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ORIGINAL ARTICLE

# Effects of Er:YAG and Er,Cr:YSGG laser irradiation and adhesive systems on microtensile bond strength of a self-adhering composite

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## Abstract

This study was aimed to evaluate the effects of Er:YAG and Er,Cr:YSGG laser irradiation and adhesive systems on the microtensile bond strength of Fusio Liquid Dentin (FLD) which is a self-adhering composite (SAC). Twenty-four freshly extracted human molar teeth were collected, and the enamel was removed from the occlusal surface to obtain a flat dentin surface. Twenty-four teeth were randomly divided into eight groups: Group 1: only Fusio Liquid Dentin (FLD) (Petron Clinical, Orange, California, USA) was applied to the dentin surface; Group 2: 37% Phosphoricacid (i-GEL, Medicinos Linija UAB, Lithuania) + FLD; Group 3: Single Bond Universal (SBU) (3 M ESPE, Germany) + FLD; Group 4: Adper Easy One (AEO) (3 M ESPE, Germany) + FLD; Group 5: Er:YAG laser + AEO + FLD; Group 6: Er:YAG laser + SBU + FLD; Group 7: Er,Cr:YSGG laser + AEO + FLD; and Group 8: Er,Cr:YSGG laser + SBU + FLD. After thermocycling, $1 \times 1$ mm$^2$ sticks were used for the μTBS test ($n = 10$). Two sticks per group were used for SEM analysis. Fractured sample surfaces were evaluated using a stereomicroscope. Group 8 showed the highest μTBS value (13.70 MPa), whereas Group 1 showed the lowest μTBS value (5.60 MPa). There were no significant differences between Groups 2, 3, and 4 ($P = 0.324$), but Groups 5–8 showed statistically significant results that were higher than Groups 1–4 ($P = 0.012$). Adhesive failure mode was predominant followed by mixed failure. The evaluation of bonding of the FLD to dentin showed that the combined use of Er:YAG and Er,Cr:YSGG lasers with SBU and AEO on dentin surfaces improved the dentinal bond strength of the FLD.

**Keywords** Self-adhering composite · Composite · Surface preparation · Erbium laser · Microtensile bond strength

## Introduction

Dental composites developed during the 1950s were mixtures of silicate glass particles acting as fillers within an acrylic monomer matrix polymerized during application. Some of those currently used are flowable, packable, microhybrid, with controlled shrinkage, smart, and nanohybrid composites, which were developed in the late 1990s and the early 2000s. These dental composites can be self-cured, UV light-cured, or visible light-cured. Flowable composites have the advantage of reaching inaccessible areas in Class II cavities, which have a lower filler content than conventional composites [1–3].

Recent developments in adhesive and aesthetic dentistry have enabled the incorporation of adhesives into flowable resin composites. Self-adhering composites (SACs) have been introduced to overcome the complications of multiple-step procedures and to facilitate clinical placement. SACs do not require separate bonding and eliminate the need for adhesive application [4]. They are practical to use and can be quickly applied, making them advantageous in clinical practice. Accordingly, the use of self-adhering flowable resin composites during a single visit is preferable for uncooperative patients [5].

Dental composites require adhesive systems to bond with the hard dental tissues. There are two categories of adhesive systems, namely, self-etch (or etch-and-dry) and etch-and-rinse. Self-etch adhesive systems were preferred because of easier application and fewer application steps, resulting in reduced technique sensitivity [6, 7]. Etch-and-rinse adhesive systems are generally preferred for indirect restorations and

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when large areas of enamel are still present. Conversely, self-etch adhesives that are used on direct composite resin restorations supported by dentin provide more predictable bond strength and are recommended as a result [8].

Some factors, such as the type of adhesive system, restorative materials, and cavity preparation, affect the bond strength of resin to tooth structure. Recent research has emphasized the necessity of better tooth preparation to enhance the penetration of resin into the tooth structure. Dentin surface treatment using various agents, such as ultrasonic/sonic techniques, phosphoric acid, polyacrylic acid, and laser treatments, can affect the structural properties of dentin, which can change its microhardness, permeability, and solubility. The bonding strength between resin and dentin can be affected by these changes [9, 10].

Various types of lasers have been used for cutting hard dental tissue, for example, neodynium: yttrium aluminum garnet and the erbium group of lasers. Erbium-based lasers, Erbium; Yttrium Aluminum Garnet (Er:YAG) ($\lambda = 2.94$ µm) and Erbium, Chromium:Yttrium Scandium Gallium Garnet (Er,Cr:YSGG) ($\lambda = 2.78$ µm), known as hard tissue lasers, have high power and affect the surface morphology of dental tissues. Irregular surfaces opened dentinal tubules and prominent peritubular dentin without a smear layer were observed when the laser applied to dentin led to a microretentive surface, possibly favorable to bonding procedures [3, 11–15].

The Erbium lasers' handpiece did not touch the teeth during ablation. By eliminating vibrations this way, it protects the tooth from microscopic cracks and prevents the formation of grooves on the adjacent tooth surfaces [16]. The laser effects on dental tissues consist of thermomechanical wear and evaporation of water content. This causes expansion and disposal of organic and inorganic tissue contents and ultimately a surface with open dentinal tubules without a smear layer [17, 18]. The bond strength to tooth surfaces prepared with a laser is often confusing and accompanied by contradictory results. Some studies have shown that the bond strength to tooth surfaces prepared by low-power Er:YAG and Er,Cr:YSGG lasers is less than that to surfaces with acid-induced conditioning [17, 19].

In other studies, the laser efficiency in conditioning the tooth surface could become comparable to that with acid etching by changing some variables that belong to the laser equipment, such as its distance from the tooth surface and the output power [16]. Wajdowicz et al. suggested that laser irradiation was not effective in increasing bond strength, whereas Yazici et al. showed that the laser irradiation, as a tool for conditioning the dentin surfaces, increases the bond strength of SACs [20]. When the dental literature was examined, no study was found that investigated the effect of the combined use of erbium laser systems and different types of adhesives with SACs on the bond strength of dentin. Therefore, the primary objective of the present study was to compare the bond strength of a SAC resin to the dentin surface after acid etching, adhesives, and laser conditioning. The null hypothesis was that there would be no significant differences between the bond strengths of the different surface treatments.

