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EVALUATION OF DIODE LASER-AIDED DEBONDING OF TWO DIFFERENT TYPES OF CERAMIC BRACKETS (AN IN VITRO STUDY)

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ABSTRACT:

Objective: *To evaluate and compare the shear bond strength (SBS), enamel damage, and the Adhesive Remnant Index (ARI) following diode laser-aided debonding of monocrystalline and polycrystalline ceramic brackets.* **Materials and Methods:** *Forty extracted premolars were examined under a stereomicroscope and the frequency and lengths of enamel cracks present were recorded. The premolar teeth were then randomly and equally allocated to one of the four groups: monocrystalline control (Group MC), monocrystalline laser (Group ML), polycrystalline control (Group PC), and polycrystalline laser (Group PL). Either a monocrystalline or a polycrystalline bracket was bonded to each tooth according to the assigned group. These brackets were then debonded using a universal testing machine. In Groups ML and PL, a diode laser was applied to the teeth for 20 seconds before debonding. The SBS of each bracket was recorded. Following debonding, the ARI and the frequency and lengths of enamel cracks were examined using a stereomicroscope and recorded.* **Results:** *The SBS values of Group MC (33.22 ± 3.99 MPa) and Group PC (39.97 ± 7.61 MPa) were significantly higher than those of Group ML (19.92 ± 3.53 MPa) and Group PL (18.63 ± 4.16 MPa) respectively ($p < 0.001$). SBS values of Group ML and PL did not show significant differences. The frequency and lengths of enamel cracks at the end of the experiment were significantly higher in Group MC and Group PC when compared to Group ML and Group PL respectively. ARI scores were not significantly different among the four groups.* **Conclusion:** *Diode laser irradiation for 20 seconds before debonding can significantly lower shear bond strengths of both monocrystalline and polycrystalline brackets resulting in significantly less enamel damage during debonding.*

INTRODUCTION

The appearance of the conventionally used metallic fixed orthodontic appliances has been a noticeable cause of concern among patients (1). Additionally, with the increasing number of adults seeking orthodontic treatment, esthetics have become an important factor of consideration (2). In the 1980s, ceramic brackets were introduced in an attempt to overcome the unaesthetic appearance of metal brackets.(1) Since their introduction, these brackets have gained popularity over metal brackets due to their superior esthetics (3).

Ceramic bracket manufacturers have incorporated mechanical and chemical retention mechanisms (4), resulting in better bracket retention on teeth but posing

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difficulties during bracket debonding. Bond failure with ceramic brackets usually occurs at the enamel-adhesive interface as opposed to the bracket-adhesive interface (4). Therefore, enamel is more prone to damage during bracket debonding (4). Furthermore, the low fracture toughness of ceramic coupled with high forces required during debonding may result in bracket fracture which poses a risk as ceramic fragments can possibly be ingested, aspired or cause damage to the eyes (5).

Different methods have been advocated to decrease the possible side effect associated with the debonding of ceramic brackets including the use of special pliers (mechanical method), the ultrasonic technique and the electrothermal technique. The utilization of lasers with different wavelengths for debonding has been introduced since the 1990s (6). Lasers deliver a controlled amount of thermal energy which degrades the adhesive and allow easier removal of brackets by application of a lighter force thereby lowering the risk of enamel and bracket fracture (7–12). The applicability of various lasers for ceramic bracket debonding, including carbon dioxide (CO_2) (8), erbium-doped yttrium aluminum garnet (Er:YAG) (7,9), neodymium-doped yttrium aluminum garnet (Nd:YAG) (12), ytterbium fiber (10) and Tm:YAP lasers (13) has been studied and proved a remarkable reduction in bond strength.

CO_2 and Nd:YAG lasers are not used much due to their high costs and large size. Although erbium lasers are smaller in size, they are still expensive (14). Advantages of the diode laser over the other lasers is its small size, light weight, cost-effectiveness, portability and ease of use which makes its application in the field of orthodontics suitable and convenient (15).

