

Original Article

Shear Bond Strength of a Multi-Mode Adhesive to Bur-Cut and Er,Cr:YSGG Lased Dentin in Different Output Powers

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KEY WORDS

Adhesive;
Bond Strength, Laser;
Dentin;

ABSTRACT

Statement of the Problem: Universal or multi-mode adhesives are new adhesive systems that can be used in both etch-and-rinse (ER) and self-etch (SE) modes. Lesser technical sensitivity and dual use of these adhesives have made them popular among dentists. Studies are being conducted to analyze the advantages and disadvantages these adhesives in different conditions

Purpose: The aim of this study was to compare shear bond strength (SBS) of a multi-mode adhesive in different etching modes to Er,Cr:YSGG laser ablated and bur-cut dentin.

Materials and Method: Buccal and lingual surfaces of 30 sound human molars, randomly divided to three groups, were prepared by bur and Er,Cr:YSGG (4 Watt and 5 Watt, 20 Hz, 96% water, 60% air, and 600- μ m spot size) to reach a flat surface in superficial dentin. Each group was randomly divided into 2 subgroups (ER and SE), and then Scotchbond Universal adhesive was applied. Composite cylinders were attached to the surfaces and cured. Specimens were stored in 37 °C water for 24 hours and thermocycled (500 cycles) and were tested for SBS and failure modes were determined by stereomicroscope. Data was analyzed using SPSS19 and one-way ANOVA and Tukey's post hoc tests and $p < 0.05$ was considered as significance level.

Results: Bur-cut dentin with ER method had the highest mean SBS value (33.80 MPa). SBS in bur-cut and 4Watt laser in ER mode were significantly higher than SE mode ($p = 0.002$ and $p = 0.000$ respectively). Highest mean SBS value in lased dentin was achieved in 4 Watt ER mode.

Conclusion: SBS of Scotchbond universal adhesive to dentine is highest in bur-cut and ER mode and in 4-Watt lased-dentin is higher than 5-Watt lased-dentin. Moreover, in 4-Watt lased-dentin, SBS of ER mode is more than SE mode.

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Introduction

In 1917, Einstein presented laser theory and in 1960, the first working laser device was manufactured [1]. Er:YAG and Er,Cr:YSGG lasers are used in dentistry for hard tissues removal. Er,Cr:YSGG laser with 2.78 μ m

wavelength can remove both hard and soft tissues without the vibration and pulpal thermal stress induced by rotary instruments and less need for local anaesthetics. Therefore, it has been gaining popularity in treating anxious patients [1]. Erbium lasers wavelength targets

tissue water, causing micro explosions which removes hard tissue. This process is called laser ablation. Because of micro explosions in laser-ablated surfaces, we cannot expect a flat surface, but a rough one. With this property and the lack of smear layer in lased surfaces, better and stronger adhesion properties are expected but in studies, we see rather contradictory results [2].

Katuami *et al.* [3] observed microcracks under hybrid layer in Er:YAG laser irradiated dentin. Moreover, Dela Rosa *et al.* [4] described areas of dehydration and loss of protein with malformed hydroxyapatite crystals in Er:YAG laser irradiated dentin. This layer was 3-4 μm in thickness [4]. It is suggested that laser ablated surfaces have fused collagen fibrils and loss of interfibrillar space which prevents diffusion of resin to intertubular dentin [2]. Others described various patterns of micro irregularities, which cause lower bond strengths [5]. All these superficial changes are related to intensity of laser radiation [6]. Laser thermomechanical effects will affect subsurface layer, leading to loss of integrity and weakening of superficial layer, which is often explained as the reason for prevalence of cohesive failure modes in dentin and enamel [4]. For enhancement of bond strength, this altered surface should be either changed or removed by chemical or mechanical means [7].

Universal or multi-mode adhesives are new adhesive systems that can be used in both etch-and-rinse (ER) and self-etch (SE) modes. Lesser technical sensitivity and dual use of these adhesives have made them popular amongst dentist. Studies are being conducted to analyse them in different conditions [8]. Lately, a new adhesive from this category has been introduced to market under the trade name of Scotchbond Universal (3M, ESPE, USA). Manufacturers claim that this adhesive has strong and stable bonding properties in both ER and SE modes that result from its special formulation. Recent studies report various results [8-12], but none of them studied this adhesive in laser-ablated teeth.

