Review Article

Debonding of Orthodontic Ceramic brackets: A comprehensive review of the literature – Part 2

Karthikeyan Subramani[1],*, Prashanti Bollu[1]

[1]*Advanced Education in Orthodontics and Dentofacial Orthopedics, College of Dental Medicine, Roseman University of Health Sciences, Nevada, United States*

A R T I C L E   I N F O

A B S T R A C T

The purpose of this 2 part review is to evaluate various debonding techniques for orthodontic ceramic bracket removal and their clinical applications. In this part 2 of the literature review, *in vitro* and *in vivo* studies on electrothermal debonding and Laser debonding techniques have been reviewed. Electrothermal debonding is a physiologically acceptable alternative to mechanical debonding. It requires minimal force following thermal softening of adhesive material and produces minimal changes to enamel surfaces compared to conventional methods. Minimal effects on enamel and intrapulpal temperature changes are noted with ytterbium fiber laser, diode laser and Tm:YAP laser. Different parameters are possible with CO_2 laser, Nd:YAG laser and Er:YAG laser that may need further research before considering them in clinical practice.

1. Introduction

In part 1 of the 2 part literature review, studies on mechanical and ultrasonic debonding techniques have been reviewed. In this part 2 of the literature review, *in vitro* and *in vivo* studies on electrothermal and laser debonding have been reviewed.

1.1. Electrothermal Debonding (ETD)

Electrothermal debonding (ETD) focuses on softening of adhesive material leading to bracket removal with minimal to no force. ETD was first described by Sheridan et al[1] as a method to debond ceramic brackets utilizing cordless battery devices that generated heat, which was transferred to ceramic brackets resulting in softening of adhesive material and bracket removal without use of excessive force. Sheridan et al[1] studied the rise in temperature at pulpal wall with ETD on primate teeth. Results showed that ETD elicited pulpal wall temperatures that were significantly lower than the baseline. They

also concluded that, when water spray was used in conjunction with ETD, the mean increase in pulpal wall temperature was less than 1°C. In a follow-up study Sheridan et al[2] investigated the histologic features of primate pulp after ETD. Histologic examination revealed no evidence of cellular pathosis or modification other than cellular modification that corresponded to placement of the extraction forceps. From both these studies, they concluded that ETD is a physiologically acceptable alternative to conventional debonding techniques. Bishara et al[3] compared electrothermal, ultrasonic and conventional debonding technique recommended by manufacturer and concluded that ETD resulted in reduced incidence of bracket failure, shorter debonding time and decreased enamel damage when compared to the other two methods.

Sernetz et al[4] evaluated the increase in pulpal temperatures on extracted mandibular incisors as these teeth have low thermal mass and low heat sensitivity. Ceramic brackets from GAC (Allure III), Unitek (Transcend) and Dentaurum (Fascination) were debonded using the Dentaurum Ceramic Debonding Unit. An electrothermal element was placed in the pulp chamber filled with a

* Corresponding author.
E-mail address: ksubramani@roseman.edu (K. Subramani).

conducting paste and the change in temperature was recorded. All brackets were debonded under 3 seconds with the rise in intrapulpal temperature under the 5°C biocompatible threshold. Scanning electron microscopic evaluation showed a predictable and favorable adhesive failure pattern at the bracket base/resin interface with no enamel damage. They concluded that ETD using Dentaurum Ceramic Debonding Unit as a safe, reliable, efficient method to debond ceramic brackets while maintaining a physiologically acceptable rise in pulpal temperature without damage to tooth enamel or pulpal tissue. A similar result was observed by Brouns et al[5] in a study utilizing two different kinds of devices for ETD of ceramic brackets. The rise in pulpal wall temperature stayed below the established primate threshold temperatures and significantly below that of the simulated control groups. They also noted significant difference when air cooling was initiated during ETD. Histologic evaluations by Kailasam et al[6] and Jost-Brinkmann et al[7] following ETD have confirmed that there was no pulpal tissue damage. Kearns et al[8] evaluated the amount of shear forces necessary to debond ceramic brackets from human premolar teeth using ETD and mechanical debonding techniques and temperature rise in the pulp cavity during ETD. The results showed that ETD required less force than the mechanical debonding technique. The results also showed that the associated pulp temperature rise appeared to be within currently established biologically acceptable limits.

