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## Temperature evolution on human teeth root surface after diode laser assisted endodontic treatment

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**Abstract** The thermal rise threshold of an 810-nm semiconductor diode laser on the root surface when used in root canals in vitro for laser assisted root canal treatment is investigated in this study. A total of 50 human single-rooted extracted teeth were included. For this study, the canals were enlarged up to an apical size of ISO#50 file. Laser irradiation was performed with six different settings. Specimens were irradiated at 0.6–1 W output power at the distal end of the fiber and about 1–1.5 W output power in the continuous mode (CW) as two groups. In the third group, 0.6–1 W output power, 10 ms pulse length (PL) and 10 ms interval duration (ID) were selected. In three other groups 1–1.5 W output power were used with different PL and ID as following: PL 10 and ID 10 ms, PL 10 and ID 20 ms and PL 20 and ID 20 ms. The total irradiation time was from 5 to 20 s per canal with a 200  $\mu\text{m}$  in diameter and 25 mm long tip. After laser treatment, the temperature changes at the outer root surface were registered by means of NiCr-Ni measuring sensors and a T 202 thermometer. The safe temperature threshold for applying this diode laser in root canal is considered as 7°C increase. To avoid increasing the temperature changes at the outer root surface related to this threshold, following total irradiation times were found: 0.6–1 W output power (10 ms PL/10 ms ID): 20 s (s), 1–1.5 W output power (10 ms/10 ms and 20 ms/20 ms): 15 s, 0.6–1 W output power CW and 1–1.5 W output power (20 ms PL/10 ms ID): 10 s and 1–1.5 W output power CW: 5 s. In the first three groups, 5 s irradiation and 5 s rest period avoided a temperature increase above the threshold of 7°C).

**Keywords** Diode laser · Endodontics · Root canal disinfecting · Root surface temperature · Output energy

### Introduction

One of the most important challenges in laser dentistry is the heat production that is going to be controlled by different technical and dental procedure strategies [1]. Depending on the type of laser and procedure that is done as “laser assisted root canal treatment”, there is a temperature increase between 10.3 and 14.4°C [2–4]. In an in vitro situation, this would correspond to 47.3–51.4°C that was uncomfortably close to a temperature of 47–50°C that has been reported as dangerous for bone tissue [5]. The maximum acceptable temperature is described as 53°C, while higher temperatures will result in bone necrosis [2, 3]. Ramic et al. and Ramsköld et al. have explained that laser irradiation is related to temperature increases that can be deleterious to the tissues surrounding the tooth. An increase of 10°C above body temperature for 1 min is considered to be the safety threshold for the periodontal tissue [6, 7]. Bone is more susceptible to thermal injuries than the periodontal membrane because of its lower degree of vascularization. Because of possible thermal damage, the temperature on the root surface should be known before any laser treatment within a root canal is attempted in vivo.

Another study using a Nd:YAG laser showed that the heat generation during laser treatment of the root canals in the teeth of dogs resulted in necrosis of periodontal tissue and subsequent ankylosis [8], but in the current investigations on human teeth, the average rise in root surface temperature during using Nd:YAG laser in root canal was maximum  $9.56 \pm 0.28^\circ\text{C}$ , which safe for periodontal ligaments and surrounding bone [9].

In the latest published report of Kreisler et al. [10] the temperature is recorded during the irradiation with an 809 nm GaAlAs-laser with a 200  $\mu\text{m}$  optical fiber at 1.5,

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3.0 and 4.5 W setting powers in the canal at three measuring points. Temperature elevations were highest in points with a remaining dentin thickness of 0.5 mm followed by 1 and 2 mm, corresponding to the distance of the measuring point from the spot of irradiation. A temperature of 47°C was not exceeded during the irradiation process [10]. Kreisler et al. also noted that these kinds of in vitro studies are not complete because the absorption of laser radiation in root surrounding tissue is not involved. It seems necessary to remember that the degree of transitivity of 810-nm diode laser through 1 mm dentin block is only 17% [2, 3].

Moritz et al. demonstrated that heat generation on the root surface induced by semiconductor laser irradiation (810 nm, 4 W, 10 ms pulse length (PL)/10 ms interval duration (ID) of the root canal was proportional to the duration of laser irradiation. When the fiber was kept in one spot for 1, 2 and 3 s, temperatures evaluations of 6, 12 and 18°C were registered [11]. It must therefore be stressed that the fiber should be kept in constant motion in the root canal. On the other hand, the duration of work and pauses between any time that the root is treated by lasers is very important in order to give enough cooling rest period to tooth material that have not yet been accurately recorded until now.

The aim of this in vitro study was to find the most effective 810 nm diode laser irradiation time protocol for preventing the increase of temperature on the root surface. The most effective "Laser assisted endodontics protocols" that are recommended for bacteria reduction suggest that the laser fiber should be rotationally moved into the canals to prevent the overheating [1, 11–13].

