ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

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Comparison of the Different Self-Adhesive Composite's Shear Bond Strength and Microleakage on Caries-Affected Dentin with Using Er:YAG Laser

Er:YAG Lazer Kullanılarak Hazırlanmış Çürükten Etkilenmiş Dentinde Farklı Self-Adeziv Kompozitlerin Bağlantılarının ve Mikrosızıntılarının Karşılaştırılması

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This study was presented as an oral presentation and poster at CED-IAD.R/NOF meeting 15-17 October 2015, Antalya, Turkey.

ABSTRACT Objective: The aims of this study was to evaluate the bond strength of the self-adhesive composites (SAC; Vertise Flow, Fusio Liquid Dentin, Constic) on caries-affected dentin, which was prepared using an Er:YAG laser, and microleakage of sound dentin by employing Er:YAG laser etching. **Material and Methods:** Two hundred twenty carious molar teeth were divided into two groups, i.e., laser and bur, respectively, according to different caries removal methods. SAC were applied with three adhesive techniques (i.e., no adhesive, self-etch, total etch, respectively). Shear bond strength tests were performed, and data were then analyzed by using one-way and two-way ANOVA and Tukey HSD tests ($p<0.05$). Class V cavities were prepared on the buccal and lingual surfaces of one hundred and ten non-carious molar teeth for microleakage evaluation. Laser etching was applied only on buccal cavities. The teeth were divided into subgroups for the evaluation of the bond strength of composite systems. The dye penetration method was employed to evaluate microleakage. Data were analyzed with the Friedman, Wilcoxon Signed Ranks, and Mann–Whitney U tests ($p<0.05$). **Results:** Significant differences between the caries removal methods and the shear bond strength of the composites were observed ($p<0.05$). The bond strength of the SAC group was less than that of the control group. The microleakage evaluation revealed statistically significant differences between the composites ($p<0.05$). A better sealing performance was observed for the control group. **Conclusion:** SAC did not provide good bonding and sealing performance without adhesive systems. Further clinical and laboratory studies are required to estimate the bond strength and microleakage values of SAC.

Keywords: Caries-affected dentin; Er: YAG laser; microleakage; self-adhesive composite; shear bond strength

ÖZET Amaç: Çalışmanın amacı; farklı self-adeziv kompozitlerin (SAC; Vertise Flow, Fusio Liquid Dentin, Constic) Er:YAG lazer kullanılarak hazırlanan çürükten etkilenmiş dentinde bağlanma dayanımlarını ve Er:YAG lazer ile etching yapılarak sağlam dentinde mikrosızıntılarını karşılaştırmaktır. **Gereç ve Yöntemler:** Çalışma için 220 çürüklü molar diş farklı çürük temizleme yöntemleri uygulanmak üzere (lazer-frez) önce iki gruba, sonra farklı adeziv teknikler (adeziv yok, self-etch, total-etch) ile beraber self-adeziv kompozitler ve geleneksel akıcı kompozit (ultimate flow) uygulanmak üzere alt gruplara ayrıldı (n=10). Makaslama bağlanma dayanımı testi uygulandı. Veriler iki yönlü ANOVA, tek yönlü ANOVA ve Tukey testleri ile analiz edildi ($p<0,05$). Mikrosızıntı deneyi için, 110 çürüksüz molar dişin bukkal ve palatinal yüzeylerine sınıf V kaviteler frezle açıldı. Sadece bukkal yüzdeki kavitelere lazer ile pürüzlendirme yapıldı. Dişler bağlanma dayanımında olduğu gibi adeziv sistemler ve kompozitler uygulanmak üzere alt gruplara ayrıldı. Mikrosızıntı deneyi için boya penetrasyon yöntemi kullanıldı. Elde edilen veriler Friedman, Wilcoxon Signed Ranks and Mann-Whitney U testleri ile analiz edildi ($p<0,05$). **Bulgular:** Sonuçlara göre, çürük temizleme yöntemleri ve kompozitler arasında bağlanma dayanımı değerlerinde farklılık tespit edildi ($p<0,05$). Self-adeziv kompozitler kontrol grubuna oranla daha düşük bağlanma dayanımı değerleri gösterdi. Mikrosızıntı değerlendirmesi sonrası ise kompozitler arasında istatistiksel olarak anlamlı farklılık tespit edildi ($p<0,05$). Kontrol grubunda daha iyi bir sızdırmazlık performansı görüldü. **Sonuç:** Self-adeziv kompozitler adeziv sistemler olmadan yeterli bağlanma ve sızdırmazlık sağlayamadılar. Self-adeziv kompozitlerin bağlanma dayanımları ve mikrosızıntıları ile ilgili daha fazla labaratuvar ve klinik çalışmaya ihtiyaç vardır.

