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Laboratory Research

Effects of Er,Cr:YSGG Laser Pulse Frequency on Microtensile Bond Strength to Enamel

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Clinical Relevance

This study revealed that bonding to Er,Cr:YSGG laser–irradiated enamel depends on pulse frequency. Six watt–50 Hz parameters might be safe options for enamel ablation. However, 3 W–50 Hz parameters might improve resin-bond strength significantly when laser conditioning.

SUMMARY

Literature regarding the influence of Er, Cr:YSGG laser pulse frequency with different output power levels on adhesion properties of adhesive resin to lased enamel is limited. Therefore, the aim of the present study was to evaluate the effects of laser pulse frequency (20, 35, and 50 Hz) at two different output power settings (3 and 6 W) of Er,Cr:YSGG on the microtensile bond strength (µTBS) of adhesive resin to enamel. Crowns of 35 intact bovine incisors were embedded into self-cure acrylic resin individually, and then flat enamel surfaces were prepared with 600-grit silicon carbide papers under water cooling. Teeth were divided randomly into seven groups. Enamel surfaces were irradiated with Er, Cr:YSGG laser operated at one of six output power–pulse frequency combinations (6 W20 Hz, 6 W–35 Hz, 6 W–50 Hz, 3 W–20 Hz, 3 W–35 Hz, and 3 W–50 Hz) in groups 1-6, respectively. Bur-treated surfaces served as a control in group 7. After surface treatments and bonding procedures, composite build-ups were done in three layers up to a height of 4 mm. Next, all bonded teeth were sectioned into the resin-enamel sticks to be tested in a µTBS testing machine. The µTBS data were analyzed with univariate analysis of variance under a general linear model with the factor 'tooth' added as a random effect to the design. Resin-enamel interfaces were evaluated with scanning electron microscopy (SEM). The µTBS to laser-irradiated enamel in group 1 (6 W–20 Hz) was significantly lower than those of bur-treated enamel ($p<0.05$). However, group 6 (3 W–50 Hz) showed significantly higher µTBS values than did bur-treated teeth ($p<0.05$). SEM evaluation revealed enormous morphological alterations of laser-irradiated specimens, such as extensive vertical and horizontal microcracks and gaps, with the exception of group 6. The bonding effectiveness of adhesive resin to laser-irradiated enamel was affected by the pulse frequen-

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cy of the Er,Cr:YSGG laser. Although the parameters recommended by the manufacturer lowered μTBS, increasing the pulse rate may maintain optimum μTBS.

INTRODUCTION

The Er,Cr:YSGG laser device has been considered one of the most efficient and safe dental hard tissue laser systems for dental hard tissue procedures, including cavity preparation[1] and laser conditioning.[2] The Er,Cr:YSGG laser has the noteworthy ability to remove dental hard tissues, in addition to providing minimum side effects to the pulp and surrounding tissues.[3,4] Additionally, in comparison with conventional mechanical drilling systems, Er,Cr:YSGG laser did not significantly alter the composition and microhardness of dentin tissue.[5] In addition, if Er,Cr:YSGG laser preparation was combined with self-etching adhesive, there was no difference in the composite fillings' microleakage among the laser and conventional bur preparations.[6] Therefore, the Er,Cr:YSGG laser device has been accepted as a safe and effective hard tissue laser.

The extensive interest and usage of erbium lasers in operative dentistry have caused an increase in the numbers of studies covering the effects of erbium lasers on resin bonding to dental hard tissues.[7] Although the effects of the Er,Cr:YSGG laser on the effectiveness of resin adhesives applied to enamel and dentin were investigated primarily, the effects of Er,Cr:YSGG laser parameters were assessed in a much more limited fashion. Currently, the bonding to Er,Cr:YSGG laser–irradiated enamel remains a controversial issue. A discrepancy exists among the findings of previous studies[8-11] on the influence of Er,Cr:YSGG laser irradiation on resin-enamel bonding. Lin and others[11] reported that Er,Cr:YSGG laser irradiation with a 5 W–20 Hz parameter showed no adverse effect on the resin-enamel bond strength of the etch-and-rinse adhesive tested. Despite that finding, several researchers[10,12] have stated that Er,Cr:YSGG laser irradiation with 5.5 W–20 Hz parameters significantly reduced resin bond strength to enamel. Cardoso and others[8] also reported that Er,Cr:YSGG laser irradiation with 6 W–20 Hz parameters resulted in a significant reduction in the bond strength of etch-and-rinse adhesive to enamel. These controversial findings may lead to open-ended discussions regarding the benefits of laser usage in conjunction with current adhesive systems.

