ORIGINAL PAPERS

Dent. Med. Probl. 2016, **53**, 3, 352–357
DOI: 10.17219/dmp/63739
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ISSN 1644-387X

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Thermal Effect of Er:YAG Laser Pulse Durations on Teeth During Ceramic Bracket Debonding

Efekt termiczny impulsowego lasera erbowego stosowanego do zdejmowania zamków ortodontycznych

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A – research concept and design; **B** – collection and/or assembly of data; **C** – data analysis and interpretation; **D** – writing the article; **E** – critical revision of the article; **F** – final approval of article

Abstract

Background. Debonіng of ceramic brackets using a Er:YAG laser has become an acceptable method to facilitate the removal of such type of brackets. Therefore, research has been conducted to establish safer and more effective techniques. The pulse duration is one of the most critical parameters with respect to thermal effect on the pulp vitality.

Objectives. The goal of the current research is to evaluate the thermal effect of different Er:YAG laser pulse durations in order to establish safe and effective protocols of debonding ceramic brackets.

Material and Methods. The sample consisted of 45 premolars extracted for orthodontic purposes. A ceramic bracket was bonded to each tooth. The sample was divided into three groups: 15 teeth for pulse duration of 50 µs, 15 teeth for pulse duration of 100 µs, and 15 teeth for pulse duration of 300 µs. All the ceramic brackets were exposed to the Er:YAG laser for 6 s by laser scanning method, with the same air and water conditions, as well as the same pulse energy and repetition rate. The tooth temperature was monitored during debonding the brackets by a thermal camera, and the ceramic bracket was debonded after 18 s. Then, the samples were examined under a microscope to evaluate the presence of the adhesive material.

Results. The results showed the absence of a statistically significant difference between the pulse duration of 50, 100 and 300 µs in relation to the rise in temperature of the tooth. However, a statistically significant difference was found in relation to the presence of adhesive materials between pulse duration 50 µs and both 100 and 300 µs, with no statistically significant difference between 100 and 300 µs.

Conclusions. Within the limits of this study, both Er: YAG pulse durations of 100 and 300 µs are preferred during ceramic brackets debonding using the laser scanning method (**Dent. Med. Probl. 2016, 53, 3, 352–357).**

Key words: thermal effect, Er:YAG, pulse durations, ceramic bracket, debonding.

Słowa kluczowe: efekt termiczny, Er:YAG, czas trwania impulsu, ceramiczny zamek ortodontyczny, odklejanie.

Debonding of the ceramic brackets with the aid of laser technology has become a certified technique in the field of orthodontics, as the use of a laser eliminates the problems of debonding that are associated with the traditional method. These problems may include enamel cracking and broken ceramic brackets, as well as the pain experienced by the patient during the removal of ceramic brackets [1]. Moreover, the use of a laser reduced the efforts and time needed for brackets debonding through thermal annealing of orthodontic brackets [2].

However, the effects of different lasers on the teeth and pulp tissue have not been fully determined.

Many studies have been conducted on the selection of the appropriate laser parameters to debond the ceramic brackets. The major focus of such studies was on other variables including the laser type [3, 4], energy levels, different types of brackets, composite, or the application method [5–7].

It must be noted that most studies, which evaluated the increase in the temperature of teeth during ceramic brackets debonding, adopted the estimated safety threshold of 5.5°C that has been described by Zach and Cohen [8]. This threshold was considered as a critical value in order to prevent pulp damage [8].

The direct effect of the Er:YAG laser on ceramic brackets debonding can be summarized by annealing the adhesive composite. This annealing effect weakens the adhesion strength between the composite and the ceramic brackets base. The characteristic parameters of this procedure result in a thermal effect, which may facilitate debonding brackets carried out by means of traditional tools [9].

A newly developed, effective and safe method for debonding ceramic brackets is called the scanning method by the Er:YAG laser, which was described by Nalbantgil et al. [10]. This method is performed by applying the Er:YAG laser beam on a ceramic bracket while moving the hand piece horizontally over the entire surface of the ceramic bracket with a specific scanning time, frequency and specific energy [2].

