

The effects of Er:YAG, Nd:YAG, and Diode (940nm) Lasers irradiation on Microtensile bond strength of two steps self-etch adhesives

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Background and aims: Nowadays, studies show the effective laser irradiation role on the adhesion of bonding agents to the dentin. Therefore, the present study was set to find an appropriate protocol for the use of Nd:YAG, Er:YAG, and Diode lasers during the application of two steps self-etch adhesives in direct dental restorations in order to achieve higher microtensile strength.

Materials and Methods: A total number of 100 extracted healthy teeth were selected. After removing occlusal enamel and exposing dentin, samples randomly divided into ten groups: Group Control (C), two steps self-etch adhesives was applied in accordance with the manufacturer instructions, without using laser systems; Groups Er-YAG, laser (2940 nm, 10 Hz, 0.4w, 40 mJ) irradiated Before applying Primer (Er-BP subgroup), After applying Primer (Er-AP subgroup), After applying Bonding (Er-AB subgroup); Groups Nd-YAG, laser (1064 nm, 10 Hz, 1.2w, 40 mJ) irradiated Before applying Primer (Nd-BP subgroup), After applying Primer (Nd-AP subgroup), After applying Bonding (Nd-AB subgroup); Groups Diode, laser (940 nm, 10 Hz, 0.7w, 70 mJ) irradiated Before applying Primer (D-BP subgroup), After applying Primer (D-AP subgroup), After applying Bonding (D-AB subgroup). After intervention and composite build up, the samples were stored 24 hours in 37°C distilled water. The microtensile strength was measured using the universal testing machine. The data were analyzed by one-way ANOVA test and post hoc Tukey test. ($p < 0.05$)

Results: The Means and standard deviations of the groups were as follow: C = 30.09 ± 4.21 , Er-BP = 18.83 ± 4.21 , Er-AP = 14.43 ± 3.12 , Er-AB = 19.67 ± 4.96 , Nd-BP = 20.35 ± 5.55 , Nd-AP = 39.85 ± 4.13 , Nd-AB = 18.16 ± 3.36 , D-BP = 26.74 ± 5.05 , D-AP = 28.11 ± 5.12 , D-AB = 37.28 ± 5.61 . The mean microtensile strength achieved in groups: Nd-AP and D-AB were significantly higher than control group ($p < 0.05$). Groups D-BP and D-AP had no significant difference in comparison with control group while the remaining groups had significantly lower values ($P < 0.05$).

Conclusions: Nd:YAG laser irradiation after applying the primer, and diode laser irradiation after applying the bonding agent, both can improve the microtensile bond strength in two steps self-etch adhesive systems significantly.

Key words: Adhesive • Bond strength • Nd:YAG • Er:YAG • Diode laser

Introduction

Preparation of dental tissues before applying adhesive restorations is a step with paramount importance in bonding protocol with a detrimental effect on the overall treatment successfulness ¹. Nowadays, providing a reli-

able connection between dentin and composite restoration is a challenging area ².

Self-etch adhesives have a lower level of technical sensitivity compared to that of etch & rinse counterparts ^{3, 4}, because of several reasons, including, elimination of rinsing and drying steps, saving time, as well as reduction of human errors during the preparation ^{5, 6}. Moreover, collagen matrix would remain stable during the etching and bonding process because the drying step is not required ⁷.

Considering the capabilities of laser systems, it can

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be used in dentistry for several purposes. For example, it can be used for preparation of dental cavities, caries removal, removing previous restorations, etching of enamel and dentin, dentin hypersensitivity treatment, prevention of dental caries, and tooth bleaching⁸⁾.

Laser systems have other advantages, as well. They can be used for surface processing, controlling the light frequency, having a wide range of frequency, high energy density, and the ability to focus light onto a point⁹⁾. CO₂ laser, Nd: YAG (Neodymium: Yttrium-Aluminum-Garnet), Er: YAG (Erbium: Yttrium-Aluminum-Garnet) and Diode lasers are some types of laser systems that have found many applications in dentistry¹⁰⁾.