Anahtar Kelimeler: Çürükten etkilenmiş dentin; Er: YAG lazer; mikrosızıntı; self-adeziv kompozit; makaslama bağlanma dayanımı

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Self-adhesive composites (SAC) constitute one of the recent innovations in adhesive dentistry. The SAC are all-in-one adhesive resins that do not require the application of an adhesive system.[1] Bonding to the tooth surface is achieved using acidic monomers, which can acidify the enamel and dentin.[1] By eliminating the application of the bonding agent, the procedure times for patients can be reduced, and the adverse effects that can be caused by errors during the application of the bonding agent can be minimized. The SAC are used for the restoration of small class I and class V cavities as well as cervical lesions; and as a liner for class I and class II cavities; as a pit fissure sealant; and for the porcelain repair and orthodontic treatment.[2] Kerr Vertise Flow (VF) is the first SAC, which contains an acidic monomer, glycerol phosphate dimethacrylate (GPDM), that is responsible for etching as well as the chemical linkage to the calcium ions in the tooth structure. The mechanical linkage is formed by the cross-linking between functional methacrylate groups.[2] FLD and C were the other composites. FLD contains 4-methacryloxyethyl trimellitic acid (4-META), which demineralizes dentin and forms ionic bonds between the carboxylate groups and calcium in hydroxyapatite.[3] C contains 10-methacryloyloxydecyl dihydrogen phosphate (MDP) monomer, which provides strong chemical bonding with hydroxyapatite.[4]

The chemical content and histological structure of dentin affect the bond strength. Previous studies reported on non-carious dentin.[5-7] On the other hand, restorations typically comprise caries-affected dentin, which occurs after the removal of the infected dentin in clinics.[8] Caries-affected dentin exhibits a sclerotic structure. The collagen fibrillar spaces are filled with calcium carbonate apatite crystals. This structural difference leads to a change in the bonding performance.[9]

Several methods were employed as alternatives to remove caries.[10,11] Several researchers typically employ a laser technique because lasers require a conservative approach, where caries are safely and effectively removed without damage to the intact tooth surface.[12,13]

The bonding effectiveness of SAC on caries-affected dentin was not reported previously. Hence, the bond strength of SAC applied with or without using two adhesive systems on caries-affected dentin prepared with bur or laser is compared in this study. Moreover, the effect of laser etching on class V cavities is evaluated.

In this study, SAC was hypothesized to exhibit lower bond strength and higher microleakage than those of SAC applied with an adhesive system and a conventional flowable composite. Furthermore, the bond strength of bur-prepared dentin was greater than that of laser-prepared dentin.

MATERIAL AND METHODS

The study was carried out in accordance with the principles of Declaration of Helsinki, and it was approved by the Non-Interventional Clinical Investigation Evaluation Commission of Selçuk University (25.03.2014, 2014/03 decision date and number). Table 1 summarizes the materials used in the study.

PREPARATION OF DENTIN SPECIMENS FOR SHEAR BOND STRENGTH TESTS

Two hundred twenty human molar teeth with proximal decay were used. Teeth crowns were removed under water cooling using a polishing machine until the proximal caries level was exposed (Figure 1 a,b). The specimens were embedded in a self-curing acrylic resin in cylindrical rubber molds. The teeth were randomly divided into two groups for the purpose of using two caries removal methods (i.e., Er:YAG and steel bur, respectively). The Er:YAG laser (Fidelis PlusII, Fotona Medical Lasers, Ljubljana, Slovenia) with a tall wave of 2.94 µm was utilized for the removal of caries in the contact mode according to the manufacturer's instructions under water cooling ~1 mm away from the tooth surface using the following parameters: 200 mJ (13 J/J/cm^2), 20 Hz, 4 parameter air, and 5 parameter water. Caries were removed until DIAGNOdent (KaVo Dental GmbH, Biberach, Germany) exhibited a score of 11-20.[8] The dentin surfaces were ground with 320- and 600-grit silicon carbide paper to obtain smooth occlusal surfaces. Then, the teeth were divided into 11 subgroups (n=10) according to adhesive systems and SAC (VF, C, FLD). The control group comprised a conventional flowable compos-

TABLE 1: Materials used in this study.

