J Dent Mater Tech 2025; 14 (3):141-146
https:// 10.22038/jdmt.2025.85683.1780

J Dent Mater Tech

Original Article Open Access

Effect of disinfection with Er:YAG laser or chlorhexidine on composite bond strength to dentin using two adhesive systems

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Abstract

Objective: This study evaluated the effects of 2% chlorhexidine (CHX) and Er:YAG laser on the shear bond strength (SBS) of resin composite to affected dentin using two adhesive systems.

Methods: Sixty extracted third molars were randomly assigned to three disinfection groups (control, 2% CHX, and Er:YAG laser). Each disinfection group was further divided into two subgroups based on the adhesive system used (an etch-and-rinse or a universal self-etch system), yielding a total of six groups (n=10). After caries excavation, dentin surfaces were treated according to the assigned disinfection and adhesive protocols. The resin composite was then applied to the treated surface using a cylindrical mold. Samples underwent 10,000 thermal cycles, followed by shear bond strength (SBS) testing and failure mode analysis. Data were analyzed using two-way ANOVA and chi-square test at the significance level of $P < 0.05$.

Results: ANOVA revealed no significant differences in mean bond strength among the disinfection groups with either adhesive system ($P > 0.05$). However, the etch-and-rinse adhesive showed significantly higher SBS compared to the universal self-etch adhesive across all disinfection groups ($P < 0.05$). Chi-square analysis revealed no significant differences in failure modes among the groups ($P = 0.71$).

Conclusions: Disinfection of affected dentin with either Er:YAG laser or 2% CHX does not reduce the bond strength of adhesive systems. The etch-and-rinse adhesive consistently achieved higher SBS than the universal adhesive after dentin disinfection, suggesting that it may be preferred for clinical use.

Keywords: Affected dentin, Bond strength, Chlorhexidine, Disinfection, Erbium, Laser

Introduction

Dental caries remains one of the most prevalent oral diseases worldwide. Restorative treatment aims not only to remove carious tissue but also to preserve tooth vitality. In contemporary dentistry, conservative caries removal techniques are emphasized to avoid pulp exposure by eliminating only the infected dentin while maintaining the affected dentin. Although preserving affected dentin is beneficial for pulp protection, its partially demineralized and collagen-degraded structure poses challenges for bonding. Enzymatic activity, particularly involving matrix metalloproteinases (MMPs), can weaken the resin–dentin interface, leading to reduced bond strength and a higher risk of microleakage, restoration failure, and recurrent caries in affected dentin (1).

Another potential concern with affected dentin is the presence of cariogenic bacteria within the smear layer or dentinal tubules, which survive under restorations (2) and may cause pulpal sensitivity, inflammation, and secondary caries (3-5). Therefore, disinfection of affected dentin before cavity restoration is essential.

An ideal dentin disinfectant should provide antimicrobial activity without interfering with the adhesive system (6). Chlorhexidine (CHX) is a widely used disinfectant with broad-spectrum antibacterial effects (4). Its strong cationic properties give it a high affinity for tooth surfaces (2). Depending on the concentration, CHX can act either bacteriostatically or bactericidally by disrupting bacterial cell membranes. In addition, CHX can enhance adhesive penetration for both etch-and-rinse and self-etch systems by increasing surface porosity through the opening of dentinal tubules (4).

Various types of lasers exhibit antibacterial effects against different microorganisms (7, 8). The Er:YAG laser is highly effective at removing debris and the smear layer (9). It emits infrared light at a wavelength of 2940 nm, which is strongly absorbed by water and hydroxyapatite, enabling efficient ablation of hard dental tissue (10).

Previous studies on the effect of disinfectants on the bond strength of various adhesive systems have

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Accepted: 3 August 2025. Submitted: 27 January 2025.

reported inconsistent results. One study evaluated the impact of four disinfectant solutions (NaOCl, chlorhexidine, super-oxidized water, and aqueous ozone) and two lasers (KTP and Er:YAG) on micro-shear bond strength using two self-etch adhesives. The results showed that the bond strength in the laser-treated groups was higher than in the disinfectant-treated groups (4). In contrast, Menezello et al. (11) investigated the effect of chlorhexidine (CHX) and Nd:YAG laser on the micro-tensile bond strength of a self-etch adhesive and reported that the lowest bond strength was observed in the Nd:YAG laser group, while there was no significant difference between the chlorhexidine and control groups.

Different adhesive bonding systems are available on the market, and their interactions with disinfected dentin surfaces may vary. Fifth-generation adhesives are classified as etch-and-rinse or total-etch systems, in which acid etching is performed first, followed by a combined priming and adhesive application as a single step. In contrast, eighth-generation adhesives, commonly referred to as universal adhesives, are advanced self-etch systems that integrate etchant, primer, and adhesive into one application. These universal adhesives often contain additional components, such as bioactive or antibacterial agents, to enhance bond strength and long-term durability.

