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ORIGINAL ARTICLE

Different pulse modes of Er:YAG laser irradiation: effects on bond strength achieved with self-etching primers

Er:YAG-Laser-Bestrahlung mit unterschiedlichen Pulsmodi Effekte auf die Haftfestigkeit beim Kleben mit selbstätzenden Primern

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Abstract

Objective The aim of this study was to compare the effects of different pulse modes of Er:YAG laser on shear bond strength (SBS) of orthodontic brackets bonded with self-etching primers (SEP) and phosphoric acid etching.

Materials and methods A total of 120 human mandibular third molars were randomly assigned to 3 groups of 40 specimens depending on the bonding procedure to be used. The groups were divided into two subgroups according to the pulse mode of the erbium-doped yttrium aluminum garnet (Er:YAG) laser irradiation as medium-short pulse (MSP) mode and quantum-square pulse (QSP) mode at 120 mJ, 10 Hz, 1.2 W. In each subgroup, the mesio- or distobuccal tooth surfaces were randomly assigned as experimental or control sides. After surface preparation with different modes of Er:YAG laser on experimental side, whole buccal tooth surfaces were treated with phosphoric acid etching or two different SEPs. Then metallic brackets were bonded with Transbond XT (3 M Unitek, Monrovia, CA, USA) or Kurasper F (Kuraray, Okayama, Japan). SBS values and the amount of adhesive remaining on the tooth after debonding were assessed. One-way analysis of variance (ANOVA) was used to evaluate the changes in mean SBS between groups resulting from laser etching, followed by post hoc test of Tukey.

Results There were statistically significant differences between the experimental and control sides of all groups ($p < 0.05$).

Conclusion Laser etching with QSP and MSP modes increases the SBS of metallic brackets and Er:YAG laser irradiation with QSP mode increases the SBS of SEPs.

Keywords Dental bonding · Orthodontic brackets · Metallic brackets · Shear bond strength · Bonding failure

Zusammenfassung

Ziel In der Studie sollten die Effekte unterschiedlicher Er:YAG("erbium-doped yttrium aluminum garnet")-Laser-Pulsmodi auf die Scherhaftfestigkeit ("shear bond strength", SBS) kieferorthopädischer Brackets untersucht werden, nach dem Kleben unter Verwendung selbstätzender Primer ("self-etching primers", SEP) und Ätzung mit Phosphorsäure.

Material und Methoden Insgesamt 120 humane dritte Molaren (Mandibula) wurden in 3 Gruppen à 40 Proben randomisiert, je nach verwendetem Klebe-Verfahren. Diese Gruppen wurden weiter unterteilt in jeweils 2 Untergruppen, je nach dem eingesetzten Pulsmodus des Er:YAGLasers: MSP(medium-short pulse)- bzw. QSP(quantum-square pulse)-Modus, 120 mJ, 10 Hz, 1,2 W. In jeder Untergruppe wurden die mesio- bzw. distobukkalen Zahnoberflächen randomisiert als experimentelle Seiten bzw. Kontrollseiten gewählt. Nach Oberflächenvorbereitung mit unterschiedlichen Er:YAG-Laser-Pulsmodi auf der experimentellen Seite wurden die gesamten bukkalen Zahnoberflächen mit Phosphorsäure oder mit 2 unterschiedlichen SEPs behandelt. Anschließend wurden Metall-Brackets mit Transbond XT (3 M Unitek, Monrovia, CA, USA) oder

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Kurasper F (Kuraray, Okayama, Japan) aufgebracht. Bestimmt wurden SBS-Werte und die Adhäsivmenge, die nach Debonding auf dem Zahn verblieben war. Zur Evaluierung der durch Laserätzung entstandenen SBS-Veränderungen zwischen den Gruppen dienten der Ein-Wege-ANOVA("analysis of variance")-Test und der anschließend durgeführte Post-hoc-Text nach Tukey.

