OSR
ORAL SCIENCES REPORTS

Review Article

Received: January 13, 2026
Revised: March 6, 2026
Accepted: March 16, 2026

Corresponding Author:
Pornpat Theerasopon, Department of Orthodontics, School of Dentistry, University of Phayao, Phayao 56000, Thailand.
E-mail: pornpat.th@up.ac.th

Utilizing Laser Technology for Debonding of Orthodontic Ceramic Brackets: A Literature Review

Todsaphon Inprakhon[1], Natapat Tarapun[2], Napat Srisooksombat[2], Praesai Khattipan[2], Vilasinee Vichitrananda[3], Pornpat Theerasopon[3]

[1]Department of Prosthodontics, School of Dentistry, University of Phayao, Thailand
[2]School of Dentistry, University of Phayao, Thailand
[3]Department of Orthodontics, School of Dentistry, University of Phayao, Thailand

Abstract

Ceramic brackets have become increasingly popular and are now widely used in orthodontic treatment because of their less noticeable and aesthetically pleasing appearance. However, conventional debonding of ceramic brackets can result in enamel cracks, bracket breakage and discomfort to patients from shear and torsional forces. Laser-assisted debonding of ceramic brackets had been evidenced in several studies to search for the laser irradiation for bracket debonding which could reduce shear bond strength and debonding time without a significant increase in intra-pulpal temperature, bonding failure, or enamel damage. Consequently, laser-assisted debonding emerges as an efficient technique, reducing patient discomfort while maintaining safety by minimizing enamel surface impact and intra-pulpal temperature elevation. This review article aimed to compile and consider the types of lasers used in ceramic bracket debonding, including diode laser, Nd:YAG laser, Er,Cr:YSGG laser, Er:YAG laser, and CO_2 laser, along with their specific settings and various testing conditions. Additionally, the variables investigated, including adhesive remnant index, shear bond strength, intra-pulpal temperature, and enamel damage were described.

Keywords: ceramic bracket, debonding, laser in dentistry, orthodontic bracket

Introduction

Fixed orthodontic treatment using less visible material has seen a surge in demand across all age groups, which has driven the worldwide use of ceramic brackets because of their less noticeable and aesthetically pleasing appearance.(1) Ceramic brackets are composed of aluminum oxide, which offers an attractive visibility alternative to metallic brackets.(2) However, they exhibit higher bond strength and lower fracture toughness, making them more prone to fracture compared to their metallic counterpart.(3) Ceramic brackets could be classified into two types; polycrystalline alumina and single-crystal (monocrystalline) alumina, which are derived from variances in the fabrication processes employed in their manufacture.(1)

In the midst of more attractiveness of ceramic brackets, the consideration of debonding procedure has to be mentioned. Conventional debonding of ceramic brackets typically used bracket-removing pliers, which apply shear and torsional forces, pose risks such as enamel cracks, bracket breakage and patient discomfort.(4) Despite numerous attempts, no mechanical debonding method has been discovered that can remove brackets without causing any damage to the enamel surface or breakage of brackets.(5) Consequently, alternative approaches for debonding have been explored, with laser-assisted techniques emerging as a promising option. The term “LASER” is an abbreviation for “Light Amplification by Stimulated Emission of Radiation”.(6) Since the introduction of the Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) and Carbon Dioxide (CO_2) lasers in 1964, researchers have explored the application of laser technology in dentistry. This included the debonding of orthodontic brackets using laser. While early attempts with the ruby laser were limited due to its high energy requirement and risk of collateral damage, the Nd:YAG laser gained traction for dental applications. Subsequent advancements led to the approval of Erbium and diode lasers for dental procedures, thereby expanding the array of available laser technologies.(7) The use of laser technology in bracket debonding offers several potential advantages, including reduced force application and softening of adhesive resin materials.(8) However, concerns exist regarding heat diffusion to tooth structures, which could lead to intra-pulpal damage.(9) Given that an increase in pulpal temperature of 5.5°C can trigger pulpal necrosis, careful attention to safety measures is imperative when employing lasers for debonding.(10)

This article undertook a comprehensive review of the literature concerning the use of lasers in facilitating the debonding of ceramic brackets. Our focus was on examining key factors such as shear bond strength, intra-pulpal temperature, and enamel damage, taking into account variables such as bracket type, adhesive resin systems, laser types, lasing parameters, duration of lasing, and the time interval between lasing and debonding. Through this analysis, we sought to enhance understanding and inform decision-making in the utilization of laser-assisted debonding techniques.

The effects of laser-assisted debonding on shear bond strength

The effects of laser irradiation on orthodontic bracket removal have been the subject of extensive investigation in orthodontic research, primarily concerning its influence on shear bond strength (SBS), which refers to the maximum stress that a material can withstand before failure under shear loading.(11) Among these studies, various variables, including adhesive bonding systems, bracket types and laser parameter settings, were selected to demonstrate the efficacy of laser-assisted debonding (Table 1).

Currently, the bonding of dental substrates relies on three primary strategies: 1. etch-and-rinse, 2. self-etch and 3. the resin-modified glass-ionomer approach, which is recognized for its unique property of self-adherence to tooth tissue.(12) Interestingly, Saito *et al*., introduced a novel approach to debond a ceramic bracket by adding 30 and 40 wt% thermal expansion microcapsules to orthodontic adhesive in conjunction with using a CO_2 laser. The findings indicated a significant decrease in SBS after 5 and 6 seconds of irradiation, to approximately 0.40-0.48 times the strength observed without laser irradiation. As laser-assisted debonding appears to be beneficial in assisting bracket removal.(13) Hayagawa *et al*.,(14) revealed that different types of adhesive, including 4-META/MMA-based adhesive containing no fillers and a Bis-GMA-based photoactivated type containing fillers, yielded no significant effect on the reduction of SBS following Nd:YAG laser-assisted debonding. Similarly, Iijima *et al*.,(15) consistently demonstrated that etch-and-rinse adhesive and self-etch adhesive also had no significant effect on the SBS of debonding a ceramic bracket after irradiation with a CO_2 laser. Different adhesive types yield no significant effect on the reduction of SBS following laser-assisted debonding. Incorporating microcapsules into adhesive materials, effectively enhancing the debonding process for ceramic brackets. Despite advancements, both conventional and laser methods have shown to decrease SBS, with laser treatment exhibiting a greater efficacy in reducing SBS.[13]

Orthodontic bracket types used in laser-assisted debonding process apparently were related to a significant decrease in SBS outcomes after laser irradiation, particularly ceramic bracket. Investigations by Han *et al*., revealed that ceramic bracket, which exhibited a higher SBS compared with metallic bracket in the experiment, demonstrated a significant decrease in SBS after Nd:YAG laser irradiation.[2] Ceramic brackets primarily derive from aluminum oxide, existing in both polycrystalline and monocrystalline forms. Generally, the prevailing method for fabricating polycrystalline brackets is through ceramic injection molding, which entails amalgamating the aluminum oxide (Al_2O_3) particles with a binder, and subsequent injection into a bracket mold, facilitating their fluidity through the application of heat and pressure. Post-injection, the removal of the binder, or burnout, precedes sintering, a technique whereby a coherent mass forms through heating without melting. Conversely, the fabrication process for monocrystalline ceramic brackets, colloquially termed sapphire brackets, diverges significantly. The Al_2O_3 particles are melted, followed by a gradual cooling process conducive to controlled crystallization. This meticulous procedure results in the formation of a substantial, singular crystal, typically in rod or bar configurations. Consequently, the material undergoes shaping into brackets via precision techniques such as ultrasonic cutting or diamond cutting tools. Post-milling, the monocrystalline bracket undergoes a heat treatment regimen aimed at rectifying surface imperfections and mitigating stress induced by milling processes.[16] Feldon *et al*.,[17] stated that the application of the diode laser, both the 3 Watts and the 5 Watts per square centimeter laser protocols, proved highly effective in substantially reducing the force needed for debonding when using monocrystalline brackets compared to conventional debonding techniques. Similarly, Hayakawa *et al*.,[14] found that using a 2 J power setting of Nd:YAG laser was more effective in reducing SBS in monocrystalline brackets compared to polycrystalline. The notable distinctions observed between the monocrystalline and polycrystalline groups hinge on the bracket crystal's structure. Monocrystalline brackets feature a uniform crystal arrangement that enhances transmissibility, thereby minimizing laser energy loss. Consequently, the laser proves more effective on monocrystalline brackets compared to their polycrystalline counterparts.[14] Furthermore, the retention system of brackets plays a crucial role, as highlighted by Matos *et al*., who reported a significant decrease in bond strength in chemically retained brackets compared to mechanically retained ones.[18] Therefore, bracket selection can significantly impact SBS during laser-assisted debonding procedures, particularly noteworthy with monocrystalline ceramic brackets due to their specific properties regarding laser transmission, and with chemically retained brackets due to the retention mechanism of the bracket system.

