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ORIGINAL ARTICLE

Does ultra-pulse CO_2 laser reduce the risk of enamel damage during debonding of ceramic brackets?

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Abstract This study seeks to evaluate the enamel surface characteristics of teeth after debonding of ceramic brackets with or without laser light. Eighty premolars were bonded with either of the chemically retained or the mechanically retained ceramic brackets and later debonded conventionally or through a CO_2 laser (188 W, 400 Hz). The laser was applied for 5 s with scanning movement. After debonding, the adhesive remnant index (ARI), the incidence of bracket and enamel fracture, and the lengths, frequency, and directions of enamel cracks were compared among the groups. The increase in intrapulpal temperature was measured in ten extra specimens. The data were analyzed with SPSS software. There was one case of enamel fracture in the chemical retention/conventional debonding group. When brackets were removed with pliers, incidences of bracket fracture were 45% for the chemical retention, and 15% for the mechanical retention brackets. No case of enamel or bracket fracture was seen in the laser-debonded teeth. A significant difference was observed in ARI scores among the groups. Laser debonding caused a significant decrease in the frequency of enamel cracks, compared to conventional debonding. The increase in intrapulpal temperatures was below the benchmark of 5.5 °C for all the specimens. Laser-assisted debonding of ceramic brackets could reduce the risk of enamel damage and bracket fracture, and produce the more desirable ARI scores without causing thermal damage to the pulp. However, some augmentations in the length and frequency of enamel cracks should be expected with all debonding methods.

Keywords Ceramic bracket · CO_2 laser · Debonding · Enamel crack · Enamel fracture · Enamel damage · Intrapulpal temperature

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Introduction

The introduction of ceramic brackets in the mid-1980s could be considered a great step towards achieving aesthetic orthodontic appliances, and so it was well received by adult patients usually concerned with aesthetics of their teeth. Although ceramic brackets enjoy both durability and resistance to discoloration, problems have been faced with their clinical performance in orthodontics. Enamel damage and bracket fracture are common complications with conventional debonding of ceramic brackets [1–3], which are attributed to the high bond strength combined with the low fracture toughness (the ability to resist breakage) of ceramics [4–6]. Enamel damage, either in the form of enamel tear out (fracture) or as enamel crack, detracts from the esthetics of the teeth and may need costly restorative treatment. Bracket breakage precludes reuse of the same bracket at a corrected position and may result in eye damage, ingestion, or aspiration of bracket fragments. In addition, the remaining bracket sometimes demands removal with a diamond bur in a high-speed handpiece.

Several methods have been suggested for debonding of ceramic brackets, including ultrasonic tools, electrothermal devices, and lasers. The electrothermal method is based on softening the adhesive resin at a temperature above 150–200°C to allow removing the brackets at a significantly reduced force level [7]. Pulp damage was, however, reported in some studies,[8, 9] and thus reducing the popularity of electrothermal method among orthodontists. The main mechanism for the performance of laser light is through photothermal interaction that results in thermal softening of the composite [7, 10–12]. Different laser wavelengths have been experimentally used to remove ceramic brackets. Stroble et al. [7] used CO_2 or Nd:YAG lasers for debonding both monocrystalline and polycrystalline ceramic brackets and concluded that laser-assisted debonding significantly reduced the debonding force, the risk of enamel damage, and the incidence of bracket failure. Using excimer lasers or Nd:YAG laser for debonding of ceramic brackets, Tocchio et al. [13] reported no enamel or bracket damage in any of the irradiated specimens. Hayakawa [14] indicated that the application of Nd:YAG laser caused a significant decrease in debonding force of ceramic brackets and created the most optimal ARI scores. Recently, the Er:YAG laser has been used with scanning movement for debonding of ceramic brackets and the results showed its effectiveness for bracket removal without damaging the enamel or pulpal tissues [11, 15]. Despite the success achieved with different types of lasers, many investigators believe that the CO_2 laser is the best option for removal of ceramic brackets [7, 10, 12, 16, 17]. This is related to the high surface absorption of this wavelength in ceramics, which results in effective thermal softening of the adhesive resin and facilitates bracket removal.