## Materials and methods

After obtaining approval from Cumhuriyet University Clinical Research Ethics Committee (2017–05/01), 24 sound human third molars ($N = 24$) were collected, stored in saline solution at 4 °C, and were used within one month. All the root surfaces were cleaned to remove organic debris and deposits. Occlusal enamel was removed with a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). The sample surfaces were examined under a stereomicroscope to ensure that there was no enamel or pulp tissue on the surface. Standard dentin surfaces were obtained after sanding the occlusal surfaces on wet #180-grit SiC paper (60). #600-grit SiC was used to obtain a standardized smear layer.

Twenty-four teeth were randomly divided into eight groups, and three teeth were used in each group to obtain sticks for the µTBS test.

1. Group 1: Only Fusio Liquid Dentin (FLD, Pentron Clinical, Orange, CA, USA) was used as the SAC for this group. A stainless steel matrix was used to build a 3 mm height composite restoration on the dentin surface. The FLD was applied and cured with an LED curing device (Elipar S-10, 3 M ESPE, Germany) for 20 s.
2. Group 2: The flat dentin surfaces were etched with 37% phosphoric acid (i-GEL, Medicinos Linija UAB, Lithuania) for 15 s, rinsed, and then dried. FLD was applied and cured as described for Group 1.
3. Group 3: A universal adhesive Single Bond Universal (SBU, 3 M ESPE, Germany) was applied to the dentin surface for 20 s, gently dried for 5 s, and then light-cured for 10 s according to the manufacturer's instructions. Then, the FLD was applied and cured for 20 s as in Group 1.
4. Group 4: A self-etch adhesive Adper Easy One (AEO, 3 M ESPE) was applied to the dentin surface for 20 s, gently dried for 5 s, and then light-cured for 10 s. Following the adhesive application, FLD was applied and cured as in Group 1.
5. Group 5: Er:YAG laser (Smart 2940D Plus, Deka Laser, Florence, Italy) was applied to the dentin surface in non-contact mode with a tipless handpiece ( Deka Laser, Florence, Italy). Laser energy was delivered at a wavelength of 2.94 µm, pulse duration of 150 µs for 30 s at 100 mJ energy output, 1 W, 10 Hz frequency, fluence 2.6 J/cm2, and focal distance of 10 mm with a water

spray (70% water, 65% air), 5 mL/min with free-handed irridation. Before and during sample irradiation, the output power of the laser beam was measured using a power meter (GS™ FieldMaster Power, Energy Analyzer, Coherent, Inc., Germany), and no power loss was observed. Then, AEO was applied to the dentin surface for 20 s, gently dried for 5 s, and then light-cured for 10 s. Following the adhesive application, FLD was applied and cured as in Group 1.

6. Group 6: After applying the Er:YAG laser according to the protocol of Group 5, SBU was applied to the dentin surface for 20 s, gently dried for 5 s, and then light-cured for 10 s. Then, FLD was applied and cured as in Group 1.
7. Group 7: Er,Cr:YSGG laser (Waterlase; Biolase Technology, San Clemente, CA, USA) was applied to the dentin surface. The laser parameters were as follows: power, 1.5 W; frequency, 30 Hz; cooling, air/water spray (70% water, 65% air), and water flow of nearly 14.5 mL/min; wavelength, 2780 nm; pulse duration, 60 µs; fluence 4.5 J/cm$^2$; and pulse energy 50 mJ in hard mode for 15 s [15]. The target was scanned homogenously with a 600-µm tip diameter from a distance of approximately 2 mm with free-handedness. Before and during sample irradiation, the output power of the laser beam was measured using a power meter (GS™ FieldMaster Power, Energy Analyzer, Coherent, Inc., Germany), and no power loss was observed. Then, AEO was applied to the dentin surface for 20 s, gently dried for 5 s, and then light-cured for 10 s. Following the adhesive application, FLD was applied and cured as in Group 1.
8. Group 8: After applying the Er,Cr:YSGG laser according to the protocol of Group 7, SBU was applied to the dentin surface for 20 s, gently dried for 5 s, and then light cured for 10 s. Following the adhesive application, FLD was applied and cured as in Group 1.

### Aging procedure

All specimens in the groups were thermocycled between 5 °C and 55 °C (5000 cycles; Gokceler Mechanical, Sivas, Turkey) with a dwell time of 30 s in a water bath. The transfer time was 5 s to see aging affects on µTBSs.

### Microtensile bond strength (µTBS) testing

A nontrimming technique was used for microtensile testing. The specimens were sectioned (in the x and y directions) using a diamond saw. The sticks obtained from three teeth were measured using a digital caliper, and the closest 10 sticks ($1 \times 1$ mm$^2$) were selected for each group ($n = 10$). Samples were stored in distilled water for 24 h at room temperature under daylight, and then attached to a universal testing machine (LF Plus, LLOYD Instruments, Ametek Inc., England) with cyanoacrylate adhesive and an accelerator (404 Super cyanoplast, 404 Kimya Sanayi, İstanbul, Türkiye). The samples were tested under tension at a crosshead speed of 0.5 mm/min until failure. The µTBS values were then calculated and expressed in MPa.

Fractured sample surfaces were evaluated using a stereomicroscope (Olympus SZX7, Germany) to examine failure types such as adhesive, mix, or cohesive failure.

For each group, two sticks were randomly allocated for examination using a scanning electron microscope (SEM).

## Statistical analysis

The obtained data were analyzed using the IBM SPSS Statistics 25.0 (IBM Corporation) software. Analysis of microtensile bond strength was performed using one-way ANOVA, and multiple comparisons were performed using Tukey's posthoc test. Statistical significance was set at $P < 0.05$.