Finally the most reliable investigations recommend that temperature on the root surface during different procedure of endodontics treatments should not rise more than 7°C [14]. This threshold temperature level of 7°C is commonly considered as the highest temperature limit biologically accepted to avoid periodontal damage [15–17]. In this study, this safety threshold level is selected as the standard index for finding the suitable exposure and rest time protocols for different settings of 810 nm diode laser.

## Materials and methods

A total of 50 human anterior upper single-rooted extracted teeth were included—Teeth which were extracted because of the periodontal severe diseases saved in the normal saline during the collecting time not exceeding 6 weeks. Access cavities were prepared with diamond burs (Shofu, CA, USA). The canals enlarged up to an apical size of ISO#50 with hand and rotary files (Maillefer, Switzerland & MITY ROTO 360, Sultan Chemists, Inc., USA). All the canals were completely cleaned and washed with normal saline. Next, their moisture was collected with paper cones. Some canals did not dry completely in order to enable us to make a side pilot

study to see the probably different condition in wet canals.

An 810-nm ( $\pm 20$  nm) gallium-aluminium-arsenide (GaAlAs) diode laser was selected for this study (Dentek LD-15, Austria). This instrument emits laser light in a power range of 0.5–15 W. Pulse duration and interval duration (ID) can be changed independently in a range of 2–32 ms.

Laser irradiation was performed with six different settings as follows:

Group	Settings
1	3 W, 10 ms PL and 10 ms interval duration ID
2	3.0 W, continuous mode (CW)
3	4 W, PL 10 and ID 10 ms
4	4 W, PL 20 and ID 10 ms
5	4 W, PL 20 and ID 20 ms
6	4 W in the (CW)

It is important to mention that the power emitted at the distal end of tip was reduced to 20–30% of the value indicated on the laser controls, mainly due to the jointing parts and very thin fiber that was used. It means that for 3 W set power, only 0.6–1 W output energy was measured and for 4 W about 1–1.5 W.

As the first part of our study, the total irradiation time was 20 s per canal with a 200  $\mu$ m in diameter and 25 mm long tip and only for once 25 s (5 $\times$ 5 s with 5 s pause between the irradiations). The optical fiber was first entered till apex. Then the laser was activated and fiber was rotated during movement from apex to coronal part of the root by one examiner. For 20 s irradiation, this method was repeated for the same period of time.

After laser treatment, the temperature changes at the outer one third apical part of roots surface were recorded by means of NiCr–Ni measuring sensors (Greisinger, Germany) and a T202 thermometer for 40 s to monitor the cooling process. The average measuring rate was one time per second. The temperatures that were shown on the display of the thermometer subject to sensor errors had a deviation of  $\pm 0.2^\circ\text{C}$ . It means that the accuracy of this measurement technique was in the range of  $-0.2$  to  $+0.2^\circ\text{C}$  varied. The room temperature that was used as the base of measurements was 20°C.

For part two of the study, dentin slices were used. They were prepared by mounting four of the teeth in self cure acrylic blocks (Technovit 4071, Heraeus Kulzer, Germany) and were then cut by a microtom (Model 1600, Leica) in horizontal and vertical directions to the size of 1 and 2 mm thickness. They were stored in isotonic normal saline for the time of laser treating. At the time of study, dentin slices were fixed by a retainer as the sensor was connected to one side and laser fiber was positioned on the opposite side in contact. Irradiation was done for 20 s toward to 1 and 2 mm thick dentin slices. The temperature was measured on the other side of bulk with the view to compare heat transmission in two different thicknesses.

**Table 1** The mean and standard deviation of recorded outer surface temperature of different 20 s irradiation groups is reported (The temperature before irradiation is 20°C)( $n=8$ )

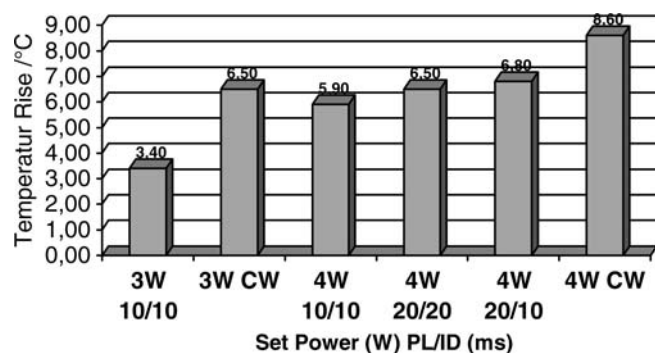
Time	S.D.				
	Instrument setting	After 5 s	After 10 s	After 15 s	After 20 s
0.6–1 W 10/10	22.1°C (0.9)	24.0°C (1.1)	25.0°C (0.9)	25.7°C (1.2)	25.7°C (1.2)
0.6–1 W CW	22.8°C (1.1)	25.2°C (0.8)	27.9°C (0.7)	29.6°C (1.2)	29.6°C (1.2)
1–1.5 W 10/10	21.9°C (0.4)	23.4°C (0.4)	25.5°C (0.5)	27.8°C (1.1)	27.8°C (1.1)
1–1.5 W 20/20	22.2°C (0.9)	24.2°C (0.3)	26.0°C (0.8)	27.1°C (0.3)	27.1°C (0.3)
1–1.5 W 20/10	22.1°C (0.9)	25.1°C (1.6)	27.4°C (2.0)	30.3°C (3.7)	30.3°C (3.7)
1–1.5 W CW	24.1°C (1.1)	28.0°C (1.3)	30.8°C (1.9)	36.3°C (4.5)	36.3°C (4.5)