Several studies [7, 10–12, 15, 16, 18] have demonstrated the effectiveness of lasers in reducing the bond strengths of ceramic brackets, but few have dealt with the effects of laser light in reducing the enamel damage, and the method used in these studies was not precise enough. For example, Hayakawa [14] relied on SEM evaluation to report minimal enamel roughness and enamel loss, following removal of ceramic brackets with the Nd:YAG laser. However, the use of a scanning electron microscope (SEM) to detect any enamel damage requires a special gold treatment of the enamel surface and this is what makes the lesion detection difficult [19]. The present study, therefore, aims to compare the adhesive remnant index (ARI), the incidence of bracket and enamel fractures, and the lengths, frequency, and directions of enamel cracks after removal of two types of ceramic brackets with or without laser light.

Materials and methods

A total of 90 human upper and lower premolar teeth extracted for orthodontic purpose were cleaned and stored in distilled water at room temperature. The selected teeth had intact buccal surface and were free of carious lesions. Eighty teeth were used for enamel damage assessment and ten for temperature measurement. In order to achieve a reproducible tooth position in the stereomicroscope, the teeth were mounted horizontally in rectangular metal molds with the use of a self-curing acrylic resin. The mounted teeth were randomly divided into four groups of 20, and each tooth was assigned a number.

The buccal surfaces of the teeth were cleaned with non-fluoridated pumice slurry and rubber prophylactic cups for 10 s, rinsed with water, and then air-dried. A magnified image (23.5×) from the buccal surface of each tooth was then achieved using a stereomicroscope (Blue Light Industry, Waltham, MA, USA) equipped with a color digital video camera (Exwave HAD, Sony Corporation, Tokyo, Japan). The lengths and directions of the enamel cracks relative to the long axis of the tooth were determined using Adobe Photoshop CS software (Adobe Systems Incorporated, San Jose, CA, USA). The directions of the enamel cracks were defined as: vertical (0–30 degrees to the long axis of the tooth), oblique (30–60 degrees to the long axis of the tooth), and horizontal (60–90 degrees to the long axis of the tooth). The number of enamel cracks in the microscopic images and the number of pronounced cracks were also determined. The pronounced cracks were those that were being seen by the naked eyes under normal office illumination without the use of diagnostic aids [20, 21].

Bracket bonding

Two types of ceramic brackets were used in this study: Fascination (Dentaurum, Ispringen, Germany), a polycrystalline ceramic bracket that features chemical retention and Inspire Ice (Ormco, Orange, CA, USA), a monocrystalline ceramic bracket with mechanical retention. The brackets were for the maxillary left second premolar tooth with 0.022-inch slot (Roth prescription).

The buccal surface to be bonded was etched with a 37% phosphoric acid gel for 30 s, rinsed thoroughly with water for 20 s, and then dried with an oil-free air spray until it appeared dull and frosty. A thin layer of Transbond XT primer (3M Unitek, Monrovia, CA, USA) was then painted onto the tooth and the brackets were bonded on the center of the buccal surface with the use of Transbond XT adhesive (3M Unitek). The excess composite was removed from the edge of the bracket with a dental explorer and the adhesive was cured for 20 s (10 s for each of the mesial and distal directions) by Bluephase C8 (Ivoclar Vivadent, Schaan, Liechtenstein) light-emitting diode (LED) irradiating a light intensity of 650 mW/cm^2. The teeth were then kept in water at 37°C for at least 24 h to allow achieving the maximum bond strength [22].

Bracket debonding

For each type of bracket, half of the specimens were debonded conventionally, i.e., with the use of pliers recommended by the manufacturer (control groups), and others were debonded by the aid of laser light (laser-assisted debonding groups). All debondings were performed by the same investigator.

Control groups Twenty Fascination (Group CC=chemical retention/conventional debonding) and 20 Inspire Ice brackets (Group MC=mechanical retention/conventional debonding) were removed with the pliers recommended by the manufacturers. Fascination brackets were debonded by placing the tips of the Weingart pliers on the mesial and distal sides of the bracket and applying a tortional rotation from right to left. The Inspire Ice ceramic brackets were removed by a peel force, applied with disposable plastic debonding pliers (Ormco). The tips of the instrument were placed under the occlusal and gingival tie-wings. The handles of the pliers were then squeezed and the debonding instrument was rotated from the gingival towards the occlusal edge of the bracket, using gradually increasing force until the bracket was released from the tooth.