## Results

The mean bond strength values of the groups are shown in Table 1. Group 8 showed the highest µTBS value (13.70 MPa), whereas Group 1 showed the lowest µTBS value (5.60 MPa). There were no significant differences between Groups 6 and 8, and both groups showed statistically significant differences compared with Groups 5 and 7 ($P = 0.001$). Group 7 showed higher values than Group 5, but the difference was not statistically significant. There were no significant differences between Groups 2, 3, and 4 ($P = 0.324$), but Groups 5 and 7 showed significantly higher results than these groups ($P = 0.001$). Group 2 showed higher results than Groups 3 and 4, but there were no statistically significant differences. Other groups (2–8) showed higher results than Group 1, and they were statistically different ($P = 0.001$).

In SEM analysis, it was hard to see hybrid layer and resin tags especially in Group 1 (Fig. 1 (1a, 1b)). As there were fully bonded areas there were cracks in most samples (Fig. 1 (2a, 2b)). The FLD resin showed limited penetration to tubules, and therefore, shortened resin tags were seen (Fig. 2). There was discontinuity of the hybrid layer with broken resin tags in Groups 3 and 4 (Fig. 1 (3a, 3b)). Adhesive failure mode was predominant (between adhesive and dentin), followed by mixed failure in all groups (Table 2). Example SEM images of fracture types are shown in Fig. 3.

**Table 1** The mean, standard deviations, maximum and minimum values of the groups. The letters show the statistically differences between groups

| Groups | n | Mean ± Std. dev. (MPa) | Min. (MPa) | Max. (MPa) |
|---|---|---|---|---|
| Group 1 (FLD) | 10 | $5.60^{A} \pm 1.34$ | 3.93 | 7.68 |
| Group 2 (Acid-etch + FLD) | 10 | $8.91^{B} \pm 1.23$ | 6.74 | 10.67 |
| Group 3 (SBU + FLD) | 10 | $7.81^{B} \pm 0.69$ | 6.74 | 8.91 |
| Group 4 (AEO + FLD) | 10 | $7.64^{B} \pm 0.64$ | 6.27 | 8.42 |
| Group 5 (Er:YAG + AEO + FLD) | 10 | $11.26^{C} \pm 1.62$ | 9.02 | 14.42 |
| Group 6 (Er:YAG + SBU + FLD) | 10 | $13.64^{C,D} \pm 1.34$ | 11.58 | 15.40 |
| Group 7 (Er.Cr:YSGG + AEO + FLD) | 10 | $11.44^{C} \pm 1.58$ | 9.32 | 13.67 |
| Group 8 (Er.Cr:YSGG + SBU + FLD) | 10 | $13.70^{D} \pm 1.91$ | 11.31 | 16.60 |

*Std. dev.* standard deviation, *Min* minimum, *Max* maximum

*In each column, groups with different capital superscripts are significantly different ($P < 0.05$)

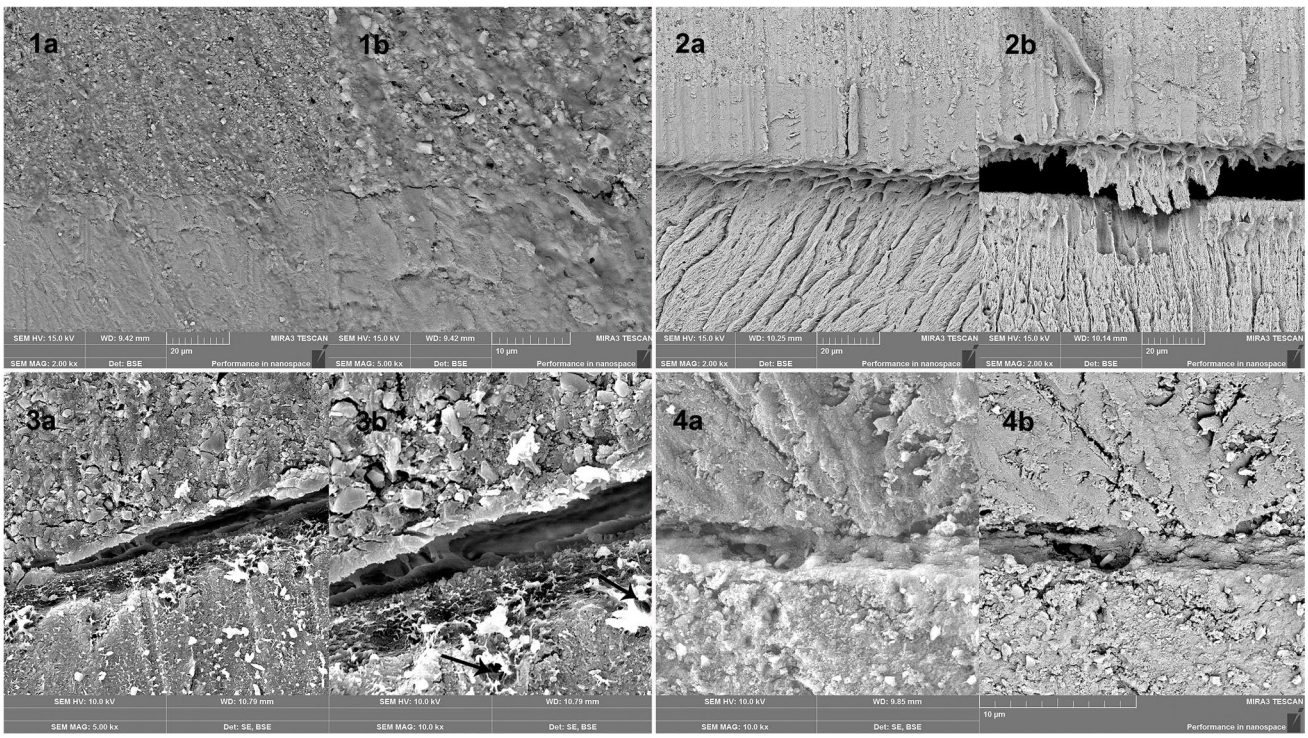


**Fig. 1** (1a, 1b) Hybrid layer and resin tags could not be seen easily in Group 1. (2a, 2b) There were fully bonded areas but most of them were cracked in Group 2. (3a, 3b) There were opened dentin tubules (black arrow) in lased surfaces but unable to detect full-filled resin tags in Group 5. (4a, 4b) Discontinuity of a hybrid layer with broken resin tags in Group 3

## Discussion

Bonding to dental tissues is considered to be of great importance in restorative dentistry to reestablish aesthetics and function within the concepts of maximum preservation of the tooth structure. Different dentin surface treatments can influence the effectiveness of dentin bonding systems [21, 22].