Dunn *et al.* [5] reported lower shear bond strengths (SBS) in lased dentin and enamel from other adhesives and considered loss of uniformity of hybrid layer as the reason. Lee *et al.* [13] reported that after acid conditioning, lased dentin surfaces reached bond strengths equal to bur-cut dentin, but without acid conditioning, lower bond strengths were observed.

Marginal integrity and bond strength are the major factors in assessing success of a restoration and both of these properties are related to adhesive system performance and the condition it is used [14].

In this laboratory study, we aimed to assess and compare SBS of Scotchbond Universal to Er,Cr:YSGG lased dentin with different output powers and bur-cut dentin in two conditioning modes, ER and SE. The null hypothesis is that mean SBS values do not differ between different methods of removing dentin and ER or SE modes.

Materials and Method

In this *in vitro* experimental study, 30 sound human extracted third molars were used that were either impacted or extracted for orthodontic reasons. Teeth were cleaned of debris and remaining soft tissues, disinfected in 0.5% sodium hypochlorite for 10 minutes, and stored in tap water the whole time.

Plastic cylinders (2.5×2.5cm) were used for mounting teeth in self-cured acrylic resin (Acropars, Marlic, Tehran, Iran), 1mm beneath the CEJ line. Buccal and lingual surfaces of each tooth were cut perpendicular to the horizontal line to remove enamel using a water-cooled air turbine and a diamond bur (long and flat-end cylindrical 837L, TeezKavan, Tehran, Iran) attached to a custom surveyor so that the cut surfaces were completely flat. After exposing superficial dentin (3×3 mm dentin surface), samples were randomly divided to three groups including bur-cut (Bur), 4Watt Laser (4W), and 5Watt Laser (5W). Bur-cut samples received no further preparation other than using a 600-grit silicon carbide paper to produce a uniform smear layer. 4W laser samples were lased with Er,Cr:YSGG laser (Waterlase: Biolase, Irvine, CA, USA) with following parameters: 4W output power, water pressure 95% and air pressure 60%. The MZ₆ tip with the spot size of 600 μm was used; holding it 1-2 mm above dentin surface with a constant sweeping motion until at least 1mm of dentin was ablated uniformly. 5W laser samples were prepared just as above, only differing in output power. Each group was randomly divided to two subgroups of SE and ER and then Scotchbond Universal adhesive (3M, ESPE, USA) was applied (Table 1).

Materials used in this study are described in Table 1. Another plastic cylinder 2mm in height and an inner

Table 1: Materials used in this study and application techniques of adhesive

Material	Type	Manufacturer	Composition	Application technique
Scotchbond Universal	2-step ER or 1-step SE adhesive	3M, ESPE, USA	10-MDP, HEMA, Vitre-bond copolymer, filler, ethanol, water, initiators, silane	Etch-and-rinse: acid etching (15s), rinsing (15s), blot-drying, two-coats of adhesive applied (20s) and gently air-drying (5s), light cured for 20s. Self-Etch: two-coats of adhesive applied (20s) and gently air-drying (5s), light cured for 20s.
Filtek Z-250 XT	Light-cure nano Hybrid resin composite	3M, ESPE, USA	BIS-GMA, UDMA, BIS-EMA, PEGDMA, TEGDMA, zirconium, silica	
Ultra Etch	Etching agent	Ultradent, USA	35% phosphoric acid	

diameter of 2mm was placed and fixed by sticky wax on the bonded surface before composite placement and curing. Light curing for adhesive and composite was 20 and 40 seconds respectively (Optilux 501, Kerr, USA) at a light irradiance level of 600 mW/cm². After curing, composite plastic mold was removed. Then specimens were stored in tap water in 37 °C for 24 hours (Incubator 6520, Behdad, Iran) before receiving 500 cycles of thermocycling between 5 and 55 °C (with a 60 s dwell time and a 15 s transfer time). The specimens were loaded to failure at 0.5mm/min using the Testometric machine (Testometric M350-10 CT, England) with a metal rod with a chisel-shaped end adjacent to the flat ground dentin surface. The SBS values (MPa) were calculated by dividing peak load at failure at bonded surface area. One-way ANOVA and Tukey's post hoc tests were used with the $p < 0.05$ considered as the level of significance. Tested specimens were observed under a stereomicroscope (SEM) (Olympus, DP12, Germany) at 16x magnification by two calibrated observers (specialist in operative dentistry) separately for determining failure modes. Four types of failure modes were considered in this study including adhesive failure, cohesive failure in dentin, cohesive failure in composite, and finally, mixed failure- partially adhesive and partially cohesive [15].