Laser-assisted debonding groups Twenty Fascination (Group CL=chemical retention/laser debonding) and 20 Inspire Ice brackets (Group ML=mechanical retention/laser debonding) were removed by the aid of laser light. For this purpose, a carbon dioxide laser (Daeshin, model DS-40U, Daeshin Enterprise Corp, Guro-gu, Seoul, Korea) with a wavelength of 10.6 μm was selected. The laser operated at ultra-pulse mode with peak power of 188 W, frequency of 400 Hz, and pulse duration of 500 μs (interval time: 2,000 μs). The laser tip was held perpendicularly at a 5-mm distance from the bracket surface and the light was delivered in focused mode with a spot size of 1 mm. The irradiation was performed on the labial surface of the bracket for 5 s through horizontal scanning movements parallel to the bracket slot, initiating from the upper wings and continuing to the slot and the lower wings, as described previously [11, 15]. Following laser irradiation, the brackets were debonded with the use of recommended pliers in a similar manner as the control groups. The time delay between laser irradiation and force application was 3 s. The incidence of bracket fracture was recorded during debonding in all groups. Bracket fractures were defined as tie-wing breakage or fracture of the bracket base. In the latter case, it was not possible to remove the remaining bracket from the enamel surface without grinding by a rotating instrument.

Following debonding, the buccal surfaces of the teeth were examined with a stereomicroscope at 10× magnification to assess the amount of resin material adhered to the enamel surface. The adhesive remnant index (ARI) scores were determined for each tooth, according to the definition of Artun and Bergland [23]: 0: no adhesive remained on the tooth, 1: less than 50% of the adhesive remained on the tooth, 2: more than 50% of the adhesive remained on the tooth, 3: the entire adhesive remained on the tooth with a distinct impression of the bracket base.

After evaluation of the ARI, the remaining adhesive was removed from the buccal surface of the teeth with a 12-fluted tungsten carbide bur operated in a slow speed handpiece; a new bur was used for each group. The second photographic images of the teeth were then taken in a similar condition as the first one. The lengths, directions, and number of enamel cracks were measured in these images and the number of pronounced cracks was also determined. All photographs were analyzed by the same investigator.

Temperature measurement

The thermal effects of ultra-pulse CO_2 laser during debonding was measured in five teeth bonded with each type of bracket at a constant temperature of 25.5°C. The teeth used for thermal measurement were not embedded in acrylic resin and were held by hand. The apical third of the root was cut off, an access opening was made, and the pulp chamber remnants were removed by endodontic files. The pulp chamber was then injected with a viscous conducting medium and a k-type thermocouple was inserted into the pulp chamber so that its sensor tip was placed on the lingual surface of the pulp wall directly beneath the bracket. The thermocouple was connected to a computer via a Data logger system. The change in intrapulpal temperature was recorded continuously during and after lasing of the specimen using the software package.

Statistical analysis

The enamel crack data were compared between groups by analysis of variance (for crack length) and Kruskal–Wallis test (for crack number). When a significant difference was noted, the Tukey or Mann–Whitney *U* tests were performed to identify significant between-group differences. For each group, the change in the lengths of enamel cracks (before bonding and after debonding) was determined by paired-sample *t* test and the change in the number of cracks by Wilcoxon signed-rank test. Fisher's exact test was used to detect significant differences in crack directions and ARI scores among the groups. A level of 0.05 was considered significant for all statistical analyses.

