Thermal effect of Er:YAG and Er,Cr:YSGG used for debonding ceramic and metal orthodontic brackets: An experimental analysis

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Abstract

Background. In orthodontics, erbium (Er:YAG) lasers can be used for bracket debonding.

Objectives. To assess the changes in temperature of pulp and enamel during laser debonding of brackets.

Material and methods. A total of 13 brackets (n = 13; 2 metal and 11 ceramic brackets) were bonded to 13 caries-free premolars extracted for orthodontic reasons. Brackets were irradiated with 2 lasers. Laser No. 1 was an erbium-chromium (Er,Cr:YSGG) laser (Waterlase Express; Biolase, Irvine, USA) with a wavelength of 2,780 nm at a power of 2.78–2.85 W, energy of 185–190 mJ, fluence of 10 ns, frequency of 25 Hz, pulse duration of 300 µs, tip diameter of 0.6 mm, air/fluid cooling of 3.5 mL/s, and time of irradiation of 5–25 s. Laser No. 2 was an Er:YAG laser (LiteTouch; Light Instruments Ltd., Yokneam, Israel) with a wavelength of 2,940 nm at a power of 4 W, energy of 200 mJ, fluence of 10 ns, frequency of 20 Hz, pulse duration of 300 µs, tip diameter of 0.8 mm, air/fluid cooling of 3.5 mL/s, and time of irradiation of 5–15 s. Two thermographic cameras (FLIR Zenmuse XT and FLIR P65; FLIR Systems, Wilsonville, USA) and type K thermocouple (Zhangzhou Weihua Electronic Co., Fujian, China) were used for precise temperature measurement on the surface of the teeth and inside them.

Results. When laser No. 1 was in use, the mean difference between the inner and outer temperature of the examined teeth (1.4°C) was higher than when the laser No. 2 was in use (0.6°C) (p = 0.0974). The study found that the temperature inside the tooth did not increase, and it even decreased during treatment with Er:YAG laser using water cooling, provided that appropriate proportion of water and air was used. For laser No. 1, confidence interval (CI) was between 0.7 and 2.2 and for laser No. 2 it was between 0.500 and 1.23. Only experiment for ceramic brackets was described.

Conclusions. These findings confirm that the use of Er:YAG family lasers for orthodontic bracket debonding in an in vitro study is safe and effective.

Key words: thermography, enamel, orthodontic treatment, thermocouple, tooth temperature

Introduction

Lasers are used in all areas of dentistry, ranging from the treatment of soft and hard tissues, periodontal and peri-implant therapy, infections caused by bacteria and fungi, to orthodontic treatment.[1–6]

Orthodontic treatment using fixed appliances with metal or ceramic brackets is a common therapy of malocclusion.[7] Removal of the bracket with conventional debonding pliers, however, can results in enamel cracks, pain and ceramic bracket damage.[8] The available single reports of in vitro studies using the 2,940 nm wavelength erbium (Er:YAG) lasers for ceramic bracket debonding indicate that the procedure is effective and safe for the pulp and enamel.[9–14] Lasers are effective in softening the adhesion at the bracket/resin interface by producing heat energy. Energy transfers into heat within the bonding material vapor and debond the brackets from the enamel.[9] Therefore, problems such as enamel break, bracket detachment and pain during debonding can be solved. The literature concerning the effect of the 2,780 nm wavelength erbium-chromium lasers (Er,Cr:YSGG) is scarce.[15] In addition, lasers have such advantages as decreasing debonding force and shortening debonding time.[16] The Er:YAG laser (2,940 nm) has a high absorbance coefficient in water.[17] Particular care should be taken to prevent thermal injury of the dental pulp with high-power lasers.[18] For example, an intrapulpal increase of 5.5°C causes pulpitis or pulp necrosis in 15% of irradiated teeth.[19] A temperature increase by 10°C on the outer root surfaces causes bone resorption and tooth ankylosis.[20] The use of high-power lasers requires well-defined parameters to prevent thermal damage and to ensure predictable debonding of brackets. However, there is no data on the effect of the 2,780 nm wavelength Er:YAG laser.

The objective of the research was to assess the changes in temperature of pulp and enamel during laser debonding of ceramic and metal brackets.