Ergebnisse Zwischen den experimentellen Seiten und den Kontrollseiten aller Gruppen bestanden statistisch signifikante Unterschiede ($p < 0{,}05$).

Schlussfolgerung Eine Laserätzung in den Modi QSP und MSP verstärkt die SBS bei Metall-Brackets, und eine Er:YAG-Laser-Bestrahlung im QSP-Modus verstärkt die SBS bei Verwendung von SEPs.

Schlüsselwörter Bonding · Kieferorthopädische brackets · Metall-brackets · Scherhaftfestigkeit · Bonding-Insuffizienz

Introduction

Direct bonding of orthodontic brackets to the teeth is one of the most important advancements in modern dentistry. The shear bond strength (SBS) of orthodontic brackets should be high enough to prevent bonding failure and should offer adequate resistance against chewing forces and stresses from archwires [4].

The SBS between the bracket and enamel surface depends on three factors: the design of the bracket base, the adhesive material or bonding resin itself, and the preparation of the tooth surface [35]. Today, acid etching is the most common method of preparing enamel for bonding orthodontic brackets. The irregular enamel surface created by dissolving hydroxyapatite crystals permits penetration of the fluid adhesive components and this penetration provides micromechanical retention [5]. Although this method results in high bond strength, its great disadvantage is the potential for caries formation. Acid etching removes and demineralizes the most superficial layer of enamel and makes the teeth more susceptible to long-term acid attacks [24]. In addition, the acid etch bonding technique involves many steps [27]. To simplify the bonding procedure, alternative methods such as application of self-etching primers (SEP) or laser irradiation have been published [7, 33].

SEPs combine the conditioning and priming agents in a single acidic primer solution [28] and have the advantages of faster and simpler application. In addition to saving time, fewer steps in the bonding process lead to fewer procedural errors, such as contamination with saliva and water [27]. Although self-etching primer was conservative on enamel, with short resin tags, it was reported to produce SBSs that were clinically acceptable, with lower rates of bond failure [22, 32].

Laser irradiation enables localized melting and ablation of the enamel surface. It affects etching through a process of continuous vaporization and micro-explosions, which occur due to the vaporization of the water trapped within the hydroxyapatite matrix [37]. Laser etching of dental hard tissue changes the calcium to phosphate ratio, and forms a more stable and less acid-soluble compound, therefore, decreases the susceptibility to acid attack and caries [36].

For many years, the erbium-doped yttrium aluminum garnet (Er:YAG) laser has been applied in dentistry for carious lesion removal, cavity preparation, endodontic procedures, and surface conditioning [2, 12, 24]. The Er:YAG laser can effectively alter enamel and dentin surfaces because of its wavelength of 2.94 μm, which matches the absorption peak of water (wavelength 3.0 μm) and hydroxy (OH^-) groups in hydroxyapatite (wavelength 2.8 μm) [2, 3, 9]. Tanji et al. [33] reported that the Er:YAG laser interacts well with dental hard tissue and produced higher SBS in comparison to acid etching. By contrast, Hossain et al. [20] showed that the mean SBS was lower after laser etching than after acid etching.

Quantum-square pulse (QSP; LightWalker, Fotona, Ljubljana, Slovenia) mode has been recently introduced in Er:YAG laser technology. QSP mode is a patented technological advancement, optimized to avoid scattering of laser light in the ablated particle cloud during hard-tissue dental treatments. By avoiding the hard-tissue debris cloud, the laser ablates more efficiently and with greater precision because the laser beam is not affected by the debris. By being able to ablate more efficiently, the edges of individual craters are virtually straight, which provides higher levels of precision and preservation in hard-tissue treatments [21].

Numerous studies have evaluated the effects of SEPs on the SBSs of brackets [7, 8] or compared the different enamel conditioning techniques for orthodontic bonding [34]. The aim of this study was to evaluate the effects of different pulse modes of Er:YAG laser on bonding orthodontic brackets to enamel with SEP in comparison to phosphoric acid etching in terms of SBS and adhesive remnant index (ARI).