Dovgan et al[9] clinically evaluated ETD of premolars which were planned for orthodontic extraction in patients. They studied the time required for debonding, patient acceptance and histologic effect on the pulp. Monocrystalline sapphire ceramic brackets were bonded on the teeth and ETD was used to debond the brackets. Sensation during debonding was recorded from the patients. After ETD, the teeth were extracted at time intervals between 5 to 7 or 28 to 32 days and histologically prepared. The results showed that the brackets were removed at an average of 2.1 seconds, usually at the bracket/adhesive interface. Patient acceptance was generally positive. Pulpal necrosis was not observed histologically but, in a number of specimens, there was slight inflammation and odontoblastic disruption. In another study, Kraut et al[10] clinically evaluated patient discomfort, enamel fracture and bracket failure when using mechanical debonding with pliers and ETD using the Dentaurum thermal debonding device. Ceramic bracket removal was performed on 15 healthy patients' maxillary or mandibular premolars that were scheduled for extraction. The teeth were later extracted and histologically analyzed. The results showed that the patients reported that ETD was comfortable than mechanical debonding. Histologic evaluations showed that there was no pulpal damage following ETD. The study concluded that ETD was less traumatic and produced minimal enamel

surface changes compared to a mechanical debonding plier.

1.2. Laser Debonding

Laser-aided debonding of ceramic brackets is conceptually similar to the use of the electrothermal approach by heat generation to soften the adhesive.[8] Adhesive softening occurs through three processes: thermal softening, thermal ablation and photoablation. The process of thermal softening occurs when the bonding agent is heated and the bracket slides off the tooth surface. Thermal ablation is the process whereby the temperature increases rapidly in an adhesive resin vaporization range and the bracket blows off the tooth surface. In photoablation, the energy level of the bonds between the bonding-resin atoms rapidly increases above their dissociation energy levels resulting in decomposition of the material. There are 4 major types of lasers classified by their lasing mediums: gas, liquid, solid, and semiconductor (or laser diode). Various studies have been conducted to explore the applicability of lasers for ceramic bracket removal.

1.2.1. CO₂ Laser

Macri et al[11] tested several parameters of CO_2 lasers by evaluating the temperature in the bonding composite and in pulp chamber, shear bond strength (SBS) after irradiation with laser, and Adhesive Remnant Index (ARI) after debonding of ceramic brackets in an *in vitro* study on one hundred and five extracted human premolar teeth. A thermocouple probe was placed at composite interface and measurements were taken at bracket bonding, but before photoactivation. Intrapulpal temperature measurements were also taken. Twelve different protocols were employed including CO_2 lasers output power (5W, 8W and 10W), pulse duration (0.01S and 0.03s), and irradiation time (3s and 5s). The study concluded that CO_2 lasers could be utilized in debonding ceramic brackets using the protocol 10W/0.01s/3s, which was the least harmful to pulpal temperature rise that is below the threshold temperature of 5.5°C in the pulp chamber. Shear bond test and ARI values obtained showed that debonding occurred at the composite-bracket interface and were effective in preserving dental enamel.

Tehranchi et al[12] evaluated the effects of super plus CO_2 laser on SBS, site of debonding and ARI of ceramic brackets compared to the conventional method. Their study concluded that the control group had a higher SBS in comparison with the experimental super plus CO_2 laser group. The site of debonding in control group was closer to enamel-adhesive interface with a reduced ARI during debonding. Similar result was observed by Ahrari et al[13] in a study utilizing ultra-pulse CO_2 laser (10,600 nm) to debond ceramic brackets in a scanning movement and their effects on enamel damage during debonding compared to conventional debonding method. Significant decrease

in frequency of enamel cracks and specific direction (vertical/oblique), ARI and minimal intrapulpal temperature changes of 4.4°C for monocrystalline brackets (Inspire Ice) and 3.9°C for polycrystalline brackets (Fascination) were noted. 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.

