Reconditioning of ceramic orthodontic brackets with an Er,Cr:YSGG laser

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Reconditioning of ceramic orthodontic brackets with an Er,Cr:YSGG laser

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Abstract It is now known that erbium lasers are effective in composite removal, but there is minimal information about their efficacy on recycling of ceramic brackets. This study, therefore, aimed to determine the percentage of remaining adhesive on the base and the shear bond strength of debonded ceramic brackets after being reconditioned by an Er,Cr:YSGG (erbium, chromium: yttrium–scandium–gallium–garnet) laser. Thirty premolars were divided into three groups, then bonded with mechanical retention ceramic brackets according to the bracket base conditions: (1) new brackets; (2) debonded brackets cleaned of adhesive with the Er,Cr:YSGG laser at 3.5 W; and (3) debonded brackets cleaned of adhesive with the Er,Cr:YSGG laser at 4 W. Before bonding, the percentage of remaining adhesive on the bases of reconditioned brackets was calculated by using stereomicroscopic images through an image processing software. The brackets were then tested in shear mode in a universal testing machine and the adhesive remnant index scores were determined. The percentage of remaining adhesive on the bases of brackets that were cleaned by the Er,Cr:YSGG laser at 4 W (3.1 %) was significantly lower than that of the 3.5-W laser group (5.9 %) (p=0.03). No significant difference was found in bond strengths between the new and the reconditioned brackets (p=0.19). The frequency of bond failure at the enamel-adhesive interface was lower in the laser-reconditioned brackets when compared to the new brackets. The application of Er,Cr:YSGG laser was efficient in removing adhesive from bases of debonded ceramic brackets because it produced comparable bond strengths to new brackets while reducing the risk of enamel damage during debonding.

Keywords Ceramic bracket · Shear bond strength · Er,Cr:YSGG · Laser · Composite · Recycling · Reconditioning · Orthodontic

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Introduction

Since their introduction in the mid-1980s, ceramic brackets have gained a growing popularity in orthodontic practice to satisfy the aesthetic demands of adult patients. The first generation of ceramic brackets used a silane coupling agent as a chemical mediator between the bracket base and the adhesive. Because of the excessive bond strength of chemical retention, enamel damage during bracket removal was reported in several studies [1–5], occurring as the development of fractures or increase in the length and frequency of available cracks on the enamel surface. Today, most practitioners prefer to use ceramic brackets that feature mechanical retention because this type of retention has caused a lower incidence of enamel damage which is in turn a result of its lower bond strength when compared to that of the chemical bonding brackets [3–5].

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Bracket failure is an undesirable experience frequently observed in clinical orthodontic practice. This usually occurs as a result of patients' applying heavy forces to orthodontic attachments or because of shortcomings in the bonding technique. Furthermore, the clinician may occasionally decide to intentionally reposition one or more attachments to achieve the best treatment results. If the optimum bond strength is maintained and on the condition that no damage is caused to the bracket base or slot dimensions, reusing a dislodged ceramic bracket after removing adhesive from the base can be considered as a suitable option to reduce treatment costs and to save office inventory. Various techniques have been employed for recycling metal orthodontic brackets [6–13]. However, the delicate base surface of ceramic brackets is more prone to damage than that of the metal brackets, and thus, selecting an appropriate in-office method for reconditioning of ceramic brackets becomes challenging.

Previous studies suggested a variety of techniques to remove adhesive remnants from ceramic bases in preparation for a rebonding procedure. Burning off the composite residue followed by application of a silane coupling agent was among the methods used for preparation of debonded chemically retained ceramic brackets, but the resulting bond strength, though clinically adequate, was approximately 30 % lower than that of the new brackets group [14]. Harris et al. [15] recommended to rinse debonded ceramic brackets and to rebond them without removing adhesive remnants from the base in order to achieve comparable bond strength to new attachments. Due to its suitable etching effect on porcelain surfaces, hydrofluoric acid was also tried as a ceramic bracket base conditioner on heated or non-heated ceramic brackets, but it caused a significant reduction in rebond strength to the level of virtual nonbonding [16, 17], and therefore it cannot be considered as a suitable surface treatment technique in clinical practice. Several studies have used aluminum oxide sandblasting to remove the adhesive and to help roughen the base of debonded ceramic brackets, but the results showed significantly lower bond strengths as compared to new attachments [16, 18].