Most previous studies evaluating diode laser-aided debonding focused on the effect of laser on shear bond strength (14,16–19). Only a few well-designed ones have investigated both the Adhesive Remnant Index and enamel damage after debonding (15,20). Furthermore, some studies have revealed controversial results regarding the effect of diode laser-aided debonding on monocrystalline and polycrystalline brackets (17,18).

The aim of the current study was to evaluate and compare the shear bond strength (SBS), enamel damage, and the Adhesive Remnant Index (ARI) associated with diode laser-aided debonding of monocrystalline and polycrystalline ceramic brackets. The null hypothesis is that the diode laser has no significant effect on the SBS, enamel damage or ARI of monocrystalline and polycrystalline ceramic brackets.

MATERIALS AND METHODS

The study sample used for this study was upper premolars extracted for orthodontic purposes. The sample size estimate was 5 premolars per group. This was calculated using MedCalc computer software (version 18.2.1) using an α error of 0.05 and a study power of 80%. Calculation of the sample size was based on a study by Feldon et al (17) and another study by Reddy et al (21). To cater for any damage or loss during the study, 40 premolars were used and divided equally and randomly into four groups.

The selected teeth had intact enamel surfaces which had not been previously bonded and had no caries, restorations, fractures or decalcifications. The teeth were thoroughly cleaned with tap water and any calculus or soft tissue remnants present on the teeth was removed using an ultrasonic scaler. Thereafter, each tooth was stored in a separate container containing isotonic saline solution which was changed daily.

Microphotographs of the buccal surfaces of the teeth under a 23.5x magnification using a stereomicroscope (Olympus, SZ1145TR, Japan) were captured with a digital camera (XCAM1080PHB, ToupCam, Japan) and the frequency and lengths of any enamel cracks present were measured and recorded (20) using a micro-image processing software (ToupView, version 3.7) (Fig. 1a). Each premolar was assigned a number and randomly allocated to one of four groups using Random Allocation Software (Version 1.0) (22). The groups comprising 10 premolars each were as follows:

1. **Group MC: Monocrystalline control group**
2. **Group PC: Polycrystalline control group**
3. **Group ML: Monocrystalline laser group**
4. **Group PL: Polycrystalline laser group**

Each tooth was cleaned with fluoride-free pumice using a rubber cup for 15 seconds, rinsed for another 15 seconds and then dried with air (19). According to the assigned group, either a monocrystalline (ClearViz+ Mini, DynaFlex, USA) or a polycrystalline (Glam, Forestadent, Germany) ceramic bracket was bonded to the buccal surface of each tooth.

The enamel of each tooth was etched with 37% phosphoric acid etching gel (Reliance, Reliance Ortho Prod., USA) for 30 seconds, rinsed with a water spray for 20 seconds, and then dried with an air spray until the enamel surface appeared chalky white. A thin layer of bonding primer (OrthoSolo, Ormco Corp., USA) was applied on the surface of the tooth while adhesive (BluGloo, Ormco Corp., USA) was applied on the base of the ceramic bracket. The bracket was then placed at the center of the crown and firmly pressed to expel excess adhesive which was removed with a sharp explorer. The adhesive was then light-cured for 20 seconds. Each bonded tooth were stored for 24 hours in a separate container containing distilled water (15,20).

Self-cure acrylic resin blocks were prepared using a brass mold. Using a surveyor, each tooth was vertically mounted in these blocks up to the cementoenamel junction leaving the crown exposed (Fig. 2) (20).

Brackets in all four groups were shear tested to failure. The embedded teeth with the bonded ceramic brackets were firmly fixed in the holding ring of a universal testing machine (5ST, Tinius Olsen, England) with the bracket slot parallel to the horizontal (8). The tapered blade of the machine was adjusted between the tooth and the bracket base and force applied at a crosshead speed of 0.5mm/min (Fig. 3). Brackets in Groups MC and PC were debonded without the use of laser whereas those in Groups ML and PL were irradiated with a diode laser with a wavelength of 980 nm and an output of 2.5 W (Simpler diode laser, Doctor Smile, Italy) (Fig. 4) before debonding. The laser tip was positioned at a 5 mm distance from the bracket and moved with a sweeping motion applying laser irradiation to the brackets in continuous wave mode for 20 seconds: 5 seconds mesially, 5 seconds occlusally, 5 seconds distally and 5 seconds gingivally. Shear testing was performed three seconds after laser application (20). SBS was recorded for every specimen. Forces required for the debonding of each bracket was recorded in Newtons (N) and converted to megapascals (MPa). (Forces in megapascals = Forces in Newtons / the base area of the brackets provided by the manufacturers) (16,17).