Lasers have been recommended to increase the adhesion of the resin to tooth structures [20]. It has also been used to etch or modify the surface of teeth as a substitute for acid etching. However, the effectiveness of this technique is controversial. While some researchers support the preparation or etching ability of laser to dentin [23–25], others deny its efficacy [26–28].

When the electromicrographs (SEM) were evaluated, the morphological features of the conventionally prepared dentin surface (i.e., diamond bur) differed from those of dentin treated with erbium lasers [29]. In the former, there was an evident smear layer obliterating the dentinal tubule entrances, whereas in the latter, the laser-irradiated dentin presented an irregular surface without a smear layer, with open dentinal tubules and prominent peritubular dentin,

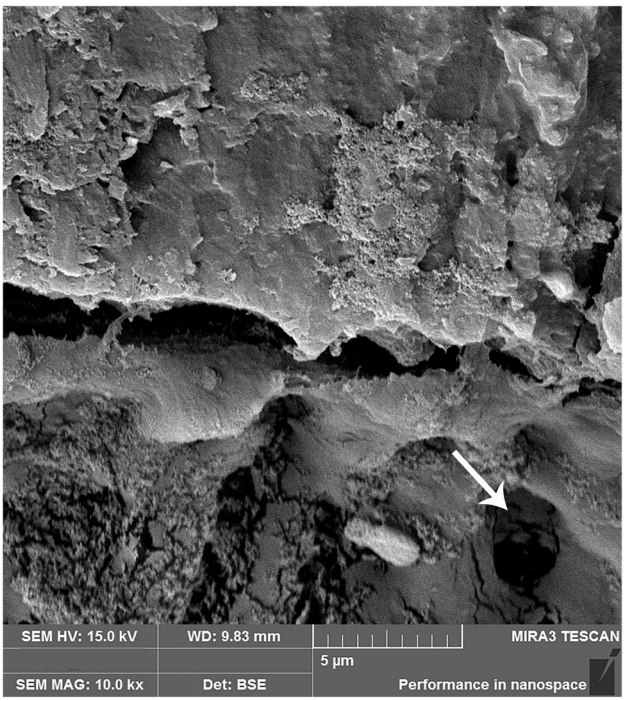


**Fig. 2** A cracked resin-dentin interface with a thin hybrid layer and shortened resin tags (white arrow) in acid-etched and lased surface in Group 8

**Table 2** Failure distribution of groups

| Groups | Adhesive failure (%) | Cohesive failure (%) | Mix failure (%) |
|---|---|---|---|
| Group 1 (FLD) | 90 | - | 10 |
| Group 2 (Acid-etch + FLD) | 90 | - | 10 |
| Group 3 (SBU + FLD) | 70 | - | 30 |
| Group 4 (AEO + FLD) | 60 | - | 40 |
| Group 5 (Er:YAG + AEO + FLD) | 50 | 10 | 40 |
| Group 6 (Er:YAG + SBU + FLD) | 60 | 20 | 20 |
| Group 7 (Er,Cr:YSGG + AEO + FLD) | 70 | - | 30 |
| Group 8 (Er,Cr:YSGG + SBU + FLD) | 60 | - | 40 |

suggesting a microretentive morphology favorable to bonding procedures [30–34].

This study determined how Er:YAG and Er,Cr:YSGG lasers, which are used for ablation of mineralized tissue in dentistry, affect the bonding of composites on the irridated dentin surface. The irradiation parameters proposed were lower than those reported in previous studies because the goal was to modify the eroded dentin surface without necessarily promoting ablation or cavity formation [12, 35].

Another factor affecting the success of composite restorations is the use of complicated adhesive systems to treat dentin, which requires various steps and therefore is associated with technique sensitivity, leading to increased chair time. By eliminating etching, rinsing, priming, and bonding [36], new self-adhesive flowable resins may help to reduce chair time and can be useful in uncooperative patient treatment, such as in children. [5, 20].

Self-adhesive flowable composites differ in their composition and feature various functional monomers. Fusio Liquid Dentin chemically bonds to hydroxyapatite using 4-methacryloxyethyl trimetellitic acid (4-META), which can partially demineralize dentin and form ionic bonds between its carboxylate groups and calcium in hydroxyapatite [37].

In the present study, Group 1 (FLD) showed the lowest µTBS. FLD partially demineralizes dentin and obtains the remaining hydroxyapatite partially attached to collagen within a submicron hybrid layer. It can be concluded from research that being less acidic causes decreased bond strength [2, 38, 39]. In previous studies, FLD showed decreased bond strengths like other SACs and the authors of this paper are of the same opinion that FLD showed statistically less µTBS values than that of the other groups [2, 7, 38–41]. A possible reason for the low bond strength is the less acidic effect and the occurrence of water droplets between the resin and dentin [42]. In addition, the blockage of dentin tubules with the smear layer that occurred after SiC preparation may account for the improper penetration of the FLD. When FLD was applied to dentin, thin and sparse tags were seen in some studies [7, 42], and the hybrid layer and resin tags could not be viewed [38, 42].