In recent years, researchers have tried to utilize such systems in reinforcing adhesive bonds¹¹⁾. Firstly, the technique was used by Goncalve et al¹²⁾, suggesting that dentin treatment with Nd:YLF laser irradiation (1.31 J/cm²; 250 mJ per pulse) after the application of the adhesive system is useful in enhancing resin shear bond strength. In another study carried out by Franke et al¹³⁾, the Nd:YAG laser (200 µs light pulses, 10 Hz, 1064 nm, 5J/cm²) was irradiated on the dentin surface before applying adhesive polymerization which resulted in a higher level of bond strength. In contrast, the results of studies carried out by Matos¹⁴⁾ using Nd:YAG laser (1064 nm, 150 µs pulse duration, 0.6W, 15 Hz, 40 mJ per pulse) and Malta¹⁵⁾ irradiating Nd:YAG laser (1064 nm, 120-160 µs pulse duration, 1W, 10 Hz, 100 mJ per pulse) have demonstrated that applying laser beams did not have a significant effect on the bond strength.

Considering the possible effect of laser beams on the penetration depth of acidic monomers and the fact that there has not been conducted a comprehensive study yet to compare the effect of various lasers, the present study was set to find the most appropriate clinical protocol in the use of Er:YAG, Nd:YAG, and diode lasers during treatments based on two steps self-etch adhesives such that the highest bond strength can be resulted.

Materials and methods

A total number of 100 human third molar teeth, free of any caries or previous restoration, were selected to be investigated in the present study. These teeth were cleaned out from periodontal tissues and placed in 0.1 percent thymol solution for a month. After this period of time, all samples were stored in distilled water at 4 centigrade degrees¹⁶⁾.

Teeth were mounted in self-cured acrylic resin (Acropars, Iran). The enamel of occlusal surface was removed so that dentin became exposed. In order to standardize the smear layer, waterproof silicon-carbide abrasive paper (A. P. C, Iran) with a sequence of 150, 240, 400, and 600 grit was employed.

Teeth samples were randomly divided into ten

groups, each containing ten teeth. Following protocols were used preparing each group;

- 1) Control group (C): Two steps self-etch adhesives (Clearfil SE bond, Kuraray Medical Inc., Tokyo, Japan) was applied in accordance with the manufacturer instructions, without using laser systems. Accordingly, the prepared dentin was firstly covered by a layer of primer using micro-brush (Ese international, Taiwan). After 20 seconds, the tooth was exposed to a stream of dry air in order for solvent to be evaporated. A layer of bonding was added and cured using a light cure device (Kerr, USA) with the intensity of 800 mW/cm² from a distance of 1 mm for 10 seconds. The light intensity was checked using a radiometer (Kerr, USA) for all groups in order to establish the same condition among samples.
- 2) Group Er:YAG-Before applying Primer (Er-BP): Er: YAG laser (Fotona, Slovenia) beam was irradiated before applying the primer. The characteristics of the laser beam were as follows; wavelength: 2940 nm, frequency: 10 Hz, power: 0.4 w, energy: 40 mJ, mode: short plus, distance 5 mm, motion style: swiping motion, irradiation time: 30 s, hand piece: R14. All other steps were similar to those implemented in control group.
- 3) Group Er:YAG-After applying Primer (Er-AP): Er: YAG laser beam was irradiated after applying the primer, before adding bonding layer. The characteristics of the laser beam were similar to those of group Er-BP and all other steps were similar to the control group.
- 4) Group Er:YAG-After applying Bonding (Er-AB): Er: YAG laser beam was irradiated after the bonding step was done. The characteristics of the laser beam were similar to those of group Er-BP and all other steps were similar to the control group.
- 5) Group Nd:YAG-Before applying Primer (Nd-BP): Nd: YAG laser beam (Fotona, Slovenia) was irradiated before applying the primer. The characteristics of the laser beam were as follows; wavelength: 1064 nm, frequency: 10 Hz, power: 1.2 w, energy: 40 mJ, mode: short plus, distance 5 mm, motion style: swiping motion, irradiation time: 30 s, hand piece: 300 microns. All other steps were similar to those implemented in the control group.
- 6) Group Nd:YAG-After applying Primer (Nd-AP): Nd: YAG laser beam was irradiated after applying the primer and before adding bonding layer. The characteristics of the laser beam were similar to those of group Nd-BP and all other steps were similar to the steps applied to the control group.
- 7) Group Nd:YAG-After applying Bonding (Nd-AB): Nd: YAG laser beam was irradiated after the bonding step was done. The characteristics of the laser beam were similar to those of group Nd-BP and all

