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Original Article

Shear bond strength of resin composite bonded with two adhesives: Influence of Er: YAG laser irradiation distance

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ABSTRACT

Background: Dental surfaces prepared with different Er:YAG laser distance may have different characteristics compared with those prepared with conventional instruments. The aim of this study was to investigate the effect of Er:YAG laser irradiation distance from enamel and dentin surfaces on the shear bond strength of composite with self-etch and etch and rinse bonding systems compared with conventional preparation method.

Materials and Methods: Two hundred caries-free human third molars were randomly divided into twenty groups (n = 10). Ten groups were designated for enamel surface (E1-E10) and ten for dentin surface (D1-D10). Er: YAG laser (2940 nm) was used on the E1-E8 (240 mJ, 25 Hz) and D1-D8 (140 mJ, 30 Hz) groups at four different distances of 0.5 (standard), 2, 4 and 11 mm. Control groups (E9, E10, D9 and D10) were ground with medium grit diamond bur. The enamel and dentin specimens were divided into two subgroups that were bonded with either Single Bond or Clearfil SE Bond. Resin composite (Z100) was dispensed on prepared dentin and enamel. The shear bond strengths were tested using a universal testing machine. Data were analyzed by SPSS12 statistical software using three way analysis of variance, Tukey and independent t-test. $P < 0.05$ was considered as significant.

Results: There was a significant difference between enamel and dentin substrates ($P < 0.001$) and between lased and un-lased groups; the un-lased group had significantly higher bond strength ($P < 0.001$). Shear bond strength increased significantly with an increase in the laser irradiation distance ($P < 0.05$) on enamel surfaces (in both bonding agent subgroups) and on dentin surfaces (in the Single Bond subgroup).

Conclusion: Laser irradiation decreases shear bond strength. Irradiation distance affects shear bond strength and increasing the distance would decrease the negative effects of laser irradiation.

Key Words: Dentin, enamel, Er: YAG laser, irradiation distance, resin composite, shear bond strength

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INTRODUCTION

Conventional cavity preparation and direct bonding is an acceptable clinical procedure in operative dentistry.

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To achieve effective adhesion between dental tissue and restorative materials, the smear layer which is formed during removal of dental caries must be either removed or modified. Traditionally, after cavity preparation by rotary instruments, the enamel and dentin are prepared for resin bonding through acid etching and application of bonding agent. Self-etching primers have been developed that include both acid etchant and priming agents into a single acidic primer for simplified and faster conditioning of enamel and dentin.[1]

Laser irradiation has been introduced as an alternative method for preparing dental hard tissues. The Er:YAG laser is well-known for its ability to remove dental hard tissues with minimal injury to the pulp and without causing severe thermal side-effects such as cracking, melting or charring of the remaining tooth structure and/or surrounding tissues. The accepted theory about the mechanism of the Er:YAG laser is that the emitted laser is predominantly absorbed by the water molecules on tooth hard tissues causing abrupt heating and evaporation of water. The high vapor pressure causes a micro-explosion sequence, which shoots small tissue particles; this is called ablation. Er:YAG laser is used for conservative removal of dental caries and has disinfecting and anti-bacterial properties.[2,3] The following items are commonly considered to be laser setting parameters: Laser wavelength, emission mode, energy density, tissue water content, air/water spray cooling, pulse duration, irradiation time, pulse energy, pulse repetition rate, nature of any post-irradiation surface's treatment such as acid etching, ultrasonic cleaning and air abrasion. The amount of tissue removed by Er:YAG laser and the impact upon adjacent tissues depend on the setting parameters and the distance between the laser device and the tooth surface.[4]

The irradiation distance is an important parameter because it is directly related to the laser ablation ability, surface morphology and the consequent success of the bonding procedure.[4,5] Different manufacturers offer various hand pieces; none of these handpieces has direct contact with the tooth surface during cavity preparation, even in contact mode (at very low distance). Considering the possibility of changing laser irradiation distance during operation, per the manufacturer's instruction, the operator can change the mode of operation, such as a contact or non-contact mode and focused or defocused mode, which results in different morphologic features of the bonding area for adhesion.[5-8] The effect of different irradiation distances has been tested on handpieces with non-contact mode but there is no study considering this matter on handpieces with contact mode.