According to the SEM analysis, in Group 1, a thin hybrid layer that was difficult to observe was present, which showed discontinuity in most parts of the resin-dentin bonding surface. (Fig. 1) In Groups 2–8, a short hybrid layer can be observed with short resin tags. (Fig. 2) Adhesive failure mode was predominant, followed by mixed failure. Adhesive failures were observed in groups that showed decreased µTBS values with weak micromechanical bonding to dentin, and mixed fractures were mostly observed in groups that showed increased µTBS values (Table 2) (Fig. 3).

Different surface treatments have been widely used to obtain increased µTBS values, such as surface acid etching, laser irradiation, sandblasting, abrasion with a diamond bur followed by silica coating, and using intermediate bonding agents [43, 44].

Acid etching is used for demineralization of subsurface intact dentin and complete removal of the smear layer [39]. Acid etching not only exposes the network of the collagen matrix in dentin but also makes the dentinal tubules wide and open [40]. When acid is applied to the surface, it removes the smear layer and partially demineralizes the dentin to allow adhesive penetration into the collagen fibrils [15]. Shafiei and Saadat [6] evaluated the micromorphology and shear bond strength of SAC and found that the

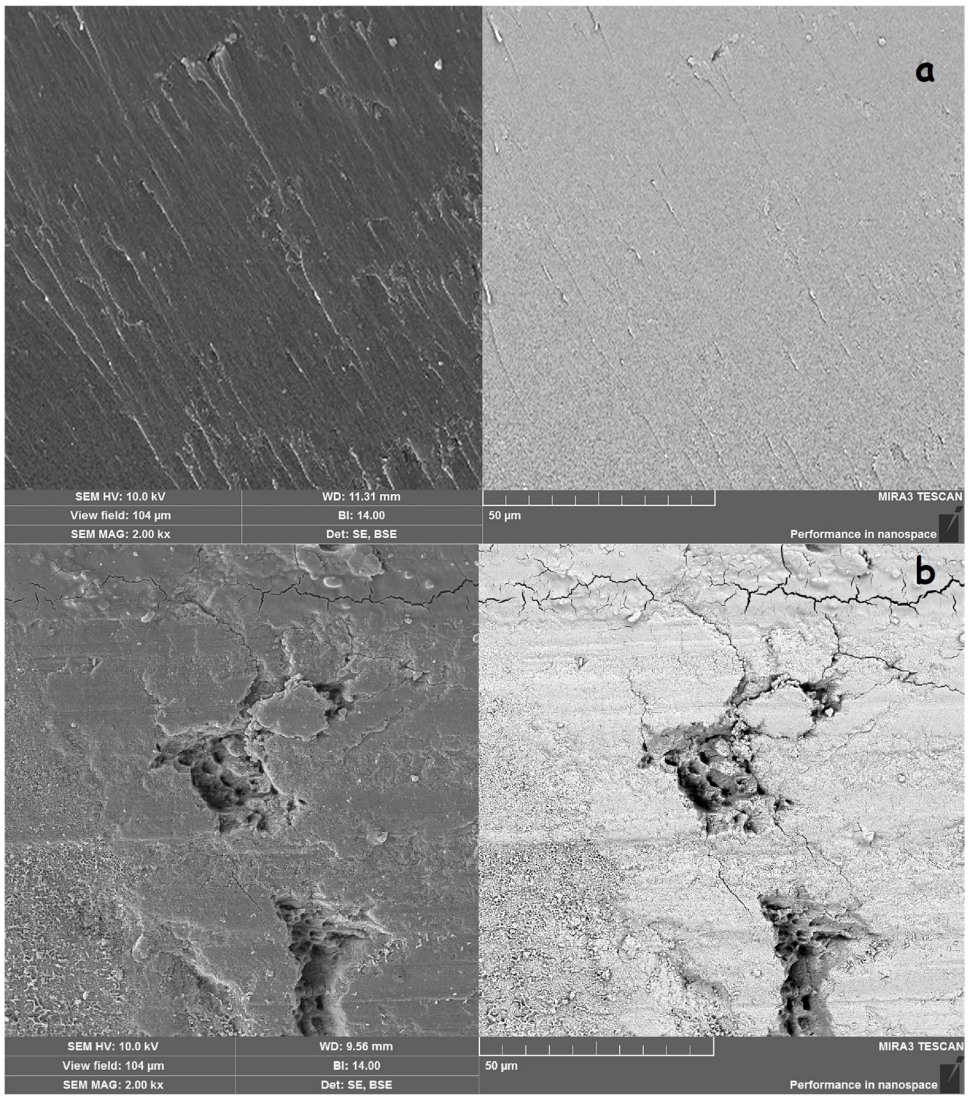


**Fig. 3** SEM images of failure types. (a) Adhesive and (b) mix failures

phosphoric acid-treated group had the highest bond strength. Altunsoy et al. [40] evaluated the effect of different surface treatments on the μTBS of two different SACs to dentin and showed that acid etching increased the μTBS of SACs. Poitevin et al. [41] evaluated the bonding effectiveness of SAC and reported that phosphoric acid etching of dentin/enamel significantly improved the bonding effectiveness of SAC. In Group 2, phosphoric acid (37%) was used, and increased values were observed in the μTBS values of SAC. The current values are in line with the studies that acid etching before applying SAC can increase the bond strength of these materials.

The bond strength between the dental substrate and adhesive system is one of the most important factors to consider for successful restorative treatment. When an adhesive agent was used with SACs as in conventional composites, increased μTBS values were observed in both Groups 3 and 4. A universal bond (SBU) was used in Group 3, and a self-etch bond (AEO) was used in Group 4. Cengiz and Unal [38] compared two SACs with universal adhesives in two modes, total-etch and self-etch, and Single Bond Universal showed higher μTBS values than FLD when FLD was applied alone in their study. Sismanoglu [44] tested an SAC for the repair of composites and showed increased μTBS values in the use of Single Bond Universal with SAC.