Results

The results of mean SBS values for each subgroup are shown in Table 2.

Bur-cut dentin with ER mode had the highest mean SBS value (33.80 MPa). In similar etching modes, Bur-cut groups showed significantly higher SBS values than laser ablated groups. In ER mode, 4W laser showed significantly higher SBS values than 5W laser, however; it was not statistically significant in SE mode ($p = 0.571$). Generally, etching mode affected

SBS values and produced significantly higher bond strength in ER mode in Bur-cut ($p = 0.00$) and 4W laser ($p = 0.00$) but was not statistically significant in 5W laser ($p = 0.294$). The highest mean SBS value (28.31 MPa) in lased dentin was achieved in 4W ER mode. Failure patterns are shown in table 3. The Bur-ER subgroup showed more non-cohesive failure pattern while other subgroups showed mainly adhesive failure pattern.

Table 2: Mean shear bond strength (MPa)±SD and p Value between groups

Groups (bond strength ±SD)	Groups comparison	p Value
Bur-ER (33.8±2.65 MPa)	Bur-ER	0.002
	4W-ER	0.018
	4W-SE	0.000
	5W-ER	0.000
	5W-SE	0.000
Bur-SE (26.98±4.74 MPa)	4W-ER	0.964
	4W-SE	0.002
	5W-ER	0.010
4W-ER (28.31±1.78 MPa)	5W-SE	0.000
	4W-SE	0.000
	5W-ER	0.001
4W-SE (20.37±3.34 MPa)	5W-ER	0.997
	5W-SE	0.571
5W-ER (21.14± 4.75MPa)	5W-SE	0.294
5W-SE (17.66±3.79MPa)	Mentioned above	Mentioned Above

Table 3: Failure modes of groups

	Adhesive failure	Cohesive failure in Composite	Cohesive failure in Dentin	Mix
Bur-ER	4	0	4	2
Bur-SE	5	0	3	2
4W-ER	4	1	2	3
4W-SE	7	0	1	2
5W-ER	5	1	2	2
5W-SE	7	0	1	2

Discussion

Laser has the ability of removing caries without surface

fracture and stress caused by rotary instruments [16]. Thermal injury to pulp, vibration, and annoying noise are all disadvantages related to rotary instruments, which are not present in use of laser ablation. Such matters would help in treatment of anxious patients and reducing the dose of anesthesia needed [17].

In similar modes of application of Scotchbond Universal, SBS mean values in bur-cut dentin were significantly higher than both 4W and 5W laser ablated groups. In Esteves-Oliviera *et al.* study [18], SBS values in both laser-ablated enamel and dentin were lower than bur-cut surfaces. They concluded that thermal effects of Er,Cr:YSGG laser causes changes in hydroxyapatite, leading to more resistance of the surfaces to acid, the issue, which does not happen in bur-cut dentine [18]. On the other hand, denatured matrix proteins prevent proper permeation of adhesive in collagen matrix causing lower bond strengths [4]. In a review of the literature by Lopes *et al.*, [19] it was mentioned a reduction in bond strength in laser irradiated dentin compared with conventional methods. Lee *et al.* [13] reported better tensile bond strengths in laser-ablated dentin after acid etching of the surface, equal to bur-cut dentin. In SEM images, acid etched lased dentin was almost similar to acid etched bur-cut dentin, but without acid conditioning, lased dentin showed an uneven scaly surface. The reduced bond strengths of lased dentin without acid etch is due to improper formation of hybrid layer, as collagen matrix is not fully exposed or permeable for resin penetration. [13] Shahabi *et al.* [20] reported similar tensile bond strengths in lased and bur-cut dentin after acid conditioning.