The null hypothesis tested was that laser irradiation has no effect on SBS of SEPs.

Materials and methods

A power analysis established by G*Power Version 3.1.3 (Franz Faul, Universität Kiel, Germany) software, based on an equal ratio among groups, and a sample size of 120 teeth

would give more than 80 % (actual power = 0.8387827) power to detect significant differences with 0.35 effect size and at the $\alpha = 0.05$ significance level (critical $F = 2.2939112$; non-centrality parameter $\lambda = 14.7000000$).

Specimen preparation

A total of 120 human mandibular third molars with intact buccal enamel that had been extracted within 2 months of the start of the study were used. The teeth were stored at room temperature in distilled water containing 0.2 % thymol to inhibit bacterial growth until use. The teeth were cleaned and polished with a fluoride-free pumice slurry and rubber cups for 10 s and thoroughly washed and dried by exposure to oil-free air stream. Under transillumination examination, the teeth showed healthy enamel on the buccal surface, without attrition, fracture, restorations, congenital anomalies or structural defects. Teeth with caries, restorations, and surface abnormalities were excluded from the study.

Each tooth was vertically mounted in cold-curing acrylic (Orthocryl; Dentaurum, Ispringen, Germany) cylinder. The long axis of each tooth was aligned vertically to the base of the cylinder. The teeth were randomly assigned to 3 groups of 40 specimens each, by using a random numbers table. The groups were divided into two subgroups according to the pulse settings of the laser as QSP and MSP mode groups. In each subgroup, the mesio- or distobuccal tooth surfaces were randomly assigned as experimental or control sides.

Bonding procedure

The bonding procedures of the groups were as follows (Fig. 1).

Group 1

The mesiobuccal or distobuccal surface of the teeth, as experimental side, was etched with Er:YAG laser (2.94 µm wavelength; LightWalker, Fotona, Slovenia) in MSP (100 µs) or QSP mode with settings of 120 mJ, 10 Hz, 1.20 W, water [50 ml/min] for 20 s. The laser was applied on enamel with contact mode and water spray, and then the teeth were dried with an oil-free air spray until the chalky frosty appearance of enamel was visible. Then phosphoric acid (37 %) gel (Gel Etch; 3 M Unitek, Monrovia, CA, USA) was used to etch both the experimental and the control sides for 15 s with applicator sponges. The teeth were then rinsed with water dispensed from a 3-in-1 syringe for 15 s and dried with an oil- and moisture-free source for 10 s.

Group 2

The mesiobuccal or distobuccal surface of the teeth was etched with Er:YAG laser as in group 1. Then whole buccal tooth surfaces were conditioned with a SEP (Transbond Plus; 3 M Unitek), which was rubbed onto the enamel by gentle pressure for 5 s with the applicator sponge supplied with the system. Then, a gentle airburst was applied to dry the primer into a thin film.

Group 3

The mesiobuccal or distobuccal surface of the teeth was etched with an Er:YAG laser device as in group 1. Then Clearfil S^3 Bond Plus self-etching primer (Kuraray, Okayama, Japan) was used to etch both the experimental and the control sides according to the manufacturer's instruction. The primer was applied onto the enamel for 20 s, dried with mild pressure air flow for 1–2 s and light cured for 5 s with a light-emitting diode (LED) curing light (Elipar Free Light 2, 3 M ESPE Dental Products, St. Paul, MN, USA).

In all groups, the area to be bonded was scanned for 20 s with horizontal movements perpendicular to the enamel at a distance of 1 mm with a contact-type handpiece. The laser irradiation of enamel was performed manually, and no special setup was used. After laser etching in all groups, the teeth were again washed and dried with an oil-free air source.