other steps were similar to the steps applied to the control group.

- 8) Group Diode-Before applying Primer (D-BP): Diode laser (Epic 10, Biolase, USA) beam was irradiated after preparing dentin and before applying the primer. The characteristics of the laser beam were as follows; wavelength: 940 nm, frequency: 10 Hz, power: 0.7 w, energy: 40 mJ, mode: continuous, distance 5 mm, motion style: swiping motion, irradiation time: 30 s, hand piece: E4. All other steps were similar to those implemented in the control group.
- 9) Group Diode-After applying Primer (D-AP): Diode laser beam was irradiated after applying the primer and before adding bonding layer. The characteristics of the laser beam were similar to those of group D-BP and all other steps were similar to the steps applied to the control group.
- 10) Group Diode-After applying Bonding (D-AB): Diode laser beam was irradiated after the bonding step was done. The characteristics of the laser beam were similar to those of group D-BP and all other steps were similar to the steps applied to the control group.

Samples were covered by resin composite (Filtek Z250, 3M ESPE, USA) with A2 shade, 4 mm height, and 2 mm thickness. They were cured for 40 seconds. Samples were preserved in distilled water at 37°C for 24 hours. Then, samples were cut in the longitudinal direction in order to prepare samples with a cross sectional area of 1 mm² using a cutting saw (Fanavaran Pars, Mashhad, Iran) at low speed under water cooling.

Samples were fixed to jig using the Cyanoacrylate adhesive (Superbonder, Loctite, Brazil). Microtensile bonds strength were assessed by universal testing machine. For doing so, the tensile force was uniformly im-

plemented to the resin-dentin junction at a consistent speed of 1 mm/min until the failure was occurred and the values were recorded. In order to determine which type of failure (adhesive, cohesive in dentin, cohesive in resin, and mixed) had been occurred, the junctions were observed under stereomicroscope (Olympus, Japan) at 40-times magnification.

Results

The average bond strength for various groups are presented in **Table 1**. As evident in this table, the highest bond strength was associated with the Nd-AP and D-AB groups. Whereas, the weakest bond strength was observed among the Er-AP group.

Kolmogorov-Smirnov test demonstrated that all data had a normal distribution ($p = 0.119$). Accordingly, parametric statistics was employed for further analyses.

The result of ANOVA test indicated a significant difference among groups ($p < 0.05$). This test was followed by Tukey post hoc test in order to obtain a deeper insight into the differences between each pair of groups. The results are presented in **Table 2**. Accordingly, as evident in this table, the average bond strength D-AB and Nd-AP groups were significantly higher than those of other groups ($p < 0.05$), while the difference between these two groups was not significant. Moreover, the bond strength of Nd-AB, Nd-BP, Er-AB, Er-AP, and D-BP groups were significantly lower than that of the control group. Two groups showed the same bond strength as did control group, i.e. D-AP and D-BP. Moreover, the average bond strength of these two groups were also significantly higher than those of Nd-AB, Nd-BP, Er-AB, Er-AP, and D-BP, with the exception that the Nd-BP group had a better bond strength than that of D-BP group, and weaker