Studies on SACs have reported that the bond strengths of SACs are improved with the use of an adhesive layer [1, 5, 36, 45]. Although SBU showed higher μTBS values than AEO, there were no significant differences between them. (Table 1) Two adhesives, SBU and AEO, include Vitrebond copolymer (1–5%), which may also provide chemical bonding to hydroxyapatite. For self-etch adhesives, chemical bonding between polycarboxylic monomers and hydroxyapatite plays a crucial role in their bonding mechanism [46]. Depending upon the acid dissociation constants (pKa values), the etching aggressiveness of self-etch adhesive

systems can also be classified into "strong" (pH < 1), "intermediately strong" (pH≈1.5), "mild" (pH≈2), and "ultramild" (pH ≥ 2.5). The bonding used in this study SBU had a pH of 2.7 and AEO had a pH 0.8–1. As expected, the strong acidity of the AEO could solve more smears and provide increased bond strength. However, no statistically significant differences were observed between the two bonding agents. AEO contains a methacrylohexyl phosphate monomer, and SBU contains a methacryloyloxi-decyl-dihydrogen-phosphate (MDP) monomer. MDP has a phosphoric-acid functional group that interacts chemically with hydroxyapatite crystals and forms stable calcium phosphate and calcium carboxylate salts, with a limited surface-decalcification effect. MDP has another methacrylate polymerizable group that is responsible for the curing potential and a 10-carbon chain group that separates the other active groups. The carbon spacer influences the hydrophobicity-hydrophilicity balance, monomer flexibility, solubility, and wetting. One of the most important reasons for bond durability is the interaction between MDP and the additional chemical interaction of dentin [47]. This seems to be the most likely cause of the nearest μTBS values of SBU and AEO, and the authors of this study are in the same opinion as Pashaev et al. [46] who reported that when universal adhesives were used in the self-etch application mode, SBU exhibited μTBS values similar to AEO.

In the current study, all laser-treated groups (Groups 5–8) showed significantly higher bonding strength values than the untreated groups (Groups 1–4). This is because of three features of the tooth surface as a result of laser irradiation: (1) roughness of the surface, (2) open dentinal tubules, and (3) the lack of a smear layer on the surface [48]. Er:YAG and Er,Cr:YSGG lasers showed similar bond strength values when used with the same adhesive agent. There were no statistically significant differences between Groups 5 and 7 and between Groups 6 and 8 in terms of bond strength. (Table 1). However, the groups in which SBU was applied together with laser applications (Groups 6 and 8) showed higher bond strength values than the groups in which AEO was applied with laser applications (Groups 5 and 7). While Group 8 differed significantly from Group 7, there was no statistically significant difference between Groups 6 and 5.

Altunsoy et al. [40] evaluated the influence of various surface preparations on the μTBS of two SACs and reported that Er:YAG laser irradiation increased μTBS when using FLD. Nahas et al. [14] investigated the bond strength of SAC in Er:YAG laser-pretreated surfaces and reported that with an optimal energy level, the Er:YAG laser may enhance the bond strength of SAC. Yazici et al. [20] evaluated the effect of Er:YAG laser preparation on the μTBS of SAC and found increased bond strengths in their study. Zarabian et al. [49] reported increased bond strength after evaluating the bond strength of an SAC to Er,Cr: YSGG-treated enamel. Moslemi et al. [13] evaluated the effect of an Er, Cr: YSGG laser on the bond strength of SAC and reported that laser irradiation can improve bond strength. The authors of the present study are in the same opinion as in the aforementioned literature that laser irradiation can improve bond strengths of SACs [13, 14, 20, 40]. Memarpour et al. [1] evaluated the effect of laser preparation on the adhesion of SAC and found lower bond strength values. The main reason for the decreased result may be the SACs monomers used in that study, and the laser parameters may have an effect on the bond strength. In the current study, the application of dental adhesives to dentin surfaces after laser application increased the bond strength of SAC. This increase may have been due to the content of Vitrebond copolymer (1%–5%) (which might also provide chemical bonding to hydroxyapatite) and the adhesives that have acidic pH values (SBU pH 2.7 and AEO pH 0.8–1).

This study has some limtitations. Firstly, this study conducted an in vitro study design. Thus, it is not possible to fully reflect the oral environment. Another limitation is that different parameters have been tested in the current study as it may be possible to argue that it would effect the reliability of the findings. However, it should be noted that several methologies have been performed in previous studies and all tested parameters in the current study have also been confirmed in previous studies. Therefore, further in vitro and in vivo studies with eroded dentin are necessary to assess the new parameters of Er:YAG and Er,Cr:YSGG laser irradiation. In addition, Erbium laser application was combined with adhesive systems in this study. There is a need for studies where laser systems are applied only with SACs.

## Conclusion

According to the results of the current in vitro study, it is clear that FLD provides insufficient adhesion when used alone. Therefore, an alternative surface preparation is advised to have better adhesion. When the bonding of the FLD to dentin was evaluated, the combined use of Er:YAG and Er,Cr:YSGG lasers with SBU and AEO on dentin surfaces improved the dentinal bond strength of the FLD.

**Author contribution** Alper Kaptan contributed to conception, design, collecting data, statistical analysis, and writing some parts of manuscript. Fatih Oznurhan contributed to conception, design, data acquisition and interpretation, and SEM analysis writing of the manuscript.

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**Data availability** The data that support the findings of this study are available from the corresponding author [FO], upon reasonable request.