Considering the previous experiments with erbium lasers in composite removal [19–21] and roughening of the surface of composite restorations [22], the use of this technique may be applicable for removing adhesive from bases of debonded ceramic brackets. Previous studies reported that Er,Cr:YSGG (erbium, chromium: yttrium–scandium–gallium–garnet) laser was efficient in reconditioning metallic orthodontic brackets [23, 24], but as far as we know, there have been no study regarding the use of erbium lasers in cleaning the bases of ceramic brackets. Therefore, the objectives of this study were to evaluate (1) the base surface appearance and the percentage of remaining adhesive after reconditioning mechanically retentive ceramic brackets with an Er,Cr:YSGG laser at different powers; (2) the shear bond strengths of new and laser-reconditioned ceramic brackets; and (3) the mode of bond failure in new and reconditioned attachments.

Materials and methods

Twenty debonded mechanically retentive ceramic brackets (Inspire Ice, Ormco, Orange, California, USA) were obtained from a previous study [25]. They were of a maxillary left second premolar type with a 0.022-in. slot (Roth prescription). The brackets were inspected under a stereomicroscope for any damage that might have occurred during the debonding procedure, and then were randomly divided into two groups of 10 each. The adhesive remnants on the bases of debonded brackets were removed by an Er,Cr:YSGG laser device (Waterlase, Biolase Technology, Irvine, CA, USA), emitting a wavelength of 2,780 nm. The laser beam was irradiated in a focused, non-contact mode at a distance of approximately 1 mm and perpendicular to the bracket base, using 55 % water and 65 % air spray. The pulse duration and the pulse repetition rate of the device were constant at 140 μs and 20 Hz, respectively. The output power was set manually at 3.5 W for reconditioning 10 brackets and the power of 4 W was selected for the cleanup of another 10. Laser application continued until the adhesive was totally removed from the bracket base and was no longer visible on inspection. Then a magnified image (×46) was taken from the base of each bracket with a stereomicroscope (Blue Light Industry, Waltham, MA, USA) equipped with a color digital video camera (Exwave HAD, Sony Corporation, Tokyo, Japan). The percentage of the remaining adhesive on each bracket was calculated in terms of the total base area of the bracket using stereomicroscopic images and a microstructure image processing software (Nahamin Pardazan Asia, Iran).

Shear bond strength testing

Thirty human upper premolar teeth that were free of cracks, caries, or developmental defects on the enamel surface were collected and stored in normal saline solution until the time of the experiment. The teeth were cleaned from debris and soft tissue remnants using a hand scaler, and then they were randomly divided into three groups of 10, according to the treatment conditions of the bracket bases. In the first group (control group), new brackets were used. In the second group, brackets cleaned with the Er,Cr:YSGG laser at 3.5 W were bonded on the enamel surface; and finally in the third group, brackets prepared with the Er,Cr:YSGG laser at 4 W were employed.

Before bracket placement, the facial surfaces of the teeth were cleaned by a non-fluoride pumice slurry and rubber prophylactic cups, then rinsed and dried. A 37 % orthophosphoric acid gel (Ortho Organizers Inc., San Marcos, CA, USA) was later applied on the enamel surface for 30 s, rinsed by a copious amount of water, and dried thoroughly with a compressed air source. The enamel surface was then coated by a thin layer of Transbond XT primer (3 M Unitek, Monrovia, California, USA) and light cured for 10 s. Subsequently, a sufficient amount of Transbond XT adhesive (3 M Unitek) was placed on the base and the bracket was pressed at the middle of the buccal surface along the access of the crown. The flash material was removed carefully with a sharp explorer and the adhesive was cured for a total of 40 s from occlusal, gingival, mesial, and distal directions with a light-emitting diode curing device (Bluephase C8, Ivoclar Vivadent, Schaan, Liechtenstein) at a power density of 650 mW/cm^2.

The bonded specimens were left undisturbed in distilled water in an incubator at 37°C for 24 h, and then they were embedded in individual holders with self-curing methyl methacrylate so that the bonded surface would be parallel to the direction of the debonding force. The shear bond strength testing was performed by a Zwick Universal testing machine (model Z250, Zwick GmbH & Co, Ulm, Germany) using a crosshead speed of 1 mm/min. The specimens were stressed until failure and the shear force required to fracture the bracket–enamel bond was measured in newtons and subsequently converted to megapascals (newtons per square millimeter) by dividing the force value by the surface area of the bracket base (10.8 mm^2). After debonding, the enamel surfaces were examined under a stereomicroscope at ×10 magnification to determine the amount of adhesive remained on the tooth, according to the adhesive remnant index (ARI) of Artun and Bergland [26]. Score 0 indicated no adhesive remained on the enamel surface; score 1 indicated that less than 50 % of the adhesive remained on the enamel surface; score 2 revealed that more than 50 % of the adhesive was left on the enamel surface; and score 3 implied that the entire adhesive remained on the enamel surface, with a distinct impression of the bracket base.