Material	Contents	Manufacturer	Lot No
Clearfil SE Bond	Self-etching primer: MDP, HEMA, hydrophilic dimethacrylate, dicampharacinon, N,N-diethanol-ptoluidine, water, adhesive resin: MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, dicampharacinon, N, N-diethanol-ptoluidine, silanized colloidal silica	Kuraray Noritake Dental, Tokyo, Japan	000077
Optibond FL	Unpolymerized methacrylate ester, triethyleneglycol, monomers, dimethacrylate, ytterbium trifluoride, inert mineral fillers, polymerization initiators and stabilizers	Kerr, Orange, CA, USA	5156291
Filtek Ultimate	Bis-GMA, Bis-EMA, TEGDMA, Procrylat resins ytterbium trifluoride Silica fillers	3M ESPE, St. Paul MN, USA	N488361
Vertise Flow	Resin: GPDMA, HEMA, Bis-GMA, catalysts Fillers: prepolymers, silanized Ba glass, SiO_2, YF_3	Kerr, Orange, CA, USA	2970580
Constic	Resin: Bis-GMA matrix, catalysts, pigments Fillers: Ba glass	DMG Chemisch, Elbgaustraβe, Hamburg	697646
Fusio Liquid Dentin	Resin: UEDMA, TEGDMA, HEMA, 4-MET, catalysts Fillers: SiO_{qw}, NaF	Pentron Clinical, Orange, CA, USA	5085184

Bis-GMA: bisphenol-aglycidylmethacrylate; GPDM: glycero-phosphate dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; GPDM: glycerol phosphate dimethacrylate; MDP: 10-Methacryloyloxydecyl dihydrogen phosphate; HEMA: 2-hydroxyethyl methacrylate; BIS: EMA: Ethoxylated bisphenol-A dimethacrylate; 4 MET: 4-methacryloyloxyethyl trimellitic acid.

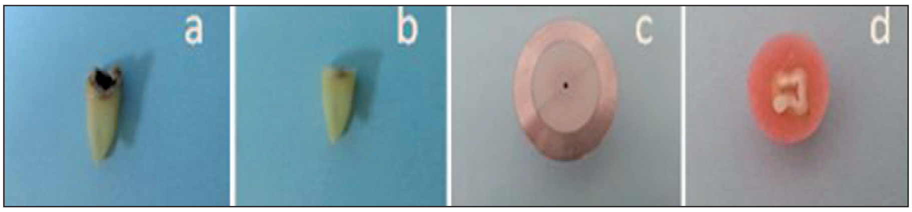

FIGURE 1: (a) Decay molar tooth; **(b)** occlusal-surface-removed tooth; **(c)** teflon mold; and **(d)** composite prepared with a teflon mold on caries-affected dentin.

ite [Filtek Ultimate (UF)]. Table 2 summarizes the groups in this study.

BONDING PROCEDURE

A 3-mm-high cylindrical teflon mold with an internal diameter of 2 mm was placed on the caries-affected dentin surface (Figure 1c). SAC were injected in two steps, and both layers were polymerized for 20 s using an LED curing unit (Monitex BlueLex GT-1200, Monitex Industrial Co., Ltd.; light intensity: 1,000 mW/cm^2; Figure 1d). If the adhesive systems were applied, composites were injected after the application of the adhesive system. Teeth were stored in distilled water at 37°C for 48 h before the application of the shear bond strength (SBS) test (1 mm/min).

TABLE 2: Groups in the study.

Composites	Steel Bur	Er-YAG laser
Vertise Flow	1.group VF 1	4.group VF 2
	2.group SE + VF 1	5.group SE + VF 2
	3.group OFL+ VF 1	6.group OFL+VF 2
Constic	7.group C 1	10.group C 2
	8.group SE + C 1	11.group SE + C 2
	9.group OFL+C 1	12.group OFL+C 2
Fusio Liquid Dentin	13.group FLD 1	16.group FLD 2
	14.group SE + FLD 1	17.group SE + FLD 2
	15.group OFL + FLD 1	18.group OFL + FLD 2
Ultimate Flow (Control)	19.grup SE + UF 1	21.group SE +UF 2
	20.grup OFL + UF 1	22.group OFL + UF2

VF: Vertise Flow; C: Constic; FLD: Fusio Liquid Dentin; UF: Ultimate Flow; SE: SE Bond; OFL: OptiBond FL.

SBS TEST

The SBS of the prepared specimens was measured by using the push-out tester (Instron Universal) at the Research Center of the Selcuk University. The Ultradent device was operated at 1 mm/min, and a rapidly transmitted force was applied to the restoration-tooth joint area until the restoration was separated from the tooth. The SBS values were calculated in megapascals (MPa) with the software program of the Instron device (Trapezium 2, Shimadzu Corp., Kyoto, Japan).