## Results

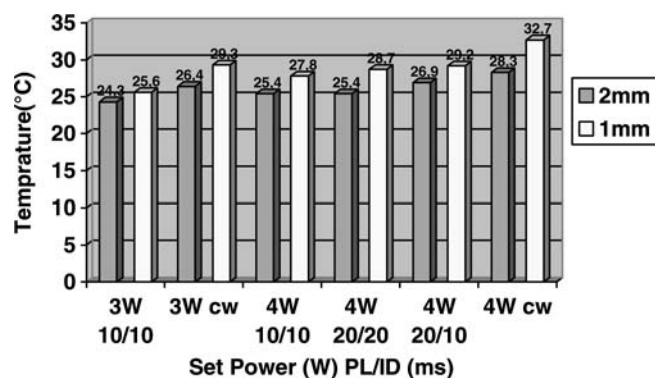
In the first part of the study, the mean and standard deviation of the recorded outer surface temperature of different 20 s irradiation groups are reported (Table 1).

The maximum temperature during 5×5 s irradiation is reported as 23.4, 26.5, 25.9, 26.6, 26.8 and 28.6°C in Group I, Group II, Group III, Group IV, Group V, Group VI, respectively. (Fig. 1)

In the second part, the heat transmission in 1 and 2 mm thick dentin slices was recorded after 20 s laser radiation (Fig. 2).



**Fig. 1** The maximum temperature change recorded 5 s after irradiation in different groups ( $n=8$ )



**Fig. 2** Heat transmissions in 1 and 2 mm thick dentin slices is reported ( $n=8$ )

According to the safety threshold level of a 7°C temperature rise on the root surface, the safe in-vitro protocols for applying this diode laser in root canal is recorded as follows:

Group	Setting	Exposure time
1	3 W (10 ms PL/10 ms ID)	20 s
2	4 W (10 ms/10 ms) and 4 W (20 ms/20 ms)	15 s
3	3 W CW and 4 W (20 ms PL/10 ms ID)	10 s
4	4 W CW	5 s

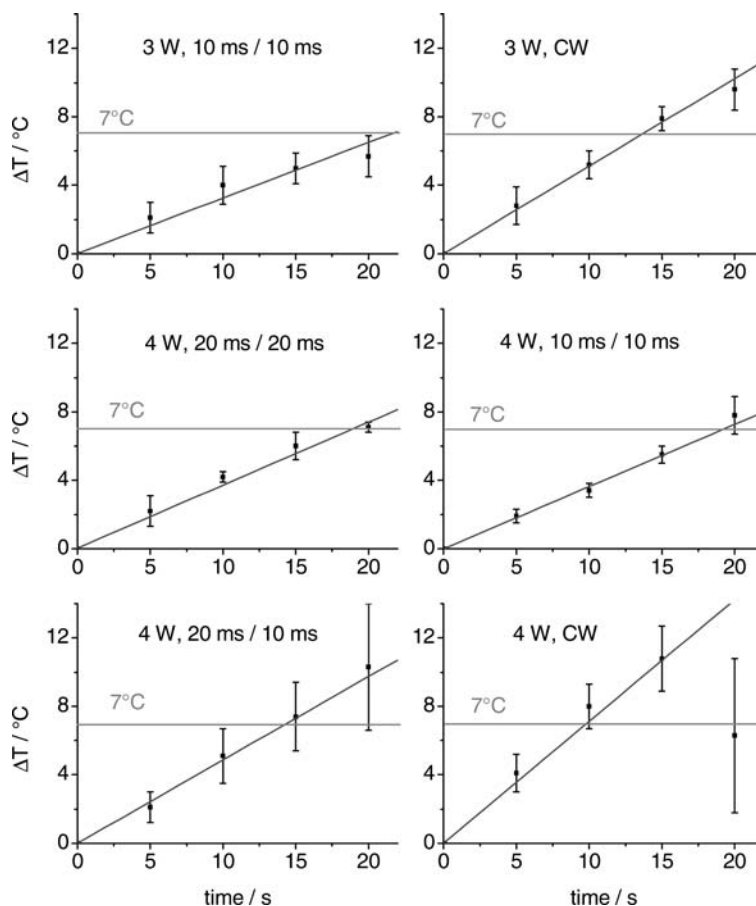
In the first three groups, 5 s irradiation and 5 s rest period eliminated the critical temperature, but in the last group 10 s of pause for taking rest from the produced heat on root surface is recommended.