After the enamel-conditioning procedures of all groups, the stainless steel premolar brackets Equilibrium®

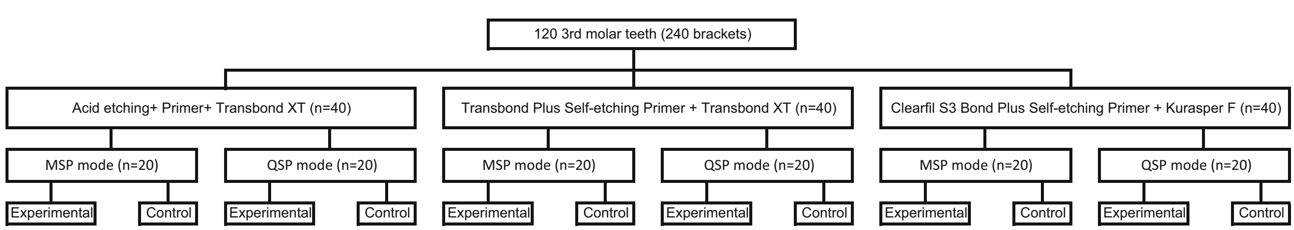

Fig. 1 Diagrammatic representation of study groups
Abb. 1 Darstellung der Studienkollektive

(Dentaurum, Ispringen, Germany) without a hook were bonded onto the mesio- and distobucal surfaces of the anatomic crowns at the level of their middle third. In group 1, Transbond XT primer (3 M Unitek) was applied as a thin, uniform coat to the etched enamel surfaces and cured for 10 s using LED. Transbond XT (3 M Unitek) adhesive resin was placed onto the bracket surfaces. The bracket was placed onto the tooth surface, adjusted to its final position, and pressed firmly into place. Excessive adhesive was removed from the periphery of the bracket base to ensure uniform bonding areas. Light curing was performed for a total of 40 s by irradiating the mesial, distal, occlusal, and gingival aspects of the tooth for 10 s each. In group 2, Transbond XT (3 M Unitek) adhesive resin was used in the same manner as in group 1. In group 3, Kurasper F (Kuraray) was applied. The brackets were pressed firmly onto the tooth surface, and excessive adhesive was removed using a sharp scaler. The emitting tip of the LED was held at 45 ° to the tooth surface and as close to the bracket as possible. The exposure was performed from both the mesial and distal sides for 20 s, respectively.

Test procedure

After bracket bonding, all specimens were stored in distilled water at 37 °C for 24 h and later subjected to thermocycling 5000 times in distilled water between 5 and 55 °C, with a dwell time in each bath of 30 s and a transfer time of 15 s.

The SBS test was performed using a chisel edge, mounted on the crosshead of a universal testing machine (Elista TSTM 02500, Elista, Istanbul, Turkey). The specimens were subjected to stress at the bracket and enamel interface from a vertical direction, with a crosshead speed of 0.5 mm/min. The maximum shear force necessary to debond each bracket was recorded in Newton and then converted into megapascal by dividing the value by the surface area of the bracket base. The average base surface areas of the brackets were calculated as 12.2 mm^2 by using a digital caliper (Absolute Digimatic, Mitutoyo Corp, Kawasaki, Japan).

Adhesive remnant index

After debonding, the enamel surface of either tooth side was examined by the same operator (M.A.) under an optical microscope (CX41, Olympus, Tokyo, Japan) at 40× magnification to determine the amount of residual adhesive remaining on each tooth. The amount of adhesive left on the enamel surface was scored for each tooth using the modified adhesive remnant index (ARI) [26]: (1) all adhesive remaining on the enamel surface; (2) >90 % of the adhesive remaining on the enamel surface; (3) between 10 and 90 % of the adhesive remaining on the enamel surface; (4) less than 10 % of the adhesive remaining on the enamel surface; and (5) no adhesive remaining on the enamel surface.

Statistical analysis

The data were analyzed with Statistical Package for Social Sciences software (SPSS for Windows, version 11.0 SPSS Inc., Chicago, IL, USA). Descriptive statistics, which included the mean, standard deviation, maximum and minimum, were evaluated for each group. Normal distribution of the data was verified with the Kolmogorov–Smirnov test. The data were found to be normally distributed, and there was homogeneity of variance among the groups. Thus, the statistical evaluation was performed using parametric tests.