Beyond bracket selection, the influence of laser settings on SBS in laser-assisted debonding techniques has been recognized as a significant factor. Numerous studies have explored the effect of different energy levels of laser settings across various laser types on SBS. For instance, Hayakawa *et al*., demonstrated a significant decrease in SBS when debonding ceramic brackets with a Nd:YAG laser at 2.0 and 3.0 J. However, exposure to 1.0 J of laser energy showed no significant decrease compared to non-lasing, likely due to inadequate energy levels.[14] In a separate study, Nalbantgil *et al*.,[19] also investigated the effect of Erbium-doped Yttrium Aluminum Garnet (Er:YAG) laser with different energy levels on debonding and concluded that all lasing groups significantly decreased SBS, particularly at power levels of 4W and 6W.[19] Furthermore, Macri *et al*., in an investigation of CO_2 laser settings, found that lasing for 3 seconds at 5 W with a pulse duration of 0.01 s resulted in the lowest SBS.[20] Meanwhile, Hoteit *et al*.,[21] studied Er,Cr:YSGG and Er:YAG with different laser settings and found that Er,Cr:YSGG significantly reduced SBS across all settings, while Er:YAG showed no significant reduction, especially at power levels of 4W and 6W.

In addition to different energy levels of laser settings, factors such as lasing duration, time lag, and water-cooling play significant roles in affecting SBS. Studies by Nalbantgil *et al*.,[22] demonstrated that prolonged exposure time correlated with a greater decrease in SBS. Specifically, a 9-second lasing duration significantly reduced SBS compared to a 3-second lasing duration. Following this, in 2011, Tozlu *et al*.,[23] demonstrated that an increase in time lag resulted in higher SBS. Furthermore, water-cooling during laser-assisted debonding has been shown to enhance SBS compared to procedures without cooling mechanisms, as indicated by Nalbantgil *et al*.[24] Recent advancements have expanded the scope of debonding techniques, with Khalil *et al*.'s comparative study of five methods demonstrating the efficacy of lasers in reducing SBS compared to conventional techniques.[25] In light of these findings, laser-assisted debonding techniques have shown promise in reducing SBS effectively. However, optimal parameters must be carefully considered to ensure both efficacy and safety in orthodontic practice.

The effects of laser-assisted debonding on intra-pulpal temperature

One of the primary concerns associated with using lasers for debonding ceramic brackets is the potential thermal impact in the pulp tissue due to laser irradiation. According to Zach and Cohen, an increase of 1.8°C in intra-pulpal temperature can result in minimal pulp damage, which is reversible within three months. Conversely, a temperature rise of 5.5°C raises the risk of pulp necrosis by 15%. Moreover, an increase of 11°C in temperature can substantially heighten the risk of pulp necrosis by as much as 60%.[26] Several research studies had shown that using different types of laser or laser settings was safe as long as the temperature increase remained below the threshold of 5.5 C (Table 2). Yassaei *et al*.,[27] reported that among different laser modes and energy levels, the 3 W group showed the highest temperature compared to other energy levels. Additionally, continuous wave mode resulted in a higher temperature than pulse mode. In 2010, Feldon *et al*., compared different energy levels of a diode laser and different types of ceramic brackets. The results showed that the temperature increase did not exceed the threshold of 5.5°C significantly in all groups, except for the group that used an energy level of 5 W for debonding monocrystalline ceramic brackets. In this group, the temperature increase was significantly greater than the standard of 1.8°C but was not significantly different from the threshold of 5.5°C.[17]

The studies conducted by Hayakawa *et al*., Rao *et al*., and Nalbantgil *et al*., delved into the exploration of distinct laser settings employed for bracket debonding, utilizing Nd:YAG, Erbium, Chromium:Yttrium Scandium Gallium Garnet (Er,Cr:YSGG), and Er:YAG lasers, respectively. Collectively, these investigations yielded congruent findings, revealing a consistent pattern of intra-pulpal temperature elevation subsequent to laser irradiation, all of which remained below the critical threshold of 5.5°C.[14,19,28] Two studies investigated the use of CO_2 laser: Iijima *et al*., and Macri *et al*. Iijima *et al*.,[15] measured the intra-pulpal temperature using an infrared thermographic microscope system. After 5 seconds of lasing, the temperature of enamel cross-sections rose by approximately 200°C when exposed to 5 and 6 watts, and between 100°C and 150°C when exposed to 3 and 4 watts. After 30 seconds of lasing, all temperatures returned to the standard room level.[15] Likewise, Macri *et al*.,[20] found that the temperature increase during lasing for 3 seconds with a pulse duration of 0.01 seconds at every energy level did not exceed the threshold of 5.5°C. These findings are consistent with those of Nalbantgil *et al*., in 2011, who studied the duration of time using Er:YAG laser and found that an increase in duration led to a significant rise in intra-pulpal temperature in all groups.[22]

In addition to different types of laser and laser settings, other factors including water-cooling, laser motion and types of brackets can be considered to affect intra-pulpal temperature in laser-assisted debonding. In 2014, Nalbantgil *et al*., found that using a laser along with water cooling has the potential to decrease the intra-pulpal temperature and ensure safety for the pulp.[24] Grzech *et al*., studied laser motion and found that scanning motion resulted in a significantly lower temperature increase compared to circular motion around ceramic brackets.[9] Furthermore, they observed that scanning motion on ceramic brackets resulted in the lowest temperature increase.[9,24] Both Grzech *et al*.,[9] and Dostalova *et al*.,[29] investigated the comparison between the ceramic bracket and metallic bracket by using Er:YAG for debonding and found contradictory results. Grzech *et al*.,[9] revealed that when comparing both bracket types with circular motion, ceramic brackets had higher temperatures than metal ones[9], whereas Dostalova *et al*.,[29] reported the contrary result.

Hence, laser-assisted debonding of ceramic brackets is considered a safe method, as it results in an increase in intra-pulpal temperatures that increase below the critical threshold of 5.5°C. The duration of laser exposure and the energy level applied are primary factors influencing temperature elevation. Furthermore, variables such as water cooling, bracket type, and laser motion can impact temperature fluctuations. However, current research findings do not indicate any substantial relationship between the adhesive bonding system utilized and alterations in intra-pulpal temperature.

The effects of laser-assisted debonding on enamel damage

The conventional method of debonding ceramic brackets typically involves applying sufficient force to break the bond, potentially leading to enamel damage through tearing. Concerns about enamel damage persist even with the use of lasers for ceramic bracket removal. Several studies have examined the effects of various laser types, including diode, Nd:YAG, Er,Cr:YSGG, Er:YAG, and CO_2 lasers, on enamel integrity during such procedures (Table 3).