After the development of this method, multiple research works followed on the use of the Er:YAG laser in order to reach the best parameters to facilitate the process of debonding brackets and to eliminate the negative effects on teeth, especially on the dental pulp. While several published works tested different laser scanning durations, other works have tested different time gaps between the laser irradiation and ceramic brackets debonding [9, 10].

However, an important parameter has not been addressed in such works, which is the pulse duration, as it has a major influence on ceramic brackets debonding. The goal of this in vitro study is to investigate several durations of Er:YAG pulses in terms of the thermal effects on the teeth during ceramic brackets debonding, by evaluating the changes in temperature of the enamel surface and the adhesive remnant index (ARI). This may determine the optimum pulse duration for safe and easy debonding of the ceramic brackets.

Material and Methods

The research sample consisted of 45 non-carious premolars newly extracted for orthodontic purposes. The research protocol was approved by the Damascus University Ethics Committee (No. 114 M.B.D 14-9-2014). The teeth were stored in distilled water until further processing. The root of each tooth was removed; then, the buccal surface of each tooth was cleaned by pumice powder. Silicon molds were poured with dental plaster stone, and shortly before curing the tooth, it was embedded within plaster, while keeping the buccal surface prominent slightly above the plaster in order to mount the ceramic bracket on it. After the plaster hardened, traditional steps were followed to attach the ceramic brackets. The surface of the tooth was etched by phosphoric acid for 30 seconds, rinsed for 20 seconds, and dried by a stream of air. Orthodontic bonding was applied on the tooth and cured by halogen light, and then the orthodontic composite was placed (3M Unitek®, Transbond® XT) on the ceramic bracket (20/40™ Ceramic Brackets, American Orthodontics, USA), and adhered onto the buccal surface. These steps were repeated for the entire sample and curing was performed by a halogen light. Before applying the laser to the sample, the sample was stored in a container of distilled water at room temperature for a period of 48 hours to ensure complete polymerization. The sample was separated into groups of 15 premolar teeth in a random manner, and thus the groups were ready for the application of the Er:YAG laser with the scanning method.

The laser system used in this study was an Er:YAG laser operated at a wave length of 2940 nm (Lightwalker® ST-E, 8 W, Fotona Inc., Ljubljana, Slovenia). The laser beam was delivered to the non-contact hand piece (R02C, Fotona® Inc., Ljubljana, Slovenia) via articulated arms. The laser energy of 140 mJ (average power 4.2 W) was applied for 6 s at a fixed distance of 0.7 cm above the specimen and with a laser spot size of 0.9 mm, which was in accordance to the manufacturer's instructions. As for the pulse duration, which is the major variable in our study, the following values were used after the sample was divided randomly and evenly: 50, 100, and 300 μs. The frequency was set at 30 Hz. A water and air spray system was employed to cool the irradiated surface. The water/air was set at 2 mL/s and 2 mL/s, respectively, for all tests involved.

A schematic description of the experimental setup is shown in Figure 1. All the experimental work was conducted at the Higher Institute for Laser Research and Applications, Damascus University. Temperature of enamel surface was monitored during laser irradiation with a thermal camera (Fluke, Ti55, Fluke Corporation, USA) (Fig. 2) connected to a computer for thermal video recording. The recordings were analyzed off-time and the minimum and maximum temper-