After bracket removal, the enamel surface was examined under a stereomicroscope at 10x magnification and ARI scoring was done, as described by Artun and Bergland (23), as follows:

0: no adhesive remaining on the tooth surface

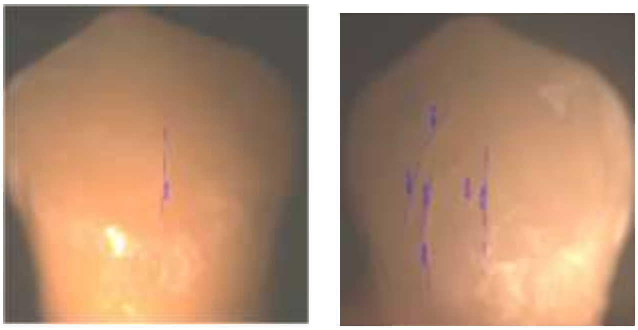
1: less than half of the adhesive remaining on the tooth surface

2: more than half of the adhesive remaining on the tooth surface

3: all the adhesive remaining on the tooth surface with a distinct impression of the bracket mesh

Finally, all adhesive remnants were completely removed from the enamel surface using a 12 fluted tungsten carbide bur and microphotographs of the buccal surfaces of each tooth from the stereomicroscope at a 23.5x magnification were taken. The frequency and lengths of any enamel cracks present were measured and recorded again (20) using the same micro-image processing software (ToupView, version 3.7) (Fig. 1b). The increase in frequency and lengths of enamel cracks was then calculated by subtracting the initial frequency and lengths of enamel cracks from the final.

ARI scores and change in frequency and lengths of enamel cracks for all specimens were reassessed by the same examiner after two weeks to determine intra-examiner reliability.



(a) **(b)**

Fig. 1: Measurement of **(a)** initial and **(b)** final enamel crack frequencies and lengths

Fig. 2: Tooth mounted in acrylic block

Fig 3: Position of the tapered blade in relation to the tooth

Fig. 4: Diode laser

DATA MANAGEMENT AND STATISTICAL ANALYSIS

The data obtained was analyzed using the IBM SPSS software package version 20.0 (Armonk, NY: IBM Corp). Qualitative data was described using numbers and percentages. Quantitative data was described using range (minimum and maximum), mean, standard deviation and median interquartile range (IQR). The Kolmogorov-Smirnov test was used to verify data normality of distribution. For categorical variables, the Chi-square test was used to compare between different groups. When more than 20% of the cells had an expected count of less than 5, correction for chi-square was conducted using the Monte Carlo correction. For normally distributed quantitative variables, the F-test (ANOVA) was used to compare between more than two groups while the Tukey post-hoc test was used for pairwise comparisons. For abnormally distributed quantitative variables, the Kruskal Wallis test was used to compare between more than two groups while the Dunn's multiple comparisons post hoc test was used for pairwise comparisons. For these variables, the Wilcoxon signed ranks test was used to compare between two periods. Intra-examiner reliability was determined using the Kappa statistic and the Intra-class correlation coefficient. Significance of the obtained results was judged at the 5% level.

RESULTS

Intra-Examiner Reliability

Intra-examiner reliability for change in frequency and lengths of enamel cracks and for ARI were determined using the Kappa statistic and was found to be 0.859 and 0.882 respectively, indicating a very good strength of agreement.

Shear Bond Strength

Mean SBS values of Groups MC and PC did not show any significant difference. Laser aided-debonding resulted in a significant decrease in SBS values. Group ML and Group PL showed significantly lower mean SBS values than those of Group MC and Group PC respectively ($p < 0.01$). However, the mean SBS values of Groups ML and PL did not show any significant difference. Mean SBS, standard deviation, minimum and maximum values for the four groups and comparisons of SBS between different study groups are shown in Table 1.