In this study, in ER mode of 4W subgroup, the mean SBS value was significantly higher than 5W subgroup. Few studies have assessed different settings of Er,Cr:YSGG laser on tooth surface and resulting bond strengths [19-21]. Most studies have employed manufacturer's recommended settings (4W, 20 Hz, 65% Air, 55% Water) [18-20, 22].

It is asserted that greater power outputs of device produces more surface heat, causing melting in hydroxyapatite, which subsequently leads to more acid resistance [4]. Consequently, more microcracks are observed in SEM evaluations [5], which might be the reason for lower mean SBS value in 5W than 4W subgroups. In SE mode, because of lower acidity of adhe-

sive and less penetration of it to dentin, a thinner hybrid layer will be produced; which might explain why bond strength was lower in 4W subgroup, though the difference between 4W and 5W subgroups was not statistically significant. Higher mean SBS value of Scotchbond Universal for bur-cut dentin than lased dentin in SE mode might be due to the mentioned superficial thermal effects induced by laser as Scotchbond Universal has mild acidic monomers (pH=2.6) and acts less efficient in removing mineral content. [23] Sun *et al.* [6] studied different output powers of Er,Cr:YSGG laser from 1 to 6 Watt on sclerotic dentin with the rest of the settings unchanged (20 Hz, 65% Air, 55% Water). They observed that surface roughness increased with higher outputs but decreased in 5W and 6W. Furthermore, mean open tubular area increased from 1W to 6W but the difference between 4W, 5W, and 6W groups was not statistically significant. As a result, 4W group produced highest mean microSBS value. They considered surface cracks, observed by SEM, responsible for these lower bond strengths [6] Likewise, these findings can be relevant in explaining our results. In studying Er,Cr:YSGG lased tooth surfaces under SEM, Lee *et al.* [13] reported that in output powers higher than 3.5W microcracks have appeared, air spray at 80% produced the roughest surface and finally, maximum water output produced the least carbonized surface. In the present study, device settings were adopted regarding the previous studies [6, 13] and considering manufacturer's recommendations. Maximum water pressure was selected as in pressures under 90%, carbonization and charring of dentin surface was observed, and dry bur-cut dentin odor was smelled in pilot study.

In the present study, in bur-cut and 4W lased dentin, Scotchbond Universal mean SBS value was higher in ER mode than SE mode. Various bond strength of Scotchbond Universal has been reported in ER and SE mode in different studies [8, 10, 12]. Munoz *et al.* [10] reported no statistically significant difference in microtensile bond strength of different etching modes and in Takamizawa *et al.* study, [12] SBS was reported significantly higher in SE mode. Wagner *et al.* [8] reported no statistically significant difference in microtensile bond strength between the two modes. They observed that although the length of resin tags and hybrid layer thickness differed between ER and SE modes (both ER>SE),

the bond strength did not differ significantly. In addition, in Ayar *et al.* study [24], similar bond strength was concluded between two methods. Competitive property of MDP monomer and Vitrebond copolymer for bonding to hydroxyapatite calcium has been used as an explanation of these various results [8]. On the other hand, Shadman *et al.* [9] reported significantly higher SBS values for ER mode than SE mode in sound and caries affected dentin. They considered better surface morphology and more penetration of resin tags in ER mode and weak acidity of Scotchbond Universal self-etching monomers as the reason for higher SBS values of ER mode [9]. Similar results were revealed in some studies [25-26]. Difference between the results of these studies can be due to technical sensitivity of ER mode, dry/wet bonding [27], samples morphology in microtensile tests (matchstick or dumbbell shape), type of bond strength tested (shear or tensile) and the condition samples are stored in after preparation [28].

Shallow and superficial etching and reduced micro-mechanical retention is the main worry of mild SE adhesives [29]. Conditioning with phosphoric acid in dentin before applying SE adhesives can produce better interfacial morphology by creating a thicker hybrid layer and longer resin tags. Elimination of smear layer and smear plugs by acid conditioning can facilitate permeation of mild SE adhesives [8].