The null hypotheses tested were:

a. There is no significant difference in bond strengths of the different adhesive systems (self-etching versus etch and rinse) when applied to laser irradiated enamel and dentin at different laser irradiation distances; and
b. there is no significant difference in the bonding of self-etching or etch and rinse adhesives to either bur-cut or laser-ablated enamel and dentin.

The aim of this study was to investigate the effect of Er:YAG laser irradiation distances of contact mode handpiece on enamel and dentin shear bond strength using self-etch and etch and rinse bonding systems.

MATERIALS AND METHODS

This experimental *in-vitro* study has been approved by Isfahan University of Medical Sciences, Isfahan, Iran and has no conflict with the declaration of Helsinki. The current study evaluated the effect of 3 independent variables including the type of cavity preparation, substrate and also bonding agent on composite shear bond strength.

Two hundred healthy human third molars extracted for orthodontic reasons were collected during 3 months and were stored in Thymol (0.2%) solution at 5 ± 2°C and then mounted in an self-cure acrylic resin (Acropars, Tehran, Iran) surrounded by a PVC cylinder; the cylinders were then discarded. The specimens were randomly divided into twenty groups of ten. Ten groups were designated for enamel surfaces and ten others for dentin surfaces. In dentin specimens 2 mm of the facial enamel surfaces of the crowns were ground under water cooling in a polishing machine (Politriz, Struers A⁄S, Copenhagen, Denmark) using #320-to #400-grit silicon carbide paper. This process removed the overlying enamel to provide uniform superficial dentin surfaces. The exposed dentin surfaces were inspected with a stereomicroscope (16x) (SMP-200, HP, USA) to ensure that no enamel was left and no pulpal exposure had occurred. The enamel and dentin specimens were divided into two subgroups with different bonding agents including Clearfil SE Bond (Kuraray, Osaka, Japan) and Single Bond (3 M ESPE, St. Paul, MN, USA). Subgroups one to eight in enamel and dentin groups were laser irradiated (16 subgroups) with an Er:YAG laser (Fidelis Plus, Fotona 1210 Ljubljana, Slovenia) (wavelength of 2490 nm) at a pulse energy of 240 mJ, a repetition rate of 25 Hz and a pulsed duration of 150 µs (Short Puls [SP]) for enamel and pulse energy of 140 mJ, repetition rate of 30 Hz and a pulsed duration of 150 µs (SP) for dentin at four different distances (0.5, 2, 4, 11 mm)[9] under 7 ml⁄min water cooling. At first the laser beam (spot size = 2 mm) was delivered in contact and focused mode in a distance of 0.5 mm, for 40 s and then was delivered in distances of 2, 4 and 11 mm in a non-contact and defocused mode. The calculated energy density at the first setting was 0.0339 J/cm^2 for enamel and 0.01981 J/cm^2 for dentin. The handpiece (RO7) was fixed to the experimental surface of the specimens by very short, short, medium and long clamps, which were mounted on the handpiece in order to standardize the distance of handpiece from the surface at 0.5, 2, 2, 11 mm. After adjusting the tip of the probe and the surface of the sample, the laser was applied. Control subgroups in enamel and dentin groups (4 subgroups) were not laser irradiated and their surfaces were only ground with medium grit (100 µm) diamond burs (ISO TF-12F, DIA Burs, Japan) in a water-cooled high-speed turbine (Trend, Tc-95BC/W & H, Austria). The bonding area with 4 mm diameter was delineated on specimens by a demographic pencil. Immediately after preparing the specimen with laser or turbine either the etch-and-rinse (Single Bond) adhesive system or self-etch adhesive system (Clearfil SE Bond) was applied on enamel and dentin surfaces, as prescribed by the manufacturer. Detailed information about the selected adhesives is presented in Table 1. After that, bonding layer was cured with a visible light curing unit (460 mW/cm^2) (Optilux 501, Kerr/Demetron, Danbury, CT, USA) for 20 s. The light output of the polymerizing unit was checked before bonding procedure using a radiometer (Curing Radiometer, Kerr, Orange, CA, USA). Then, transparent plastic tubes with diameter and height of 3 mm were filled with resin composite (Z100, 3M ESPE, USA). The filled tubes were placed on the bonding area that was prepared with a bonding agent and were cured for 40 s from all directions. The plastic tubes were discarded after the bonding process. All specimens were stored in distilled water for 24 h, then placed in an incubator (01154 Behdad, Tehran, Iran) at 37°C. Thermo cycling (Delta Tpo2, Nemo, Mashhad, Iran) was done (500 cycles between 5°C and 55°C) with a dwell time of 30 s in each bath and a transfer time of 5-10 s between the two baths.[10] Finally, the specimens were tested for shear bond strength with a universal testing machine (Dartec, Series HC10, West Midland, England). A knife-edge blade with terminal thickness of 0.5 mm was fixed in the machine and applied the shearing force perpendicular to the tooth at the rate of 1 mm/min at the closest distance possible from the composite connection. The maximum load to failure (N) was recorded for each sample in machine's monitor. Shear bond strength was calculated as the ratio of fracture load and bonding area, expressed in megapascals (MPa).

