization. To simulate aging in the clinical setting, the specimens were immersed in distilled water at 37°C for one week followed by thermocycling for 20,000 cycles at 5-55±2°C with a dwell time of 30 seconds and a transfer time of 5 seconds. The specimens were then stored in distilled water at 37°C for 7 days [10]. Finally, the specimens were placed back in the molds, and were randomly assigned to 4 groups (n=15) for the following surface treatments:

Control group (bur abrasion + acid etching): In this group, the specimen surface was abraded by a diamond bur and highspeed handpiece under air/water coolant. To standardize the process of bur abrasion, the surface of the specimens was abraded in a custom-made device with 10 back-and-forth movements of the bur [30]. The bur was replaced after abrading 5 specimens. Next, the surface of the specimens was etched with 35% phosphoric acid (Ultra-Etch, Ultradent Products, South Jordan, Utah, USA) for 15 seconds, rinsed with water for 10 seconds, and air-dried [31].

Other specimens were subjected to Er:YAG laser irradiation (2940 D Plus, DEKA, Italy) with 2940nm wavelength, 700µs pulse duration, and 4mm focal size for 20 seconds [18]. Laser was irradiated with 50% air and 50% water spray by a titanium handpiece with 4 mm tip diameter in a circular motion vertical to the surface of the specimens and at 1 mm distance from them.

1W laser group: The specimens underwent Er:YAG laser irradiation with 1W power, 100mJ energy, 79.61J/cm^2 energy density, and 10Hz frequency.

2W laser group: The specimens underwent Er:YAG laser irradiation with 2W power, 200mJ energy, 159.23J/cm^2 energy density, and 10Hz frequency.

4.5W laser group: The specimens underwent Er:YAG laser irradiation with 4.5W power, 300mJ energy, 238.83J/cm^2 energy density, and 15Hz frequency.

A thin layer of bonding agent (PermaSeal, Ultradent Products, South Jordan, Utah, USA) was applied on the top surface of the specimens for 5 seconds and then cured for 20 seconds after evaporating the solvent by gentle air spray as recommended by the manufacturer. Another cylindrical plexiglass mold with 4mm diameter and 4mm height was placed over the first mold and fixed with metal rods with 2.5mm diameter to pack layers of composite resin with 1- and 1.5-mm thicknesses in an orderly manner. Curing of each layer was separately performed as explained earlier.

After removing the specimens from the mold and polishing them by a rubber cup, they were immersed in distilled water at 37°C for one week followed by thermocycling for 20,000 cycles at 5-55±2°C with a dwell time of 30 seconds and a transfer time of 5 seconds, simulating 2 years of clinical service [32]. Finally, the specimens were immersed in distilled water for another one week at 37°C [10].

The SBS test was carried out by using an extensometer (STM-20, Santam Corporation, Tehran, Iran). For this purpose, a chisel-shaped cutting blade applied load to the interface of the old and repair composite at a crosshead speed of 0.5mm/minute to record load at fracture, which was then divided by the interface surface area (12.56mm^2) to obtain the SBS in Megapascals (MPa).

The mode of failure was assessed by a stereomicroscope (MSZ5000, A. KRÜSS Optronic, Hamburg, Germany) at x20 magnification and categorized as adhesive (fracture at the interface of new and aged composite), cohesive (fracture within the composite mass), and mixed (a combination of adhesive and cohesive fractures) (Fig 1) [33].

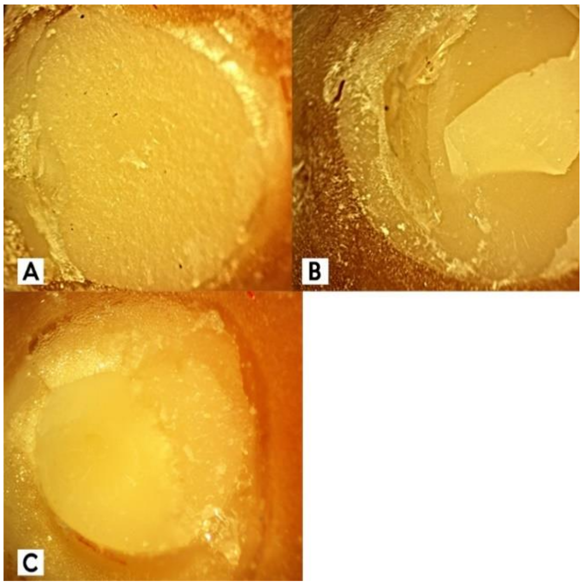

Fig 1. Stereomicroscopic images of (A) adhesive, (B) cohesive, and (C) mixed failures