## Declarations

**Ethics approval** This study was approved by Cumhuriyet University Clinical Research Ethic Committee (2017–05/01).

**Conflict of interest** The authors decalre no competing interests.

## References


1. Memarpour M, Shafiei F, Razmjoei F, Kianimanesh N (2016) Effect of laser preparation on adhesion of a self-adhesive flowable composite resin to primary teeth. Microsc Res Tech 79(4):334–41
2. Brueckner C, Schneider H, Haak R (2017) Shear bond strength and tooth-composite interaction with self-adhering flowable composites. Oper Dent 42(1):90–100
3. Jhingan P, Sachdev V, Sandhu M, Sharma K (2015) Shear bond strength of self-etching adhesives to cavities prepared by diamond bur or Er, Cr:YSGG laser and effect of prior acid etching. J Adhes Dent 17(6):505–512
4. Inokoshi M, Poitevin A, De Munck J, Minakuchi S, Van Meerbeek B (2014) Bonding effectiveness to different chemically pre-treated dental zirconia. Clin Oral Inv 18(7):1803–12
5. Bektas OO, Eren D, Akin EG, Akin H (2013) Evaluation of a self-adhering flowable composite in terms of micro-shear bond strength and microleakage. Acta Odontol Scand 71(3–4):541–6
6. Shafiei F, Saadat M (2016) Micromorphology and bond strength evaluation of adhesive interface of a self-adhering flowable composite resin-dentin: effect of surface treatment. Microsc Res Tech 79(5):403–7
7. Peterson J, Rizk M, Hoch M, Wiegand A (2017) Bonding performance of self-adhesive flowable composites to enamel, dentin and a nano-hybrid composite Odontology
8. Ozer F, Blatz MB (2013) Self-etch and etch-and-rinse adhesive systems in clinical dentistry Compendium of continuing education in dentistry (Jamesburg, N.J. : 1995).34(1): p. 12-4, 16, 18; quiz 20, 30
9. Celik EU, Kucukyilmaz E, Savas S (2015) Effect of different surface pre-treatment methods on the microleakage of two different self-adhesive composites in Class V cavities. Eur J Paediatr Dent 16(1):33–38
10. Kirmali O, Kustarci A, Kapdan A, Er K (2015) Effects of dentin surface treatments including Er, Cr:YSGG laser irradiation with different intensities on the push-out bond strength of the glass fiber posts to root dentin. Acta Odontol Scand 73(5):380–386
11. Tuna EB, Ozel E, Kasimoglu Y, Firatli E (2017) Investigation of the Er: YAG laser and diamond bur cavity preparation on the marginal microleakage of Class V cavities restored with different flowable composites. Microsc Res Tech 80(5):530–536
12. Ramos TM, Ramos-Oliveira TM, de Freitas PM, Azambuja N Jr, Esteves-Oliveira M, Gutknecht N, de Paula Eduardo C (2015) Effects of Er:YAG and Er, Cr:YSGG laser irradiation on the adhesion to eroded dentin. Lasers Med Sci 30(1):17–26
13 Moslemi M, FotouhiArdakani F, Javadi F, KhaliliSadrabad Z, Shadkar Z, Shadkar MS (2016) Evaluation of Er, Cr:YSGG laser effect on microshear bond strength of a self-adhesive flowable composite in the dentin of permanent molar: an in vitro study. Scientifica Cairo. 2016:4856285
14. Nahas P, Zeinoun T, Majzoub Z, Corbani K, Nammour S (2016) The effect of energy densities on the shear bond strength of self-adhering flowable composite to Er:YAG pretreated dentin. Biomed Res Int 2016:6507924
15. Ramos TM, Ramos-Oliveira TM, Moretto SG, de Freitas PM, Esteves-Oliveira M, Eduardo CD (2014) Microtensile bond strength analysis of adhesive systems to Er:YAG and Er, Cr:YSGG laser-treated dentin. Lasers Med Sci 29(2):565–573
16 de Souza AE, Corona SA, Dibb RG, Borsatto MC, Pecora JD (2004) Influence of Er:YAG laser on tensile bond strength of a self-etching system and a flowable resin in different dentin depths. J Dent 32(4):269–75
17. Omae M, Inoue M, Itota T, Finger WJ, Inoue M, Tanaka K, Yamamoto K, Yoshiyama M (2007) Effect of a desensitizing agent containing glutaraldehyde and HEMA on bond strength to Er:YAG laser-irradiated dentine. J Dent 35(5):398–402
18. Chimello-Sousa DT, de Souza AE, Chinelatti MA, Pecora JD, Palma-Dibb RG, Milori Corona SA (2006) Influence of Er:YAG laser irradiation distance on the bond strength of a restorative system to enamel. J Dent 34(3):245–51
19. Sung EC, Chenard T, Caputo AA, Amodeo M, Chung EM, Rizoiu IM (2005) Composite resin bond strength to primary dentin prepared with Er, Cr:YSSG laser. J Clin Pediatr Dent 30(1):45–9
20. Yazici AR, Agarwal I, Campillo-Funollet M, Munoz-Viveros C, Antonson SA, Antonson DE, Mang T (2013) Effect of laser preparation on bond strength of a self-adhesive flowable resin. Lasers Med Sci 28(1):343–7
21. de Oliveira MT, de Freitas PM, de Paula Eduardo C, Ambrosano GM, Giannini M (2007) Influence of diamond sono-abrasion, air-abrasion and Er:YAG laser irradiation on bonding of different adhesive systems to dentin. Eur J Dent 1(3):158–66
22. Montes MA, de Goes MF, Sinhoreti MA (2005) The in vitro morphological effects of some current pre-treatments on dentin surface: a SEM evaluation. Oper Dent 30(2):201–12
23. Gurgan S, Kiremitci A, Cakir FY, Gorucu J, Alpaslan T, Yazici E, Gutknecht N (2008) Shear bond strength of composite bonded to Er, Cr:YSGG laser-prepared dentin. Photomed Laser Surg 26(5):495–500
24 Ramos AC, Esteves-Oliveira M, Arana-Chavez VE, de Paula Eduardo C (2010) Adhesives bonded to erbium:yttrium-aluminum-garnet laser-irradiated dentin: transmission electron microscopy, scanning electron microscopy and tensile bond strength analyses. Laser Med Sci 25(2):181–9
25. Bahrami B, Askari N, Tielemans M, Heysselaer D, Lamard L, Peremans A, Nyssen-Behets C, Nammour S (2011) Effect of low fluency dentin conditioning on tensile bond strength of composite bonded to Er:YAG laser-prepared dentin: a preliminary study. Laser Med Sci 26(2):187–91
26. Dunn WJ, Davis JT, Bush AC (2005) Shear bond strength and SEM evaluation of composite bonded to Er:YAG laser-prepared dentin and enamel. Dent Mater : Off Publ Acad Dent Mater 21(7):616–24
27. Tarcin B, Gunday M, Ovecoglu HS, Turkmen C, Ovecoglu ML, Oksuz M, Ay M (2009) Tensile bond strength of dentin adhesives on acid- and laser-etched dentin surfaces. Quintessence Int 40(10):865–74
28. Marotti J, Geraldo-Martins VR, Bello-Silva MS, de Paula Eduardo C, Apel C, Gutknecht N (2010) Influence of etching with erbium, chromium:yttrium-scandium-gallium-garnet laser on microleakage of class V restoration. Laser Med Sci 25(3):325–9
29. Ramos TM, Ramos-Oliveira TM, Moretto SG, de Freitas PM, Esteves-Oliveira M, de Paula Eduardo C (2014) Microtensile bond strength analysis of adhesive systems to Er:YAG and Er, Cr:YSGG laser-treated dentin. Laser Med Sci 29(2):565–73
30. Visuri SR, Gilbert JL, Wright DD, Wigdor HA, Walsh JT Jr (1996) Shear strength of composite bonded to Er:YAG laser-prepared dentin. J Dent Res 75(1):599–605
31. Esteves-Oliveira M, Zezell DM, Apel C, Turbino ML, Aranha AC, Eduardo Cde P, Gutknecht N (2007) Bond strength of self-etching primer to bur cut, Er, Cr:YSGG, and Er:YAG lased dental surfaces. Photomed Laser Surg 25(5):373–80