Group	Mean	SD	SE	Min	Max	Median	95% Confidence Interval	
							Lower	Upper
C	30.0980	4.21608	1.33	23.28	36.92	30.26	27.08	33.11
Er-BP	18.8360	4.21609	1.33	14.00	25.70	17.71	15.82	21.85
Er-AP	14.4300	3.12376	0.99	10.60	19.90	14.35	12.19	16.66
Er-AB	19.6760	4.96388	1.60	15.40	28.36	17.40	16.12	23.23
Nd-BP	20.3510	5.55680	1.76	15.68	29.57	17.96	16.38	24.33
Nd-AP	39.8530	4.13145	1.31	33.00	45.85	40.64	36.90	42.80
Nd-AB	18.1660	3.36762	1.06	13.00	24.00	17.65	15.76	20.58
D-BP	26.7480	5.05132	1.60	19.60	32.73	27.47	23.13	30.36
D-AP	28.1100	5.12418	1.62	21.44	35.17	27.67	24.44	31.78
D-AB	37.2830	5.61992	1.78	30.00	45.55	36.61	33.26	41.30

Table 2: The results of Tukey post hoc test (paired comparison among groups).

Group	Er-BP	Er-AP	Er-AB	Nd-BP	Nd-AP	Nd-AB	D-BP	D-AP	D-AB
C	0.000	0.000	0.000	0.000	0.000	0.000	0.833	0.994	0.025
Er-BP		0.507	1.000	0.999	0.000	1.000	0.008	0.001	0.000
Er-AP			0.260	0.129	0.000	0.726	0.000	0.000	0.000
Er-AB				1.000	0.000	0.999	0.030	0.004	0.000
Nd-BP					0.000	0.987	0.073	0.011	0.000
Nd-AP						0.000	0.000	0.000	0.962
Nd-AB							0.003	0.000	0.000
D-BP								1.000	0.000
D-AP									0.001

* $P < 0.05$, statistically significant difference between study groups.

than those of Nd-AP and D-AB groups.

Homogeneity Test (**Figure 1**) were applied to each cluster of groups containing groups without significant differences among their bond strength values [i.e. (Er-BP, Er-AP, Er-AB, Nd-BP, Nd-AB), (Nd-BP, D-BP), (D-AP, D-BP, C) and (Nd-AP, D-AB)] and the results showed that the variances of groups within the same cluster have significantly been similar to each other.

Moreover, the results indicated that the most prevalent type of failure observed in the present study was the adhesive type.

Discussion

In the present study, we used various laser systems to find the best way through which the maximum bond strength can be achieved from such systems. The results of the present study demonstrated that the use of Nd:YAG laser system after applying primer (Nd-AP group) and utilization of Diode laser system after bonding agent implementation and before polymerization (D-AB group) improved the bond strength significantly, higher than what can be obtained from applying the ordinary protocol (control group). The increase in microtensile bond strength can be due to an increased penetration depth induced by a hot stream created by the laser system²⁾. In this regard, Franke and Marimoto^{17, 18)} have explained the role played by heat and hot air in increasing the penetration depth of adhesive systems and thereby improving bond strength. The local hot spot created by Diode laser irradiation can promote the transformation of adhesive. Similar to the present study, Maenosono et al²⁾ also have observed that the application of Diode laser beam after the bonding step would improve bond strength, mainly because of the heat produced in adhesive as a result of laser beam absorption. They also postulated that the ab-

sorption of laser beam by adhesive can create a new substrate which improves the dentin-adhesive bond strength. The heat produced by laser system and the low viscosity of the primer are two possible causes why an improvement in penetration depth of primer followed by an increased penetration of the bonding agent was observed. Moreover, it has been shown by Dayem¹⁹⁾ that the use of Nd: YAG laser beam after etching of dentin will promote the resin penetration, which can be why an increase in bond strength is observed after the use of primer and acidic molecules.