One of the unfavorable features of the dental hard tissue lasers, including Er,Cr:YSGG and Er:YAG lasers, is the potential for thermomechanical damage to the surface and subsurface of enamel and dentin during laser irradiation, yielding significantly reduced bond strength.[8,12] Therefore, assessment of the precise laser parameters with which to decrease peripheral thermomechanical damage to a minimum is particularly crucial for long-lasting resin composite restorations. However, it has been suggested[13] that by correctly matching laser parameters (ie, output power and pulse frequency) these thermomechanical side effects can be minimized.

The Er,Cr:YSGG laser device used in the present study is able to emit laser irradiation at different pulse frequencies up to 50 Hz. To the authors' best knowledge, the most common Er,Cr:YSGG laser pulse frequency is 20 Hz, which is recommended by the Er,Cr:YSGG laser device manufacturer in the studies covering the effects of laser irradiation on resin-enamel bond strength. However, this pulse frequency commonly reduced bond strength to enamel.[8,10,12] In addition, a study on the optimization of output power and pulse frequency combinations in terms of bond strength to enamel does not exist in the literature. Thus, the aim of the present study was to evaluate the influence of Er,Cr:YSGG laser irradiation with different pulse frequency (20, 35, and 50 Hz) and output power (6 and 3 W) settings on microtensile bond strength (μTBS) to enamel. Subsurface damage of enamel due to laser irradiation was also assessed by scanning electron microscopy (SEM). The null hypothesis tested was that there is no difference in μTBS to enamel regardless of the different surface treatments used.

METHODS AND MATERIALS

Specimen Preparation

Thirty-five permanent bovine incisors were used in this study. The teeth were cleaned to remove any tissue remnants. All teeth were embedded in self-curing acrylic resin with labial surfaces parallel to the floor using double-faced adhesive tape. Labial surfaces of teeth were ground using 320-grit abrasive paper. Then surfaces were further ground with 600-grit abrasive paper for 60 seconds to obtain standardized smear layers. An area of 1 cm^2 on the flattened surface was demarcated by means of a marker pen to determine an exact area to be irradiated. Then teeth were divided into seven groups (n=5) randomly according to the study design (Table 1), as follows:

- Group 1 (G1): Enamel irradiated using Er,Cr:YSGG laser with 6 W–20 Hz power–pulse

Table 1: *Study Design of the Present Study*

Groups (G)	Output Power, W	Pulse Frequency, Hz	Energy per Pulse, mJ/pulse
G1 (Er,Cr:YSGG laser+acid-etching)	6	20	300
G2 (Er,Cr:YSGG laser+acid-etching)	6	35	200
G3 (Er,Cr:YSGG laser+acid-etching)	6	50	120
G4 (Er,Cr:YSGG laser+acid-etching)	3	20	150
G5 (Er,Cr:YSGG laser+acid-etching)	3	30	100
G6 (Er,Cr:YSGG laser+acid-etching)	3	50	60
G7 (Bur+acid-etching)	—	—	—

frequency combination (300 mJ per pulse, 90 J/cm^2 of energy density).