Table 1: Mean SBS in MPa, standard deviation, minimum and maximum values for the four groups and comparisons of SBS between different study groups

SBS	Group MC (n = 10)	Group PC (n = 10)	Group ML (n = 10)	Group PL (n = 10)	F	p
Min.- Max.	27.84- 41.29	30.18- 54.88	13.15- 25.94	13.22- 24.78	41.620^*	$<0.001^*$
Mean ± SD	33.22± 3.99	39.97± 7.61	19.92± 3.53	18.63± 4.16		
Median (IQR)	32.73(30.9-35)	37.03(35.4-45)	19.91(17.5-22)	18.89(14.2-22)		
Sig. with control			$p_1<0.001^*$	$p_2<0.001^*$		
Sig. bet. Gp. ML vs PL			$p_3=0.941$			

F: F for ANOVA test, Pairwise comparison between each 2 groups was done using Post Hoc Test (Tukey)
p_1: p value for comparing between group MC and ML
p_2: p value for comparing between group PC and PL
p_3: p value for comparing between group ML and PL
*: Statistically significant at $p \leq 0.05$

Enamel Damage

At the beginning of the experiment, the frequencies and lengths of enamel cracks were not significantly different between the four groups. The difference in enamel crack frequency and lengths at the end of the experiment was statistically significant between Groups MC and ML and between Groups PC and PL. Specimens in Groups MC and PC showed a significantly higher number of enamel cracks and significantly longer enamel cracks when compared to those in Groups ML and PL respectively. On the other hand, when enamel crack frequencies and lengths at the end of the experiment were compared between the two laser groups (ML and PL), no significant difference was found. None of the specimens exhibited enamel fractures when observed under a stereomicroscope after debonding. Initial and final mean frequencies and lengths of enamel cracks, and comparison of initial and final enamel crack frequencies and lengths among the four groups is shown in Table 2 and 3 respectively.

Adhesive Remnant Index

All brackets were debonded completely from the tooth surface and none of the teeth had brackets fragments left. The most recorded ARI scores in the control groups were score 0 and score 1 whereas the laser groups predominantly recorded ARI scores of 2 and 3. The Chi square test indicated no significant differences in ARI scores among the four groups. ARI score distribution in the four groups is shown in Table 4.

Table 2: Initial and final mean frequencies of enamel cracks, and comparison of initial and final enamel crack frequency among the four groups

Frequency of Cracks	Group MC (n = 10)	Group PC (n = 10)	Group ML (n = 10)	Group PL (n = 10)	H	p
Initial						
Min.- Max.	0.0 – 3.0	0.0 – 8.0	0.0 – 3.0	0.0 – 6.0	6.421	0.093
Mean ± SD	1.30± 1.06	3.30± 2.31	1.50± 1.27	2.40± 1.84		
Median (IQR)	1.50(0.0-2.0)	3.50(1.0-4.0)	1.50(0.0-3.0)	2.0(1.0-3.0)		
End						
Min.- Max.	3.0 – 7.0	5.0 – 11.0	1.0 – 3.0	0.0 – 6.0	24.343^*	$<0.001^*$
Mean ± SD	4.50± 1.58	7.40± 2.07	2.10± 0.74	3.10± 1.97		
Median (IQR)	4.50(3.0-5.0)	7.0(6.0-9.0)	2.0(2.0-3.0)	3.0(2.0-4.0)		
Sig. with control			$p_1=0.007^*$	$p_2=0.001^*$		
Sig. bet. Gp. ML vs PL			$p_3=0.233$			

H: H for Kruskal Wallis test, Pairwise comparison between each 2 groups was done using Post Hoc Test (Dunn's for multiple comparisons test)
p_1: p value for comparing between group MC and ML
p_2: p value for comparing between group PC and PL
p_3: p value for comparing between group ML and PL
*: Statistically significant at $p \le 0.05$