PREPARATION OF CAVITIES TO DETERMINE MICROLEAKAGE

Class V cavities were prepared 1.5 mm below the occlusal margin and 1.5 mm above the gingival margin on the buccal and palatal surfaces of 110 non-carious molar teeth. The cavities were prepared at a width, height, and depth of 4 mm, 3 mm, and 2 mm, respectively. Cavities were prepared with diamond fissure burs under air-water cooling, and the burs were changed every five cavities. Laser etching was applied on the palatal surface of the cavities. On the other hand, laser etching was not applied to the buccal cavities. Adhesive systems and composites were applied as bond strength test groups according to the manufacturer's instructions.

The Er:YAG laser with a non-contact head (R02-C) was used for etching, which was performed 7 mm away from the tooth surface under air-water cooling. The device was applied at 120 mJ/10 Hz at the enamel and 80 mJ/10 Hz at the dentin with a pulse interval of 100 µs (MSP mode), and the surfaces were observed for 15 s under air-water cooling.

Restorations were polished and then placed in the dark in distilled water at 37° C for 24 h in an incubator. One thousand cycles of thermal aging between 5±2° C and 55±2° C were applied to the teeth.[14,15] The dye penetration method was employed to examine the microleakage. The teeth were incubated for 24 h in a 0.5% basic fuchsin solution at 37° C and then washed. Teeth were cut from the buccolingual direction. The penetration of the dye into the samples was examined using a stereomicroscope (Leica Microsystems, 16 FA, Switzerland) at 40 x magnification.

The following score scale (0-5) was used for determining the microleakage.[14]

0= No dye penetration;

1= dye penetration in 1/3rd of the occlusal or gingival cavity wall;

2= dye extension to the end of the occlusal or gingival cavity wall;

3= dye penetration overlaps the occlusal or gingival cavity wall and over 1/3rd of the axial wall;

4= dye penetration over the occlusal or gingival cavity wall and covering 2/3rd of the axial wall;

5= dye extension in all of the axial wall through the occlusal or gingival cavity wall.

SEM ANALYSIS

One sample from each group prepared for SEM evaluation was the same as that prepared for the bond strength test before. The prepared specimens were cut under water cooling perpendicular to the mesiodistal interface at a low speed by using a diamond disk. Two bonding interfaces were obtained for each adhesive system. After discarding one side, the specimen surface was polished using a water-cooled silicon carbide paper (600 grit; 800 grit; 1000 grit; 1200 grit; 2000 grit) to achieve a flat surface. The samples were incubated for 15 min using an ultrasonic cleaner and then using 10% phosphoric acid for 10 s. The samples were again incubated for 15 min using the ultrasonic cleaner and then treated with 5% sodium hypochlorite for 5 min. After incubating the samples in the ultrasonic cleaner again for 15 min, the samples were dehydrated with increasing concentrations (50%, 70%, 95%, 100%) of ethanol for 15 min. The samples were dried under air for 24 h, and their surfaces were covered under a gold-plated device (Hummer VII coater, Anatech Corp. Alexandria, USA). SEM images (JEOL, JSM 5410, Tokyo, Japan) were recorded at 1000x and 2000x magnification.

STATISTICAL ANALYSIS

Statistical analyses were performed using the SPSS ver. 17.0 software program ($p<0.05$). Two-way ANOVA was employed for the general comparison of the SBS of composites, caries removal methods, and adhesive systems. One-way ANOVA was employed for the pair comparison between the groups, and Tukey HSD analysis was employed for binary comparison.

The Friedman test was employed for the general comparison of the microleakage values for the occlusal and gingival margins. The Wilcoxon signed-ranks test was employed to compare the leakage at the gingival-occlusal margin within each group. The Mann-Whitney U test was employed for the pair comparison between the gingival margins of the groups and the pair comparison between the occlusal margins of the groups.

RESULTS

ANALYSIS OF SBS VALUES

According to the two-way ANOVA test results, significant differences were observed among composites (VF, C, FLD, UF) and between caries removal methods (Er:YAG laser, Bur) and the adhesive tecniques (no adhesive, self-etch, total etch) ($p<0.05$). Table 3 summarizes the results obtained from two-way ANOVA. Compared to SAC group ($p<0.05$), the control group (UF) (24.23 MPa±6.238) exhibited higher SBS values. Compared to the laser group ($p<0.05$), the bur groups (15.69 MPa±10,031) exhibited significantly higher SBS values. Compared with the groups with SE and OFL ($p<0.05$), those without the adhesive system exhibited significantly lower SBS values (1.48±2.349). Moreover, significant differences in the SBS values were not observed between the SE and OFL groups ($p>0.05$).