Paired sample *t* test evaluated the control and experimental side differences in all subgroups and two-way analysis of variance (ANOVA) was used to determine composite–laser interactions. One-way analysis of variance (ANOVA) evaluated the increases in mean SBS between groups resulting from laser etching, followed by post hoc test of Tukey. The *G* test was used to determine significant differences in the ARI scores between the groups. Significance for all statistical tests was predetermined at $p < 0.05$.

Results

Descriptive statistics including mean, standard deviation, minimum and maximum value for SBS in MPa are summarized in Table 1. There were significant differences between experimental and control sides of all groups ($p < 0.05$). The subgroup subjected to QSP mode laser and phosphoric acid etching produced the highest mean SBS values (23.22 ± 2.15 MPa) and the subgroup subjected to QSP mode laser and Transbond SEP yielded the lowest mean SBS values (8.76 ± 1.22 MPa). Two-way ANOVA showed no significant interaction in debonding force between laser modes and composites used. On the other hand, significant differences were found in group interaction for debonding force ($p < 0.05$; Table 2). Increases in SBS that resulted from laser etching are shown in Table 3. The highest increase was found with SEPs when used with QSP mode. The lowest increase was shown in the subgroup subjected to MSP mode laser and phosphoric acid etching.

The frequency distribution of ARI scores are shown in Table 4. According to *G*-test, there was significant difference among all subgroups. ($p < 0.05$) With regard to ARI scores, the least amount of adhesive remnant was found in the group subjected to Transbond SEP and QSP mode

Tab. 1 Descriptive statistics and comparison of shear bond strengths
Tab. 1 Deskriptive statistische Angaben und Vergleich der Scherhaftfestigkeiten

Groups	Mode	Side	*N*	Mean	SD	Min	Max	*P*
Group 1	MSP	Control	20	17.19	1.84	13.94	20.84	0.007
		Experimental	20	23.02	2.36	18.56	27.81	
Group 2		Control	20	8.86	1.47	5.33	12.48	0.000
		Experimental	20	13.82	1.68	8.90	16.83	
Group 3		Control	20	10.54	1.26	7.08	15.62	0.005
		Experimental	20	16.21	1.92	12.38	20.69	
Group 1	QSP	Control	20	14.68	2.04	10.37	18.8	0.000
		Experimental	20	23.22	2.15	17.96	28.12	
Group 2		Control	20	8.76	1.22	5.04	12.38	0.000
		Experimental	20	17.64	2.08	12.66	21.42	
Group 3		Control	20	9.46	1.81	4.95	13.58	0.000
		Experimental	20	18.68	2.26	13.07	22.47	

N sample size, *SD* standard deviation, *Min* minimum values, *Max* maximum values, *Group 1* Phosphoric acid etching, *Group 2*, Transbond Plus SEP, *Group 3* Clearfil S^3 Bond Plus

Tab. 2 Two-way analysis of variance for debonding force
Tab. 2 Zwei-Wege-Varianzanalyse der Kraft für das Debonding

Source of variation	Sum of squares	*df*	Mean squares	*F*	*p*
Composites	614.282	2	307.141	4.147	0.024*
Laser	364.623	1	364.623	12.419	0.006**
Between groups	41.927	2	20.963	0.098	0.906

* $p < 0.05$, ** $p < 0.01$

Tab. 3 Comparison of increases in SBS, resulting from laser etching
Tab. 3 Vergleich von Erhöhungen der SBS, die sich aus Laser-Etching ergeben

Groups	Mode	N	Mean (%)	SD	Min	Max	TUKEY
Group I	MSP	20	33.5	2.6	30.4	36.5	A
Group II		20	56.4	3.8	51.0	60.8	B
Group III		20	54.8	2.5	50.2	57.6	B
Group I	QSP	20	58.3	3.4	52.5	62.0	B
Group II		20	101.2	3.6	95.4	106.8	C
Group III		20	97.4	2.9	92.7	102.1	C

* Groups with different letters are significantly different from each other

laser. Comparable scores were found in groups 2 and 3 with MSP mode and group 3 with QSP mode. Er:YAG laser application with either MSP or QSP mode did not decrease the amount of adhesive remnant.