Failure modes in shear tests can differ because of mechanics of the test and distribution of stress in the interface, thus it does not necessarily imply bond efficacy [30]. After reviewing failure modes in this study, non-adhesive failure modes were seen in bur-cut and 4W laser groups, probably because of higher bond strengths. In Takamizawa *et al.* study [12], most frequent failure pattern of Scotchbond Universal adhesive in ER and SE modes was cohesive failure in dentin. In Marchesi *et al.* study [31] on microtensile bond strength of Scotchbond Universal, most frequent failure pattern in ER mode was cohesive type. The SEM evaluation of the effect of other laser outputs is suggested for future studies.

Conclusion

Bur-cut dentin had significantly higher SBS values than lased dentin. In ER mode, 4W lased-dentin had significantly higher SBS values than 5W lased-dentin. In bur-cut and 4W lased-dentin, Scotchbond Universal had significantly higher SBS values in ER mode. Dominant

failure mode in low SBS value subgroups, such as 5W-ER and 5W-SE, was adhesive failure.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

- [1] Martens LC. Laser physics and a review of laser applications in dentistry for children. *Eur Arch Paediatr Dent.* 2011; 12: 61-67.
- [2] Hibst R. Lasers for caries removal and cavity preparation: State of the art and future directions. *J Oral Laser Applications.* 2002; 2: 202-212.
- [3] Kataumi M, Nakajima M, Yamada T, Tagami J. Tensile bond strength and SEM evaluation of Er:YAG laser irradiated dentin using dentin adhesive. *Dent Mater J.* 1998; 17: 125-138.
- [4] Dela Rosa A, Sarma AV, Le CQ, Jones RS, Fried D. Peripheral thermal and mechanical damage to dentin with microsecond and sub-microsecond 9.6 microm, 2.79 microm, and 0.355 microm laser pulses. *Lasers Surg Med.* 2004; 35: 214-228.
- [5] Dunn WJ, Davis JT, Bush AC. Shear bond strength and SEM evaluation of composite bonded to Er:YAG laser-prepared dentin and enamel. *Dent Mater.* 2005; 21: 616-624.
- [6] Sun X, Ban J, Sha X, Wang W, Jiao Y, Wang W, et al. Effect of Er,Cr:YSGG Laser at Different Output Powers on the Micromorphology and the Bond Property of Non-Carious Sclerotic Dentin to Resin Composites. *PLoS One.* 2015; 10: e0142311.
- [7] Obeidi A, McCracken MS, Liu PR, Litaker MS, Beck P, Rahemtulla F. Enhancement of bonding to enamel and dentin prepared by Er,Cr:YSGG laser. *Lasers Surg Med.* 2009; 41: 454-462.
- [8] Wagner A, Wendler M, Petschelt A, Belli R, Lohbauer U. Bonding performance of universal adhesives in different etching modes. *J Dent.* 2014; 42: 800-807.
- [9] Shadman N, Farzin-Ebrahimi Sh, Mortazavi-Lahijani E,