32. Malkoc MA, Tasdemir ST, Ozturk AN, Ozturk B, Berk G (2011) Effects of laser and acid etching and air abrasion on mineral content of dentin. Laser Med Sci 26(1):21–7
33. Lee BS, Lin PY, Chen MH, Hsieh TT, Lin CP, Lai JY, Lan WH (2007) Tensile bond strength of Er, Cr:YSGG laser-irradiated human dentin and analysis of dentin-resin interface. Dent Mater: Off Publ Acad Dent Mater 23(5):570–8
34 Beer F, Buchmair A, Korpert W, Marvastian L, Wernisch J, Moritz A (2012) Morphology of resin-dentin interfaces after Er, Cr:YSGG laser and acid etching preparation and application of different bonding systems. Laser Med Sci 27(4):835–41
35. Öznurhan F, Ölmez A (2013) Nanoleakage in primary teeth prepared by laser irradiation or bur. Lasers Med Sci 28(4):1099–105
36. Durmuslar S, Olmez A (2017) Microtensile bond strength and failure modes of flowable composites on primary dentin with application of different adhesive strategies. Contemp Clin Dent 8(3):373–379
37. Nagakane K, Yoshida Y, Hirata I, Fukuda R, Nakayama Y, Shirai K, Ogawa T, Suzuki K, Van Meerbeek B, Okazaki M (2006) Analysis of chemical interaction of 4-MET with hydroxyapatite using XPS. Dent Mater J 25(4):645–9
38. Cengiz T, Unal M (2019) Comparison of microtensile bond strength and resin-dentin interfaces of two self-adhesive flowable composite resins by using different universal adhesives: scanning electron microscope study. Microsc Res Tech 82(7):1032–1040
39. Sachdeva P, Goswami M, Singh D (2016) Comparative evaluation of shear bond strength and nanoleakage of conventional and self-adhering flowable composites to primary teeth dentin. Contemp Clin Dent 7(3):326–31
40. Altunsoy M, Botsali MS, Sari T, Onat H (2015) Effect of different surface treatments on the microtensile bond strength of two self-adhesive flowable composites. Lasers Med Sci 30(6):1667–73
41. Poitevin A, De Munck J, Van Ende A, Suyama Y, Mine A, Peumans M, Van Meerbeek B (2013) Bonding effectiveness of self-adhesive composites to dentin and enamel. Dent Mater 29(2):221–30
42. Fu J, Kakuda S, Pan F, Hoshika S, Ting S, Fukuoka A, Bao Y, Ikeda T, Nakaoki Y, Selimovic D, Sano H, Sidhu SK (2013) Bonding performance of a newly developed step-less all-in-one system on dentin. Dent Mater J 32(2):203–11
43. Palasuk J, Platt JA, Cho SD, Levon JA, Brown DT, Hovijitra ST (2013) Effect of surface treatments on microtensile bond strength of repaired aged silorane resin composite. Oper Dent 38(1):91–9
44. Sismanoglu S (2019) Efficiency of self-adhering flowable resin composite and different surface treatments in composite repair using a universal adhesive. Niger J Clin Pract 22(12):1675–1679
45. El-Zeiny HM, Wegdan M, El-Fattah A, Abd-Elmotie MA (2016) Shear bond strength of self adhering flowable composites after preliminary acid etching of dentin. Alexandria Dent J 41:318–322
46. Pashaev D, Demirci M, Tekce N, Tuncer S, Baydemir C (2017) The effect of double-coating and times on the immediate and 6-month dentin bonding of universal adhesives. Biomed Mater Eng 28(2):169–185
47. Zecin-Deren A, Sokolowski J, Szczesio-Wlodarczyk A, Piwonski I, Lukomska-Szymanska M, Lapinska B (2019) Multi-layer application of self-etch and universal adhesives and the effect on dentin bond strength. Molecules 24(2):345
48. Kantorowitz Z, Featherstone JD, Fried D (1998) Caries prevention by CO2 laser treatment: dependency on the number of pulses used. J Am Dent Assoc 129(5):585–91
49. Zarabian T, Azadi Mood S, Kiomarsi N, Noorollahian H, Hakimiha N (2020) Microshear bond strength of a self-adhesive composite to erbium laser-treated primary enamel. J Lasers Med Sci 11(2):181–186