To assess the surface morphology of the specimens after surface treatment, one additional specimen was fabricated in each group as explained earlier, and underwent AFM (DualScope DS95-50-5 E, DME, Denmark). For this purpose, a silicon nitride tip with 50nm radius and 45-degree apex angle was used. The image resolution was 312 x 271 pixels, and the speed was 80μm/second. The surface of each specimen was scanned in pixels measuring 30 x 30μm. The AFM images were analyzed in DME SPM software.

Normal distribution of SBS data was analyzed by the Kolmogorov-Smirnov test; while, homogeneity of the variances was analyzed by the Levene's test. The results showed normal distribution of data in all groups (P>0.05). However, the assumption of homogeneity of the variances was not met (P=0.015, Levene's statistic=3.81). Thus, one-way ANOVA and the Games-Howell nonparametric post-hoc test were applied to analyze the differences among and between the groups. Since the assumption for the use of Chi-square test was not met for comparing the modes of failure among the experimental groups, the Fisher's exact test was utilized for this purpose. Statistical analyses were carried out using SPSS version 24 (SPSS Inc., Chicago, IL, USA) at 0.05 level of significance.

RESULTS

Table 1 shows the mean SBS of the study groups. The results showed a significant difference in the mean SBS among the experimental groups (P<0.001), such that the maximum SBS was found in the control group (20.93±7.86MPa) while the minimum SBS was noted in the 1W laser group (12.83±4.82MPa).

Table 1. Mean and standard deviation of shear bond strength (MPa) in the study groups (n=15)

Group	Mean ± standard deviation
1W	12.83 ± 4.82
2W	14.01 ± 4.94
4.5W	19.60 ± 5.05
Control	20.93 ± 7.86

Pairwise comparisons of the groups with the Games-Howell test showed no significant difference between the control and 4.5W laser (P=0.946), and the 1W and 2W laser (P=0.909) groups regarding the SBS. Nonetheless, the mean SBS in both the 1W and 2W laser groups was significantly lower than that in the 4.5W laser and control groups (P<0.05, Table 2).

Table 2. Pairwise comparisons of shear bond strength (MPa) of the study groups using the Games-Howell test (P<0.05)

Group	1W	2W	4.5W	Control
1W	-	-	-	-
2W	0.909	-	-	-
4.5W	0.004	0.023	-	-
Control	0.012	0.038	0.946	-

A significant difference was also found among the groups in the modes of failure (P=0.035). The mode of failure was dominantly mixed in the 1W and 4.5W laser groups and the control group. The dominant mode of failure was adhesive and then mixed in the 2W laser group. In total, the dominant mode of failure was mixed followed by adhesive, and then cohesive (Fig 2).

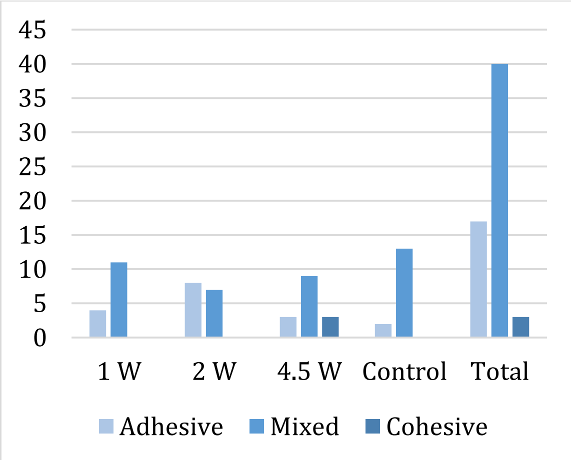

Fig. 2. Results of the Fisher's exact test regarding the mode of failure of the study groups

Figure 3 illustrates the AFM images of the center of specimen surfaces. The mean surface roughness (Ra) and the root mean square of roughness (Rq) were 110nm and 138nm, respectively in the control group, 113nm and 141nm, respectively in the 1W laser group, 115nm and 140nm, respectively in the 2W laser group, and 121nm and 150nm, respectively in the 4.5W laser group.