Regarding the use of diode lasers, studies by Feldon *et al*.,[17] Khalil *et al*.,[25] and Yassaei *et al*.,[27] found no significant difference in Adhesive Remnant Index (ARI) scores between using a diode laser for debonding and the conventional method. Most findings reported high ARI scores of 2 and 3. In contrast, Stein *et al*., reported a significant difference in ARI scores between laser and conventional methods, predominantly observing ARI scores of 0. Additionally, they noted no discernible differences in enamel damage between lasing and conventional methods before debonding, as observed through Scanning Electron Microscopy (SEM). However, they did observe a significant number of enamel cracks when using the laser compared to the conventional method.[3]

In their investigation of Nd:YAG laser application, Han *et al*.,[2] observed a significant decrease in ARI scores within the lasing group compared to conventional methods. Furthermore, SEM analysis revealed reduced enamel damage in the lasing group relative to the conventional technique, observed in both metallic and ceramic brackets. Similarly, Rao *et al*.,[28] reported a notable difference in ARI scores, with SEM analysis revealing the absence of enamel cracks when utilizing the Er,Cr:YSGG laser for debonding. Additionally, Hoteit *et al*.,[21] found that the proportion of teeth with intact enamel topography was significantly smaller in the conventional group compared to the Er,Cr:YSGG lasing groups (4W/20 Hz and 5W/20Hz). Microcracks were only found in the 3W/20 Hz group, while statistically significant intact enamel was observed in the 4W/20 Hz and 5W/20 Hz groups, both displaying the most homogeneous topography. Furthermore, the enamel surface in the 4W/20 Hz group exhibited slightly more uniformity than in the 5W/20 Hz group.

In their investigation of Er:YAG lasers, Oztoprak *et al*.,[30] employed the laser at 4.2 W with a scanning motion for 9 seconds, revealing a significant difference in ARI scores between the lasing group, predominantly scoring 3, and the conventional method, consistent with the findings of Nalbantgil *et al*.,[22] Comparing time lag studied by Tozlu *et al*.,[23] found no significant difference in ARI scores between Er:YAG laser use and conventional methods for bracket removal. However, Nalbantgil *et al*.,[19] examined various energy levels of the Er:YAG laser and identified significant ARI scores only at 6 W power, predominantly scoring 3. Furthermore, Dostalova *et al*.,[29] utilized SEM to examine adhesive remnants, noting a reduced presence when using the laser compared to conventional methods. Additionally, Hoteit *et al*.,[21] analyzed enamel topography using SEM, reporting no significant differences between the conventional method and the use of the Er:YAG laser.

In a study conducted by Grzech *et al*.,[9] Energy-Dispersive X-ray Spectroscopy (EDS) analysis, focusing on the calcium element, revealed higher percentages of calcium in all lasing groups compared to the conventional technique, suggesting enhanced enamel safety. They recommended further investigation into long-term effects, as well as hardness and Young's modulus testing. Reflecting on research from 2010, Iijima *et al*.,[15] explored the effects of CO_2 laser-assisted debonding on hardness and Young's modulus. The results indicated a significant decrease in both parameters at a distance of 1 μm from the enamel surface across all samples, relative to other distances. Additionally, no significant differences were observed in ARI scores between lasing and conventional techniques.

In their investigation into the application of CO_2 lasers with different types of ceramic brackets, Ahrari *et al*.,[31] discovered a significant difference in ARI scores between monocrystalline brackets treated with CO_2 laser and those treated with conventional methods, whereas no such difference was found with polycrystalline bracket. Conversely, Matos *et al*., found that combining a CO_2

laser with Z250 composite resin and polycrystalline ceramic brackets resulted in the highest mean ARI score and reduced enamel damage, particularly with Fascination brackets, while the greatest damage was observed with Mystique brackets. Additionally, they examined the type of fracture after debonding, revealing that cohesive resin fractures resulted in minimal enamel damage, whereas cohesive enamel fractures caused more significant damage to the enamel surface.[18]

Therefore, laser debonding appears to be a promising alternative to conventional methods for ceramic bracket removal, showing potential benefits such as reduced enamel damage and improved adhesive remnant removal. However, further research is needed to fully understand the long-term effects, optimal parameters, and potential variations based on bracket type and laser settings. Nonetheless, the findings from these studies suggest that lasers can contribute to enhancing the safety and efficacy of orthodontic procedures, particularly in terms of preserving enamel integrity and minimizing post-debonding complications.

Table 1: Summary of studies investigating shear bond strength during laser-assisted ceramic bracket debonding.

Author/Year	Objective of study	Groups	Laser settings	Type of bracket/ Adhesive used	Results/Conclusions
Feldon *et al.*, 2010[17]	Comparative Mono-/ Poly-crystalline brackets, Laser/ No Laser	Bovine maxillary left central incisors (n=60, 5 groups) (1) No laser, Poly (2) No laser, Mono (3) Laser 2 W, Poly (4) Laser 2 W, Mono (5) Laser 5 W, Poly (6) Laser 5 W, Mono	diode WL: - P: 2 W CW T: 3 s	Ceramic (Inspire and Clarity) Transbond XT	The diode laser was ineffective with polycrystalline brackets and efficient with monocrystalline brackets in significantly decreasing the shear bond strength (p<0.05). Diode laser significantly decreased the force needed for removing monocrystalline brackets without causing a significant elevation in pulp temperature. However, the use of diode lasers did not result in a significant reduction in the debonding force required for polycrystalline brackets with stainless steel slots.
Hayakawa *et al.*, 2005[14]	Comparative different energy levels of Nd:YAG laser, Mono-/ Poly-crystalline brackets	Extract/ Intact bovine mandibular incisors (n=80, 16 groups) Monocrystalline (1) MMA, No laser (2) MMA, 1 J (3) MMA, 2 J (4) MMA, 3 J (5) Bis-GMA, No laser (6) Bis-GMA, 1 J (7) Bis-GMA, 2 J (8) Bis-GMA, 3 J Polycrystalline (9) MMA, No laser (10) MMA, 1 J (11) MMA, 2 J (12) MMA, 3 J (13) Bis-GMA, No laser (14) Bis-GMA, 1 J (15) Bis-GMA, 2 J (16) Bis-GMA, 3 J	Nd:YAG WL: 1060 nm E: 1, 2, 3 J PD: 1.2 ms 1 pulse per location	Ceramic (Inspire and Clarity) Super-Bond (4META/ MMA), Transbond (Bis-GMA)	All specimens in the 2.0 J and 3.0 J groups demonstrated a significant reduction in bonding strength compared to the non-lasing group. However, this difference was not observed in the 1.0 J group. At the 2.0 J energy level, there was a significant decrease in bond strength found in monocrystalline ceramic brackets compared to polycrystalline ceramic brackets. However, no significant differences were found among various types of adhesive resins.
Han *et al.*, 2008[2]	Comparative Laser/ No Laser, Metallic/ Ceramic brackets	Freshly extracted premolars (n=30, 3 groups) (1) Metallic, No laser (2) Ceramic, No laser (3) Ceramic, Laser	Nd:YAG WL: 1060 nm P: 3 W PD: 0.2 ms T: 2 s	Metallic (MBT), Ceramic (Clarity)	The lasing group significantly reduces shear bond strengths.