Results

Bracket fracture and enamel tear out

There was one case of enamel tear out and three cases of bracket base fracture in the group of chemically retained ceramic brackets debonded conventionally. Removal of

Table 1 Lengths of enamel cracks (mm) before bracket bonding and after debonding

Bracket	Debonding method	Group abbreviation	Before mean±SD	After mean±SD	Difference mean±SD	*p* value[a]
Fascination	Conventional	CC	6.7±3.1	13.4±3.37	6.7±2.6	0.000
	Laser-assisted	CL	6.5±3.3	11.5±3.8	5.0±2.6	0.000
Inspire Ice	Conventional	MC	6.3±3.5	11.2±3.7	4.9±2.4	0.000
	Laser-assisted	ML	5.3±3.7	9.2±4.5	3.9±2.9	0.000
p value[b]			0.116	0.026	0.031	

[a] Paired *t* test

[b] ANOVA

bracket fragments with the use of pliers was not possible in the fractured specimens. Therefore, the number of teeth included for crack assessment and ARI scores was decreased to 16 in the CC group. The tie-wing breakage was observed in six specimens of chemical retention and three specimens of mechanical retention groups debonded conventionally. No case of enamel or bracket fracture was seen in the groups of ceramic brackets debonded with the aid of laser light.

Length of cracks

There were no significant between-group differences in the lengths of enamel cracks before bonding, but a significant difference was noted after bracket removal (Table 1). Tukey test indicated a statistically significant difference in the lengths of enamel cracks between CC and ML groups. The mean increases in the lengths of enamel cracks following debonding were 6.7 mm (100%) for CC group, 5.0 mm (77%) for CL group, 4.9 mm (78%) for MC group, and 3.9 mm (73%) in ML group. Paired sample *t* test indicated that the increase in the lengths of enamel cracks after debonding was statistically significant in all groups (Table 1).

Number of cracks

The number of cracks increased significantly in all groups after debonding ($p<0.05$). The Kruskal–Wallis test indicated no significant between-group differences in the number of enamel cracks before bonding, but a significant difference was noted after debonding (Table 2). Mann–Whitney *U* test indicated a significant difference between conventional and laser debondings for both types of brackets, and also between CC and ML groups ($p<0.05$).

The number of pronounced cracks also increased significantly in all groups following debonding ($p<0.05$), with the exception of ML group, in which the increase was not statistically significant ($p=0.317$). Although there were no between-group differences in the number of pronounced cracks before bonding, a significant difference was noted after debonding (Table 3). Mann–Whitney *U* test indicated that this difference occurred between CC and ML groups ($p=0.008$).

Directions of cracks

Before bracket placement, 91.7% of enamel cracks had vertical direction and 8.3% were oblique in direction (Table 4). Following debonding and adhesive removal, the percentage of vertical cracks fell to 75% and the percentage of oblique cracks rose to 23.8 (Table 5). Although there was no case of horizontal cracks before bonding, 1.2% of cracks after debonding ran horizontally. The results of the Fisher's exact test indicated no significant between group differences in the directions of enamel cracks either before bonding ($p=0.368$) or after debonding ($p=0.264$). A significant correlation was observed between the directions of enamel cracks before bonding and after bracket removal (contingency coefficient=0.38, $p<0.0001$).

Table 2 Number of enamel cracks before bonding and after debonding

Bracket	Debonding method	Group abbreviation	Before bonding mean rank	After debonding mean rank
Fascination	Conventional	CC	40.9	47.0
	Laser-assisted	CL	35.4	31.1
Inspire-Ice	Conventional	MC	37.9	40.1
	Laser-assisted	ML	31.2	28.2
p value[a]			0.12	0.005

[a] Kruskal–Wallis test

Table 3 Number of pronounced enamel cracks before bonding and after debonding

Bracket	Debonding method	Group abbreviation	Before bonding mean rank	After debonding mean rank
Fascination	Conventional	CC	42.3	47.8
	Laser-assisted	CL	36.4	38.9
Inspire-Ice	Conventional	MC	39.9	37.7
	Laser-assisted	ML	34.4	29.7
p value[a]			0.415	0.034

[a] Kruskal–Wallis test

Adhesive remnant index (ARI)

The results for the ARI scores are presented in Table 6. The ARI is considered to be a method of determination of bond failure interface. The Fisher's exact test showed a significant difference in the distribution of ARI scores among the groups (p=0.001). There was a higher percentage of ARI score 0 in both groups of brackets debonded conventionally. Laser-assisted debonding of chemically retained ceramic brackets increased the incidence of cohesive failure in the adhesive resin. Mechanically retained ceramic brackets that were debonded by the aid of laser light showed a high frequency (70%) of ARI score 3, indicating that bond failure occurred predominantly at the bracket–adhesive interface, leaving most of the adhesive on the enamel surface.