The fracture surface analysis of the samples was performed using a light microscope with a 20x magnification (Olympus SZ4045 TRPT, Osaka, Japan). Failure types were categorized into the adhesive, cohesive, and mix failure groups. Table 4 summarizes the failure types and percentages.

Table 5 summarizes the mean, standard deviation, and minimum and maximum values of the SBS values of the groups.

SEM OBSERVATIONS

Figure 2 shows acid-etched and laser-etched enamel surfaces. A hybrid layer and a resin tag were not observed in the groups in which SAC was applied without the adhesive system (Figure 3; 1000x and 2000x). On the contrary, groups with the adhesive system clearly exhibited the hybrid layer and resin tag (Figure 4; 1000x and 2000x).

MICROLEAKAGE ANALYSIS

The Kruskal Wallis test revealed significant differences ($p<0.05$) between the gingival and occlusal edges of different composites. The gingival and occlusal margins of the control group exhibited minimal leakage, and the comparison of the gingival and occlusal margins of the composites revealed that significant differences between the FLD, VF, and C groups are not observed ($p>0.05$).

The Mann-Whitney U test revealed that the microleakages at the gingival and occlusal margins by different preparation methods (laser etching made-not made) do not exhibit significant differences ($p>0.05$). The microleakage values for the gingival and occlusal

TABLE 3: Two-way ANOVA results of shear bond strength.

	df	Mean square	F	P(Sig)
Corrected Model	21	1039,785	19,463	0,00
Intercept	1	56172,859	1051,485	0,00
Composite	3	213,280	3,992	0,00
Method	1	311,961	5,840	0,01
Bonding	2	8817,853	165,059	0,00
Composite + Method	3	1,904	0,036	0,99
Composite + Bonding	5	63,043	1,180	0,32
Method + Bonding	2	168,833	3,160	0,04
Composite + Method + Bonding	5	3,231	0,060	0,99

TABLE 4: Failure types and percentages of the groups.

Composites	Method	Bonding	Adhesive	Cohesive	Mix	Group
Vertise Flow	Bur	No Agent	10 (%100)	0 (%0)	0 (%0)	1
		SE Bond	5 (%50)	4 (%40)	1 (%10)	2
		OptiBond FL	6 (%60)	3 (%30)	1 (%10)	3
	Laser	No Agent	10 (%100)	0 (%0)	0 (%0)	4
		SE Bond	6 (%60)	3 (%30)	1 (%10)	5
		OptiBond FL	5 (%50)	5 (%50)	0 (%0)	6
Constic	Bur	No Agent	10 (%100)	0 (%0)	0 (%0)	7
		SE Bond	6 (%60)	3 (%30)	1 (%10)	8
		OptiBond FL	5 (%50)	4 (%40)	1 (%10)	9
	Laser	No Agent	10 (%100)	0 (%0)	0 (%0)	10
		SE Bond	5 (%50)	5 (%50)	0 (%0)	11
		OptiBond FL	6 (%60)	4 (%40)	0 (%0)	12
Fusio Liquid Dentin	Bur	No Agent	10 (%100)	0 (%0)	0 (%0)	13
		SE Bond	4 (%40)	5 (%50)	1 (%10)	14
		OptiBond FL	5 (%50)	3 (%30)	2 (%20)	15
	Laser	No Agent	10 (%100)	0 (%0)	0 (%0)	16
		SE Bond	5 (%50)	4 (%40)	1 (%10)	17
		OptiBond FL	5 (%50)	2 (%20)	3 (%30)	18
Ultimate Flow	Bur	SE Bond	3 (%30)	4 (%40)	3 (%30)	19
		OptiBond FL	4 (%40)	4 (%40)	2 (%20)	20
	Laser	SE Bond	3 (%30)	5 (%50)	2 (%20)	21
		OptiBond FL	5 (%50)	4 (%40)	1 (%10)	22

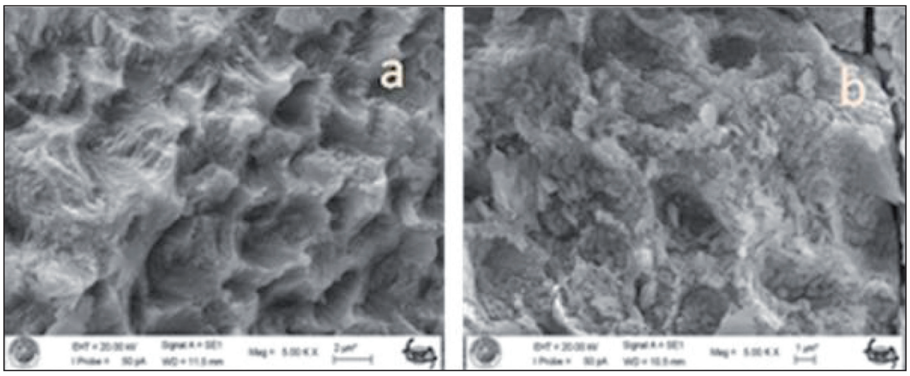

FIGURE 2: (a) Acid etching on the enamel and **(b)** laser etching on the enamel.