Table 3: Initial and final mean lengths of enamel cracks, and comparison of initial and final enamel crack lengths among the four groups

Lengths of Cracks	Group MC	Group PC	Group ML	Group PL	H	p
Initial	**(n = 13)**	**(n = 33)**	**(n = 15)**	**(n = 24)**		
Min.- Max.	337.9-3300.2	404.9-2697.3	572.5-3129.6	540.3-2139.3	5.966	0.113
Mean ± SD	1512.2±768.4	1079.6±544.6	1113.7±603.8	1010.0±399.6		
Median (IQR)	1418.9(1009-1890)	1077.4(614-1346)	1031.2(833-1121)	857.7(767–1304)		
End	**(n = 45)**	**(n = 72)**	**(n = 20)**	**(n = 31)**		
Min.- Max.	507.8-5639.6	722.6-7773.8	461.9-3505.1	603.0-2275.3	29.867^*	$<0.001^*$
Mean ± SD	1947.2±966.7	1762.6±1054.5	1249.8±619.7	1152.4±420.6		
Median (IQR)	1781.9(1376-2262)	1548.3(1252-1901)	1124.5(892-1424)	1033.8(834-1387)		
Sig. with control			$p_1=0.001^*$	$p_2<0.001^*$		
Sig. bet. Gp. ML vs PL			$p_3=0.754$			

H: H for Kruskal Wallis test, Pairwise comparison between each 2 groups was done using Post Hoc Test (Dunn's for multiple comparisons test)
p_1: p value for comparing between group MC and ML
p_2: p value for comparing between group PC and PL
p_3: p value for comparing between group ML and PL
*: Statistically significant at $p \le 0.05$

Table 4: ARI score distribution in the four groups

ARI	Group MC (n = 10)		Group PC (n = 10)		Group ML (n = 10)		Group PL (n = 10)		χ^2	^{MC}p
	No.	%	No.	%	No.	%	No.	%		
0	0	0.0	2	20.0	2	20.0	1	10.0	10.735	0.256
1	6	60.0	5	50.0	2	20.0	3	30.0		
2	2	20.0	3	30.0	2	20.0	5	50.0		
3	2	20.0	0	0.0	4	40.0	1	10.0		

χ^2: Chi square test
MC: Monte Carlo

DISCUSSION

Due to their very high SBS, conventional ceramic bracket debonding may result in significant enamel damage, bracket fragmentation and patient discomfort. Lasers of different wavelengths have been used for ceramic bracket debonding (7–10,12,14,17,20). In this study, a 980 nm diode laser was used to evaluate the effects of laser-aided debonding due to its favorable characteristics such as its small size, affordability, and convenience of use (17,20,24,25). In the present study, a 2.5 W power output was used as it proved to be the most effective in ceramic bracket debonding (14,18,20). Every bracket in the laser group received a total lasing time of 20 seconds divided into 5 seconds on each side of the bracket: mesially, distally, occlusally and gingivally (14,20), followed by bracket debonding 3 seconds after exposure (15,17,19,20).

In the current study, diode laser irradiation was effective in lowering the SBS of both monocrystalline brackets (mean SBS values of 19.92 ± 3.53 MPa) and polycrystalline brackets (mean SBS values of 18.63 ± 4.16 MPa) which were significantly lower than those in their corresponding control groups. However, the mean SBS values did not significantly differ between the groups that had undergone diode laser irradiation.

The significant reduction in SBS of monocrystalline brackets that were debonded with the aid of a diode laser comes in accordance with previous studies (17,19) and was expected due to the uniform crystal structure of monocrystalline brackets which enables high transmissibility of the laser through the bracket to the adhesive and minimize energy loss (26,27). On the other hand, polycrystalline brackets do not have a uniform structure. They are instead made of microcrystals with random shapes, size distribution and orientation, therefore, there is more lateral spreading and loss of laser energy (26–28) making the efficiency of diode laser in debonding polycrystalline brackets questionable. Results of previous studies showed controversies regarding the effect the diode laser had on the SBS of polycrystalline brackets. The results of the current study are consistent with results from previous studies that proved the efficiency of diode laser irradiation to significantly decrease SBS of polycrystalline brackets (14,16). However, other studies in the literature (17,18) found that the diode laser was ineffective in lowering the SBS of polycrystalline brackets. This may be explained by the fact that the polycrystalline bracket used in these studies had a stainless steel slot which may have likely reflected or absorbed the laser energy away from the adhesive and the bracket base.