Oztoprak *et al.*, 2010[26]	Comparative Laser/ No Laser	Bovine mandibular incisors (n=60, 2 groups) (1) No Laser (2) Laser	Er:YAG WL: 2940 nm P: 4.2 W PD: - T: 9 s Scanning motion	Ceramic (Transcend) Transbond XT	The lasing group significantly reduces shear bond strengths (9.52 MPa) compared to the non-lasing group (20.75 MPa).
Macri *et al.*, 2015[20]	Comparative different laser settings	Human mandibular premolars (n=75, 5 groups) (1) Control (2) 5 W, PD=0.01, T=3 (3) 5 W, PD=0.03, T=3 (4) 8 W, PD=0.01, T=3 (5) 10 W, PD=0.01, T=3	CO_2 WL: 10600 nm P: 5, 8, 10 W PD: 0.01, 0.03 s T: 3 s	Ceramic (Fascination) Transbond XT	Group 5 (10 W, 3 s, 0.01 s) showed the lowest shear bond strength.
Matos *et al.*, 2021[18]	Comparative Laser/ No Laser, different adhesive resins, different ceramic brackets	Human premolars (n=90, 6 groups) (1) TMC: Transbond+Mystique+Control (No laser) (2) TFC: Transbond+Fascination+Control (No laser) (3) TML: Transbond+Mystique+Laser (4) ZML: Z250+Mystique+Laser (5) TFL: Transbond+Fascination+Laser (6) ZFL: Z250+Fascination+Laser	CO_2 WL: 10600 nm P: 10 W PD: 0.01 s T: 3 s	Ceramic (Mystique and Fascination) Transbond XT, Z250	Significantly lower shear bond strength was found in chemically retained Fascination brackets compared to mechanically retained Mystique brackets, as well as in all lasing groups compared to non-lasing groups. After lasing, the chemically retained Fascination brackets with Z250 showed the lowest shear bond strength.
Hoteit *et al.*, 2020[21]	Comparative between Er,Cr:YSGG and Er:YAG lasers settings	Bovine incisors (n=180, 15 groups) Er,Cr:YSGG (1) Laser 3 W/20 Hz (2) Laser 3 W/40 Hz (3) Laser 4 W/20 Hz (4) Laser 4 W/40 Hz (5) Laser 5 W/20 Hz (6) Laser 5 W/40 Hz Er:YAG (7) Laser 80 mJ/20 Hz (8) Laser 80 mJ/40 Hz (9) Laser 100 mJ/20 Hz (10) Laser 100 mJ/40 Hz (11) Laser 120 mJ/20 Hz (12) Laser 120 mJ/40 Hz (13) Laser 140 mJ/20 Hz (14) Laser 140 mJ/40 Hz (15) No laser	Er,Cr:YSGG WL: 2780 nm P: 3, 4, 5 W PD: 60 µs T: - Er:YAG WL: 2940 nm E: 80, 100, 120, 140 mJ PD: 50 µs T: -	Ceramic (Clarity)	In the lasing groups, there was a statistically significantly lower shear bond strength compared to the non-lasing groups, except in Er:YAG groups (80 mJ/20 Hz, 80 mJ/40 Hz, 100 mJ/20 Hz and 120 mJ/20 Hz).
Khalil *et al.*, 2021[25]	Comparative effects of Chemical agent (peppermint oil), Ultrasonic, diode laser, and Er:YAG laser	Extracted human premolars (n=100, 5 groups) (1) No laser (2) Peppermint oil (3) Ultrasonic (4) diode laser (5) Er:YAG laser	diode WL: 980 nm P: 4 W CW T: 3 s on each side (Total 12 s) Er:YAG WL: 2940 nm P: 4 W PD: 100 µs T: 3 s on each side (Total 12s)	Ceramic (Perfect Clear) Transbond XT	A significantly lower shear bond strength was observed in group 3, group 4, and group 5 compared to the non-lasing group. Additionally, group 5 showed significantly lower SBS compared to group 2. However, using peppermint oil for debonding ceramic brackets had minimal impact on the shear bond strength.

Nalbantgil *et al.*, 2011[22]	Comparative different time exposures to laser	Bovine mandibular incisors (n=80, 4 groups) (1) No laser (2) Laser, 3 s (3) Laser, 6 s (4) Laser, 9 s	Er:YAG WL: 2940 nm P: 4.2 W PD: - T: 3, 6, 9 s Scanning motion	Ceramic (Transcend) Transbond XT	The longer the duration of lasering, the lower the shear bond strength. This study found that a statistically significant difference exists between the groups with laser durations of 3 s and 9 s.
Tozlu *et al.*, 2011[23]	Comparative different time lags	Non-carious human premolars (n=100, 5 groups) (1) No laser (2) Laser, 1 s (3) Laser, 18 s (4) Laser, 30 s (5) Laser, 60 s	Er:YAG WL: 2940 nm P: 5 W PD: - T: 6 s Scanning motion	Ceramic (Transcend) Transbond XT	The lasing group demonstrated a statistically significant decrease in shear bond strength compared to the non-lasing group (p<0.001). Moreover, there was a corresponding increase in shear bond strengths as the time lag between lasing and debonding increased.
Nalbantgil *et al.*, 2014[24]	Comparative Waterless/ Water-cooling	Upper premolars (n=60, 3 groups) (1) No laser (2) Laser, Waterless (3) Laser, Water-cooling	Er:YAG WL: 2940 nm P: 5 W PD: - T: 9 s Scanning motion	Ceramic (Transcend) Transbond XT	Er:YAG laser-assisted debonding without water-cooling reduced shear bond strength in ceramic brackets compared to debonding with water-cooling.
Nalbantgil *et al.*, 2018[19]	Comparative different energy levels of Er:YAG laser	Bovine incisors (n=80, 4 groups) (1) No laser (2) Laser 2 W (3) Laser 4 W (4) Laser 6 W	Er:YAG WL: 2940 nm P: 2, 4, 6 W PD: 300 ms T: 6 s Scanning motion	Ceramic (Transcend) Transbond XT	Lower shear bond strengths were observed in the lasing groups compared to the non-lasing group. There was a statistically significant difference between all groups, except for the 4 W and 6 W groups.
Iijima *et al.*, 2010[15]	Comparative different laser settings, different adhesive bonding systems	Human premolars (n=50, 10 groups) (1) Etch & rinse, No laser (2) Etch & rinse, 3 W (3) Etch & rinse, 4 W (4) Etch & rinse, 5 W (5) Etch & rinse, 6 W (6) Self-etching, No laser (7) Self-etching, 3 W (8) Self-etching, 4 W (9) Self-etching, 5 W (10) Self-etching, 6 W	CO_2 WL: 10600 nm P: 3, 4, 5, 6 W PD: - T: 5 s each spot	Ceramic bracket (Inspire ice) Transbond XT (Etch & rinse), Transbond Plus (Self-etching)	All lasing groups reduced shear bond strength compared to the non-lasing groups for both adhesive systems. Moreover, within the self-etching adhesive group, the 3 W showed higher shear bond strength than other laser settings.
Saito *et al.*, 2013[13]	Comparative different adhesive bonding systems	Freshly extracted bovine permanent mandibular incisors (n=96, 12 groups) No microcapsule content (1) No laser (2) Laser 4 s (3) Laser 5 s (4) Laser 6 s 30% microcapsule content (5) No laser (6) Laser 4 s (7) Laser 5 s (8) Laser 6 s 40% microcapsule content (9) No laser (10) Laser 4 s (11) Laser 5 s (12) Laser 6 s	CO_2 WL: - P: 3 W PD: - T: 2-3 s	Ceramic Orthomite Super-Bond	In non-lasing groups, shear bond strength decreased to 0.75-fold and 0.63-fold with 30 wt% and 40 wt% microcapsules, respectively, compared to adhesive without microcapsules. Additionally, the bond strength of 30 wt% or 40 wt% microcapsules decreased significantly to 0.40- 0.48-fold after lasing for either 5 or 6 seconds compared to the non-lasing groups.

n: sample size; WL: wave length; P: power; PD: pulse duration; E: energy; T: time; CW: continuous wave; F: frequency.

Table 2: Summary of studies investigating intra-pulpal temperature during laser-assisted ceramic bracket debonding.