Discussion

The durability of the bond between bracket/bonding resin and teeth in clinical use is important. The use of the SEPs in adhesive systems for enamel conditioning has become popular among orthodontists because it produces a gentler etch pattern compared to other methods [31] and the combination of the etchant and primer in this method simplifies the clinical procedure. Previous studies involved the use of laser irradiation on enamel surface and it was reported that the laser irradiation induced localized morphologic roughness [10]. In this study, we compared SBSs, enamel surface characteristics, and ARI scores of phosphoric acid etching and SEP systems following different modes of Er:YAG laser irradiation.

The technique sensitivity of the experiments is an important factor. Storage and prism orientation are known to have caused low SBS values in the past [6], which is why the authors took precautions to eliminate these sources of error. To eliminate the configuration difference of enamel prisms, the mesiobuccal or distobuccal surface of the same molar tooth was evaluated. In addition, for more standardized procedures, all teeth were kept in water for substrate storage.

Under laboratory conditions, loading forces to brackets are different from clinical conditions. In clinical conditions, brackets are influenced by a combination of tensile, shear and rotational forces. In addition, there are different kinds of stresses (e.g., thermal changes, humidity and microbial plaque) in the oral cavity that make it difficult to simulate the conditions in the laboratory [17]. To standardize the direction of the debonding force, each specimen was mounted in an acrylic block. Fox et al. [16] cautioned that a pure shear test may not be ensured but

Tab. 4 The adhesive remnant index (ARI) scores
Tab. 4 Die Klebstoff Rest-Index (ARI) Werte

Groups	Mode	Side	N	1	2	3	4	5	*p*
Group I	MSP	Control	20	0	3 (15%)	5 (25%)	8 (40%)	4 (20%)	*
		Experimental	20	5 (25%)	6 (30%)	7 (35%)	2 (10%)	0	
Group II		Control	20	0	0	2 (10%)	9 (45%)	9 (45%)	*
		Experimental	20	0	2 (10%)	8 (40%)	6 (30%)	4 (20%)	
Group III		Control	20	0	0	2 (10%)	10 (50%)	8 (40%)	*
		Experimental	20	0	4 (20%)	6 (30%)	6 (30%)	4 (20%)	
Group I	QSP	Control	20	0	3 (15%)	3 (15%)	10(50%)	4 (20%)	**
		Experimental	20	6 (30%)	6 (30%)	8 (40%)	0	0	
Group II		Control	20	0	0	2 (10%)	8 (40%)	10 (50%)	*
		Experimental	20	0	4 (20%)	8 (40%)	4 (20%)	4 (20%)	
Group III		Control	20	0	0	4 (20%)	8 (40%)	8 (40%)	**
		Experimental	20	0	6 (30%)	8 (40%)	4 (20%)	2 (10%)	

* $p < 0.05$, ** $p < 0.01$

factors such as the curvature of the enamel surface may influence the results.

There are some contradicting findings about the use of lasers for enamel etching. Although some researchers [36, 37] agree that laser etching is not suitable for etching enamel, Bishara et al. [7] reported that laser irradiation could be used to etch tooth enamel. The contrary findings among studies were contributed to the different outputs and experimental designs of these studies [27]. However, it seems reasonable that with suitable laser parameters, bond strengths of laser-etched surfaces should be comparable to those prepared by conventional acid etching [1].