According to Saito et al[14] CO_2 laser irradiation alone does not affect SBS. In their study, brackets were bonded with an orthodontic adhesive containing thermal expansion microcapsules. Furthermore, when CO_2 laser irradiation (3W) was utilized on teeth bonded with 30 wt% microcapsules for 5-6s, the SBS decreased by 0.46 fold. Similar results were noted with 40 wt% microcapsules where SBS decreased by 0.40-0.48 fold compared with the non-laser groups. The temperature increase in the pulp chamber was noted to be less than 3.4°C when teeth were irradiated for 4, 5, or 6s. The ceramic bracket absorbed much of the energy emitted by the laser and minimal heat would reach the tooth substance or the pulp chamber.

1.2.2. Er:YAG Laser

Oztoprack et al[15] utilized the Er:YAG laser to debond ceramic brackets. The Er:YAG laser contains a tip with a diameter of 1 mm. The energy from the tip of the laser was applied by scanning thorough the surface of the bracket for nine seconds in a horizontal direction parallel to the bracket slot and 2 mm away from the bracket. The study found a negative correlation between SBS and ARI score; as the SBS decreased, the ARI scores increased. The laser group had twice as much adhesive as the control group; which lead to fewer or no enamel damage. Furthermore, the authors compared the Er:YAG laser to Nd:YAG, concluding that the Er:YAG laser has less thermal effect on adhesive resin with a reduction in heat conduction to the pulp. It also requires a scanning method rather than application to one point to avoid further damage. Finally, Oztoprack et al[15] recognized the need for further investigation to evaluate the laser's true effect on pulpal tissue.

A follow-up to Oztoprack's work, Nalbantgil et al[16] confirmed similar SBS and ARI score values with the use of the Er:YAG laser. The study further investigated the effects of the laser on intrapulpal tissue by testing different durations of Er:YAG laser during debonding. A lasing time of 6s by the scanning method was found to be the most effective and safe on both enamel and pulpal tissue during bracket removal. Moreover, in another study by Nalbantgil et al,[17] examined the use of the same laser with and without water during debonding along with SBS. These two groups were also compared to the conventional mechanical method of debonding ceramic brackets. Their findings were statistically significant; the SBS was higher in the control group 22.76 MPa, followed by the water-cooling laser group

10.46 MPa and waterless laser group 6.36 MPa. The mean pulpal temperature was recorded to be 2.41°C and 4.59°C for the water-cooling and waterless laser group respectively. Concluding that the use of Er:YAG laser is safe and effective to debond ceramic brackets when using a water-cooling approach due to the lasers wavelength of 2904mm which corresponds to absorption peak of water.

Mundethu et al[18] debonded polycrystalline Damon Clear brackets via Er:YAG laser, one that is well known for its large absorption in water. The following parameters were tested in a pilot study to confirm laser safety to the enamel surface; 600mJ, 2 Hz, 800μs pulse duration. The Scanning Electron Microscope (SEM) images from the pilot study confirmed that only 100-120μm of adhesive is ablated below the brackets, which is about one fourth of the total adhesive layer thickness, therefore preserving the enamel surface. Thus, the authors concluded that laser energy is absorbed in the first 100μm of the adhesive leading to thermomechanical ablation debonding mechanism that caused a "blowoff" of the ceramic bracket. The phenomenon is explained as, when water absorbs the energy and rapidly expands causing subsurface pressure due to the expanding water vapor within the enclosed environment of the bracket–adhesive interface and consequently pushes the bracket outward in a pop-off sound. Further research is underway to examine the effects Er:YAG laser has on thermal pulpal temperature.

1.2.3. Ytterbium Fiber Laser

Sarp et al[19] tested the debonding ability of ytterbium fiber laser on polycrystalline G&H ceramic brackets. The study aimed to develop a laser debonding technique for ceramic brackets that is better than mechanical debonding while also minimizing the side effects of laser application. The lasing experiment was performed in two modes: continuous wave (CW) and modulated mode. In CW mode the laser was applied on samples with different constant power levels continuously. In the modulated mode the laser energy was delivered with on-and-off cycles by a set current (4.99A) and power (18W). Both modalities of laser irradiation significantly decreased bond strength by thermal softening, time and work done with minimal intrapulpal temperature change when compared to the 5.5°C threshold value. In the CW group, intrapulpal temperature changes increased with increasing laser power. Moreover, the modulated mode laser application provided faster and easier debonding with less temperature change.