Author/ Year	Objective of study	Groups	Laser settings	Type of bracket/ adhesive used	Results/Conclusions
Feldon *et al.*, 2010[17]	Comparative Mono-/Poly-crystalline brackets, Laser/ No Laser	Bovine maxillary left central incisors (n=60, 5 groups) (1) No laser, Poly (2) No laser, Mono (3) Laser 2 W, Poly (4) Laser 2 W, Mono (5) Laser 5 W, Poly (6) Laser 5 W, Mono	diode WL: - P: 2 W CW T: 3 s	Ceramic (Inspire and Clarity) Transbond XT	All mean increases in pulp chamber temperature for groups 3, 4, and 5 were significantly lower (p<0.01) than the threshold of 5.5°C and were not significantly different (p<0.01) from the standard of 1.8°C The increase in pulp chamber temperature for Group 6 was significantly higher than the 1.8°C standard and not significantly different (p<0.01) from the 5.5°C threshold, based on statistical analysis.
Yassaei *et al.*, 2018[28]	Comparative different modes of laser	Intact extracted premolars (n=90, 6 groups) Continuous wave (1) Laser 2 W (2) Laser 2.5 W (3) Laser 3 W Pulse mode (4) Laser 2 W (5) Laser 2.5 W (6) Laser 3 W	diode WL: 980 nm P: 2, 2.5, 3 W PD: 30 µs T: 10 s (5 s from mesial and 5 s from distal)	Ceramic (Allure) Transbond XT	There were significant differences in temperature increase among all lasing groups. The highest increase in intra-pulpal temperature was observed in G3 (3.39±0.76°C), followed by G6 (2.84±0.40°C). However, this temperature increase remained below the 5.5°C threshold.
Hayakawa *et al.*, 2005[14]	Comparative different energy levels of Nd:YAG laser, Mono-/Poly-crystalline brackets	Extract/ Intact bovine mandibular incisors (n=80, 16 groups) Monocrystalline (1) MMA, No laser (2) MMA, 1 J (3) MMA, 2 J (4) MMA, 3 J (5) Bis-GMA, No laser (6) Bis-GMA, 1 J (7) Bis-GMA, 2 J (8) Bis-GMA, 3 J Polycrystalline (9) MMA, No laser (10) MMA, 1 J (11) MMA, 2 J (12) MMA, 3 J (13) Bis-GMA, No laser (14) Bis-GMA, 1 J (15) Bis-GMA, 2 J (16) Bis-GMA, 3 J	Nd:YAG WL: 1060 nm E: 1, 2, 3 J PD: 1.2 ms 1 pulse per location	Ceramic (Inspire, Clarity) Super-Bond (4META/ MMA), Transbond (Bis-GMA)	The increase in intra-pulpal temperature induced by lasing was extremely low, with the highest temperature increase of 5.1°C.
Rao *et al.*, 2023[29]	Comparative different types of brackets, Laser/ No Laser	Extracted premolars (n=90, 6 groups) (A1) No laser (A2) Laser 4.5 W (A3) Laser 6 W (B1) No laser (B2) Laser 4.5 W (B3) Laser 6 W	Er,Cr:YSGG WL: 2780 nm P: 4.5, 6 W PD: - T: -	Group A: Metallic Group B: Ceramic Transbond XT	The pulp chamber temperature increased in all groups but were significantly lower than the 1.8°C standard and the 5.5°C threshold.
Nalbantgil *et al.*, 2011[22]	Comparative different time exposures to laser	Human premolars (n=30, 3 groups) (1) Laser, 3 s (2) Laser, 6 s (3) Laser, 9 s	Er:YAG WL: 2940 nm P: 4.2 W PD: - T: 3, 6, 9 s Scanning motion	Ceramic (Transcend) Transbond XT	The longer the duration of lasing, the higher the intra-pulpal temperature increase. This study found that the 3 s group exhibited a statistically significantly lower temperature increase compared to the 6 s and 9 s groups, while the 6-second group also showed a significantly lower increase compared to the 9 s group.

Nalbantgil *et al.*, 2014[24]	Comparative Waterless/ Water-cooling	Upper premolars (n=60, 3 groups) (1) No laser (2) Laser, Waterless (3) Laser, Water-cooling	Er:YAG WL: 2940 nm P: 5 W PD: - T: 9 s Scanning motion	Ceramic (Transcend) Transbond XT	Er-YAG laser-aided debonding with water-cooling reduced intra-pulpal temperature in ceramic brackets compared to debonding without water-cooling.
Dostalova *et al.*, 2016[30]	Comparative different types of brackets	Caries-free human third molars (n=40, 4 groups) (1) Metallic+Transbond (Laser)=10 (2) Ceramic+Transbond (Laser)=10 (3) Ceramic+Variolink (Laser)=10 (4) Control=10 (No laser, 3 for each group, one for no bracket)	Er:YAG WL: 2940 nm E: 280 mJ F: 6 Hz T: -	Metallic (Victory Series), Ceramic (Clarity) Transbond XT, Variolink II	The temperature increased in both ceramic and metallic brackets, ranging from 2 to 3.2°C, which was considered safe as it remained lower than the 5.5°C threshold.
Grzech Lesniak *et al.*, 2018[9]	Comparative Scanning/ Circular motion technique, Metallic/ Ceramic brackets	Caries-free premolars (n=55, 4 groups) (1) Metallic, circular motion=15 (Laser) (2) Ceramic, circular motion=15 (Laser) (3) Ceramic, Scanning motion=15 (Laser) (4) Ceramic=5, Metallic=5 (No laser)	Er:YAG WL: 2940 nm P: 3.4 W PD: 300 µs T: 6 s Scanning motion	Metallic (Victory Series), Ceramic (Inspire) Transbond XT	A scanning motion resulted in a significantly lower temperature increase compared to a circular motion around ceramic brackets (1.78°C). After lasing in the circular motion, the temperature increase in ceramic brackets was significantly higher than in metallic brackets. Additionally, the lowest temperature increase was found in ceramic brackets using the scanning motion.
Nalbantgil *et al.*, 2018[19]	Comparative different energy levels of Er:YAG laser	Human premolars (n=60, 3 Groups) (1) Laser 2 W (2) Laser 4 W (3) Laser 6 W	Er:YAG WL: 2940 nm P: 2, 4, 6 W PD: 300 ms T: 6 s Scanning motion	Ceramic (Transcend) Transbond XT	As the laser power increases, so does the temperature; therefore, although the 6 W group showed the highest temperature increase, it still remained below the 5.5°C threshold.
Iijima *et al.*, 2010[15]	Comparative different laser settings	Human premolars (n=3) Different laser settings (3, 4, 5, and 6 W) were compared at 5 and 60 seconds after lasing.	CO_2 WL: 10600 nm P: 3, 4, 5, 6 W PD: - T: 5 s each spot	Ceramic bracket (Inspire ice) Transbond XT (etch & rinse)	Measuring temperature using an infrared thermographic microscope system after 5 seconds of lasing, the temperature of enamel cross-sections rose to around 200°C when exposed to 5 or 6 watts, and between 100°C and 150°C when exposed to 3 and 4 watts. After 30 seconds of lasing, all temperatures returned to standard room levels.
Ahrari *et al.*, 2011[31]	Comparative Mono-/ Poly-crystalline brackets, Laser/ No Laser	Human maxillary and mandibular premolars (n=80, 4 groups) (1) CC: Fascination, No laser (2) MC: Inspire Ice, No laser (3) CL: Fascination, Laser (4) ML: Inspire Ice, Laser	CO_2 WL: 10600 nm PP: 188 W F: 400 Hz PD: 0.0005 s T: 5 s Scanning motion	Ceramic (Fascination, Inspire Ice) Transbond XT	Intra-pulpal temperature in both ceramic bracket types remained below the threshold of 5.5°C.