Material and methods

Sample preparation

Thirteen healthy human premolars, extracted as a part of orthodontic treatment, were immersed in 5% formalin solution for 24 h. All the teeth were removed on the same day before the experiment. They were kept at stable room temperature. After the 24-hour immersion, the enamel surface was polished with fluoride-free polishing paste (Super Polish; Kerr Hawe, Brea, USA) using the handpiece-attached prophy brush, rinsed and air-dried.

Bracket bonding procedure

Prior to laser exposure, metal (Mini Diamond Twin; Ormco, Glendora, USA) and esthetic (Inspire-ICE; Ormco) brackets were bonded (Primer Transbond XT and Transbond XT; 3M Unitek, Maplewood, USA) on the same day. The polymerization of orthodontic adhesive was carried out for 20 s using a LED light-curing device. Next, the study teeth were immersed in a 5% formalin solution once again at stable room temperature for 48 h to ensure that bonding was complete prior to bracket debonding. Pulpectomy was performed in most studied teeth and pulp replaced with thermal compound to enable temperature measurements using a thermocouple within a pulp cavity. Tooth preparation protocol is shown in Fig. 1.

Debonding protocol

This experimental in vitro study yielded specific settings of 2 lasers.

Laser No. 1 – Er,Cr:YSGG laser (Waterlase Express; Biolase, Irvine, USA) with a 2,780 nm wavelength, power of 2.78–2.85 W, energy of 185–190 mJ, frequency of 25 Hz, pulse duration of 300 μs, tip diameter of 0.6 mm, air/fluid cooling of 3.5 mL/s, and illumination time until spontaneous ceramic bracket detachment of 5–25 s.

Laser No. 2 – Er:YAG laser (LiteTouch; Light Instruments Ltd., Yokneam, Israel) with a 2,940 nm wavelength, power of 4 W, energy of 200 mJ, frequency of 20 Hz, pulse duration of 300 μs, tip diameter of 0.8 mm, air/fluid cooling

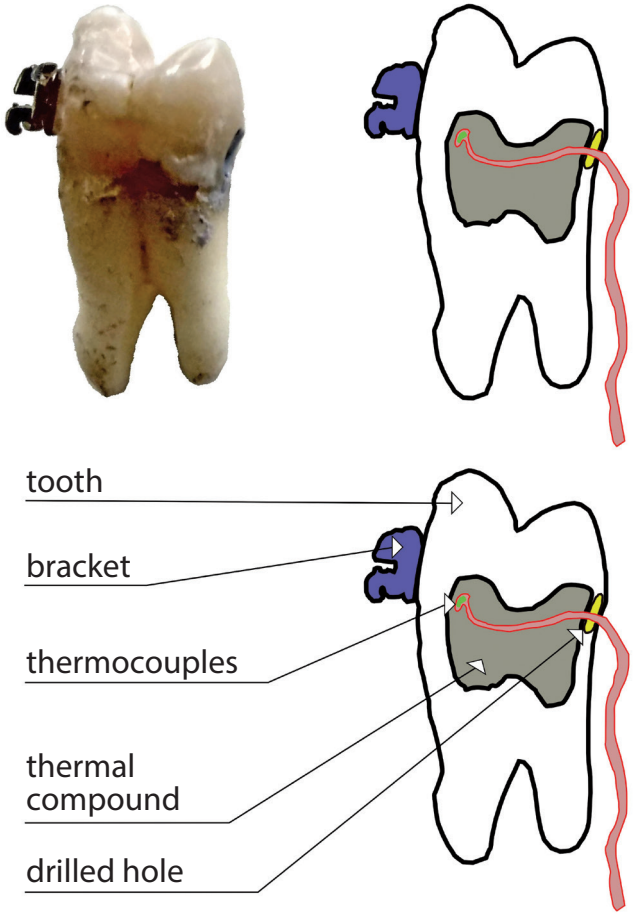

Fig. 1. Tooth preparation protocol

of 3.5 mL/s, and illumination time until spontaneous ceramic bracket detachment of 5–15 s.

The laser energy was applied from a distance of 1–2 mm. Ceramic brackets were illuminated centrally and with slight circular motion, whereas metal brackets were irradiated from all sides. All the samples were debonded with Er:YAG and Er;Cr:YSGG lasers on the same day.

Temperature measurement

The temperature measurement followed a three-step procedure:

– temperature measurement prior to switching on the laser (20 s);

– temperature measurement during laser exposure. The exposure was continued either over a predefined amount of time or until the bracket detached, whichever shorter. This step lasted between 5 s and 150 s;

– temperature measurement after the laser was switched off, as the thermal balance between the tooth and the environment was being restored. This step lasted for a few minutes.