In the study carried out by Marimoto¹⁸⁾, it was reported that applying Nd: YAG laser system after bonding agent and before curing steps resulted in a more favorable bond strength than that of the control group. This

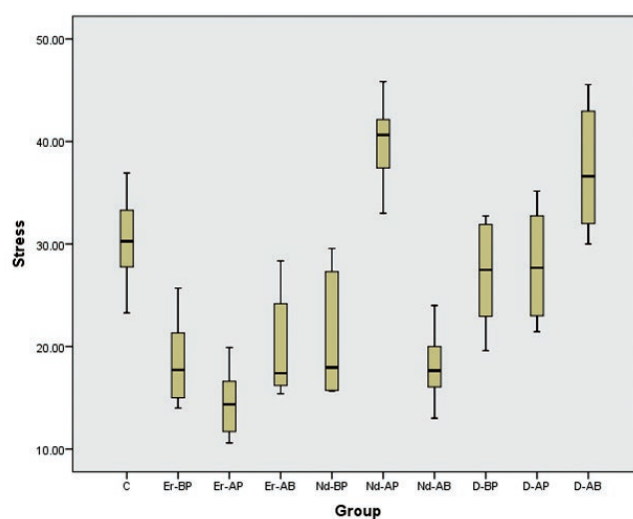


Figure 1: Homogeneity Test for comparing variances of groups.

finding is in contradiction with the results of the present study. Several reasons can be suggested for this contradiction; the power used in the present study is lower than that used in Marimoto study and in the present study we used the two steps self-etch adhesive system which is more viscous than the 5th counterpart is. Similar to Marimoto¹⁸⁾, Matos²⁰⁾ also did not report any significant improvement in bond strength of adhesive systems modified by applying Nd:YAG laser system on 5th generation adhesives.

Furthermore, the results of the present study demonstrated that the application of Er-YAG laser beam at a wavelength of 2940 nm, power of 0.4 w, and frequency of 10 Hz before applying the primer, before ap-

plying the bonding agent and after applying the bonding agent reduced the bond strength compared with control group. These findings are in line with the results obtained by other studies, including Ramos, Portillo, Firat, and Gurgan^{1, 21-23)}. Also, Souza²⁴⁾ indicated that using Er-YAG alongside a non-rinse conditioner before applying 5th generation of adhesive system did not influence bond strength significantly. According to these studies, it can be postulated that the heat produced by Er-YAG is so high that causes the solvent of adhesive systems to be evaporated before having the chance to penetrate in dentin tubules, even if according to Chen²⁵⁾ recommendation a low power of the laser system is applied. Likewise, Ramos²³⁾ reported that Er-YAG laser system at various pow-