Saito *et al.*, 2013[13]	Comparative different adhesive bonding systems	Freshly extracted bovine permanent mandibular incisors (n=96, 12 groups) No microcapsule content (1) No laser (2) Laser 4 s (3) Laser 5 s (4) Laser 6 s 30% Microcapsule content (5) No laser (6) Laser 4 s (7) Laser 5 s (8) Laser 6 s 40% Microcapsule content (9) No laser (10) Laser 4 s (11) Laser 5 s (12) Laser 6 s	CO_2 WL: - P: 3 W PD: - T: 2-3 s	Ceramic Orthomite Super-Bond	The temperature of the bracket base increased above 80°C when exposed to the laser for more than 4 s. However, all mean temperature increases in the pulp chamber remained below 4.3°C.
Macri *et al.*, 2015[20]	Comparative different laser settings	Human mandibular premolars (n=30, 12 groups) (1) 5 W, PD= 0.01, T=3 (2) 5 W, PD= 0.03, T=3 (3) 5 W, PD= 0.01, T=5 (4) 5 W, PD= 0.03, T=5 (5) 8 W, PD= 0.01, T=3 (6) 8 W, PD= 0.03, T=3 (7) 8 W, PD= 0.01, T=5 (8) 8 W, PD= 0.03, T=5 (9) 10 W, PD= 0.01, T=3 (10) 10 W, PD= 0.03, T=3 (11) 10 W, PD= 0.01, T=5 (12) 10 W, PD= 0.03, T=5	CO_2 WL: 10600 nm P: 5, 8, 10 W PD: 0.01, 0.03 s T: 3, 5 s	Ceramic (Fascination) Transbond XT	The lasing duration of 3 seconds and pulse duration of 0.01 seconds, at power levels of 5, 8, and 10 W were considered safe as the temperature increases did not exceed the 5.5°C threshold.

n: sample size; WL: wave length; P: power; PD: pulse duration; E: energy; T: time; CW: continuous wave; F: frequency; PP: peak power.

Table 3: Summary of studies investigating the adhesive remnant index and enamel damage during laser-assisted ceramic bracket debonding.

Author/ Year	Objective of study	Groups	Laser settings	Type of bracket/ adhesive used	Results/Conclusions
Feldon *et al.*, 2010[17]	Comparative Mono-/ Poly-crystal-line brackets, Laser/ No Laser	Bovine maxillary left central incisors (n=60, 5 groups) (1) No laser, Poly (2) No laser, Mono (3) Laser 2 W, Poly (4) Laser 2 W, Mono (5) Laser 5 W, Poly (6) Laser 5 W, Mono	diode WL: - P: 2 W CW T: 3 s	Ceramic (Inspire and Clarity) Transbond XT	No significant differences were found in adhesive remnant index scores between groups. All groups had mean ARI scores of 3, indicating that most of the adhesive remained on tooth surfaces with bracket base imprints. The diode laser did not affect the amount of adhesive left after debonding.
Stein *et al.*, 2017[3]	Comparative Laser/ No Laser	Human third molar (n=30, 2 groups) (1) No laser (2) laser	diode WL: 445 nm P: 2 W CW T: 5 s on each side (Total 15s)	Ceramic (In-Ovation C, GAC) Transbond XT	In the lasing group, there was a significantly higher percentage of ARI scores of 0, whereas the non-lasing group showed a significantly higher percentage of ARI scores of 3. The result showed no difference in enamel damage in either the lasing or non-lasing groups before debonding; however, the lasing group showed less enamel damage compared to the non-lasing group after debonding.
Yassaei *et al.*, 2018[28]	Comparative different modes of laser	Intact extracted premolars (n=90, 6 groups) Continuous wave (1) Laser 2 W (2) Laser 2.5 W (3) Laser 3 W Pulse mode (4) Laser 2 W (5) Laser 2.5 W (6) Laser 3 W	diode WL: 980 nm P: 2, 2.5, 3 W PD: 30 µs T: 10 s (5 s from mesial and 5 s from distal)	Ceramic (Allure) Transbond XT	Comparing all laser settings, there were no differences in the ARI scores among all groups, as the ARI scores of all groups were mostly 2. There was a significant increase in the number of enamel cracks after bracket debonding. Additionally, all groups, except group 3 and group 6, also showed a significant increase in the length of enamel cracks.
Han *et al.*, 2008[2]	Comparative Laser/ No Laser, Metallic/ Ceramic bracket	Freshly extracted premolars (n=30, 3 groups) (1) Metallic, No laser (2) Ceramic, No laser (3) Ceramic, Laser	Nd:YAG WL: 1060 nm P: 3 W PD: 0.2 ms T: 2 s	Metallic (MBT), Ceramic (Clarity)	The ARI scores in the lasing group were significantly lower compared to the non-lasing group. Moreover, SEM analysis indicated less enamel damage in the lasing group compared in the non-lasing group for both metallic and ceramic brackets.
Rao *et al.*, 2023[29]	Comparative different types of brackets, Laser/ No Laser	Extracted premolars (n=90, 6 groups) (A1) No laser (A2) Laser 4.5 W (A3) Laser 6 W (B1) No laser (B2) Laser 4.5 W (B3) Laser 6 W	Er,Cr:YSGG WL: 2780 nm P: 4.5, 6 W PD: - T: -	Group A: Metallic Group B: Ceramic Transbond XT	The ARI scores showed statistically significant differences ($p \leq 0.05$) between the control and study groups, particularly in metal brackets and were highly significant ($p \leq 0.001$) within the ceramic bracket group. SEM analysis of the laser debonding groups showed no cracks, whereas conventionally debonded metallic and ceramic brackets displayed pronounced fractures.
Nalbantgil *et al.*, 2011[22]	Comparative different time exposures to laser	Bovine mandibular incisors (n=80, 4 groups) (1) No laser (2) Laser, 3 s (3) Laser, 6 s (4) Laser, 9 s	Er:YAG WL: 2940 nm P: 4.2 W PD: - T: 3,6,9 s Scanning motion	Ceramic (Transcend) Transbond XT	Statistically significant differences were observed in ARI scores between the 9 s group and non-lasing group, as well as 9 s and 6 s groups. Most ARI scores of the 9 s group were 3.