## Discussion

This study was aimed to determine the temperature rise on the human tooth surface induced by a 810 nm diode laser in relation to different power levels, pulse duration intervals and rest times between the repetition periods of laser exposures.

In several studies, the temperature in different parts of the root and with noted methods are measured and reported, but this investigation is focused on preparing the safest condition for periodontal soft and hard tissues especially in the apical part of the roots where there is only a thin layer of dentin and cement between the root canal and periodontal ligaments and surrounding alveolar bone. So this area will be more susceptible to thermal damage. Thus we recorded the temperature levels with two different methods to determine what power setting and exposure time safety might be used in a clinical situation for in-vivo studies according to such in-vitro investigations. Saunders [17] demonstrated that the time factor is significant in addition to temperature elevation and recovery may be more rapidly in-vivo than in-vitro. So although the 10°C is reported as accepted maximum heat increase in root surrounding tissue but because the cooling time during the in-vitro condition in room temperature is faster than inside the tissue, 7°C is used as the safety thermal rise threshold on root surface [11, 14–16]. Also the rotary movement of the tip addi-

**Fig. 3** The average and standard deviation of temperature change recorded during irradiation in 20 s ( $n=8$ )



tional to preparing better treatment results will help to give a rest especially in the root apex area and apical third of the root. The rotary movement protocol is demonstrated as the best method for beam delivery in surrounding root structure replacing to focusing to apex [1, 18]. In the second part of this study, the temperature evolution after different time periods of irradiation was measured to ensure that the possible clinical events are not damaging, because it is shown that the temperature rise exceeding  $10^\circ\text{C}$  is considered to be harmful for periodontal tissue (except with 4 W CW). A  $10^\circ\text{C}$  temperature rise on the root surface is widely accepted as the maximum safe heat production during all the endodontic procedures [2, 3, 14]. Thus, it is strongly recommended that the tip should not be left in root at a fixed position, not even for some seconds, especially when higher energies are used.

It is important to note is that the powers that are described in this study as setting are only special to this instrument. Every clinician should measure the output energy of his/her diode laser and use it only with power outputs that are considered safe.

It is clear that the in-vitro condition that was prepared for this study cannot be complete a picture of what will happen in the in vivo situation, but as the minimum thermal rise threshold is selected, the results are not so far from the conditions in-vivo. The authors have designed an animal study to ensure the safety of

suggested protocols by looking at the periodontal tissue after the laser treatment.

Finally it is necessary to note that the output energy and energy density of the laser beam should be measured in all the similar investigations, because different instruments have different efficiency. In the condition of this study, the output power of fiber was measured between 0.6 and 1.0 W, while the instrument was set on 3 W and between 1.0 and 1.5 with 4 W set power. So it suggested that the power measurement sensors be added to dental laser instruments and even the power be measured before any time of use in dental clinics by the dentist to prevent any possible damage resulted from high amount of energy delivery to different tooth surfaces.

## Conclusion

Based on the condition of this study, 810-nm diode laser application in tooth root canal, will not increase the temperature of surrounding tissue more than the threshold of  $7^\circ\text{C}$  when irradiated with the resulted time duration set ups (Fig. 3). The laser radiation for 20 s with 0.6–1 W output power (WOP), 10 ms PL and 10 ms ID will be safe according to this conservative heat production limitation. With 1–1.5 WOP (10 ms/10 ms) and 1–1.5 WOP (20 ms/20 ms) total irradiation time of 15 s, is resulted for this purpose. Also, when the output

power is 0.6–1 W in CW or 1–1.50 W, 20 ms PL and 10 ms ID set, the laser irradiation time recorded equal to 10 s for the same temperature control. The last measurements with 0.6–1 W (CW) concluded that only 5 s laser application in root canal will increase the temperature at the outer one third apical part of roots external surface to 7°C, so irradiation time is suggested 5 s to avoid any possible disturbance of tooth supportive periodontal tissues.

According to this study, for any diode laser irradiation that is exposing to internal root surfaces, after any 5 s shooting, 5 s resting time should be considered to prevent the temperature rise from exceeding the accepted, safe threshold, as discussed. In other words, it means when the total time of radiation is 20 s, it is divided in four times of 5 s irradiation and three times of 5 s pause between the shoots.

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