- Group 2 (G2): Enamel irradiated using Er, Cr:YSGG laser with 6 W–35 Hz power–pulse frequency combination (171 mJ per pulse, 90 J/cm^2 of energy density).
- Group 3 (G3): Enamel irradiated using Er, Cr:YSGG laser with 6 W–50 Hz power–pulse frequency combination (120 mJ per pulse, 90 J/cm^2 of energy density).
- Group 4 (G4): Enamel irradiated using Er, Cr:YSGG laser with 3 W–20 Hz power–pulse frequency combination (150 mJ per pulse, 45 J/cm^2 of energy density).
- Group 5 (G5): Enamel irradiated using Er, Cr:YSGG laser with 3 W–35 Hz power–pulse frequency combination (86 mJ per pulse, 45 J/cm^2 of energy density).
- Group 6 (G6): Enamel irradiated using Er, Cr:YSGG laser with 3 W–50 Hz power–pulse frequency combination (60 mJ per pulse, 45 J/cm^2 of energy density).
- Group 7 (G7; control group): Enamel treated with coarse diamond bur (Microdont ISO 806.314.001.524.012, Sao Paulo, Brazil) using high-speed air turbine (W&H Synea TA98, Bürmoos, Austria).

Laser Treatments

The Er,Cr:YSGG laser device (Waterlase MD, Biolase Technology, San Clemente, CA, USA) was used for enamel specimens to be irradiated according to the following parameters: wavelength of 2.78 µm; pulse duration of 140 µs; spot size of 600 µm; air pressure setting of 90%; water pressure setting of 65%; irradiation time was 15 seconds; irradiation area of 1 cm^2; power of 3-6 W; and pulse frequency of 20, 35, or 50 Hz. Demarcated areas on teeth were irradiated at a 45° angle to the flattened surface in noncontact mode by hand.[14] A bur with a marker was adapted to the hand piece using a custom-made acrylic device to fix the working distance at 1 mm (Figure 1). All laser groups were treated in this manner (G1-G6). In the bur-treated control group (G7), coarse diamond bur using a high-speed air turbine was used by hand with almost no pressure for 15 seconds across the marked area.

Adhesive Procedures

Following acid-etching of all enamel surfaces in each group using 37% phosphoric acid gel for 20 seconds (All Etch, Bisco, Schaumburg, IL, USA), two consecutive coats of resin adhesive (Single Bond 2, 3M ESPE, St Paul, MN, USA) were applied to dried enamel surfaces with a cotton applicator and air-dried gently for two to five seconds. Light was activated for 20 seconds using a halogen lamp with an output intensity of 400 mW/cm^2 (Ivoclar, Astralis 3 Ivoclar Vivadent AG, Schaan, Liechtenstein). After adhesive procedures, resin composite (Valux Plus, 3M ESPE) build-ups in three layers up to a height of 4 mm were done on the surfaces. Each increment layer was cured for 40 seconds using a halogen lamp (Ivoclar, Astralis 3).

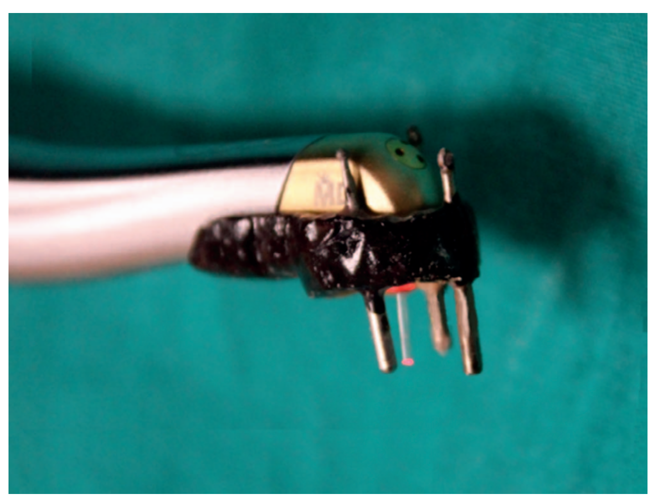

Figure 1. *A simple custom-made acrylic apparatus mounted on a laser hand piece to maintain working distance from enamel.*

Table 2: *Microtensile Bond Strength Means (μTBS; MPa), Standard Deviations (n=20), Percentage of Pretest Failures (%), and Failure Patterns (FPs) of μTBS Samples, as Analyzed Through Stereomicroscopy.* [a]