margins between the adhesive systems were analyzed by the Kruskal Wallis and one-way ANOVA tests. The results revealed significant differences between different groups ($p<0.05$). The microleakage values for the SAC groups applied without the adhesive system were significantly greater than those for the SE and OFL groups ($p<0.05$). Moreover, significant differences in the microleakage between the SE and OFL adhesive systems were not observed ($p>0.05$). The microleakage between the gingival and occlusal margins of different groups was evaluated by the Bonferroni-corrected Mann-Whitney U test. The Bur+UF+OFL (20. group) group exhibited the lowest microleakage in the gingival and occlusal margins, whereas the Bur+C (7. group) group demonstrated the highest microleakage (Figure 5).

TABLE 5: Mean ± standard deviation (Mean ± SD) and minimum and maximum values (min, max) of the bond strength results of the groups.

Composite	Method	Adhesive System	n	Mean ± SD	Min	Max		Group
Vertise Flow	Bur	-	10	0,47 ± 0,49	0,03	1,53	c	1
		SE Bond	10	27,33 ± 8,99	13,52	42,61	a	2
		OptiBond FL	10	24,76 ± 14,76	5,24	47,33	ba	3
	Laser	-	10	1,60 ± 3,46	0,03	10,89	c	4
		SE Bond	10	23,36 ± 5,74	12,45	31,42	ba	5
		OptiBond FL	10	20,83 ± 6,58	11,18	30,3	ba	6
Constic	Bur	-	10	0,85 ± 1,11	0,03	3,4	c	7
		SE Bond	10	21,97 ± 6,17	13,87	33,08	ba	8
		OptiBond FL	10	19,13 ± 11,99	8,15	47,92	ba	9
	Laser	-	10	2,35 ± 2,67	0,06	6,12	c	10
		SE Bond	10	18,50 ± 4,66	12,4	26,56	ba	11
		OptiBond FL	10	15,06 ± 8,88	6,37	29,42	b	12
Fusio Liquid Dentin	Bur	-	10	0,49 ± 0,92	0,03	3,09	c	13
		SE Bond	10	27,33 ± 6,90	18,02	38,54	a	14
		OptiBond FL	10	25,82 ± 14,31	13,49	59,29	ba	15
	Laser	-	10	3,12 ± 2,86	0,03	7,38	c	16
		SE Bond	10	23,43 ± 6,37	12,84	37,7	ba	17
		OptiBond FL	10	20,82 ± 7,38	12,84	32,33	ba	18
Ultimate Flow	Bur	SE Bond	10	27,57 ± 8,67	6,78	37,39	a	19
		OptiBond FL	10	25,79 ± 4,69	18,98	35,7	ba	20
	Laser	SE Bond	10	21,55 ± 3,91	15,76	26,74	ba	21
		OptiBond FL	10	17,01 ± 5,24	13,62	27,3	ba	22

According to the binary comparison of groups that did not exhibit statistical differences between the groups with the same letter.

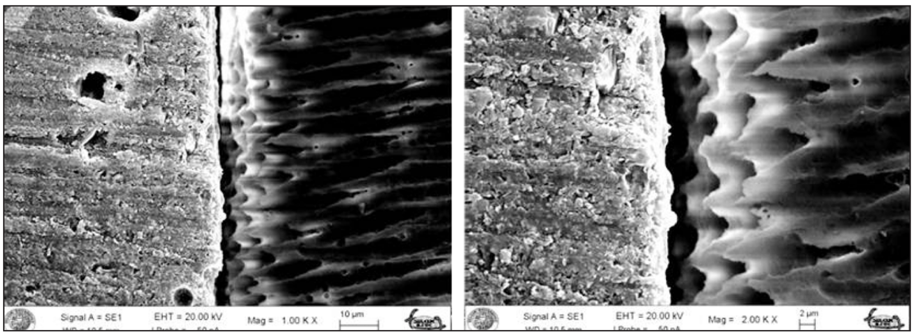

FIGURE 3: SEM images of the bur-cleaned, no adhesive system+Vertise Flow (X 1000, X 2000) (Group 1).

DISCUSSION

This study demonstrated that compared to the conventional flowable composites applied with adhesive systems, SACs exhibit lower bond strength and higher microleakage. Moreover, the bond strength of bur-cleaned dentin was greater than that of the laser-cleaned dentin. Laser etching did not adversely affect the microleakage.