1.2.4. Diode Laser

Yassaei et al[20] examined the effects of diode laser on enamel surface and pulpal temperature versus conventional methods. Thirty polycrystalline brackets were debonded using a 10s sweeping movement at a wavelength of 980nm with a power of 2.5W lasing technique on intact teeth. The

results were as follows: no enamel fractures were noted, a decrease in length and frequency of enamel cracks were detected compared with the conventional method and a 1.46°C increase in pulpal temperature was noted. The study concludes some enamel cracks can be expected regardless of debonding method.

1.2.5. Nd:YAG Laser

Hayakawa et al[21] study aim was to develop an effective method for debonding ceramic brackets with high-peak power of Nd:YAG laser at 1.2ms, 1.0, 2.0 and 3.0J at 5 pulses per seconds. Monocrystalline Inspire and Polycrystalline Clarity 3M Unitek ceramic brackets were bonded to bovine teeth with 4-META/MMA-based adhesive containing no fillers and Bis-GMA-based photoactivated containing fillers. No significant differences were found among adhesive resins in the 2.0J and 3.0J groups. The lasing energy was applied to two spots: the mesiodistal center of the gingival surface and the coronal surface under each bracket wing, which is labiolingually the thinnest part of the ceramic bracket. SBS: 3.0J and 2.0J groups showed significant decrease in bond strength in comparison to 1.0J lasing and conventional. The 2.0J group with polycrystalline ceramic bracket exhibited a significant decrease in comparison with monocrystalline group due to the non-uniform crystal structure that enables high transmissibility, which increases the energy loss passing through the bracket to the resin. All specimens in these two groups debonded immediately after irradiation, the remnant resin appeared burned out directly under the lasing points. Lasing energy is directly applied to the resin and is not absorbed by the ceramic bracket leading to gas pressure generated by either thermal ablation or photoablation functioning as the debonding force. Temperature rise reached its maximum at 5.1°C within 0.5s of lasing and dropped to prelasing level within 3.0s regardless of lasing energy level. Dramatic effects are plausible if lasing is directly placed on the tooth itself rather than the bracket base leading to thermal shock to the enamel-dentin junction and weakening the tooth. Thus further studies should be tested before the clinical use of this technique.

1.2.6. Tm:YAP Laser

Dostalova et al[22] evaluated the loss of enamel, residual resin on teeth and rise in intrapulpal temperature following Tm:YAP laser irradiation. Fascination 2 and Clarity SL APC brackets were lased at 1W and 2W laser output power with cooling water. The lasing was set for a period of 60s and the ceramic brackets were removed mechanically, with 3M Unitek band-removing pliers after adhesive softening took place. The study determined the temperature rise was different in the two ceramic bracket groups due to the metal component of Clarity SL APC bracket at a rise of 3.8°C versus 3°C for Fascination 2 bracket, both well below the

5.5°C threshold value. Furthermore, the metal component of Clarity SL APC blocked the laser radiation leading to more adhesive remnants on brackets but was still far less than the mechanical debonding mechanism. Relatively greater force was applied to the non-lasing group in comparison to the experimental leading to microscopic roughness and various degrees of gouges to the enamel surface. These findings can shed light on the potential of plaque accumulation, stain, odor and demineralization through microbial activity following debonding.