Data were analyzed with SPSS 12 (SPSS Inc., Chicago, IL, USA) statistical software. Three way variance analysis was used for comparing effective factors on shear bond strength. Analysis of variance (ANOVA) and Tukey *post hoc* were used to compare the shear bond strength in different distances of laser irradiation with the bur cut surfaces in both enamel or dentin substrates. Independent *t*-test was used to compare the effect of bonding agent on composite shear bond strength. $P < 0.05$ was considered as significant level.

RESULTS

Table 2 shows the mean shear bond strengths (MPa) of self-etch (Clearfil SE Bond) and etch and rinse (Single Bond) adhesive bonded to enamel and dentin. The maximum bond strength was recorded for the enamel control group with Single Bond adhesive and the minimum bond strength was recorded for the laser ablated dentin with Single Bond adhesive at 0.5 mm distance of laser irradiation. The results of three-way

Table 1: Compositions, specifications and manufacturers of the adhesive systems used in this study

Material	Clearfil SE bond	Single bond
Type	Self-etching primer Adhesive system	Total-etch adhesive system
Principal ingredients	Primer: HEMA, MDP, water Bond: MDP, Bis-GMA, HEMA, salinized colloidal silica	Bis-GMA, HEMA, dimethacrylates, polyalkenoic acid copolymer, ethanol/water
Batch no.	Primer: 00670A Bond: 00957A	6 KR
Manufacturer	Kuraray Co., Ltd., Osaka, Japan	3 M ESPE, St Paul, MN, USA

Bis-GMA: Bisphenol-glycidyl methacrylate; HEMA: Hydroxyethylmethacrylate; MDP: 10-Methacryloyloxydecyl dihydrogen phosphate

Table 2: Shear bond strengths (MPa) of resin composite bonded to enamel and dentin

Groups distance (mm)	Single bond		Clearfil SE bond	
	Dentin	Enamel	Dentin	Enamel
Control	14.43±4.54^{a}	20.66±5.36^{a}	18.04±2.55^{a}	20.02±5.49^{a}
0.5	6.58±2.5^{b}	12.52±3.6^{b}	10.54±3.9^{a}	11.32±4.08^{b}
2	8.2±3.8^{b,c,d}	15.99±4.8^{a,b}	12.1±3.8^{a}	15.71±6.1^{a,b}
4	12.31±4.9^{a,b,c,d}	17.9±6.1^{a,b}	12.17±6.5^{a}	17.33±3.8^{a,b}
11	12.73±3.2^{a,d}	19.6±6.8^{a}	15.28±5.1^{a}	19.1±6.5^{a}