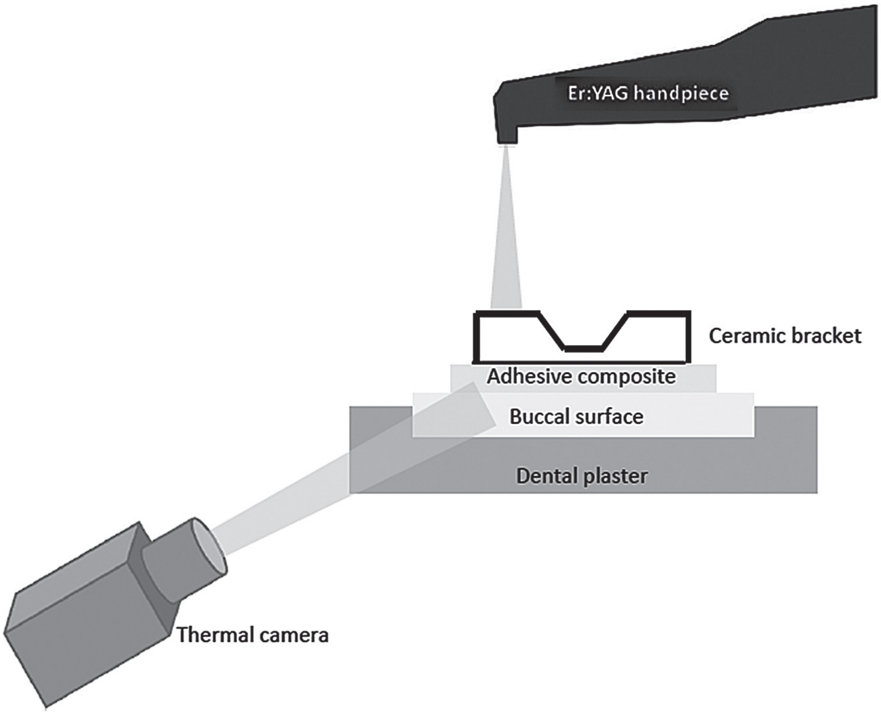

Fig. 1. Schematic description of the cross section of the sample showing ceramic bracket, adhesive composite and buccal surface. Er:YAG laser scanning pattern was used for debonding of the underlying ceramic bracket. Temperature rise in the enamel surface under the adhesive composite is monitored by a thermal camera

Fig. 2. Thermal camera (Fluke, Ti55, Fluke Corporation, USA)

ature was determined. The ceramic bracket was removed with a traditional orthodontic pliers 18 s following laser application.

Initially, the temperature on the tooth surface was determined and the maximum temperature reached on the tooth surface during the debonding of ceramic brackets for each tooth was determined from the thermal video recordings. Then the temperature change for each tooth in laser groups was calculated according to the following:

$$\Delta T = T_b - T_i$$

where T_i is the initial temperature of the tooth surface before laser irradiation, T_b is the maximum temperature of the tooth surface during ceramic bracket debonding. The number of broken ceramic brackets in all groups during the ceramic brackets debonding was counted.

Quantification of the Adhesive Remnant Index (ARI) on the teeth surface was determined after debonding the brackets, where the degree of adhesive material presence was given a value in increasing order according to the quantity of the ARI on the tooth surface. The ARI scores ranged from 0 to 3, where: 0 – no adhesive adhered to the teeth surface; 1 – less than 50% of the adhesive adhered to the teeth surface; 2 – over 50% of the adhesive adhered to the teeth surface; 3 – the entire adhesive adhered to the teeth surface.

The statistical Analysis was performed with IMB SPSS Statistics 17 (SPSS Statistics, IBM Corp., USA). The normal distribution of the data and the test of homogeneity of variances were confirmed by the Kolmogorov-Smirnov and Levene's tests. Means and standard deviation of temperature change after laser irradiation were calculated and the differences between laser groups were analyzed using ANOVA (Analysis of Variance) test. The significance was determined at a probability value of $p < 0.05$ for all statistical tests in this work.

Results

The *t*-Student test on the correlated samples with respect to the average values of the temperature change in the research sample was carried out. Statistically significant differences in the temperature change for all the pulse durations of Er:YAG laser used in this study is shown in Table 1.

Table 2 shows the mean and standard deviation, standard error and the minimum and

Table 1. Comparison in temperature values before and after bracket debonding for all laser groups

Pulse duration	Std. Error Mean	t	df	Sig. (2-tailed)
50 µs	2.97	11.919	14	0.000
100 µs	2.91	9.352	14	0.000
300 µs	3.35	28.068	14	0.000

maximum amount of change in the temperature of the sample according to Er:YAG laser pulse durations.

A one-way ANOVA of group revealed no differences between the laser groups in regard to the amount of temperature change ($F = 0.984, p = 0.382$) as seen in Table 3.