Sağır et al. [30] evaluated the effects of laser pulse duration on SBS and compared the SBS and ARI scores of bonding after QSP or MSP mode laser irradiation and phosphoric acid etching of enamel surfaces. They concluded that Er:YAG laser etching with MSP and QSP modes presents a successful alternative to acid etching by providing higher or comparable SBS values. In the present study, QSP mode that improves the efficiency of Er:YAG lasers in a high-finesse treatment regime was used.

Some previous studies [2, 23] did not use water cooling during Er:YAG laser treatment, while in the present study, water cooling was employed to closely simulate the clinical conditions used for etching the enamel surface. A previous study indicated that Er:YAG laser is effective for increasing the caries resistance either used with or without water cooling, but the degree of caries prevention was considerably higher without water mist than with water mist [19]. It is apparent that the application of Er:YAG laser without water cooling may increase the enamel surface temperature to a degree higher than achieved with water application. Therefore, the difference between the results of this study and to those of Liu et al. [23] may be related to the different surface temperature of the enamel that was achieved with different laser parameters.

Finnema et al. [15] performed a systematic review and meta-analysis to evaluate in vitro orthodontic bond strength testing. They reported that bond strength values reported in the studies ranged from 3.5 to 27.8 MPa. They showed that the clinical implications of in vitro bond strength values are generally based on the recommendation in a review article by Reynolds [29] and an in vitro bond strength of 6–8 MPa was defined as ''clinically acceptable''. Finally, they noted that because it has never actually been tested whether 6–8 MPa is a sufficient in vitro bond strength for clinical use, the use of this reference value had been criticized before [13]. Despite the fact that this reference value has been criticized, we used it as ''clinically acceptable'' to compare our results with previous studies.

In the present study, all tested groups showed clinically acceptable bond strengths. The subgroup subjected to QSP mode laser and phosphoric acid etching produced the highest mean SBS values (23.22 ± 2.15 MPa) and the subgroup subjected to QSP mode laser and Transbond SEP yielded the lowest mean SBS values (8.76 ± 1.22 MPa). Despite having the lowest SBS value, acceptable levels of bond strength were achieved in both SEP groups. Consistent with our findings, the SEP systems tested by Scougall Vilchis et al. [31] afforded SBS levels adequate for orthodontic bonding. Similarly, Ozer et al. [27] and Bishara et al. [7] reported that SEPs provided SBS values adequate for orthodontic bonding.

The results of this study revealed that the highest increase was found in SEPs when used with QSP mode. The lowest increase was shown in the group subjected to MSP mode laser and phosphoric acid etching. This shows that Er:YAG laser irradiation with QSP mode increases the SBS of SEPs.

A previous study reported that the amount of remnant adhesive tends to increase at high SBS [18]. With regard to ARI scores, the least amount of adhesive remnant was found in the group subjected to Transbond SEP and QSP mode laser. This is clinically advantageous because less adhesive would have to be removed from the tooth surface after debonding [11]. On the other hand, this could be considered as a disadvantage. Although it takes less time to remove residual adhesive on the enamel, this mode of failure may lead to enamel cracks or fracture during debonding and increases the risk of enamel loss especially with debonding of ceramic brackets [28]. It has been reported that the amount of adhesive remaining tends to be less when SEPs are used [14, 15]. Although we tried to increase the SBS of SEPs by laser irradiation, our finding is compatible with the previous studies. It should be noted that the ARI values are subjective; nevertheless, the index was useful in determining the percentage of bond failure sites by an ordinal ranking of the amount of resin remaining on the tooth after debond. O'Brien et al. [25] determined that the ARI score was dependent upon many factors, including the bracket–base design and adhesive, and not simply the bond strength at the interface.

Conclusion

Within the limitation of this in vitro study, the SBS of brackets to laser-etched surfaces with different two power modes showed higher bond strengths. In addition, Er:YAG laser irradiation with QSP mode increased the SBS of SEPs.

Compliance with ethical standards

Conflict of interest M. Akin, I. Veli, E.A. Erdur, S. Aksakalli, and Tancan Uysal state that there are no conflicts of interest. The accompanying manuscript does not include studies on humans or animals.

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