The GPDM in the VF was observed in the used total-etch adhesive OFL. The groups in which VF was applied with OFL exhibited high bond strength

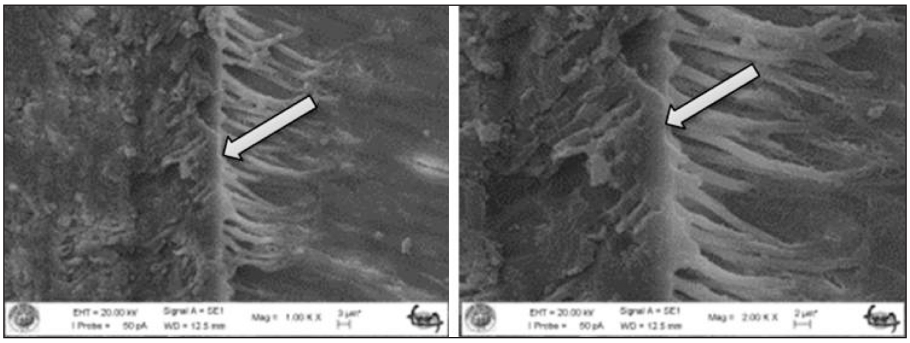

FIGURE 4: Interface SEM images of the ER-YAG laser-cleaned SE Bond + Constic group (Group 11).

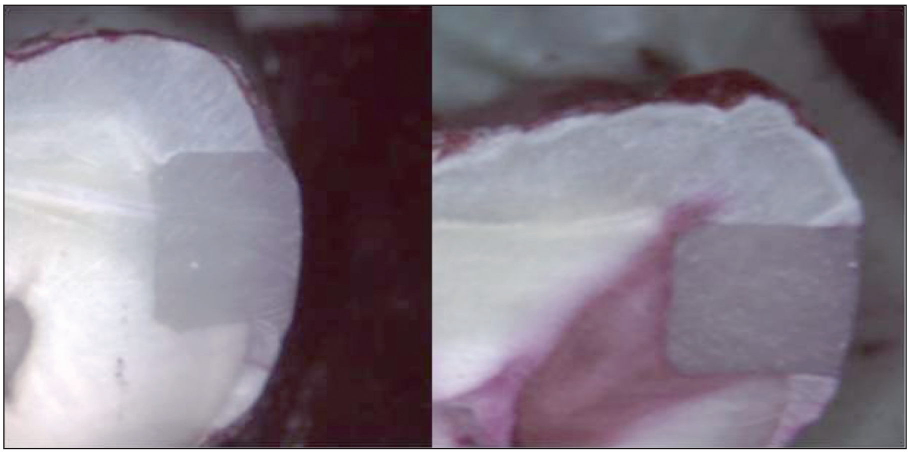

FIGURE 5: a) No etching+OFL+Ultimate Flow (Group 20); **b)** No etching + Constic (Group 7).

values. Some researchers reported that acid application leads to the increase in the shear bond strength of the SAC.[16,17] Tuloğlu et al. reported that the bond strength of an adhesive system + flowable composite group is greater than that of the self-adhesive group.[18] Fu et al. found that the bond strength of VF is greater than that of FLD.[19] Munoz-Viveros reported that the bond strength of Constic is greater than that of the other SAC.[20] Veli et al. used VF for the fixation of a lingual retainer and reported low bond strength values.[21] In this study, compared to the conventional flowable composite, SAC exhibited lower bond strength values, possibly related to the inadequate infiltration of the bonding agent into caries-affected dentin, incomplete closure of dentin tubules, exposed collagen, and degradation of resin.[22] Ceballos et al. reported that the bond strength of the total-etch adhesives is greater than that of the self-etch adhesives on caries-affected dentin.[23] The better adhesion of the total-etch adhesives on the caries-affected dentin may be related to the treatment with 32-37% phosphoric acid, which dissolves the acid-resistant layer more efficiently compared to weaker acids and improves the infiltration of the resin. The results obtained herein is in agreement with those reported in the other studies: The bond strength values for the SE bond are similar to OFL and clinically acceptable. The high strength of the SE bond possibly corresponded to the middle self-etching primer. Moreover, the monomers may be chemically bonded to the carboxyl and phosphate groups of the residual hydroxyapatite crystals.