Temperature increase during debonding

The increase in the pulpal cavity temperature started about 1.5 seconds following laser irradiation and reached its maximum value within the next 3.5 seconds, then sharply (within 2 seconds) dropped to the room temperature. The mean increase in intrapulpal temperature was 4.4±0.5°C for monocrystalline bracket (Inspire Ice) and 3.9±0.32°C for polycrystalline bracket (Fascination).

Discussion

This study manipulates the ultra-pulse CO_2 laser for the fact that it can provide short-duration pulses with sufficient intervals to allow tissues to cool down between pulses [17, 24]. The scanning movement was used during laser irradiation to transmit the heat to the total surface of the bracket and thus preventing excessive increase in intrapulpal temperature. Both monocrystalline and polycrystalline ceramic materials are highly absorptive at CO_2 laser wavelength (10,600 nm). However, to avoid high amounts of laser energy that may damage the pulp, a form of mechanical help is necessary during or after laser application. In this study, the bracket removal was performed immediately (within 3 s) after laser exposure because the findings of a previous study proved that a 1-min interval between laser exposure and force application resulted in significantly higher debonding force as compared to immediate debonding [18]. The following will discuss the findings of the present study.

Bracket fracture The incidences of bracket fracture were 45% in the chemical retention and 15% in the mechanical retention brackets removed conventionally. More importantly, three fractured brackets in the chemical retention group needed grinding with a diamond bur for removal of remained bracket fragments. This procedure is time-consuming and has the potential to damage the pulp [25] and enamel surface [26]. The incidence of bracket fracture in the chemical retention group was slightly higher than those reported previously (10-35%) [27]. In agreement with previous studies [7, 10, 13], no bracket fracture resulted from laser-assisted debonding of both types of brackets. At the process of debonding, the brackets were detached easily and without the need to apply a high amount of pressure. Lack of bracket fracture may be advantageous when bracket repositioning is desired to correct tooth position following initial alignment of the teeth.

Enamel fracture and enamel cracks One case of enamel fracture was noted in the chemically retained brackets debonded conventionally. This phenomenon could be

Table 4 Directions of enamel cracks before bracket bonding

	CC		CL		MC		ML		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%
Vertical	27	87	26	96.3	26	89.7	21	95.4	100	91.7
Oblique	4	13	1	3.7	3	10.3	1	4.6	9	8.3
Total	31	100	27	100	29	100	22	100	109	100

Table 5 Directions of enamel cracks after bracket debonding

	CC		CL		MC		ML		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%
Vertical	60	75	44	83	46	68.7	33	75	183	75
Oblique	17	21.2	9	17	21	31.3	11	25	58	23.8
Horizontal	3	3.8	0	0	0	0	0	0	3	1.2
Total	80	100	53	100	67	100	44	100	244	100

explained by the high bond strength of chemical retention brackets and has been reported in several studies [1, 3, 28–31]. Fracture of the enamel surface would be an inevitable consequence when the required force for bracket removal exceeds the cohesive strength of the enamel.

This study reports a significant increase in the number and lengths of enamel cracks for both conventional and laser-assisted debonding groups. This finding is in line with a study by Zachrisson et al. [21] who reported significantly fewer cracks in the untreated reference teeth as compared to those of orthodontic patients. In the present study, significant between-group differences were observed in the lengths and frequency of enamel cracks after debonding, implying that laser-debonded specimens had a relatively smaller increase in the lengths and frequency of enamel cracks. It was also observed that most of the enamel cracks had vertical direction before bonding. This finding confirms the study of Zachrisson et al. [21] who reported that the vast majority of cracks ran in a predominantly vertical direction before bonding, but is in contrast with the results of Heravi et al. [32] who found that most cracks were placed in two or more directions before bonding. After bracket removal, the percentage of vertical cracks decreased and the percentage of oblique cracks increased in all groups. A previous study also found that the directions of most cracks changed during debonding [32]. This was attributed to the pattern of stresses in the enamel during debonding, which may cause enamel cracks to spread in a new direction [32].