Kruskal-Wallis test was used to study the significant difference in the repetitions of ARI on teeth surface between sample groups. The Kruskal-Wallis test showed that there was a statistically significant difference in the amount of adhesive material remaining on the tooth surface between the different laser pulses, $\chi^2(2) = 6.286$, $p = 0.043$.

The Mann-Whitney *U* test showed significant differences between the 50 µs group and the other two groups, 100 and 300 µs ($U = 80$, $p = 0.048$), with no significant differences between 100 µs and 300 µs groups ($U = 112.5$, $p = 1.000$) as shown in Table 4.

Discussion

The study has important implications for clinical orthodontics because selecting the proper Er:YAG parameters ensures the effective and safe ceramic brackets debonding procedure. Therefore, a certain protocol for Er:YAG usage has been developed, which provides a convenient debonding technique with a minimal force application. Consequently, this may minimize the risk of the increase of the tooth temperature over the critical value, thus preventing any pulpal or periodontal damage.

The results showed that the temperature does not rise to the threshold value, estimated at 5.5°C. This is well below the level of non-response to the dental pulp as shown in Figure 3. This means that the rise in temperature during debonding ceramic brackets by means of the Er:YAG laser was below the threshold value, indicating that all pulse durations from 50 to 300 µs are safe during ceramic brackets debonding.

The present study showed, for all laser pulses, a comparable variation in the temperature rise to that of Nalbantgil et al. [10]. In their study, a thermal sensor placed inside the dental pulp was employed with no given value for the pulse duration. However, in this study a maximum temperature change of 3°C in the dental pulp was observed.

As for the ARI scores, the statistical analysis revealed significant differences between the 50

Table 2. Descriptive statistics for temperature change for different pulse durations

Pulse duration	N	Mean	Standard deviation	Standard error	Minimum	Maximum
50 µs	15	2.97	0.97	0.25	0.9	4.3
100 µs	15	2.91	1.21	0.31	1.1	5.4
300 µs	15	3.35	0.46	0.12	2.1	4.4

Table 3. Comparison of temperature change between the groups

	Sum of squares	df	Mean square	F	Sig.
Between Groups	1.71	2	0.85	0.984	0.382
Within Groups	36.44	42	0.87		
Total	38.15	44			

Table 4. Comparison of ARI scores between groups (Mann-Whitney *U* test)

Parameter	Pulse duration (a)	Pulse duration (b)	Mann-Whitney *U*	Sig.
ARI rank	50 µs	100 µs	80.0	0.048
		300 µs	80.0	0.048
	100 µs	300 µs	112.5	1.000

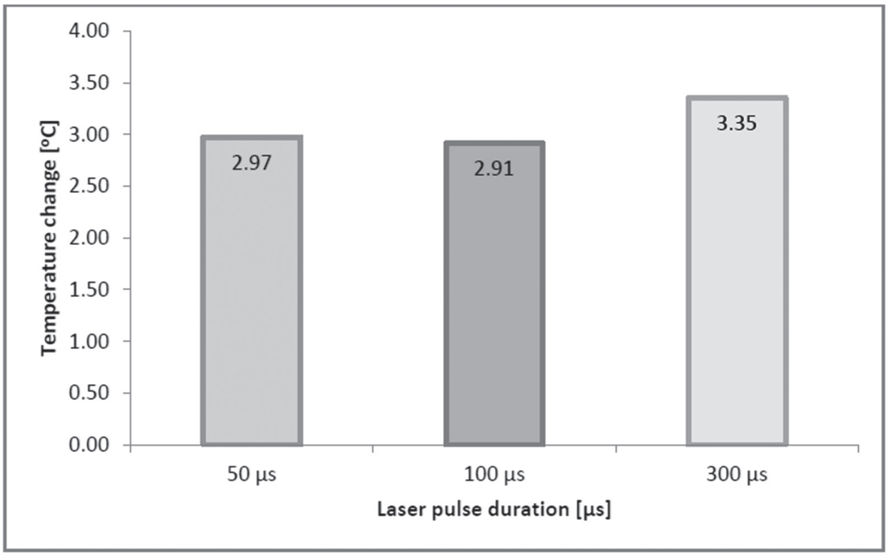

Fig. 3. Temperature change on enamel surface for different Er:YAG laser pulse durations

µs group and other groups (100 and 300 µs), with no significant differences between 100 and 300 µs groups. This difference can be related to the fact that the rank value of the presence of the adhesive material was 3 for all the samples of the second and third groups; thus, the ceramic brackets were debonded from them while the adhesive material remained on the teeth. While for the 50 µs group, three samples were given the score 2, which corresponded to the presence of more than 50% of the adhesive remnant on the tooth surface, whereas the score 3 was assigned to the remaining 12 samples.