Few studies have investigated the effect of laser treatment on dentin disinfection and its comparison with chlorhexidine (CHX). Furthermore, there is no consensus on which adhesive system performs best after laser application. Therefore, this study aimed to evaluate the effects of CHX and Er:YAG laser treatment on the shear bond strength (SBS) of composite to affected dentin using two types of adhesive: etch-and-rinse and universal self-etch systems.

Materials and Methods

Study Approval and Sample Size Determination

This in vitro study was approved by the ethics committee of Shahid Sadoughi University of Medical Sciences, Yazd, Iran (IR.SSU.REC.1400.062).

The sample size was calculated based on a previous study (4), using a 95% confidence level and 80% power. A minimum of 10 samples per group was determined. Accordingly, 60 extracted third molars meeting Code 4 criteria (caries extending up to one-third of the dentin) of the International Caries Detection and Assessment System (ICDAS) were selected.

Specimen Preparation and Disinfection Protocols

All teeth were stored for 24 hours in a 0.5% Chloramine T solution and then mounted in cold-cure acrylic resin. Class I cavity preparations were performed using a 008 fissure diamond bur (Tees Kavan, Iran) until all external walls reached sound tooth structure. Subsequently, infected dentin was removed using a No. 2 carbide bur (Tees Kavan, Iran) at stall-out speed (gradually reducing the rotational speed until complete stoppage). This procedure was repeated up to three times to ensure removal of infected dentin while preserving the affected dentin. The complete removal of infected dentin was confirmed using a caries detector solution (DHARMA, California, USA) and a dental explorer. Because caries detection and removal using dye and visual inspection can be subjective, the entire procedure was performed by a single trained dentist.

To facilitate the shear bond strength (SBS) test, the cavity walls were cut horizontally using a diamond saw. Finally, the affected dentin surface was polished with a 600-grit silicon carbide disk under water spray to create a uniform smear layer.

Study Groups

The 60 samples were randomly divided into three main groups based on the disinfection method. Each group was further divided into two subgroups according to the adhesive system used. Thus, six groups were formed in total (n = 10). The specifications of the materials used in this study are presented in Table 1. The study groups were as follows:

Group 1 (No disinfection / etch-and-rinse adhesive): In this group, the dentin surface was treated with 37% phosphoric acid (FGM, Brazil) for 15 seconds and rinsed

Table 1. Materials used in the study

Material	Brand	Manufacturer	Composition	Batch number
Adhesive	Ambar APS	FGM, Brazil	10-MDP, methacrylate monomers, photoinitiator complex (APS), coinitiators, and stabilizers	030420
	Ambar Universal APS	FGM, Brazil	10-MDP, methacrylate monomers, photoinitiator complex (APS), coinitiators, stabilizers, inert filler (silica), and vehicle (ethanol)	030321
Composite	Opallis	FGM, Brazil	Bis-GMA, Bis-EMA, UDMA, TEGDMA, fillers (barium aluminum, silanized silicate, silicon dioxide), camphorquinone, stabilizers, and pigments	030220
CHX	Maquira		Chlorhexidine digluconate 2%, methylparaben, purified water	922719

Figure 1. Mounted dental specimens in acrylic resin

with water for an additional 15 seconds. Excess moisture was gently removed with a cotton pellet, leaving the dentin surface slightly moist. Two layers of Ambar APS adhesive (FGM, Brazil) were applied using a microbrush, each air-dried for 5 seconds, and polymerized for 10 seconds. Curing was performed with an LED device (LITEX 696, Dent America, Taiwan) at 1200 mW/cm².

Group 2 (No disinfection, universal adhesive): In this group, two layers of Ambar Universal APS adhesive (FGM, Brazil) were applied directly to the dentin surface using a microbrush. Each layer was lightly air-dried and then cured for 10 seconds.

Group 3 (2% CHX disinfection, etch-and-rinse adhesive): After the application of 37% phosphoric acid, a 2% CHX solution (Maquira, Brazil) was applied to the dentin surface for 20 seconds with a microbrush. Excess solution was removed using a cotton pellet. Adhesive application was similar to that described in group 1.

Group 4 (2% CHX disinfection, universal adhesive): The dentin surfaces were treated with 2% CHX solution for 20 seconds, and excess moisture was removed with a cotton pellet. Then the universal adhesive was applied as explained in group 2.

Group 5 (Er:YAG laser disinfection, etch-and-rinse adhesive): The dentin surface was irradiated with an Er:YAG laser (Fotona, Slovenia) at 2940 nm wavelength, 15 Hz frequency, 100 mJ energy, 700 µs pulse duration, and 1.5 W/cm² power density. The laser handpiece was positioned 1-2 mm from the dentin surface, with continuous water flow at 8 ml/min for 30 seconds. After laser treatment, etch-and-rinse adhesive was applied according to the protocol described in group 1.