The findings of the present study indicate a considerable risk of enamel damage during debonding of chemically retained ceramic brackets with pliers. This confirms the findings of Kitahara-Ceia et al. [19] and Eliades et al. [33] who reported that ceramic brackets with chemical retention caused the most significant changes on the enamel surface after bracket removal. Laser-assisted debonding of chemical retention brackets created enamel characteristics comparable to the one occurred with conventional debonding of mechanical retention brackets, and laser-assisted debonding of mechanical retention brackets produced the least amount of enamel damage compared to other groups.

ARI scores The adhesive remnant index is an important criterion in evaluating the probable risks of enamel damage. Bond failure at the enamel–adhesive interface has the advantage of protecting the enamel surface, but it necessitates meticulous grinding to remove the adhesive remnants on the tooth. The frequency of ARI score 0 in non-lased groups were 43.7 and 40% for the chemical and the mechanical retention brackets, respectively. Laser debonding decreased the percentage of ARI score 0 to 5% for the chemical retention, and to 10% for the mechanical-retention brackets. It also caused a 38.7% increase in the percentage of cohesive adhesive failure for the chemical retention group and 30% increase in the percentage of adhesive-bracket failure for the mechanical-retention group. These findings imply that laser-assisted debonding of ceramic brackets can cause a significant reduction in the probability of bond failure at the enamel–adhesive interface, thus minimizing the risk of enamel damage. This finding is in agreement with some previous studies reporting more cases of failure at the ceramic–adhesive interface, and the reduced possibility of enamel fracture when using laser light [7, 12].

Intrapulpal temperature Some previous investigations have reported efficacy of lasers in debonding orthodontic

Table 6 ARI scores in the study groups

ARI	CC		CL		MC		ML		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%
0	7	43.7	1	5	8	40	2	10	18	23.7
1	3	18.8	5	25	1	5	1	5	10	13.1
2	2	12.5	9	45	3	15	3	15	17	22.4
3	4	25	5	25	8	40	14	70	31	40.8
Total	16	100	20	100	20	100	20	100	76	100

brackets, but they did not measure the change in intrapulpal temperature [7, 13]. In the present study, the increase in intrapulpal temperature started about 1.5 s following laser irradiation due to the delayed effect of thermal changes occurred intrapulpally. The temperature of the pulp wall returned to the basic level within 2 s after peaking. Hayakawa [14] also reported that the pulp wall temperature returned to the base level in less than 3 s. Regarding the effects of externally applied heat on the pulpal tissue, the histological experiment of Zach and Cohen [34] on Rhesus monkeys indicated that the increase in intrapulpal temperature should be below 5.5°C in order to prevent irreversible pulpal damage. Therefore, the findings of the present study propose no risk of thermal damage when an ultra-pulse CO_2 laser is used with scanning movement for debonding of ceramic brackets. Obata et al. [17], and Iijima et al. [16] also found similar results.

In conclusion, laser debonding can allow bracket removal to be done with minimal damage to the tooth tissues. This technique may encourage manufacturers to develop smaller and more esthetic brackets with extra retention in the base in order to supply the esthetic demands of orthodontic patients, without increasing the risk of bracket detachment during treatment. Further research will be needed to evaluate the clinical effectiveness of lasers in reducing enamel damage and to define thermal damage and patient acceptance of this method for debonding of ceramic brackets.

Conclusions

Under the experimental conditions used in the present study:

1- Bracket fracture was observed in 45% of chemical retention, and 15% of mechanical retention groups debonded with pliers. There was no case of bracket fracture in the laser-debonded groups.

2- After debonding, the lengths and frequency of enamel cracks increased significantly in all groups, and the directions of cracks changed.

3- For each type of bracket, laser debonding caused a significant decrease in the number of cracks and an insignificant decrease in the length of cracks compared to debonding with pliers. Therefore, laser debonding can reduce the risk of enamel damage following removal of ceramic brackets.

4- The laser-debonded specimens had a lower frequency of ARI score 0 than conventional debonding groups, indicating a minimized probability of enamel damage.

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