Oztoprak *et al.,* 2010[26]	Comparative Laser/ No Laser	Bovine mandibular incisors (n=60, 2 groups) (1) No Laser (2) Laser	Er:YAG WL: 2940 nm P: 4.2 W PD: - T: 9 s Scanning motion	Ceramic (Transcend) Transbond XT	The adhesive remnant index scores showed a statistically significant difference (p<0.001) with the laser group having double the number of samples with adhesive scores of 2 or 3 on the index.
Tozlu *et al.,* 2011[23]	Comparative different time lags	Non-carious human premolars (n=100, 5 groups) (1) No laser (2) Laser, 1 s (3) Laser, 18 s (4) Laser, 30 s (5) Laser, 60 s	Er:YAG WL: 2940 nm P: 5 W PD: - T: 6 s Scanning motion	Ceramic (Transcend) Transbond XT	Comparing the time lag, there was no difference in ARI scores. The ARI scores of all groups were mostly 2 and 3.
Dostalova *et al.,* 2016[30]	Comparative different types of brackets	Caries-free human third molars (n=40, 4 groups) (1) Metallic+Transbond (Laser)=10 (2) Ceramic+Transbond (Laser)=10 (3) Ceramic+Variolink II (Laser)=10 (4) Control=10 (No laser, 3 for each group, 1 for no bracket)	Er:YAG WL: 2940 nm E: 280 mJ F: 6 Hz	Metallic (Victory Series), Ceramic (Clarity) Transbond XT, Variolink II	Er:YAG laser radiation effectively removed adhesive remnants in the ceramic (Clarity Advance) with resin adhesive system (Variolink II), leaving an almost pure layer of enamel. SEM analysis indicated a higher presence of adhesive material for metallic and ceramic brackets in the non-lasing group with ceramic remnants also observed in the case of ceramic brackets. Therefore, the lasing group was shown to protect the enamel surface.
Nalbantgil *et al.,* 2018[19]	Comparative different energy levels of Er:YAG laser	Bovine incisors (n=80, 4 groups) (1) No laser (2) Laser 2W (3) Laser 4W (4) Laser 6W	Er:YAG WL: 2940 nm P: 2,4,6 W PD: 300 ms T: 6 s Scanning motion	Ceramic (Transcend) Transbond XT	There was a significant difference in ARI scores between the non-lasing group and the lasing group with a 6 W laser, which showed a significantly higher percentage of ARI scores of 3 (70%).
Grzech Lesniak *et al.,* 2018[9]	Comparative Scanning/ Circular motion technique, Metallic/ Ceramic bracket	Caries-free premolars (n=55, 4 groups) (1) Metallic, circular motion=15 (Laser) (2) Ceramic, circular motion=15 (Laser) (3) Ceramic, Scanning motion=15 (Laser) (4) Ceramic=5, Metallic=5 (No laser)	Er:YAG WL: 2940 nm P: 3.4 W PD: 300 µs T: 6 s Scanning motion	Metallic (Victory Series), Ceramic (Inspire) Transbond XT	Ceramic brackets debonded using the scanning method had the lowest average ARI score. The main finding was the absence of cracks or fractures in all lasing groups. In contrast, pronounced cracks in enamel were observed in the non-lasing group for both ceramic and metal brackets. EDS analysis indicated higher calcium element percentages in all lasing groups compared to the non-lasing group. Additionally, the calcium content was greater in metal brackets compared to ceramic brackets (higher calcium levels indicate safety).
Iijima *et al.,* 2010[15]	Comparative different laser settings, different adhesive bonding systems	Human premolars (n=50, 10 groups) (1) Etch & rinse, No laser (2) Etch & rinse, 3 W (3) Etch & rinse, 4 W (4) Etch & rinse, 5 W (5) Etch & rinse, 6 W (6) Self-etching, No laser (7) Self-etching, 3 W (8) Self-etching, 4 W (9) Self-etching, 5 W (10) Self-etching, 6 W	CO_2 WL: 10600 nm P: 3, 4, 5, 6 W PD: - T: 5 s each spot	Ceramic bracket (Inspire ice) Transbond XT (Etch & rinse), Transbond Plus (Self-etching)	No significant differences were found in ARI scores among all 10 groups. Most ARI scores in all groups were 1. The hardness and elastic modulus are significantly lower at a 1 µm distance from the enamel surface compared to other distances in all specimens.

Ahrari *et al.*, 2011[31]	Comparative Mono-/ Poly-crystal-line bracket, Laser/ No Laser	Human maxillary and mandibular premolars (n=80, 4 groups) (1) CC: Fascination, No laser (2) MC: Inspire Ice, No laser (3) CL: Fascination, laser (4) ML: Inspire Ice, laser	CO_2 WL: 10600 nm PP: 188 W F: 400 Hz PD: 0.0005 s T: 5 s Scanning motion	Ceramic (Fascination, Inspire Ice) Transbond XT	Both non-lasing groups had significantly more ARI scores of 0, while the lasing monocrystalline bracket group had significantly more ARI scores of 3 (70%). Laser debonding caused a significant decrease in the number of cracks for both ceramic bracket types, while resulting in an insignificant decrease in the length of cracks compared to the non-lasing group. Therefore, using laser debonding can reduce enamel damage.
Saito *et al.*, 2013[13]	Comparative different adhesive bonding systems	Freshly extracted bovine permanent mandibular incisors (n=96, 12 groups) No microcapsule content (1) No laser (2) Laser 4 s (3) Laser 5 s (4) Laser 6 s 30% microcapsule content (5) No laser (6) Laser 4 s (7) Laser 5 s (8) Laser 6 s 40% microcapsule content (9) No laser (10) Laser 4 s (11) Laser 5 s (12) Laser 6 s	CO_2 WL: - P: 3 W PD: - T: 2-3 s	Ceramic Orthomite SuperBond	There was no significant difference in ARI scores after debonding in the lasing or non-lasing group. However, there were many scores of 0 and 1.
Matos *et al.*, 2021[18]	Comparative Laser/ No Laser, different adhesive resin, different ceramic brackets	Human premolars (n=90, 6 groups) (1) TMC: Transbond+ Mystique+Control (No laser) (2) TFC: Transbond+ Fascination+Control (No laser) (3) TML: Transbond+ Mystique+Laser (4) ZML: Z250+Mystique+Laser (5) TFL: Transbond+ Fascination+Laser (6) ZFL: Z250+ Fascination+Laser	CO_2 P: 10 W WL: 10600 nm PD: 0.01 s T: 3 s	Ceramic (Mystique and Fascination) Transbond XT, Z250	TMC had the lowest mean ARI score of 0. The best outcomes were found in the ZFL and ZML groups, which were bonded using Z250. The most common type of fracture observed was adhesive fracture, followed by cohesive resin fracture. The lowest enamel damage was found in ZFL (mostly cohesive resin fractures), while the greatest enamel damage was found in ZML (mostly cohesive enamel fractures).

Hoteit *et al.*, 2020[21]	Comparative between Er,Cr:YSGG and Er:YAG lasers settings	Bovine incisors (n=180, 15 groups) Er,Cr:YSGG (1) Laser 3 W/20 Hz (2) Laser 3 W/40 Hz (3) Laser 4 W/20 Hz (4) Laser 4 W/40 Hz (5) Laser 5 W/20 Hz (6) Laser 5 W/40 Hz Er:YAG (7) Laser 80 mJ/20 Hz (8) Laser 80 mJ/40 Hz (9) Laser 100 mJ/20 Hz (10) Laser 100 mJ/40 Hz (11) Laser 120 mJ/20 Hz (12) Laser 120 mJ/40 Hz (13) Laser 140 mJ/20 Hz (14) Laser 140 mJ/40 Hz (15) No laser	Er,Cr:YSGG WL: 2780 nm P: 3, 4, 5 W PD: 60 µs T: - Er:YAG WL: 2940 nm E: 80, 100, 120, 140 mJ PD: 50 µs T: -	Ceramic (Clarity)	The proportion of teeth with intact enamel topography was significantly smaller in the non-lasing group compared to the Er,Cr:YSGG groups (4 W/20 Hz and 5 W/20Hz). In contrast, there were no significant differences in the non-lasing group compared to any of the Er:YAG groups. In the Er,Cr:YSGG subgroups, micro-cracks were found only in the 3 W/20 Hz group. Statistically significant intact enamel was observed in the 4 W/20 Hz and 5 W/20 Hz groups, both displaying the most homogeneous topography compared to others. The enamel surface in the 4 W/20 Hz group was slightly more uniform than in the 5 W/20 Hz group. In the Er:YAG subgroups, all exhibited changes in enamel topography. Er:YAG lasing at both 100 mJ/40 Hz and 120 mJ/40 Hz resulted in reduced enamel micro-cracks compared to the non-lasing group. However, these lasing groups did not significantly differ in the proportion of teeth with normal enamel topography compared to the non-lasing group. SEM analysis revealed rough and amorphous enamel topography in the 100 mJ/40 Hz subgroup, while the 120 mJ/40 Hz subgroup exhibited stripped and shiny changes.
Khalil *et al.*, 2021[25]	Comparative effects of Chemical agent (peppermint oil), Ultrasonic, diode laser, and Er:YAG laser	Extracted human premolars (n=100, 5 groups) (1) No laser (2) Peppermint oil (3) Ultrasonic (4) diode laser (5) Er:YAG laser	diode WL: 980 nm P: 4 W CW T: 3 s on each side (Total 12 s) Er:YAG WL: 2940 nm P: 4 W PD: 100 µs T: 3 s on each side (Total 12s)	Ceramic (Perfect Clear) Transbond XT	Statistically significantly higher ARI scores were found in group 5 (Er:YAG) compared to the other groups, and no other significant differences were found between the groups with regard to ARI. SEM analysis showed cracks and erosion in groups 1 and 2, while groups 3 and 4 showed various degrees of voids. In contrast, group 5 showed an intact enamel microstructure with minimal alterations.

n: sample size; WL: wave length; P: power; PD: pulse duration; E: energy; T: time; CW: continuous wave; F: frequency; PP: peak power; EDS: energy-dispersive X-ray spectroscopy.