Groups (G)	μTBS (%)	FP
G1 (6 W–20 Hz)	12.99 ± 9.25 A (48)	M > C > A
G2 (6 W–35 Hz)	21.17 ± 5.39 B (30)	M > C = A
G3 (6 W–50 Hz)	27.16 ± 8.64 C (12.5)	M > C = A
G4 (3 W–20 Hz)	25.63 ± 11.34 BC (13.7)	A > M > C
G5 (3 W–35 Hz)	22.28 ± 7.9 BC (11.3)	M > A > C
G6 (3 W–50 Hz)	36.22 ± 5.98 D (17.5)	C > A > M
G7 (bur)	26.60 ± 8.50 C (11.3)	C > A > M

Abbreviations: A, adhesive failure; C, cohesive failure in enamel or composite; M, mix failure.
[a] *Different superscripts indicate significant differences (p<0.05).*

Microtensile Bond Test

All bonded teeth were stored in distilled water at 37°C for 24 hours before μTBS tests were conducted. Resin-enamel sticks with approximately 0.9 × 0.9 mm^2 dimensions were obtained using a diamond saw under copious water (Micracut 125, Metkon, Bursa, Turkey) running at 300 rpm. Four of the obtained resin-enamel sticks were selected from the center of each bonded tooth to test randomly, yielding 20 sticks for each group. Next, the specimens were fixed to jig with cyanoacrylate glue (Pattex, Henkel, Dusseldorf, Germany) and loaded in tension at a crosshead speed of 1 mm/min using a Bisco microtensile testing machine (Bisco Inc, Schaumburg, IL, USA). Exact dimensions of the interface area were measured with a digital calliper (Mitutoyo, Tokyo, Japan). The μTBS was derived by dividing the load at the time of fracture by the bond area (mm^2). Occurrence of failure prior to the actual testing was not included in the analysis, but numbers of such pretest failures were noted. The mode of failure was determined by stereomicroscope under 40× magnification (Meade Bresser Biolux, Meade Bresser, Rhede, Germany) and was recorded as "adhesive" or "cohesive," neither enamel nor resin, and "mix" failures included more than one of the enamel and resin parts.

Statistical Analysis

The μTBS data were statistically analyzed with univariate analysis of variance in a general linear model with the factor 'tooth' added as a random effect to the design, in order to minimize the effect of using different teeth.[15] Multiple comparisons were made with a least significant difference test. Statistical analysis was performed with the Statistical Package for the Social Sciences (SPSS), version 13 software for Windows (SPSS Inc, Chicago, IL, USA). All tests were done at the 0.05 level of significance.

SEM Analysis Resin-lased Enamel Interfaces

In order to evaluate interfaces between resin and lased enamel, one stick from the center of each bonded tooth, a total of five sticks for each group, was embedded into self-curing acrylic resin using a two-sided adhesive band. After that, surfaces of sticks were polished using 1000-grit, 1500-grit, and 2000-grit silicon carbide abrasive papers consecutively. Polished surfaces were then etched by 37% phosphoric acid for one minute. All specimens were stored at room temperature prior to SEM evaluation. Specimens were fixed on the metal stubs using two-sided carbon bands and were covered by gold. Morphological evidence regarding large vertical and horizontal resin extensions indicating subsurface cracks, regular resin tag formation, resin-enamel interface completeness, cracks among enamel rods, and vitrification signs were evaluated. SEM evaluation was conducted using a JEOL 6400 SEM (JEOL Ltd, Tokyo, Japan) at 10 kV and at different magnifications (100×-1500×).

RESULTS

Microtensile Bond Strength Test

The mean μTBS values, standard deviations, and percentages of pretest failures for each group are shown in Table 2. The mean μTBS values ranged from 12.99 MPa (group 1) to 36.21 MPa (group 6). Group 6 showed the highest μTBS value among all groups, while group 1 showed the lowest μTBS value. The use of different teeth had no significant effect in the statistical model for the enamel specimens ($p=0.656$). A univariate general linear analysis of means revealed that there were significant differences among test groups ($p=0.000$). The highest percentage of pretest failure was seen in group 1, followed by group 2. Percentages of pretest failures of the other groups were similar to each other (Table 2).