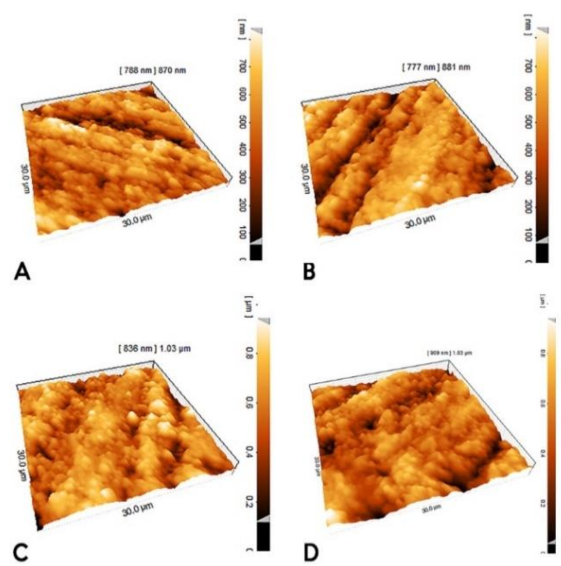

Fig. 3. AFM images of the surface of specimens: (A) control group, (B) 1W laser, (C) 2W laser, and (D) 4.5W laser group

DISCUSSION

Nanofilled composite resins showing superior compressive strength [25], reduced polymerization shrinkage while providing strength [26], and high polishability [27] can be used for restoration of both anterior and posterior teeth with direct and indirect methods [27,28]. However, due to limited knowledge regarding the effect of various power levels of Er:YAG laser on repair bond strength of nanofilled composite resins, this study evaluated the change in SBS between the repair nanofilled composite resin and aged layer after irradiation of Er:YAG laser with various power levels. According to the results of the current study, the study groups had a significant difference in SBS. Therefore, the null hypothesis of the study was rejected. Some researchers believe that the micro-SBS test is preferred to the SBS test due to easy specimen preparation, accurate results, and relatively small standard deviation values [18]. In spite of that, the micro-SBS test is used in studies in which the bond strength of adhesive or composite resin to enamel and dentin is evaluated, and the SBS test is still used for evaluating the bond strength of resin cement to ceramics and repaired composite resins [16]. Therefore, the SBS was measured in the current study. In this study, the 1W and 2W laser groups showed a significantly lower SBS than the control group (bur abrasion + acid etching). This finding was in line with the lower mean surface roughness reported in the 1W and 2W laser groups compared to the value in the control group (acid etching) in AFM analyses, which was utilized for quantitative assessment of surface roughness. Ahmadizenouz et al. [4] showed that acid etching following bur abrasion of nanofilled composite surface yielded a higher bond strength compared with irradiation of Er:YAG laser with 1.5W power, but this difference did not reach statistical significance. Since laser irradiation leads to ablation of filler particles of the resin matrix, it is believed that composite resins with stronger cohesion and filler-matrix bonding energy are more resistant to laser ablation, and the existing nanoparticles and nanoclusters in the structure of nanofilled composite resins decrease the exposed matrix for ablation [4]. De Fátima Zanirato Lizarelli et al. [21] observed a regular pattern of ablation on the laser-treated composite surface, and showed that laser irradiation with 100mJ energy could not cause ablation in packable composite resin. However, increasing the laser energy caused ablation in this type of composite. Some researchers believe that laser irradiation can cause conical depressions without undercuts in composite resins, which do not cause optimal mechanical retention [23]. However, acid etching following bur abrasion can cause micro-retentive and macro-retentive porosities, remove the smear layer, and expose the underlying layer and filler particles. Resultantly, it increases the surface area and enables better load distribution at the interface [9,34].