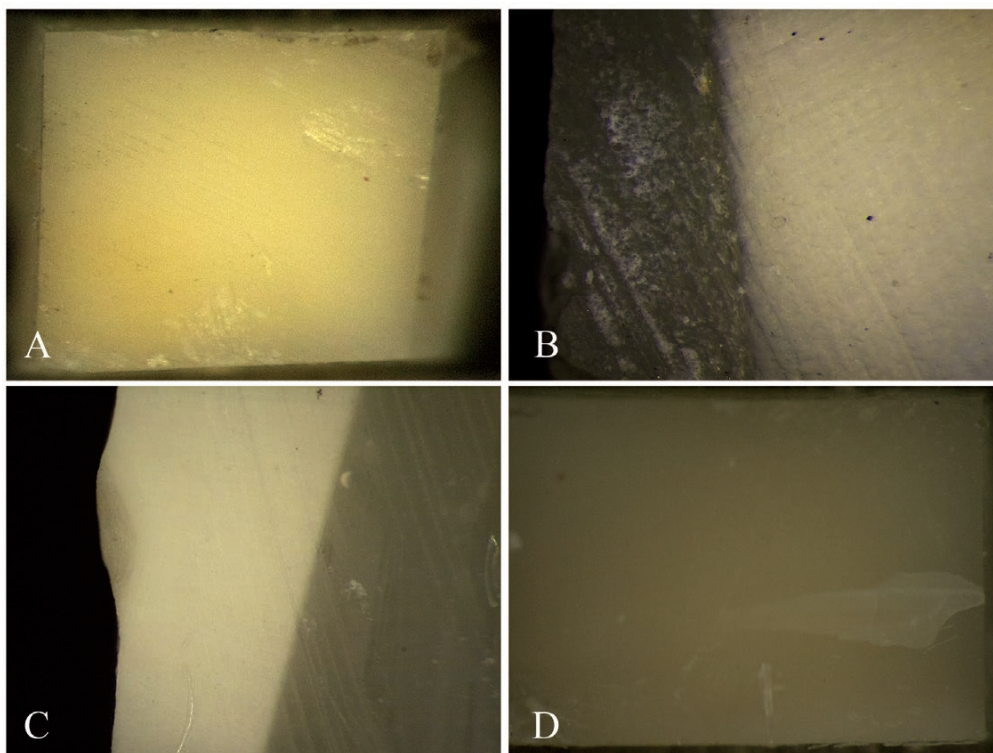


Figure 2: Various types of failures among groups. (A= adhesive, B= cohesive in dentin, C= cohesive in composite, D= mixed failure).

Table 3: Failure types in percent among groups.

Group	C	Er-BP	Er-AP	Er-AB	Nd-BP	Nd-AP	Nd-AB	D-BP	D-AP	D-AB
Fracture type										
Adhesive	70%	90%	100%	90%	90%	60%	90%	80%	80%	60%
Cohesive in tooth	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%
Cohesive in composite	10%	0%	0%	0%	0%	10%	0%	0%	10%	10%
Mixed	20%	10%	0%	10%	10%	20%	10%	20%	10%	30%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

er levels can create granular layers on dentin surface that disrupts the bonding process.

In Nd-BP group, the irradiation of the laser beam before applying the primer caused the bond strength to be degraded, which can be due to the destruction of dentin organic matrix^{26, 27)}, changes in surface morphology of dentin, followed by loss of calcium and phosphate from dentin structure, and finally changes in hydroxyapatite composition^{18, 28)}. Further, it should be noted that the irradiation of Nd: YAG laser system before applying the adhesive would cause the dentin to be melted and solidified again. It also can be due the fact that water and hydroxyapatite have a low ability to absorb electromagnetic waves at the range irradiated by Nd: YAG laser system. However, even this low level of irradiation absorption would result in increasing temperature of dentin tissues, followed by carbonization and evaporation of organic and inorganic matrix. Then, the evaporated matrix would deposit on the irradiated surface again and reduce the bond strength¹⁷⁾. The results are in line with those of Goncalves and Matos that explained the application laser before the adhesive system reduced the strength of the

microtensile bond^{20, 29)}.

And about failure types among groups, as shown in **table 3**, adhesive failure counts in groups Nd-AP and D-AB was lower in comparison with other groups. Lower adhesive failure counts and higher mixed and cohesive failures counts in mentioned groups, proves higher bond strength which is compatible with microtensile bond strength results discussed previously.

Finally, we would like to recommend for further studies using SEM and TEM to investigate microscopic changes of dentin in Nd-AP and D-AB groups in order to determine the cause of higher bond strength.

Conclusions

In conclusion, the use of Nd:YAG laser beam (wavelength: 1064 nm, power: 1.2 w, mode: short pulse, frequency: 10 Hz) after applying the primer, and the use of diode laser beam (wavelength: 940 nm, power: 0.7 w, mode: continuous) after applying a bonding agent can improve the strength of microtensile bond significantly.

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