Group 1 (6 W–20 Hz) and group 2 (6 W–35 Hz) showed significantly lower bond strengths when compared with the control group (group 7) ($p=0.000$). Group 6 (3 W–50 Hz) showed significantly higher bond strength when compared with the control group ($p=0.003$). No significant differences existed among the bond strengths of other groups and those of the control group. The bond strength of group 1 (6 W–20 Hz) was found to be the lowest, with

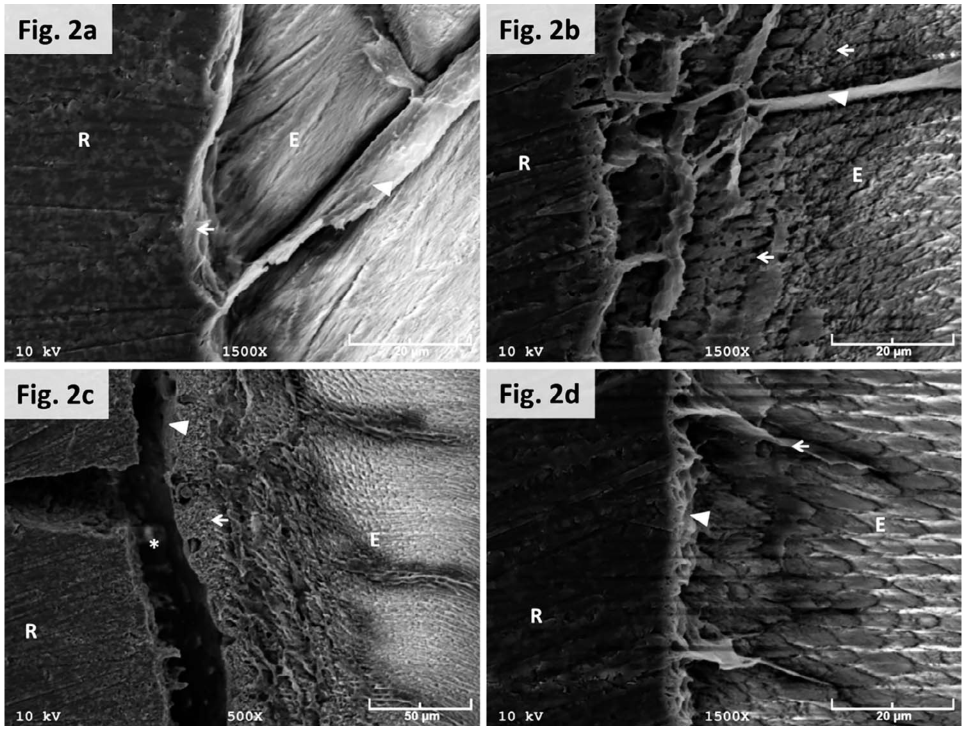

Figure 2. *(a) SEM image of an acid-etched cross section of resin-enamel interface, using acid-etching. There was no horizontal crack in the subsurface of the enamel. However, a tremendous vertical crack was seen as a result of the mechanical stress that occurred during the use of a high-speed abrading mechanism of the diamond bur (arrowhead). Adhesion occurs mainly through microretention as a result of infiltration of adhesive resin into microporosities left after partial dissolution by acid of enamel rods (arrow). (E=enamel; R=resin). (b) SEM image of acid-etched cross section of resin-enamel interface, using laser irradiation with 6 W–20 Hz parameters. Large vertical and horizontal resin extensions were evident (arrowhead). Occurrence of widening interprismatic rods indicates minor cracks throughout enamel rod interfaces (arrows). Extensive minor cracks occurred throughout enamel rods, along with horizontal subsurface cracks, possibly weakening the structure. (E=enamel; R=resin). (c) SEM image of acid-etched cross section of resin-enamel interface, using laser irradiation with 6 W–20 Hz parameters. Huge interface gap due to ineffective bonding to large vitrificated enamel surface was seen (*). Rounded enamel crystals due to vitrification were seen (white arrow). In addition, vitrificated enamel surface was evident, with characteristic recrystallized enamel surface (arrowhead). Extensive vitrification areas may play an important role in reduction of bond strength. (E=enamel; R=resin). (d) SEM image of acid-etched cross section of resin-enamel interface, using laser irradiation with 6 W–35 Hz parameters. Resin-enamel interface was intact. Typical resin tag formations were seen at the interface (arrowhead). However, large resin extensions with approximately 30-µm lengths were evident. Despite group 1, minor cracks throughout enamel rods were not extensive (arrow). (E=enamel; R=resin).*

statistical significance, when compared to those of all other groups. In the 6 W groups, increasing pulse frequency resulted in significant increments in bond strength. In the 3 W groups, improvement in bond strength was obtained when the frequency was increased from 35 Hz to 50 Hz (Table 2).