According to the current results, the mean SBS in the 4.5W laser group (300mJ) was not significantly different from that in the control group (bur abrasion + acid etching), but was significantly higher than the SBS in the 1W (100mJ) and 2W (200mJ) laser groups. Etemadi et al. [20] demonstrated that increasing the Er:YAG laser power from 1W to 5W increased the porosities of nanofilled composite. However, further increase in laser power resulted in material destruction [20]. Carrieri et al. [35] evaluated dentin surfaces and demonstrated that irradiation of Er:YAG laser with lower intensities yielded a higher tensile bond strength to composite resin, compared with higher intensities. Yet, this difference did not reach statistical significance. Ramos et al. [36] confirmed that irradiation of Er:YAG laser with different powers caused a superficial granular layer with different forms on the tooth surface, which became thicker by an increase in radiation parameters and could impair the bonding process. Such differences can be due to evaluation of different substrates (tooth surface) in these studies. Nonetheless, contrary to the current results, Duran et al. [8] assessed the effect of Er:YAG laser with 75, 100, 200 and 300mJ energies on the bond strength between new and thermocycled microhybrid composite resin and stated that laser irradiation with higher energy levels can increase the diameter, volume, and rate of ablation and decrease micromechanical retention and bond strength. However, evaluation of the AFM results in the present study indicated increased surface roughness following the use of a higher level of laser energy, which can enhance the bond strength. It must be noted that the SBS of the study groups in the present study was lower than the values reported by Duran et al, [8] (15.27 to 25.98MPa). Scatena et al. [37] found that laser irradiation of surfaces from a longer distance resulted in distribution of laser energy in a wider surface and enhanced the bond strength. In the current study, a non-contact laser irradiation mode at 1mm distance from the specimen surface was adopted; whereas in the study by Duran et al, [8] the distance between the applied laser and tooth surface was 12mm. Thus, shorter distance between the laser handpiece and aged composite specimen may be responsible for lower bond strength in the present study.

In the current study, the surface of the deboned aged specimens was inspected under a stereomicroscope to determine the mode of failure. The results indicated that most of the specimens showed mixed failure, which contradicts the results of Kiomarsi et al, [33] who reported that most failures in the laser-treated group were adhesive. This difference can be due to the use of silane in addition to the bonding agent and different laser parameters in their study. They explained that bonding agents had higher capability for formation of chemical bonds, and the groups that only received silane after laser conditioning showed higher frequency of adhesive failure.

In the present study, only the SBS of specimens was evaluated. SBS testing is commonly used to predict the behavior of dental materials and assess the bond strength of composite resins. Also, it has a simple protocol, and preparation of specimens for SBS test is easy. However, stress may distribute non-uniformly at the interface [38]. Also, it should be noted that composite resin restorations are exposed to a combination of loads in the oral environment. Furthermore, in most clinical settings, it is not feasible to determine the type of old restorations [18]; thus, different types of composite resins are bonded while repairing defective restorations. However, both the aged and repair composite resins used in this study were of the same type. Moreover, the effect of various power levels of Er:YAG laser on nanofilled composite specimens was evaluated in this study. Since the effect of laser relies on chemical composition and structural properties of composite resins, further studies on different types of composite resins are required to compile a guideline for Er:YAG laser conditioning of aged composite resins. It is worth mentioning that the bond strength between a new layer and an aged layer of composite resin in the clinical setting is affected by the saliva pH and enzymes that can reduce the amount of unreacted monomers [23]. In general, in vitro studies are fast and easy for evaluation of bond strength; however, their results cannot be reliably generalized to the clinical setting [39]. In fact, in vitro studies may not perfectly simulate the clinical setting [40]. Therefore, long-term clinical studies are imperative to obtain more reliable results.

CONCLUSION

Considering the limitation of this in vitro study, it may be concluded that the SBS value obtained by the application of average-power (4.5W) laser was comparable to the value obtained by acid etching following bur abrasion. However, application of low-level laser (1W and 2W) yielded SBS values significantly lower than that obtained by acid etching following bur abrasion.

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CONFLICT OF INTEREST STATEMENT

None declared.

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