This study revealed that the use of a laser for the removal of caries adversely affects the shear bond strength of SAC when applied with the adhesive systems, indicating that the laser adversely affects the structural integrity of dentin and reduces the effective bonding of the adhesive system. Yazıcı et al. reported that the SAC bonds better to the laser-treated surfaces, possibly related to the micro-retentive areas that are formed on the laser-treated surfaces and to the removal of the smear layer.[24] In this study, the bond strength values of SAC for the laser group were greater than those for the bur group depending on the micro-retentive areas. However, these differences were not statistically significant.

Some studies suggested that self-etch adhesives are not as effective as the total-etch adhesives, whereas other studies reported that self-etch adhesives are as efficient as the total-etch adhesives.[25-28] The aim of developing the SAC was to reduce the thickness of the hybrid layer as well as the gap between the tooth and restoration so as to minimize the microleakage.[2] Rengo et al. evaluated the effect of acid application on the microleakage before applying the self-etch adhesive and VF.[29] No differences in the enamel margins were observed; however, the acid+Vertise flow group exhibited the highest leakage in the dentin margins probably due to the wettability of the restorative material. Once the phosphoric acid is applied to the dentine, the penetration of the SAC between the dentin tubules and into the collagen fibril network may be inadequate due to the higher viscosity of the SAC than that of the adhesive system.[29] Studies reported that laser-treated surfaces are harder than conventional surfaces, and the microvoids that form on the margins increase microleakage.[25-30] In this study, differences in the self-etch and total-etch adhesive systems used in combination with the laser were not observed, suggesting that the adverse effects of the laser in terms of microleakage can be compensated by the successful bonding performance of the adhesive systems. The microleakage observed for the self-etch groups was less than that observed for the total-etch groups from the assessment of the bonding agents; however, the differences were not statistically significant. Hence, the self-etch adhesives may be preferred due to their facile use in clinics and less technical precision requirements compared with those required with the use of total-etch adhesives.

The microleakage of SAC applied without the adhesive system was significantly greater microleakage than that observed for the self-etch and total-etch groups due to the poor acidity of the SAC, leading to fewer microbubbles between the restoration and tooth. Moreover, the smear layer was not sufficiently modified, and it was less fluidic than the bonding agents, exhibiting a low degree of adaptation to the cavity.

The microleakage in the control group was significantly less than in the SAC. Studies on SAC reported different results. Ferrari and Vichi reported that the microleakage of SAC is less than that of the self-etch adhesive+flowable composite.[2] These results may be related to hygroscopic expansion and relatively low polymerization shrinkage. Hygroscopic expansion compensates for the polymerization shrinkage in the VF material; therefore, acceptable microleakage values are obtained. Vichi et al. reported low microleakage values in other SAC groups without the self-adhesive system.[2] In this study, the microleakage of SAC without the adhesive system was greater than that of the control group and the other groups in which the SAC were applied with the adhesive system, suggested that the low viscosity of SAC affects its bonding performance to the dental tissue as well as the adhesive systems. Moreover, the differences in the shape and design of the cavity should be considered.

The microleakage in the gingival margins was greater than that in the occlusal margins despite the type of adhesive bonding and composite; this difference is probably related to the fact that the thickness of the remaining enamel layer is positively affected and that the enamel layer remaining on the cervical wall is thinner and more permeable than the occlusal edges.[31,32]

A type 1 acidification pattern for the acid-etch enamel surface with enhanced dissolution in the prismatic cores compared to the periphery was observed in the SEM images. The laser-etch enamel surface exhibited cracks and a type 3 acidification image (Figure 2). However, these findings did not significantly alter the microleakage.

Adhesive failure types were observed in all of the SAC applied without the adhesive system in the bur and laser groups. Some researchers reported that cohesive failure types are indicative of high bond stength and adhesive failure types are indicative of low bond strength.[33,34] The presence of cohesive fracture types in composite groups applied with adhesive systems was compatible with higher bond strength values.

CONCLUSION

Within the limitations of this study, the application of SAC without adhesive systems does not exhibit sufficient bonding and closure. Laser etching can be employed as an alternative to acid etching. Further clinical and laboratory studies are required for the sealing and bonding performance of SAC.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

***Idea/Concept:** Bora Öztürk; **Design:** Bora Öztürk; **Control/Supervision:** Makbule Tuğba Tunçdemir; **Data Collection and/or Processing:** Makbule Tuğba Tunçdemir; **Analysis and/or Interpretation:** Makbule Tuğba Tunçdemir, Bora Öztürk; **Literature Review:** Makbule Tuğba Tunçdemir;**Writing the Article:** Makbule Tuğba Tunçdemir; **Critical Review:** Bora Öztürk, Makbule Tuğba Tunçdemir; **References and Fundings:** Makbule Tuğba Tunçdemir; **Materials:** Makbule Tuğba Tunçdemir.*

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