Conclusions

Based on the available evidences, laser-assisted debonding of ceramic orthodontic brackets appears to be an effective method for reducing shear bond strength and facilitating bracket removal. Most studies indicate that appropriate laser use can lower the force required for debonding while maintaining enamel integrity and keeping intra-pulpal temperature within safe limits. However, the current evidence is mainly derived from studies with varied methodologies, laser parameters, and outcome measures. This variability limits the overall strength of the conclusions and makes direct clinical translation challenging. As a result, the effectiveness of laser-assisted debonding is likely influenced by proper case selection and careful adjustment of laser settings.

Therefore, laser-assisted debonding should be considered an adjunctive technique rather than a routine replacement for conventional mechanical debonding. Further well-designed clinical studies with standardized protocols and long-term follow-up are needed before clear clinical recommendations can be established.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Deana NF, Zaror C, Sandoval P, Alves N. Effectiveness of low-level laser therapy in reducing orthodontic pain: a systematic review and meta-analysis. Pain Res Manag. 2017;2017:8560652.
2. 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.
3. Stein S, Kleye A, Schauseil M, Hellak A, Korbmacher-Steiner H, Braun A. 445-nm diode laser-assisted debonding of self-ligating ceramic brackets. Biomed Tech (Berl). 2017;62(5):513-20.
4. Strobl K, Bahns TL, Willham L, Bishara SE, Stwalley WC. Laser-aided debonding of orthodontic ceramic brackets. Am J Orthod Dentofacial Orthop. 1992;101(2):152-8.
5. Ahmed T, Rahman NA, Alam MK. Comparison of orthodontic bracket debonding force and bracket failure pattern on different teeth *in vivo* by a prototype debonding device. Biomed Res Int. 2021;2021:6663683.
6. Abohabib AM, Fayed MM, Labib AH. Effects of low-intensity laser therapy on the stability of orthodontic mini-implants: a randomised controlled clinical trial. J Orthod. 2018;45(3):149-56.
7. Goldman L, Hornby P, Meyer R, Goldman B. Impact of the laser on dental caries. Nature. 1964;203:417.
8. Ajwa N, Alfayez H, Al-Oqab H, Melibary R, Alzamil Y. The effect of erbium-doped yttrium aluminum garnet laser in debonding of orthodontic brackets: a systematic review of the literature. Photobiomodul Photomed Laser Surg. 2021;39(11):725-33.
9. Grzech-Leśniak K, Matys J, Żmuda-Stawowiak D, Mroczka K, Dominiak M, Brugnera Junior A, *et al*. Er:YAG laser for metal and ceramic bracket debonding: an *in vitro* study on intrapulpal temperature, SEM, and EDS analysis. Photomed Laser Surg. 2018;36(11):595-600.
10. Ma T, Marangoni RD, Flint W. *In vitro* comparison of debonding force and intrapulpal temperature changes during ceramic orthodontic bracket removal using a carbon dioxide laser. Am J Orthod Dentofacial Orthop. 1997;111(2):203-10.
11. El Mourad AM. Assessment of bonding effectiveness of adhesive materials to tooth structure using bond strength test methods: a review of literature. Open Dent J. 2018;12: 664-78.
12. Sofan E, Sofan A, Palaia G, Tenore G, Romeo U, Migliau G. Classification review of dental adhesive systems: from the IV generation to the universal type. Ann Stomatol (Roma). 2017;8(1):1-17.
13. Saito A, Namura Y, Isokawa K, Shimizu N. CO_2 laser debonding of a ceramic bracket bonded with orthodontic adhesive containing thermal expansion microcapsules. Lasers Med Sci. 2015;30(2):869-74.
14. Hayakawa K. Nd: YAG laser for debonding ceramic orthodontic brackets. Am J Orthod Dentofacial Orthop. 2005;128(5):638-47.
15. Iijima M, Yasuda Y, Muguruma T, Mizoguchi I. Effects of CO_2 laser debonding of a ceramic bracket on the mechanical properties of enamel. Angle Orthod. 2010;80(6):1029-35.
16. Selma ET, Hüdanur Y. Ceramic Brackets Revisited. In: Belma Işık A, Fatma Deniz U, editors. Current Approaches in Orthodontics. Rijeka: IntechOpen; 2018. p. Ch. 2.
17. Feldon PJ, Murray PE, Burch JG, Meister M, Freedman MA. Diode laser debonding of ceramic brackets. Am J Orthod Dentofacial Orthop. 2010;138(4):458-62.
18. Matos DS, Küchler EC, Borsatto MC, Matsumoto MAN, Marques FV, Romano FL. CO_2 laser irradiation for debonding ceramic orthodontic brackets. Braz Dent J. 2021;32(2):45-52.
19. Nalbantgil D, Tozlu M, Oztoprak MO. Comparison of different energy levels of Er:YAG laser regarding intrapulpal temperature change during safe ceramic bracket removal. Photomed Laser Surg. 2018;36(4):209-13.
20. Macri RT, de Lima FA, Bachmann L, Galo R, Romano FL, Borsatto MC, *et al*. CO_2 laser as auxiliary in the debonding of ceramic brackets. Lasers Med Sci. 2015;30(7):1835-41.
21. Hoteit M, Nammour S, Zeinoun T. Evaluation of enamel topography after debonding orthodontic ceramic brackets

by different Er,Cr:YSGG and Er:YAG lasers settings. Dent J (Basel). 2020;8(1):6.
22. Nalbantgil D, Oztoprak MO, Tozlu M, Arun T. Effects of different application durations of ER:YAG laser on intrapulpal temperature change during debonding. Lasers Med Sci. 2011;26(6):735-40.
23. 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.
24. Nalbantgil D, Tozlu M, Oztoprak MO. Pulpal thermal changes following Er-YAG laser debonding of ceramic brackets. ScientificWorldJournal. 2014;2014:912429.
25. Khalil AS, Tamish NM, Elkalza AR. Assessment of chemical, ultrasonic, diode laser, and Er:YAG laser application on debonding of ceramic brackets. BMC Oral Health. 2022;22(1):79.
26. Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol. 1965;19:515-30.
27. 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.
28. Rao A, Deenadayalan P, Deepak C, Dilipkumar D, Angrish N, Shetty SS. Effect of ER, CR: YSGG laser debonding on enamel surface changes in stainless steel and ceramic brackets - an *in vitro* study. J Orthod Sci. 2023;12:7.
29. Dostalova T, Jelinkova H, Remes M, Šulc J, Němec M. The use of the Er:YAG laser for bracket debonding and its effect on enamel damage. Photomed Laser Surg. 2016;34(9): 394-9.
30. Oztoprak MO, Nalbantgil D, Erdem AS, Tozlu M, Arun T. Debonding of ceramic brackets by a new scanning laser method. Am J Orthod Dentofacial Orthop. 2010;138(2): 195-200.
31. 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.