Fracture Patterns

The distribution of fracture patterns is presented in Table 2. In all groups, with the exception of groups 6 and 7, the predominant type of fracture was mix. In contrast, in groups 6 and 7, the most frequent fracture type was cohesive.

SEM Examination of Interface Cross Sections

In the present study, four types of micromorphological changes within the resin-enamel interface and subsurface enamel due to laser irradiations with different power and pulse rate parameters were observed by SEM. These were 1) large vertical cracks presented by infiltration of adhesive resin into cracks, which served as an infiltration highway for adhesive resin; 2) large horizontal cracks presented by infiltration of adhesive resin into macrocracks, which served as an infiltration highway for adhesive resin; 3) minor horizontal cracks, which occurred among sound enamel rods; and 4) localized vitrification areas.

1) Large vertical microcracks were rarely seen in cross sections of resin-enamel sticks in the bur-treated control group (Figure 2a) and the laser group with 3 W–50 Hz parameters (Figure 3d). In contrast, large vertical microcracks were always evident in all other laser groups (Figures 2b–3c). 2) Large horizontal microcracks were not seen in cross sections of resin-enamel sticks in the bur-treated control group.

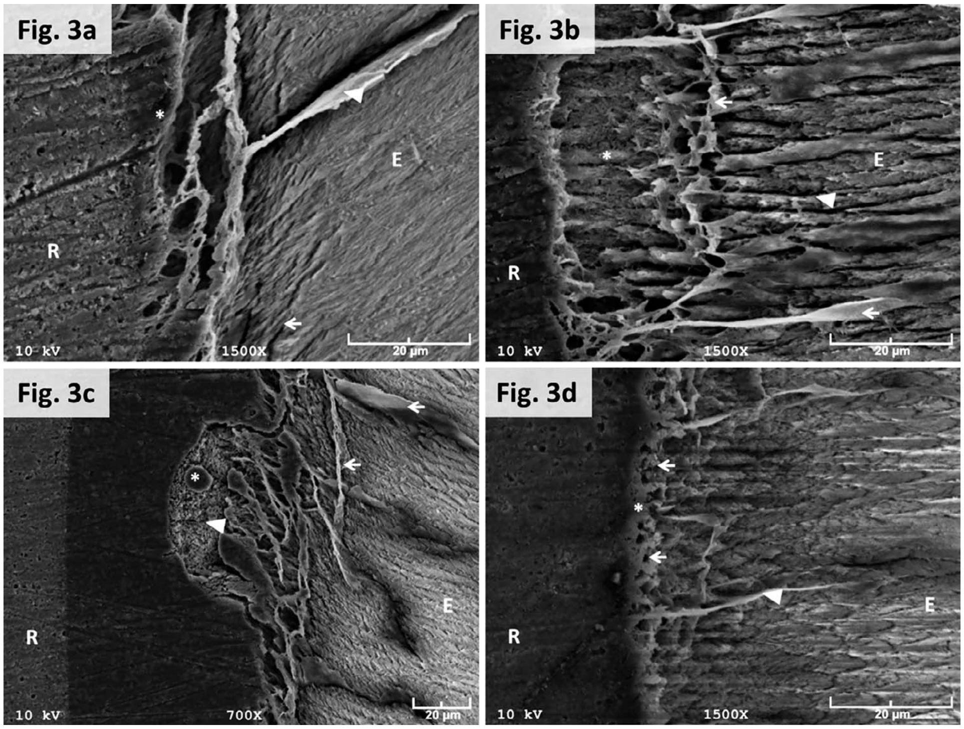

Figure 3. *(a) SEM image of acid-etched cross section of resin-enamel interface, using laser irradiation with 6 W–50 Hz parameters. Although the resin-enamel interface was intact (*), extensive subsurface fissuring resulting in large vertical resin extensions was evident. In addition, large vertical resin extensions exist (arrowhead). Minor cracks among enamel rods were seen (arrows). (E=enamel; R=resin). (b) SEM image of acid-etched cross section of resin-enamel interface, using laser irradiation with 3 W–20 Hz parameters. Subsurface cracks resulting in vertical and horizontal large resin extensions were evident (arrows). Widening interprismatic areas indicating minor cracks among enamel rods were seen (arrowhead). A cavity at the interface due to defragmented surface enamel fragment is indicated by an asterisk. Note that crystallinity of enamel was normal. No vitrification sign was evident. (E=enamel; R=resin). (c) SEM image of acid-etched cross section of resin-enamel interface, using laser irradiation with 3 W–35 Hz parameters. An irregular resin-enamel interface due to a smaller, partially defragmented vitrification area that was encapsulated by adhesive resin was seen (*). Different surface texture indicates vitrification of enamel surface exposed to laser irradiation with 3 W–35 Hz parameters. Texture of vitrification area seemed to comprise rounded atypical apatite crystals (arrowhead). Micro- and macroporosities (Resin Island was indicated by white asterisk) were evident within vitrification area. In addition, large vertical and horizontal cracks were seen. (d) SEM image of acid-etched cross section of resin-enamel interface, using laser irradiation with 3 W–50 Hz parameters. The resin-enamel interface was intact (*). Although large vertical resin extensions were evident, they were narrower than those of other groups (arrowhead). Thinner horizontal resin extensions were positioned at 10 μm below the interface (arrows). Cracks among enamel rods were absent (E=enamel; R=resin).*