During each step of the procedure, the temperature on the surface of the tooth was measured using the thermographic camera every 10 s, whereas the temperature inside the tooth was measured using a thermocouple every 1 s. If the bracket did not detach spontaneously within a few minutes following laser exposure, manual debonding was attempted. A following test stand was designed: 2 thermographic cameras, i.e., FLIR Zenmuse XT (FLIR Systems, Wilsonville USA) with a 640 × 512 pixel resolution and thermal sensitivity <50 mK, and FLIR P65 camera (FLIR Systems) with a 320 × 240 pixel resolution and thermal sensitivity <80 mK; relative humidity and ambient temperature sensor; and a temperature sensor attached to type K thermocouples (Zhangzhou Weihua Electronic Co., Fujian, China) (Fig. 1). The measurements recorded under different conditions are shown in Table 1.

Statistical analysis

The obtained outcomes were subject to statistical analysis using STATISTICA v. 12.0 (StatSoft, Inc., Tulsa, USA) software and Student's t-test ($p = 0.0974$). The test for the assessment of normality was Kolmogorov–Smirnov (K–S).

Results

When laser No. 1 was used, the outside temperature of the examined teeth (23.3°C) was significantly higher than their inner temperature (21.4°C) ($p = 0.0004$). Using

Table 1. The measurements performed under different conditions.

Laser No. 1 – Waterlase Express, Er,Cr:YSGG, 2,780 nm (2.78 µm) wavelength, manufacturer: Biolase								
1	2	3	4	5	6	7	8	9
Tooth No.	laser exposure duration	energy	power	frequency	amount of water*	amount of air	bracket debonding	bracket type
[–]	[s]	[mJ]	[W]	[Hz]	[%]	[%]	[–]	[–]
1	30	120	3	25	5	10	manual, medium force	ceramic
2	30	120	3	25	5	10	manual, medium force	ceramic
3	30	120	3	25	0	10	manual, medium force	ceramic
4	15	180	2.7	25	80	60	manual, medium force	ceramic
5	10	190	2.85	25	80	60	detached spontaneously	ceramic
6	25	185	2.78	25	80	60	manual, low force	ceramic
7	5	185	2.78	25	80	60	detached spontaneously	ceramic
Laser No. 2 – Little Touch, Er:YAG, 2,940 nm (2.94 µm) wavelength								
1	2	3	4	5	6	7	8	9
Tooth No.	laser exposure duration	energy	power	frequency	amount of water and air*	nozzle type	bracket debonding	bracket type
[–]	[s]	[mJ]	[W]	[Hz]	[%]	[–]	[–]	[–]
8	15	200	4	20	50	red	detached spontaneously	ceramic
9«	15	200	4	20	50	red	detached spontaneously	ceramic
10	75	200	4	20	50	yellow	manual, low force	ceramic
11	5	200	4	20	50	red	detached spontaneously	ceramic
12	120	200	4	20	50	red	manual, did not detach	metal
13	120	500	7.5	15	50	black	manual, did not detach	metal

* 100% of air or water denotes maximum amount for a given device; ** the tooth was not filled with thermal compound – the pulp was not removed.

laser No. 2, the outside temperature of the examined teeth (24.7°C) was slightly higher than their inner temperature (24.2°C) (p = 0.1004). When using laser No. 1, the median difference between the inner and outer temperatures of the examined teeth (1.4°C) was higher than when laser No. 2 was used (0.6°C) (p = 0.0974).

The temperature changes over time both on the surface of the teeth and inside the teeth are presented in the Figures below. The temperature inside the tooth was shown in Fig. 2 and 3. Figures 4 and 5 show temperature values measured on the surface of the teeth using the FLIR P65 thermographic camera (the Zenmuse XT thermographic camera was an additional, control camera). The temperature differences between the enamel and the pulp at the same time points were computed. Positive numbers indicate that the temperature of the enamel was higher than that of the pulp. The results are shown in Fig. 6 and 7.