Means followed by different lowercase letters (column) indicate statistical differences: ($P < 0.05$)

ANOVA [Table 3] showed statistically significant differences between shear bond strength of dentin and enamel groups (*P* = 0.000) and laser ablated and non-laser ablated groups (*P* = 0.000). It should be pointed out that there was a mutual effect between the type of the bonding agent and type of substrate (*P* = 0.02), in a manner that the application of a particular bonding agent on a particular substrate could alter the shear bond strength. To compare the bond strength at different distances (0.5, 2, 4 and 11) with the control group, one-way variance analysis was carried out. There were significant differences between the bond strength of enamel groups with Single Bond (*P* = 0.007) and Clearfil SE Bond (*P* = 0.004) adhesives. Furthermore, there were significant differences in the bond strength of dentin groups with Single Bond adhesive (*P* = 0.002), but there was no statistically significant difference between bond strength of dentin groups with Clearfil SE Bond adhesive (*P* = 0.08). An independent *t*-test was performed to compare the effect of Clearfil SE Bond and Single Bond adhesive systems on bond strength. There was no significant difference between the mean bond strength of enamel substrates with different bonding agents. There was a significant difference between bond strength of groups in laser irradiated dentin substrates with different bonding agents at 0.5 mm distance (*P* = 0.009) and at 2 mm distance (*P* = 0.027). Clearfil SE Bond showed higher strength.

DISCUSSION

Advances in laser research have resulted in clinically effective wavelengths and an ability to set the physical and technical parameters for clinician.[2] The bond strength of adhesive systems is one of the major factors to be considered in composite resin restorations. Two common self-etch (Clearfil SE Bond) and etch and rinse (Single Bond) adhesive systems were used in this study and their effect on shear bond strength with different laser irradiation distances was investigated. All previous researchers considered the effect of laser irradiation distance from the tooth surface using non-contact handpieces in focused or defocused mode. The present study used the handpiece with contact mode, focused at very low distance and defocused at higher distances.

In the present study, acid etching and acidic primer were applied on the tooth surface after laser ablation to provide a strong bond between composite and dental tissue, because laser ablation alone cannot provide a strong bond to dental substrate.[3]

The results of this study on enamel substrates showed that the control groups bond strength was greater than laser ablated enamel which was similar to the findings of Chimello-Sousa *et al*. that suggested laser irradiation adversely affects adhesion to enamel.[4] This adverse effect may be explained due to enamel changes caused by laser ablation particularly in closer irradiation distances which result in a different attitude of enamel toward acid etching.[4] A significant difference between shear bond strength at different distances of 0.5 mm and 11 mm was observed. This shows that further irradiation distance increased shear bond strength which is similar to the study of Scatena *et al*.[6] As the laser irradiation distance increases, the radiation beam converts to the defocused mode and disperses on a wider surface of the substrate.[4] This may be described by the fact that at large distances, ablation is milder and attains less depth, resulting in a surface more appropriate for superficial treatment.

Most studies which evaluated the effect of laser irradiation distance on shear bond strength have concluded that elevated laser irradiation distance can be considered an effective cause for higher bond strength. A study by Basaran *et al*. showed that laser irradiation distances resulted in lower shear bond strength.[5] Basaran *et al*. found when laser was used for enamel etching alone and the conventional acid etching procedure was not performed after laser ablation, the effect of the type of laser head device and the focused and defocused mode could not be determined.[5] Souza-Gabriel *et al*. found no significant difference in morphologic characteristics of enamel after laser etching followed by acid etching at different irradiation distances.[7] However, the present study showed a significant difference in shear bond strength to enamel at different laser

Table 3: Results of 3-way ANOVA (*P* value) in comparison of effective factors on bond strength