Statistical analysis

The normality of the data was determined by the Kolmogorov–Smirnov test and the homogeneity of variances by the Levene's test. The difference in the percentage of remaining adhesive on the bases of reconditioned brackets was determined by a Student's *t* test. One-way analysis of variance (ANOVA) was run to define any significant difference in shear bond strengths among the study groups. A Fisher exact was used to make the between group comparisons of ARI scores. The significant level considered in all statistical tests was $p<0.05$.

Results

Figure 1a–c demonstrates the stereomicroscopic images taken from bases of new and laser-reconditioned ceramic brackets before the bonding procedure. The bonding pad of the representative new ceramic bracket (Fig. 1a) showed a well-defined ball-base design on the surface, providing mechanical retention areas for composite adhesion. After reconditioning with the Er,Cr:YSGG laser at 3.5 W (Fig. 1b) and 4 W (Fig. 1c) powers, the base surfaces of the specimens revealed small damaged areas which lost the ball-shaped appearance. Furthermore, there was an occasional amount of adhesive left on the base after being reconditioned by both powers of the Er,Cr:YSGG laser (Fig. 1b, c).

Table 1 presents the descriptive statistics including mean, standard deviation, and range regarding the percentage of remaining adhesive on the base and the shear bond strengths for the study groups. A Student's *t* test revealed that the percentage of the remaining adhesive was significantly lower in the group of brackets prepared with the Er,Cr:YSGG laser at 4 W as compared to that of the 3.5-W laser group (Table 1). The highest bond strength values were observed in the control group (16.2±4.4 MPa). The mean bond strength of brackets cleaned with the Er,Cr:YSGG laser at 3.5 W was 14.3±4.9 MPa and that of the 4-W laser group was 12.8±2.6 MPa. ANOVA demonstrated no statistical difference in bond strength values between the new and the reconditioned brackets (Table 1).

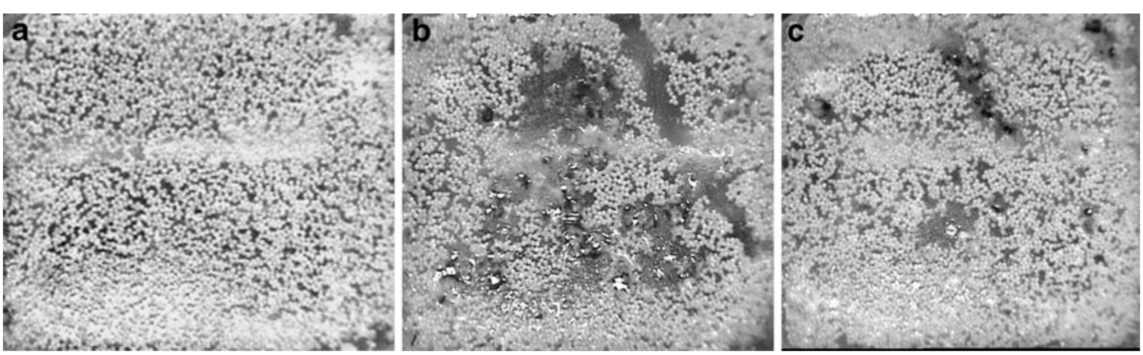

Fig. 1 Representative images taken by stereomicroscope at×46 from bases of mechanically retained ceramic brackets (Inspire Ice). **a** New bracket; **b** bracket reconditioned with Er,Cr:YSGG laser at 3.5 W; and **c** bracket reconditioned with Er,Cr:YSGG laser at 4 W

Table 1 Descriptive statistics and the results of Student's *t* test and ANOVA comparing the percentage of remaining adhesive on the base after recycling and the shear bond strengths (in megapascals) of the study groups