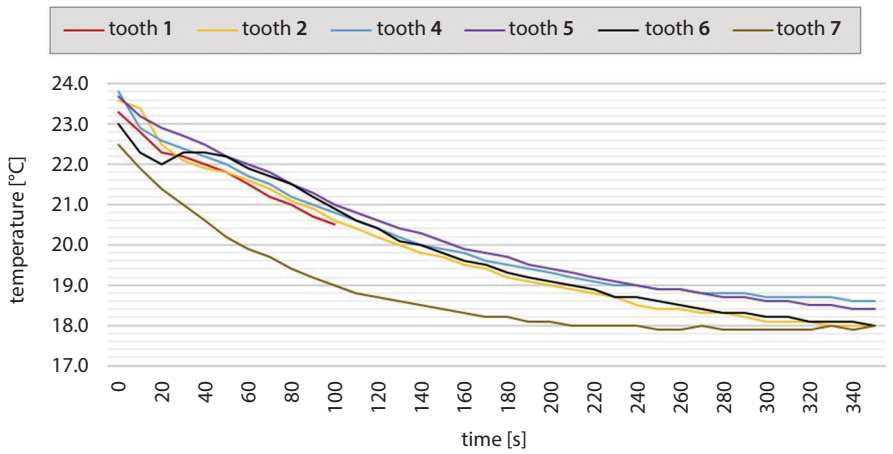

Fig. 2. The temperature inside the tooth during treatment with laser No. 1 measured using thermocouple – diagram close-up

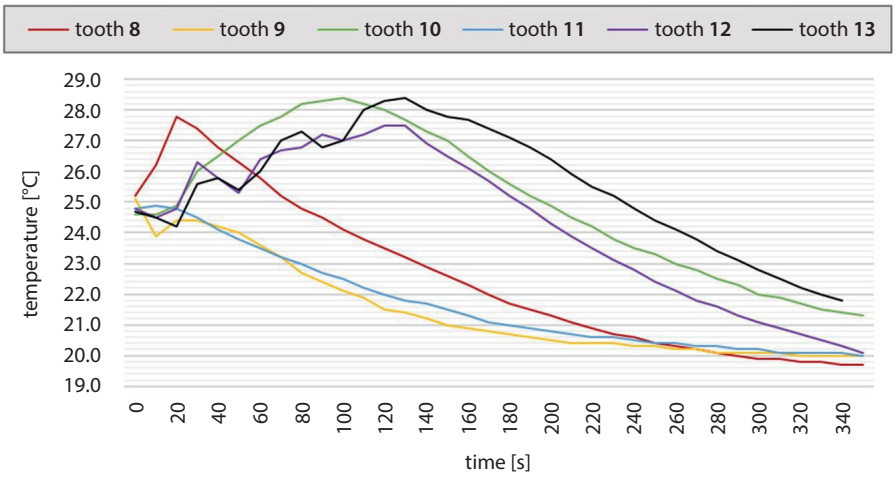

Fig. 3. The temperature inside the tooth during treatment with laser No. 2 measured using thermocouple

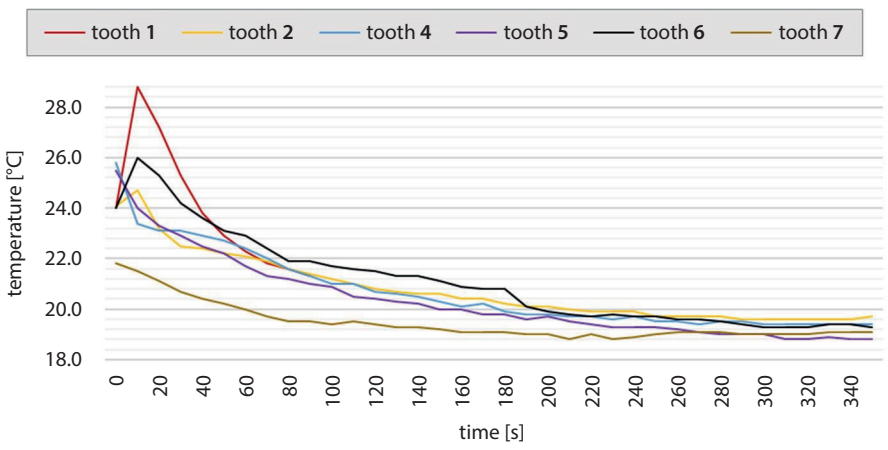

Fig. 4. The temperature on the surface of the tooth during treatment with laser No. 1 measured using thermographic camera – diagram close-up