However, they were seen in the laser group with 3 W–50 Hz parameters very rarely and in thinner form (Figure 3d). However, these were unexceptionally evident in all other laser groups (Figures 2b–3c). 3) Minor horizontal microcracks were commonly seen in all laser groups, with the exception of the group with 3 W–50 Hz parameters (Figures 2b and 3c). Locations of these cracks were approximately 20 μm below the interface and seemed to be independent of power and pulse rate. 4) Vitrification areas were noticed in the high- and low-power groups. However, the area affected from vitrification seems larger in the high-power group (Figure 2c) than in the low-power group (Figure 3c).

DISCUSSION

The Er,Cr:YSGG laser is approved by the United States of America Food and Drug Administration for dental hard tissue operations, including cavity preparation, caries removal, and laser conditioning, because of its safety with respect to pulpal responses and thermal damage.[16] Cavities prepared by the Er,Cr:YSGG laser are generally restored by adhesive resin restorative materials. It is known that the adhesion of resin adhesive systems to lased dental hard tissues may be affected by several laser irradiation parameters, including laser irradiation distance,[17] pulse duration,[18] output power,[19] pulse frequency,[20] and water flow rate.[21] However, to the knowledge of the authors there is no study covering the effects of different output power–pulse frequency combinations of Er,Cr:YSGG laser on resin bond strength to enamel in the literature. Moreover, the conflicting results obtained from previous studies on the effects of Er,Cr:YSGG laser irradiation on resin-enamel bonding using the pulse frequency that is suggested by the Er,Cr:YSGG laser manufacturer

(20 Hz) are evident.[8,10,11] Therefore, pulse frequency–output power combinations of the Er,Cr:YSGG laser that could yield optimum resin-enamel bond strength were sought in the present study.

According to μTBS findings in the present study, the output power and pulse frequency combination of 6 W–20 Hz, which is close to those (5.5 W–20 Hz) suggested by the Er,Cr:YSGG laser manufacturer for cavity preparation on enamel, significantly decreased the μTBS of resin adhesive to enamel when compared to findings in the control group. Therefore, the null hypothesis cannot be accepted. Nevertheless, only a few studies covering the effects of high-power Er,Cr:YSGG laser irradiation on resin-enamel bond strength exist in the literature. The finding in the present study is correlated with the findings of previous studies. Cardoso and others[8] and Ansari and others[10] revealed that the 6 W–20 Hz and 5.5 W–20 Hz output power and pulse frequency parameters of the Er,Cr:YSGG reduced μTBS values, respectively. A possible explanation for the significant reduction effect of the 6 W–20 Hz combination on μTBS may be that it resulted in extensive vitrification areas and subsurface vertical and horizontal microcracks within the resin-enamel interfaces (Figure 2c).