Group	% of remaining adhesive			Shear bond strength (MPa)		
	Mean	SD	Range	Mean	SD	Range
New brackets	–	–	–	16.2	4.4	10.9–26.3
Er,Cr:YSGG laser (3.5 W)	5.9	3.4	1.7–11.9	14.3	4.9	7.2–23
Er,Cr:YSGG laser (4 W)	3.1	2.1	0–7.5	12.8	2.6	8.3–16.7
Statistical analysis	*t* test (p=0.03)			ANOVA (p=0.19)		

The ARI scores for the three study groups are shown in Table 2. In the new brackets group, most (60 %) of the specimens exhibited ARI score of 1, indicating that failures occurred predominantly at the enamel-adhesive interface. In both Er,Cr:YSGG laser groups, the predominant failure site was at the bracket-adhesive interface (ARI scores of 2 and 3), implying that most of the adhesive actually remained on the enamel surface after bracket removal. Fisher's exact test revealed a significant difference in the distribution of ARI scores among the study groups (p=0.01). After shear bond strength testing, no case of enamel fracture was observed in any of the three groups.

Discussion

The present study evaluated the efficacy of Er,Cr:YSGG laser in reconditioning of mechanically retentive ceramic brackets. The absorption of Er,Cr:YSGG laser is considerably greater in dental composites than ceramic materials, making it possible to selectively remove adhesive from bases of debonded ceramic brackets. This selective ablation combined with the use of air and water spray during the adhesive removal process prevents from excessive increase in ceramic bracket temperature. Under the stereomicroscope, the new bracket bases had ball-shaped undercuts connected with each other. The balls and the spaces between them would increase the base surface area, providing micromechanical retention to composite resin. Both powers of the Er,Cr:YSGG laser produced some degrees of damage to the base, resulting in smoothening and loss of ball-base appearance in limited areas of the bonding pad. Furthermore, occasional fragments of the embedded composite were observed in small areas of the base in both groups of laser-recycled brackets. The percentage of remaining adhesive on the base was 5.9 % for the 3.5-W laser group and 3.1 % for the 4-W laser group, indicating that Er,Cr:YSGG laser was efficient in removing approximately the entire adhesive residue from the bases of debonded ceramic brackets.

Table 2 Frequency and percentage distribution of the ARI scores in the study groups

Group	ARI scores (%)		
	1	2	3
New brackets (control)	6 (60)	3 (30)	1 (10)
Er,Cr:YSGG laser (3.5 W)	–	3 (30)	7 (70)
Er,Cr:YSGG laser (4 W)	1 (10)	5 (50)	4 (40)

In the present study, Er:YAG laser was selected for bracket cleanup. Other laser wavelengths have also been investigated in previous studies for removing tooth-colored restorative materials [27–30]. Dumore and Fried [27] concluded that a Transverse Excited Atmospheric Pressure (TEA) CO_2 laser operating at 10.6 μ had the potential to ablate remaining composite after debonding of orthodontic brackets with minimal inadvertent damage to enamel. Louie et al. [28] reported selective elimination of composite sealants away the tooth structure with 355 nm laser pulses from a frequency-tripled Nd:YAG laser. A rapidly scanned CO_2 laser also proved to be effective for selective removal of dental composite without excessive damage to the underlying enamel [29]. Although these lasers may be appropriate for composite removal, they are not commonly available for clinical applications, and their use carries the risk of thermal damage to the underlying structure [30]. Previous authors demonstrated the ability of erbium family lasers in removing restorative materials [19–21] and their efficacy to roughen the surface of available composite restorations [22]. The findings of this study are in line with those of Correa-Afonso et al. [19] who verified that Er:YAG laser was effective for composite removal, although it did not manage to eliminate all the restoration from the cavity walls.

The mean shear bond strength of new mechanical retention ceramic brackets was 16.2 MPa with a range from 10.9 to 26.3 MPa. Brackets cleaned of resin with Er,Cr:YSGG laser at 3.5 and 4 W yielded bond strength values of 14.3 and 12.8 MPa, respectively. Although laser-reconditioned brackets experienced some reduction in bond strength compared to that of the new brackets, no statistical difference was found among the groups, and therefore bracket cleanup with the Er,Cr:YSGG laser can provide bond strength values that are comparable to that of new attachments and indeed sufficient for clinical applications. These results are in agreement with those of the previous studies that found Er,Cr:YSGG laser was efficient in adhesive removal from bases of metallic orthodontic brackets and produced comparable [24] or even higher [23] bond strength than the new attachments. Although sandblasting with aluminum oxide particles has been indicated to be as effective as Er,Cr:YSGG laser in composite roughening [22] and adhesive removal from bases of metallic orthodontic brackets [23], it did not prove to be appropriate for reconditioning of ceramic brackets in previous studies [16, 18]. This was possibly due to the fact that sandblasting affects the entire base surface and may remove most of the delicate undercuts on the bonding pads of the ceramic brackets. In contrast, Er,Cr:YSGG laser acts selectively on areas with residual adhesive, and thus not damaging the remaining areas of the base. Furthermore, the punctuate performance of the laser beam can potentially produce retention areas on the remaining adhesive and the bracket bonding pad.