The basis of laser-aided debonding is the ability of the laser light to cause resin degradation by thermal softening, thermal ablation or photoablation. While thermal softening occurs at relatively lower rates of energy deposition, and therefore a slower heating process which causes softening of the adhesive, thermal ablation and photoablation occurs when there is faster energy deposition and more rapid heating of the adhesive causing the brackets to “blow-off” from the tooth surface (26). In the current study, no explosive blow-offs were observed suggesting that resin degradation occurred via thermal softening. This observation was consistent with those of previous studies evaluating diode laser-aided debonding (14,17,19,20) and may be explained by the fact that irradiation from a diode laser causes relatively slower heating of the adhesive resin (26).

Removal of ceramic brackets poses a challenge because sufficiently high forces must be applied to break the strong bond formed between the tooth and the ceramic bracket. The current study showed that the mean SBS values for the control groups (Groups MC and PC) were 33.22 ± 3.99 MPa and 39.97 ± 7.61 MPa respectively and are consistent with results from other studies (1,21,29–31). These SBS values exceed the maximum bond strength of enamel which is approximately 14 MPa (32), thus raising the risk of enamel chipping or fracture associated with bracket debonding. In the current study, measurement of enamel crack length and frequency (11) was used to assess enamel damage. Initial and final frequencies and lengths of enamel cracks were measured for all four groups. Enamel crack frequencies and lengths were significantly higher in the control groups than in their corresponding laser groups at the end of the experiment. These findings were in agreement with those from previous studies that emphasized the effect of diode laser-aided debonding in significantly decreasing the number and lengths of enamel (5,15,20,33). This may be because less force is applied when debonding brackets after thermal softening of the adhesive. Nevertheless, the significant, albeit small increase in the number and lengths of enamel cracks after laser-aided debonding may be attributed to the utilization of forces that were still above the breaking strength of enamel. Despite the high SBS required for ceramic bracket debonding, no specimen in the current study exhibited enamel fractures or chipping after debonding in the control groups or the laser aided-debonding groups. Although debonding of ceramic brackets using the CO_2 laser (5) and the Er,Cr:YSGG laser (33) resulted in a significantly lower increase of enamel crack frequency and lengths, the large size of the CO_2 laser and the high cost of both CO_2 and erbium lasers pose a disadvantage (14). This encourages the use of the diode laser to aid in the debonding of ceramic brackets due to its small size, cost-effectiveness and ease of use (20).

In the current study, the most common ARI score in the control groups (Groups MC and PC) was 1 while most samples in the laser groups (Groups ML and PL) had an ARI score of 2 and 3 indicating that bond failure predominantly occurred at the enamel-adhesive interface in the control groups and at the bracket-resin interface in the laser groups. However, the ARI scores did not significantly differ among the four groups. These findings were consistent with those from numerous other studies (5,9,14,15,27,28,34,35) that revealed higher, but not statistically significant, ARI scores in samples debonded using lasers. This could be explained by the interaction of the silane coupling agent with the adhesive in chemically retained ceramic brackets forming a stronger bond compared to that formed between the adhesive and the enamel surface (4,36). During debonding of these brackets, forces applied may cause bond failure predominantly at the enamel-adhesive interface due to the relatively weaker bond at this interface. This consequentially increases the risk of enamel damage (4,36). Due to thermal softening of the resin adhesive using laser, bond failure may occur within the adhesive or at the bracket-adhesive interface protecting the enamel and minimizing the risk of enamel damage (9,26,33). On the contrary, some studies (19,20) have reported lower ARI scores in laser samples than in conventionally debonded samples. These studies have reported that lower ARI scores are more favorable because removal of remnant adhesive increases the risk of enamel damage and is time consuming. Therefore, in cases where laser-aided debonding results in higher ARI scores, cautious enamel clean-up may be necessary to avoid damaging the enamel.