Nonetheless, further observation of these three samples revealed that the temperature rise in each tooth was less than 1°C, which is the minimum temperature change that was recorded in all groups. This might be attributed to the fact that a pulse duration of 50 µs may not allow a sufficient rise in temperature of the superficial layer of the adhesive composite, and thus, part of the composite remained adhered to the ceramic brackets in those samples, which may require more force during the brackets removal. This may be accompanied with more pressure on the surrounding tissues, resulting in unwanted pain to the patient. Another important finding to emerge from this study is that no breakage in any of the ceramic brackets in sample groups during laser irradiation was observed. In other words, a selection of the appropriate Er:YAG laser pulse duration corresponding with adequate thermal annealing results in reducing the applied force needed to debond the ceramic brackets. This potentially eliminates the breakage rate in ceramic brackets compared to the breakage rate in traditional ceramic bracket debonding [11–13].

Orthodontic debonding by means of Er: YAG laser is based on a thermal mechanism [14, 15]. Therefore, temperature change was quantified with regard to pulpal damage threshold. On the other hand, ARI index estimates the easiness of bracket debonding. For example, ARI value of 3 indicates that the adhesive material remained on the tooth surface, and the debonding effect occurred between the orthodontic composite and the bracket base through thermal softening (temperature rise). This will make the debonding process clinically much easier. Since this easiness should be accompanied by safe debonding with no thermal damage to the pulp, ARI and ΔT are correlated. However, the results shown in this study regarding these tow variables are not necessarily highly consistent. The presence of temperature changes for some samples within 50 µs group demonstrated this inconsistency, which was clarified in the discussion.

The main aim of our evaluation of the ΔT index (change of temperature) is to recognize the safe margins of the clinical use of Er:YAG as an auxiliary tool in the debonding of the ceramic brackets and, thus, to ensure that there is no increase in the tooth temperature which may lead to pulpal irreversible complications. On the other hand, the ARI is an index of considerable influence on the clinical aspects as well, in which it determines the thermal softening efficacy in the Er:YAG-involved application, which affects the ease/smoothness of ceramic bracket debonding, as the presence of the cemental residues in most of the samples indicated the occurrence of the thermal softening at the hybrid layer between the ceramic bracket and the orthodontic composite. Therefore, there is no need for a great force in this debonding process, which reduces the chances of any dental and periodontal trauma, in addition to the ceramic bracket fracture incidence. Hence, this enables the orthodontist to apply Er:YAG laser on the porcelain brackets and in certain parameters ensuring a convenient bracket removal session for the patient and a minimal pulpal involvement.

Conclusions

To sum up, there is no statistically significant difference between the duration of the pulses (50, 100 and 300 μs) in terms of the temperature change of the tooth surface. However, there is a statistically significant difference between pulse duration of 50 and both 100 and 300 μs, in terms of the presence of adhesive material.

The rise of tooth temperature during the debonding of ceramic brackets is below the threshold value in all pulse durations used in this work. In addition, there is no breakage in ceramic brackets regardless of the pulse duration.

Accordingly, within the limits of this study, we may conclude that the use of the Er:YAG laser pulse duration of 100 up to 300 μs is clinically preferred over other durations, as it ensures ease and efficiency in debonding ceramic brackets. More importantly, with its use it is possible to avoid producing a thermal effect well below the critical value at which irreversible damage in the dental pulp.

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Conflict of Interest: None declared

Received: 12.05.2016
Revised: 10.06.2016
Accepted: 16.06.2016