2. Discussion

2.1. Electrothermal Debonding

A general consensus among studies lead by Sheridan et al,[1,2] Sernetz et al,[4] Brouns et al,[5] Dovgan et al[9] and Kraut et al[10] concluded that the use of ETD is physiologically acceptable alternative to conventional debonding techniques. The addition of air coolant by Brouns et al[5] saw a significant reduction in intrapulpal temperature below the 5°C biocompatible threshold, was generally accepted by all patients[9] and produced minimal changes to enamel surfaces compared to conventional methods.[10]

2.2. Laser Debonding

Evaluating use of Lasers to debond ceramic brackets has been a challenge. Currently, a clear consensus of ideal parameters does not exist for any of the Lasers that were studied: CO_2 laser,[11–14] Nd:YAG laser,[21] Er:YAG laser,[15–18] ytterbium fiber laser,[19] diode laser[20] and Tm:YAP laser.[22]

CO_2[11–14] and Tm:YAP[22] lasers debond ceramic brackets through thermal softening leading to decrease in SBS with minimal increase in pulpal temperature. For CO_2 lasers, the beam is absorbed mainly by the ceramic bracket. According to Dostalova et al[22] when metal components are present within a bracket, irradiation of Tm:YAP laser may become blocked leading to increased ARI. Both lasers lead to minimal mechanical force following thermal softening in comparison to conventional methods.

Furthermore, several aspects of CO_2 laser were tested including direct application of beam versus scanning movement and finally adhesives containing different amount of thermal expansion. The results proved that CO_2 laser maybe advantageous in bracket removal as it decreases the duration of debonding with minimal to no increase in intrapulpal temperature and no enamel damage as fracture failure occurs between enamel-adhesive inter face.

Er:YAG laser[15–18] output is strongly absorbed by water unlike Nd:YAG[21] laser which tends to increase intrapulpal temperature. Temperature proportionally increased with extended lasing time, a six second lasing time was found to be optimal in regards to safety and effectiveness,[16] the addition of water coolant also reduced thermal effects.[17]

Oztoprak et al[15] concluded that a scanning method rather than a one point contact with Er:YAG laser leads to adhesive softening followed by bracket debonding with adhesive remnants remaining on enamel. With different parameters of output power, pulse duration and lasing irradiation with Er:YAG laser a thermomechanical ablation is possible where a ceramic bracket can experience a "blow off" as it debonds from the enamel surface. Mundethu et al[18] found that with a single laser pulse, water absorbs the energy, vaporizes and rapidly expands causing subsurface pressure at the bracket-adhesive interface and subsequently pushes the bracket outward in a pop-off manner. Although this process preserves enamel surface, this method of bracket debonding may be dangerous in clinical settings. It requires protection measures to both patient and clinician. Patients are likely to swallow brackets during debonding "blowoff", the bracket may become extensively warm and painful when landing in the oral cavity or come in contact with the patient and clinician.

Similarly, thermal ablation or photoablation functioning as the debonding force in Nd:YAG laser is possible. When these parameters are set in Nd:YAG laser[21] the intrapulpal temperature rise is instantaneous and returns to base levels in less than three seconds. Caution is advised when using these settings as mentioned above. Ytterbium fiber laser utilizes two modes, continuous wave and modulated. Sarp et al[19] results confirmed significant decrease in bond strength, duration in time and work done when utilizing the modulate mode with ceramic brackets. The laser is user friendly and relatively inexpensive. When utilizing the Diode laser, a sweeping motion distributes the heat on the entire surface leading to better control of intrapulpal temperature. It is noted that use of Diode laser decreases frequency and length of enamel surface cracks when debonding.[20]

3. Conclusions

Electrothermal debonding is physiologically acceptable alternative to mechanical debonding techniques. Addition of air coolant has a positive impact on intrapulpal temperature and is generally accepted by all patients. It requires minimal force following thermal softening of adhesive material and produces minimal changes to enamel surfaces compared to conventional methods.

Lasers are a valuable technology to continue exploring. With so many options available to clinicians and minimal clinical practice use, caution should be considered when utilizing lasers for debonding ceramic brackets. Many of the lasers are clinician friendly and vary in feasibility. Patient comfort also varies depending on the laser used and parameters. Minimal effects on enamel and intrapulpal temperature changes have been noted with ytterbium fiber laser, diode laser and Tm:YAP laser. Different parameters are possible with CO_2 laser, Nd:YAG laser and Er:YAG laser that may need further research before considering them

in clinical practice.

4. Source of Funding

None.

5. Conflict of Interest

None.

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Author biography

Karthikeyan Subramani Associate Professor

Prashanti Bollu Associate Professor