CONCLUSION

Based on the findings of this in vitro study, and within its limitations, it can be concluded that:

1. The diode laser is effective in debonding both monocrystalline and polycrystalline brackets by lowering their SBS. The diode laser mostly degraded bonding resin by thermal softening.
2. Diode laser-aided debonding of monocrystalline and polycrystalline brackets resulted in less enamel damage when compared to conventional debonding.
3. Diode laser debonding did not have a significant effect on the ARI scores. However, most of the samples debonded with the aid of a diode laser had a score of 2 or 3 which is associated with less possibility of enamel damage.

REFERENCES

1. Fox NA, McCabe JF. An easily removable ceramic bracket? Br J Orthod. 1992;19(4):305–9.

2. Eliades T, Lekka M, Eliades G, Brantley WA. Surface characterization of ceramic brackets: A multitechnique approach. Am J Orthod Dentofac Orthop. 1994;105(1):10–8.

3. Karamouzos A, Athanasiou AE, Papadopoulos MA. Clinical characteristics and properties of ceramic brackets: A comprehensive review. Am J Orthod Dentofacial Orthop. 1997;112:35-40.

4. Bishara SE, Fehr DE. Ceramic brackets: something old, something new, a review. Semin Orthod. 1997;3(3):178–88.

5. Ahrari F, Heravi F, Fekrazad R, Farzanegan F, Nakhaei S. Does ultra-pulse CO 2 laser reduce the risk of enamel damage during debonding of ceramic brackets? Lasers Med Sci. 2012;27(3):567–74.

6. Bishara SE, Trulove TS. Comparisons of different debonding techniques for ceramic brackets: An in vitro study. Part II. Findings and clinical implications. Am J Orthod Dentofac Orthop. 1990;98(3):263–73.

7. Nalbantgil D, Tozlu M, Oztoprak MO. Pulpal thermal changes following Er-YAG laser debonding of ceramic brackets. Sci World J. 2014;2014:1-4.

8. Tehranchi A, Fekrazad R, Zafar M, Eslami B, Kalhori KAM, Gutknecht N. Evaluation of the effects of CO2 laser on debonding of orthodontics porcelain brackets vs. the conventional method. Lasers Med Sci. 2011;26(5):563–7.

9. Tozlu M, Oztoprak MO, Arun T. Comparison of shear bond strengths of ceramic brackets after different time lags between lasing and debonding. Lasers Med Sci. 2012;27(6):1151–5.

10. Sarp ASK, Gülsoy M. Ceramic bracket debonding with ytterbium fiber laser. Lasers Med Sci. 2011;26(5):577–84.

11. Ghazanfari R, Nokhbatolfoghahaei H, Alikhasi M. Laser-Aided ceramic bracket debonding: A comprehensive review. J Lasers Med Sci. 2016;7(1):2–11.

12. Han X, Liu X, Bai D, Meng Y, Huang L. Nd:YAG Laser-aided ceramic brackets debonding: Effects on shear bond strength and enamel surface. Appl Surf Sci. 2008;255(2):613–5.

13. Dostalova T, Jelinkova H, Sulc J, Nemec M, Jelinek M, Fibrich M, et al. Ceramic bracket debonding by Tm:YAP laser irradiation. Photomed Laser Surg. 2011;29(7):477–84.

14. Anand P, Anand PB, Prabhakar R, Rajvikram N, Rajakumar P, Atali VR, et al. Immediate and delayed effects of diode laser on debonding of ceramic brackets: An in vitro study. J Contemp Dent Pract. 2016;17(4):275–81.

15. Yassaei S, Aghili H, Ebrahimi-Nik Z. Different modes of diode laser irradiation: Effects on enamel surface and intrapulpal temperature at debonding. Laser Ther. 2018;27(3):214–8.

16. Almohaimeed M, Abd El Halim S. Diode Laser De-Bonding of Pre-Coated Ceramic Brackets. J Am Sci. 2013;9:177–81.

17. Feldon PJ, Murray PE, Burch JG, Meister M, Freedman MA. Diode laser debonding of ceramic brackets. Am J Orthod Dentofac Orthop. 2010;138(4):458–62.