Group 6 (Er:YAG laser disinfection, universal adhesive): The dentin surfaces were treated with Er:YAG laser as explained in group 5, then the universal adhesive was applied, in accordance with the methodology outlined in group 2.

Bonding Procedure

After adhesive curing, a customized cylindrical mold (2.5 mm diameter × 4 mm height) was positioned at the center of the dentin surface and incrementally filled with an A2 shade resin composite (Opallis; FGM, Brazil) (Figure 1). Each 2-mm layer was light-cured for 40 seconds using an LED curing device (LITEX 696, Dent America, Taiwan) at 1200 mW/cm². The specimens were then subjected to 10,000 thermal cycles in a thermocycling apparatus (Delta Tpo2, Nemo, Iran) between 5° ± 2°C and 55° ± 2°C, with a dwell time of 30 seconds and a transfer time of 6 seconds, simulating approximately one year of clinical function.

Shear bond strength (SBS) testing

The shear bond strength (SBS) of the specimens was measured using a universal testing machine (Koopaco TB20T, Iran) at a crosshead speed of 1 mm/min. SBS values (MPa) were calculated by dividing the peak load at failure (N) by the bonded surface area (6.25 mm²).

After SBS measurement, a trained examiner evaluated the failure modes of all specimens under a stereomicroscope (Nikon, Tokyo, Japan) at 20× magnification. Failures were classified as adhesive (at the dentin-adhesive interface), cohesive (within dentin or composite), or mixed (a combination of adhesive and cohesive failures).

Statistical analysis

The normality of the data distribution was assessed using the Shapiro-Wilk test (P>p.p5). The SBS data were analyzed using two-way ANOVA. Chi-Square test was used to compare failure modes between groups. A significance level of $P < 0.05$ was considered statistically significant.

Results

Table 2 presents the mean and standard deviation (SD) of bond strength values (MPa) in the study groups. Two-way ANOVA showed a significant interaction between the two independent variables (adhesive system and

Table 2. Mean and standard deviation (SD) of shear bond strength values in the study groups

	Etch-and-rinse adhesive	Universal adhesive	P-value
	Mean ± SD	Mean ± SD	
No disinfection (control)	5.11 ± .83	3.77 ± 1.74	0.048*
CHX	5.78 ± 2.21	3.37 ± 1.24	0.009*
Er:YAG laser	7.20 ± 2.15	4.69 ± 1.55	0.009*
P-value	0.16	0.31	

disinfection method) (P = 0.01). Therefore, the dependent variable (SBS) was analyzed separately for each adhesive system and for each disinfection method.

ANOVA revealed no significant differences in mean bond strength among the Er:YAG laser, chlorhexidine, and control groups with either the etch-and-rinse (P = 0.16) or the universal adhesive system (P = 0.31). However, significant differences were found between the two adhesive types in each disinfection method. Student t-test revealed that in all disinfection groups, the etch and rinse adhesive exhibited significantly higher SBS than the universal adhesive (P < 0.05; Table 2).

Table 3 shows the frequency and percentage of failure modes in the study groups. Chi-square test revealed no statistically significant differences in failure modes among the groups (P = 0.71).

Discussion

This study investigated the effect of different disinfection methods on the shear bond strength (SBS) of two adhesive systems. The results showed no significant difference in bond strength after application of Er:YAG laser, 2% CHX or control groups, either when the etch-and-rinse or the universal adhesive was used. However, the eth-and-rinse adhesive exhibited a significantly higher mean SBS than the universal adhesive for all disinfection groups. These results indicate that the type of adhesive system has a greater influence on dentin bond strength than the method of dentin disinfection.

One of the main advantages of laser disinfection is its ability to effectively clean the dentin surface by removing the smear layer. Scanning electron microscopy (SEM) images have shown that laser irradiation produces a microcrater-like surface, exposing peritubular dentin more prominently than intratubular dentin (4, 12). This modification creates an irregular surface free of the smear layer, which may potentially improve the bonding interface. However, in this study Er:YAG laser application did not significantly improve bond strength compared to other treatments with either of the tested adhesives.

In contrast to the outcomes of this study, Cersosimo et al. (13) indicated that Er:YAG lasers can improve micro-shear bond strength in both intact and acid-eroded dentin. Their study showed that laser-treated dentin exhibits open tubules and an irregular surface, leading to a micro-retentive structure that enhances adhesion. Karadas et al. (14) found that laser treatment significantly increases bond strength in deep dentin by facilitating resin infiltration into the tubules and promoting resin tag formation. Alsahhaf et al. (15) reported that Er:YAG laser treatment increases the bond strength of glass fiber posts to canal dentin, as compared to sodium hypochlorite. Bao et al (16) concluded that the laser's ability to remove the smear layer is a key factor in enhancing bond strength.