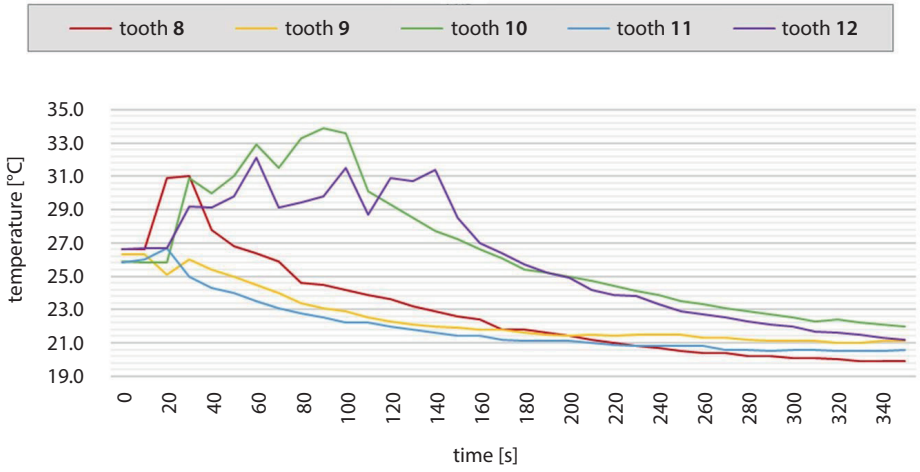

Fig. 5. The temperature on the surface of the tooth during treatment with laser No. 2 measured using thermographic camera – diagram close-up

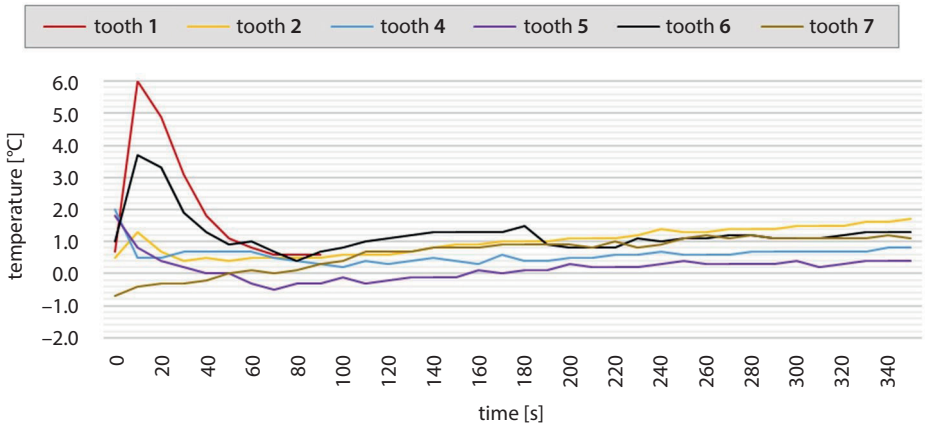

Fig. 6. Temperature differences between the enamel and pulp during exposure to laser No. 1 – diagram close-up

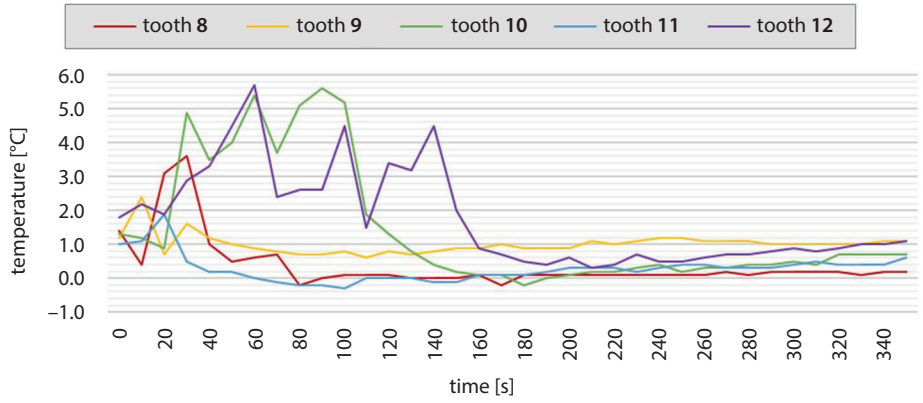

Fig. 7. Temperature differences between the enamel and pulp during exposure to laser No. 2 – diagram close-up

We found that laser debonding has caused lower temperature increase in dental pulp, which is a very good prognostic tool for in vivo study.