18. Ivanov P. Investigation of diode laser debonding of ceramic orthodontic brackets. Nova Southeastern University; 2012.

19. Sinaee N, Salahi S, Sheikhi M. Evaluation of the effect of diode laser for debonding ceramic brackets on nanomechanical properties of enamel. Dent Res J (Isfahan). 2018;15(5):354–60.

20. Yassaei S, Soleimanian A, Nik ZE. Effects of Diode Laser Debonding of Ceramic Brackets on Enamel Surface and Pulpal Temperature. J Contemp Dent Pract. 2015;16(4):270–4.

21. Reddy YG, Sharma R, Singh A, Agarwal V, Agrawal V, Saurab C. The shear bond strengths of metal and ceramic brackets: An in-vitro comparative study. J Clin Diagnostic Res. 2013;7(7):1495–7.

22. Saghaei M. Random allocation software for parallel group randomized trials. BMC Med Res Methodol. 2004;4:1–6.

23. Årtun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod. 1984;85(4):333–40.

24. Maturo P, Perugia C, Docimo R. Versatility of an 810 nm diode laser in pediatric dentistry. Oral Pathol Oral Med. 2015;2007(4):161–72.

25. Derikvand N, Chinipardaz Z, Ghasemi S, Chiniforush N. The versatility of 980 nm diode laser in dentistry: A case series. J Lasers Med Sci. 2016;7(3):205–8.

26. Tocchio RM, Williams PT, Mayer FJ, Standing KG. Laser debonding of ceramic orthodontic brackets. Am J Orthod Dentofac Orthop. 1993;103(2):155–62.

27. Strobl K, Bahns TL, Wiliham L, Bishara SE, Stwalley WC. Laser-aided debonding of orthodontic ceramic brackets. Am J Orthod Dentofac Orthop. 1992;101(2):152–8.

28. Oztoprak MO, Nalbantgil D, Erdem AS, Tozlu M, Arun T. Debonding of ceramic brackets by a new scanning laser method. Am J Orthod Dentofac Orthop. 2010;138(2):195–200.

29. Forsberg CM, Hagberg C. Shear bond strength of ceramic brackets with chemical or mechanical retention. Br J Orthod. 1992;19(3):183–9.

30. Theodorakopoulou LP, Sadowsky PL, Jacobson A, Lacefield W. Evaluation of the debonding characteristics of 2 ceramic brackets: An in vitro study. Am J Orthod Dentofac Orthop. 2004;125(3):329–36.

31. Ansari MY, Agarwal DK, Gupta A, Bhattacharya P, Ansar J, Bhandari R. Shear bond strength of ceramic brackets with different base designs: Comparative in-vitro study. J Clin Diagnostic Res. 2016;10(11):64–8.

32. Arhun N, Arman A, Sesen Ç, Karabulut E, Korkmaz Y, Gokalp S. Shear bond strength of orthodontic brackets with 3 self-etch adhesives. Am J Orthod Dentofac Orthop. 2006;129(4):547–50.

33. Naseri N, Ghasemi N, Baherimoghadam T, Azmi A. Efficacy of Er,Cr:YSGG laser for debonding of ceramic brackets and prevention of enamel damage and intrapulpal temperature change. Lasers Dent Sci. 2020;4(3):157–63.

34. Alakuş Sabuncuoğlu F, Erşahan Ş,

Ertürk E. Debonding of Ceramic Brackets by Er:YAG Laser. J Istanbul Univ Fac Dent. 2016;50(2):24–30.

35. Macri RT, de Lima FA, Bachmann L, Galo R, Romano FL, Borsatto MC, et al. CO2 laser as auxiliary in the debonding of ceramic brackets. Lasers Med Sci. 2015;30(7):1835–41.

36. Bishara SE, Trulove TS. Comparisons of different debonding techniques for ceramic brackets: An in vitro study. Part I. Background and methods. Am J Orthod Dentofac Orthop. 1990;98(2):145–53.