- Ghaderi A. Shear bond strength of different adhesive systems to normal and caries-affected dentin. *J Oral Health Oral Epidemiol.* 2015; 4: 87-93.
- [10] Muñoz MA, Luque I, Hass V, Reis A, Loguercio AD, Bombarda NH. Immediate bonding properties of universal adhesives to dentine. *J Dent.* 2013; 41: 404-411.
- [11] Perdigão J, Kose C, Mena-Serrano AP, De Paula EA, Tay LY, Reis A, et al. A new universal simplified adhesive: 18-month clinical evaluation. *Oper Dent.* 2014; 39: 113-127.
- [12] Takamizawa T, Barkmeier WW, Tsujimoto A, Berry TP, Watanabe H, Erickson RL, et al. Influence of different etching modes on bond strength and fatigue strength to dentin using universal adhesive systems. *Dent Mater.* 2016; 32: e9-e21.
- [13] Lee BS, Lin PY, Chen MH, Hsieh TT, Lin CP, Lai JY, et al. Tensile bond strength of Er,Cr:YSGG laser-irradiated human dentin and analysis of dentin-resin interface. *Dent Mater.* 2007; 23: 570-578.
- [14] Van Landuyt KL, Snauwaert J, De Munck J, Peumans M, Yoshida Y, Poitevin A, et al. Systematic review of the chemical composition of contemporary dental adhesives. *Biomaterials.* 2007; 28: 3757-3785.
- [15] Unlu N, Gunal S, Ulker M, Ozer F, Blatz MB. Influence of operator. Experience on in vitro bond strength of dentin adhesives. *J Adhes Dent.* 2012; 14: 223-227.
- [16] Baldissara P, Catapano S, Scotti R. Clinical and histological evaluation of thermal injury thresholds in human teeth: a preliminary study. *J Oral Rehabil.* 1997; 24: 791-801.
- [17] Keller U, Hibst R, Geurtsen W, Schilke R, Heidemann D, Klaiber B, et al. Erbium:YAG laser application in caries therapy. Evaluation of patient perception and acceptance. *J Dent.* 1998; 26: 649-656.
- [18] Esteves-Oliveira M, Zezell DM, Apel C, Turbino ML, Aranha AC, Eduardo Cde P, et al. Bond strength of self-etching primer to bur cut, Er,Cr:YSGG, and Er:YAG lased dental surfaces. *Photomed Laser Surg.* 2007; 25: 373-380.
- [19] Obeidi A, Liu PR, Ramp LC, Beck P, Gutknecht N. Acid-etch interval and shear bond strength of Er,Cr:YSGG laser-prepared enamel and dentin. *Lasers Med Sci.* 2010; 25: 363-369.
- [20] Shahabi S, Chiniforush N, Bahramian H, Monzavi A, Baghalian A, Kharazifard MJ. The effect of erbium family laser on tensile bond strength of composite to dentin in comparison with conventional method. *Lasers Med Sci.* 2013; 28: 139-142.
- [21] Paghdiwala AF, Vaidyanathan TK, Paghdiwala MF. Evaluation of erbium:YAG laser radiation of hard dental tissues: analysis of temperature changes, depth of cuts and structural effects. *Scanning Microsc.* 1993; 7: 989-997.
- [22] Jaber Ansari Z, Fekrazad R, Feizi S, Younessian F, Kalhori KA, Gutknecht N. The effect of an Er,Cr:YSGG laser on the micro-shear bond strength of composite to the enamel and dentin of human permanent teeth. *Lasers Med Sci.* 2012; 27: 761-765.
- [23] Isolan CP, Valente LL, Münchow EA, Basso GR, Pimentel AH, Schwantz JK, da Silva AV, Moraes RR. Bond strength of a universal bonding agent and other contemporary dental adhesives applied on enamel, dentin, composite, and porcelain. *Appl Adhes Sci.* 2014; 2: 1-10.
- [24] Ayar MK, Erdermir F. Bonding strength of universal adhesives to Er,Cr:YSGG Laser-Irradiated Dentin. *Niger J Clin Pract.* 2018; 21: 93-98.
- [25] Buyukhatipoglu I, Ozsevik AS, Secilmis A, Usumez A. Effect of dentin laser irradiation at different pulse settings on microtensile bond strength of flowable resin. *Dent Mater J.* 2016; 35: 82-88.
- [26] Yazici AR, Karaman E, Tuncer D, Berk G, Ertan A. Effect of an Er, Cr: YSGG laser preparation on dentin bond strength of a universal adhesive. *J Adhes Sci Technol.* 2016; 30: 2477-2484.
- [27] Moszner N, Salz U, Zimmermann J. Chemical aspects of self-etching enamel-dentin adhesives: a systematic review. *Dent Mater.* 2005; 21: 895-910.
- [28] Placido E, Meira JB, Lima RG, Muench A, de Souza RM, Ballester RY. Shear versus micro-shear bond strength test: a finite element stress analysis. *Dent Mater.* 2007; 23: 1086-1092.
- [29] Sabatini C. Effect of phosphoric acid etching on the shear bond strength of two self-etch adhesives. *J Appl Oral Sci.* 2013; 21: 56-62.
- [30] Wei S, Sadr A, Shimada Y, Tagami J. Effect of caries-affected dentin hardness on the shear bond strength of current adhesives. *J Adhes Dent.* 2008; 10: 431-440.
- [31] Marchesi G, Frassetto A, Mazzoni A, Apolonio F, Diolosa M, Cadenaro M, et al. Adhesive performance of a multi-mode adhesive system: 1-year in vitro study. *J Dent.* 2014; 42: 603-612.