Variable	*P* value
Substrate (enamel or dentin)	0.00
Bonding agent	0.14
Type of cavity preparation (laser or diamond bur)	0.00
Bonding × Preparation	0.91
Substrate × Preparation	0.86
Substrate × Bonding agent	0.02
Substrate × Preparation × Bonding agent	0.87

ANOVA: Analysis of variance

irradiation distances which may be due to the difference in handpiece and laser parameters settings. Since changing the laser irradiation distance results in different energy absorption and morphological changes on the tooth surface,[8] it could be expected that in different laser devices with contact or non-contact hand pieces, the absorbed energy on the tooth surface may differ in focused or defocused mode causing different morphological changes on the tooth surface. Consequently, the shear bond strength in surfaces with lower energy density was high due to fewer morphologic changes.[8]

The smear layer thickness and density has a basic role in bond strength of self-etch adhesive systems.[11,12] Strong self-etch adhesive systems with a higher concentration of acidic monomer are more able in dentin hybridization.[12] Large quantities of acidic monomers, which are available in self-etch adhesive systems, lead to dissolution of smear layer and demineralization of dentin.[13] Some studies suggest that the marginal seal of the Er:YAG laser prepared cavities depends on acid etching being comparable to the marginal seal of bur prepared cavities.[14-19] In the present study, the mean shear bond strength of the bur prepared groups in dentin substrates was higher than laser irradiated groups which was similar to the findings of several previous studies.[2,20-24] Ceballo *et al*. stated that ablation fuses dentin collagen fibrils, reduces inter fibrillar space and impedes resin penetration to these spaces.[2] It has been demonstrated that laser irradiation on dentin reduces adhesion ability.[21] The results of Ceballo *et al*. are contradictory with findings of Visuri *et al*.[25] and Stiesch-Scholz and Hannig[26] which suggested that laser irradiated surface exhibits a rough surface which provides greater surface area for adhesion.

Unfavorable effects of laser on dentin tissue (such as micro cracks, surface scaling and denatured dentin underneath hybrid layer) have been reported previously. Also, it has been demonstrated that elevating laser irradiation distances reduces the number of absorbed photon on surface.[14]

Therefore, it can be concluded that undesirable effects of the laser beam on dentin is greatest at 0.5 and 2 mm distance which leads to the lowest bond strength, in comparison to 11 mm distance.

In etch and rinse adhesive systems, acid etching is done initially for removal of smear layer and removal of hydroxyapatite crystals to expose collagen in dentinal tubules. Since no smear layer is present on laser ablated surface, it seems that the acid etching process results in greater destruction on dentin structure which impacts the bonding quality, particularly in close distances of laser irradiation. However, in further distances of laser irradiation with lower effects on tooth surface[27] and the presence of smear layer due to former enamel removal, the natural condition is prepared for applying etch and rinse adhesive systems and greater bond strength is achievable. According to all mentioned above, designing a new bonding agent for laser ablated surfaces or the use of a rotary instrument after laser ablation is suggested in order to produce smear layer.

The shear bond strength of dentin in closer distances of laser irradiation was greater with Clearfil SE Bond adhesive system in comparison to Single Bond adhesive due to more intensive laser ablation at closer distances which resulted in diminished effect of acid and the chemical bond present in the Clearfil SE Bond adhesive system.[28,29]

Dentin substrates with Clearfil SE Bond adhesive system showed higher bond strength than Single Bond adhesive system which can be explained in two ways. The first reason is that in close distances (0.5 and 2 mm) the substrate's surface is less affected by acid. The second reason is that the hydrophil 10-methacryloyloxydecyl dihydrogen phosphate monomer of Clearfil SE Bond enhances dentin surface moisturizing and two hydroxyl groups which are available in Clearfil SE Bond can chelate calcium.[13] Future studies can be designed with similar energy density in different focused, defocused and highly focused mode.

CONCLUSION

Considering the limitations of this study, it can be concluded that the use of laser in closer irradiation distances will result in lesser shear bond strength in comparison to the conventional cavity preparation and the use of different bonding agents will cause various results on laser ablated and non-laser ablated groups.

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