Our study described only the experiment for ceramic brackets.

The authors tried to debond 8 metal brackets using Er:YAG (4 brackets) and ER,Cr:YSGG (4 brackets) lasers, but neither debonded at any time (brackets were illuminated from all sides for 10–300 s). In our study, metal brackets were impossible to debond and that was the cause why the temperature was not checked. Only 2 metal brackets were measured to check the temperature.

Discussion

The application of a laser for debonding orthodontic brackets has been investigated with regard to different wavelengths[13,17] and to different types of brackets, types of adhesive materials and lasing methods.[13,20] Our study contributes to the existing knowledge by testing the use of Er:YAG laser at the indicated parameters. Such laser supports debonding of dental brackets without significant damage to the dental pulp. Hamadah et al. used the 4.2 W laser power for 6 s in order to debond ceramic brackets and observed a temperature increase of 2.91–3.35°C.[10]

Nalbantgil et al., who used the 5 W Er:YAG laser power for 9 s on orthodontic brackets with and without water cooling, obtained similar results.[11] They reported that in the group with water cooling, the pulp temperature increase was lower (about 2.41°C) than in the group without water cooling (about 4.59°C). This has shown that simultaneous cooling the tooth surface with water spray is a necessary prerequisite for safe and effective debonding of orthodontic brackets. Dostálová et al.[12] concluded that there is a temperature increase of 2.0–3.2°C during laser debonding of both metal and ceramic brackets. The Er:YAG laser energy of 280 mJ was applied for 140 s at the frequency of 6 Hz. A temperature increase observed during debonding of metal brackets was lower than during the debonding of ceramic ones. An even lower temperature increase was observed following debonding of ceramic brackets using a new scanning laser method. There is no information in literature about the thermal effect of Er,Cr:YSGG laser used for debonding orthodontic brackets. In the study conducted by Zach and Cohen, the authors demonstrated that there is a pulp temperature increase of 1.8°C during laser bracket debonding.[19] Thus, they proved that laser debonding is safe for vital teeth, as only an increase of 5.5°C or more can cause pulpitis or pulp necrosis in 15% of laser-treated teeth. According to the newest research by Grzech-Leśniak et al., ceramic and metal brackets can be debonded using a laser at specific, predefined settings.[9] In this study, Er:YAG laser irradiation was associated with a slight, statistically nonsignificant increase in temperature during the orthodontic brackets debonding. These outcomes were statistically significantly higher in comparison with the ceramic brackets debonded using the scanning technique ($p = 0.015$). The mean temperature gradient obtained for metal brackets was lower than for ceramic brackets. However, further in vivo studies are warranted to assess the impact of lasers on the rise of the temperature in the tooth and on the surface structure of the teeth as well.

The study contributes to the existing knowledge by testing the use of Er:YAG laser in ceramic and metal brackets debonding. The main finding of the study was that the Er:YAG laser supports debonding of dental brackets without significant damage to the enamel or the dental pulp. Findings regarding the use of the Er:YAG laser at the indicated parameters are important because of efficiency and safety of debonding.

The Er:YAG and Er,Cr:YSGG laser wavelengths both operate in the region of the major absorption peak for water and are the most suited to hard-tissue ablation treatments. The Er:YAG laser wavelength penetrates about 7 μm into the enamel and 5 μm into the dentin. The Er,Cr:YSGG laser wavelength penetrates deeper – 21 μm into the enamel and 15 μm into the dentin. Because of the higher absorption, the Er:YAG laser has a smaller penetration depth, and therefore, requires less time to ablate the tissue.[21]

Protecting the pulp is very important during debonding. Within the limitation of our ex vivo study, the outcomes suggest that it is safe to use lasers from the Er:YAG family during the removal of ceramic brackets. In our study, metal brackets were impossible to remove using lasers.

Conclusions

The studied Er:YAG family lasers of 2 different wavelengths can be safely used for orthodontic bracket debonding with air and water cooling only.

During the treatment with laser No. 1 with cooling, not only did the temperature inside the tooth fail to increase, but it actually decreased, which appears promising for its potential in vivo use in the oral cavity. A temperature increase (up to about 3°C) followed by a subsequent drop was observed during the first stage of treatment with laser No. 2.

Ceramic brackets detach spontaneously significantly more often than metal brackets when using discussed laser parameters.

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