There is conflicting evidence regarding the optimal laser parameters for enhancing bond strength to dentin. Goncalves et al.(17) observed that higher frequencies could reduce bond strength, while Monghini et al. (18) found no significant differences across energy levels of 60, 80, and 100 mJ. Staninec et al. (19) reported that shorter pulse durations minimize thermal damage and are therefore preferred for tooth ablation. These variations imply the need for more research to find optimal laser settings for dentin disinfection, because changes in dentin's physical and chemical properties can greatly impact bond strength.

In the present study, the SBS of the CHX-treated group was not significantly different from that of the other treatment groups. CHX's positive charge enables it to bind effectively to phosphate, increasing its affinity for tooth structure and improving surface wettability. However, the potential loss of calcium from the superficial hydroxyapatite layer and the presence of CHX residues may reduce resin infiltration, which could limit its potential effect on improving SBS (20).

In this study, the etch-and-rinse adhesive consistently exhibited higher bond strength than the universal adhesive, regardless of the cavity disinfection method used. These findings are consistent with those of Rayar et al. (21), who found that the etch-and-rinse adhesives maintained higher bond strength than the self-etch

Table 3. Frequency (N) and percentage (%) of failure modes in study groups

Groups	Definition	Adhesive N (%)	Cohesive N (%)	Mixed N (%)
1	No disinfection / etch-and-rinse adhesive	8 (80%)	0	2 (20%)
2	No disinfection, universal adhesive	9 (90%)	0	1 (10%)
3	2% CHX disinfection, etch-and-rinse adhesive	7 (70%)	0	3 (30%)
4	2% CHX disinfection, universal adhesive	8 (80%)	0	2 (20%)
5	Er:YAG laser disinfection, etch-and-rinse adhesive	6 (60%)	0	4 (40%)
6	Er:YAG laser disinfection, universal adhesive	7 (70%)	0	3 (30%)

adhesives following CHX treatment. In contrast, Say et al. (22) reported that after CHX application, a two-step etch-and-rinse adhesive showed slightly higher bond strength than a self-etch adhesive, but this difference was not statistically significant. AlQhtani et al. (23) reported that when the Er:YAG laser was used for caries removal in primary teeth, a two-step self-etch adhesive system showed higher micro-tensile bond strength than a two-step etch-and-rinse adhesive. The difference in adhesive composition and mode of application may be the reason for this discrepancy.

The superior performance of etch-and-rinse adhesives can be attributed to phosphoric acid, which demineralizes dentin to a depth of 3–5 µm, creating deeper and denser resin tags than those formed by self-etch adhesives. This deeper penetration enhances mechanical interlocking between the adhesive and the dentin surface, resulting in stronger bonding.

In the present study, no significant differences were observed in failure modes among the groups. Adhesive failure was the most frequent type, followed by mixed failure. No case of cohesive failure was observed in this study.

This study was conducted in laboratory settings, which should be considered a main limitation. In clinical conditions, factors such as tensile, shear, and torsional forces, as well as variations in temperature, humidity, acidity, and the presence of microbial plaque, create an environment that is difficult to replicate in the laboratory. In addition, extracted teeth lack the positive intra-tubular fluid pressure found in vital teeth, which can significantly affect bond strength. These limitations should be considered when interpreting the results and applying them to clinical practice. Future research should explore the effects of varying laser parameters on dentin disinfection. Additionally, well-designed clinical studies are recommended to validate these findings and to optimize adhesive protocols for better treatment outcomes.

Conclusions

While no significant differences in bond strength were observed among the disinfection groups (Er:YAG laser, chlorhexidine, or control), the etch-and-rinse adhesive consistently demonstrated higher shear bond strength compared to the universal self-etch adhesive. Failure mode distribution was similar across all groups. These findings support the use of etch-and-rinse adhesives over self-etch systems for improved bonding to affected dentin.

Acknowledgments

Not applicable.

Conflicts of interest

The authors declare no conflict of interest.

Authors contributions

F.F. contributed to the conception and design of the study, provided critical reviews and revisions, supplied resources and materials, and supervised the research. A.D. was responsible for the study design, data collection and analysis, and drafting the manuscript. Z.G. also participated in the study design, interpreted the results, and assisted in drafting the manuscript. All authors read and approved the fimal manuscript.

Ethical approval

This in vitro study was approved by the ethics committee of Shahid Sadoughi University of Medical Sciences, Yazd, Iran (IR.SSU.REC.1400.062).

Funding

Financial support was provided by Shahid Sadoughi University of Medical Sciences.

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