In the present study, no silane or adhesion booster was applied on the bases of cleaned brackets because we aimed to evaluate the exclusive effect of Er,Cr:YSGG laser on reconditioning of ceramic brackets with mechanical retention. Previous studies reported contradictory results for bond strength after the use of silane or sealant on the base surface of debonded mechanically retained ceramic brackets [15, 16, 18]. Harris et al. [15] reported the application of a silane coupling agent before rebonding ceramic brackets lowered the bond strength to clinically inadequate levels, while Toroglu and Yaylali [18] recommended silane application to provide a chemical bond in addition to micromechanical retention and thus improving the bond strength of rebonded mechanically retained ceramic brackets. Treating the debonded cleaned brackets with sealant before rebonding has also been performed in a previous study [16], resulting in comparable bond strength to that of new brackets [16]. Although the application of silane or sealant is not mandatory for mechanical retention ceramic brackets, if laser is used for cleanup of chemical retention ceramic brackets, silane application should be considered as an essential step to restore the chemical bonding of the base and enhance composite resin adhesion.

The adhesive remnant index describes the amount of remaining adhesive on the base after bracket removal and is a good indicator of the risk of enamel damage during debonding. In the control group, 60 % of the specimens had ARI score of 1, indicating that bond failure occurred predominantly at the enamel-adhesive interface. In contrast, laser-reconditioned brackets exhibited higher frequencies of ARI scores of 2 and 3, which implies that most of the adhesive remained on the tooth after debonding. A fracture site at the adhesive-bracket interface is preferred in the clinical situation because failure at the enamel-adhesive interface is frequently associated with a higher incidence of enamel damage at debonding.

In the present study, the bond strengths of both new and laser-reconditioned brackets exceeded 6–8 MPa, which has been suggested as the minimum bond strength required in the clinical situations to meet orthodontic needs [31]. On the other hand, the mean linear tensile strength of enamel has been indicated to be 14.51 MPa [32], and enamel fracture during bracket removal may occur with bond strengths as low as 13.7 MPa [33]. Therefore, Bishara and Fehr [34] suggested that bond strengths should be lower than 12.75 MPa to ensure safe debonding. With these backgrounds, the results of this study suggest that the bond strength of new Inspire Ice brackets appeared to be sufficient and even to surpass the safety threshold of enamel, while laser-reconditioned brackets provided bond strength values that cleared the clinical requirements of orthodontic therapy and were indeed closer to the enamel safety threshold. Erbium lasers are extensively used in dentistry for hard and soft tissue ablation, and reconditioning of ceramic brackets can be considered as another useful application of them in orthodontics. Further research should focus on the clinical efficiency of laser-reconditioned ceramic brackets and to determine the effects of erbium lasers in reconditioning of ceramic brackets with chemical retention. The possibility of chemical alteration on the base surface of laser-reconditioned ceramic brackets also needs further clarification in a future study.

Conclusions

1. The percentage of remaining adhesive on the base was 5.9 and 3.1 % in brackets cleaned with the Er,Cr:YSGG laser at 3.5 and 4 W, respectively. These minimal remnants of adhesive on the base indicate the efficacy of Er,Cr:YSGG laser in preparing debonded ceramic brackets for a rebonding procedure.
2. The shear bond strengths of laser-reconditioned brackets were comparable to that of the control group and could be considered clinically acceptable.
3. The frequency distribution of ARI scores was significantly different among the study groups, exhibiting a higher frequency of bond failure at the bracket-adhesive interface in laser-reconditioned groups, thereby reducing the risk of enamel damage at debonding.
4. Bracket reconditioning with the Er,Cr:YSGG laser proved to be an efficient and convenient technique that could be used for rebonding an accidentally dislodged mechanically retained ceramic bracket in the dental office.

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