When Er,Cr:YSGG laser irradiation is focused on enamel, it causes different surface morphology compared with that associated with bur-abraded enamel surfaces and morphological alterations on the surface and within the subsurface of enamel.[11,22,23] It was discovered that enamel lased with the Er,Cr:YSGG laser was smear-layer free, with microretentive characteristics. These observations led researchers[11] to suggest that lased enamel was more favorable with respect to resin bonding. Nevertheless, studies[8,23,24] indicated that high-power laser irradiation affected resin-enamel bond strength in an unfavorable way, revealing that corresponding laser parameters resulted in subsurface damage to enamel. In addition, although laser irradiation was applied by coupling with water spray, vitrifications were observed in the previous studies.[8] It was presumed that these subsurface morphological alterations might affect resin-enamel bond strength unfavorably.[7,8,24]

Other laser groups, including the 6 W–50 Hz, 3 W–20 Hz, and 3 W–35 Hz groups, yielded statistically similar bond strength values compared with the control group. These findings may imply that when the Er,Cr:YSGG laser is needed to cut enamel more quickly, increasing pulse frequency at a high power level may maintain resin-enamel bond strength in a manner similar to that associated with bur treating. However, it was found that the 3 W–50 Hz combination significantly increased μTBS when compared to the bur-treated group in the present study. SEM images showed tight adaptation of adhesive resin with lased enamel. However, no vitrification signs were seen. Nevertheless, subsurface microcracks were rarely observed (Figure 3d).

"Pulse frequency" represents the number of pulses that have equal pulse energy with each other delivered to target tissue per second. Increasing pulse frequency does not affect the total energy delivered to target tissue, while it does decrease the amount of energy that is carried by each pulse. The findings of the present study indicate that 300 mJ per pulse (6 W–20 Hz) and 171 mJ per pulse (6 W–35 Hz) rates are detrimental to resin enamel bond strength, whereas 120 mJ per pulse (6 W–50 Hz), 150 mJ per pulse (3 W–20 Hz), and 86 mJ per pulse (3 W–35 Hz) rates did not affect resin-enamel bonding in comparison to bur treating, respectively. However, further increasing pulse frequency to 50 Hz at a low output power level, yielding 60 mJ per pulse, significantly increased the bond strength of resin to lased enamel.

A microtensile bond strength test, which uses specimens of smaller diameter, was selected as a bond strength test in the present study to evaluate the effects of test variables on bond strength values. The higher means obtained from specimens of smaller diameter enable the microtensile bond strength test to be discriminative enough for detecting differences arising from treatment variables with the use of a smaller number of actual tooth specimens.[25]

In the present study, bovine incisors were used as enamel specimens. Bovine enamel is an accepted substitute for human dental hard tissue for bond strength testing studies. In addition, the use of bovine incisors provides the ready availability and increased enamel surface for enamel bond strength tests.[26,27]

CONCLUSIONS

Within the limitations of the present *in vitro* study, it can be concluded that

1) Er,Cr:YSGG laser pulse frequency and output power are important parameters that might have significant effects on resin bond strength to irradiated enamel. A power–pulse frequency parameter combination of 6 W–20 Hz, which is

one of the commonly used output power–pulse frequency combinations of Er,Cr:YSGG laser irradiation for enamel preparation, significantly reduced μTBS when compared to the control (bur-treated) group.

2) The power–pulse frequency parameter combination of 6 W–50 Hz yielded similar μTBS when compared to the control. Therefore, high power with high pulse rate might be suggested for faster enamel ablation.
3) The power–pulse frequency parameter combination of 3 W–50 Hz significantly increased μTBS when comparing all groups. The use of this power–pulse frequency combination can be recommended to increase the μTBS of adhesive resin to laser-irradiated enamel.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Biruni University in Istanbul, Turkey.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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