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Intra-pulpal and subsurface temperature rise during tooth irradiation with 808 nm diode laser: an *in vitro* study

ABSTRACT

Aim *This* in vitro *study evaluated the pulpal and subsurface temperatures during proximal tooth surface irradiation with different settings of an 808 nm diode laser.*
Materials and methods *The elevation of pulpal and subsurface temperature during irradiation was measured using thermocouples positioned in the centre of the pulp chamber (n=30) and in the centre of a prepared 1.5 mm deep coronal cavity (n=30). Each sample was irradiated 3 times within one-week interval using different exposure settings. A temperature increase of 3.5°C was regarded as critical value for pulpal heath. Results were analysed with one-way ANOVA and Duncan post hoc tests. Micromorphological investigation by digital microscopy was carried out for the irradiated and non-irradiated tooth surface.*
Results *Measurable temperature increase within the pulp chamber (ΔPT) and the subsurface (ΔST) were observed with all laser settings tested. The highest recorded ΔPT and ΔST were 3.1°C and 8.5°C, respectively. Delivery mode, beam diameter, and exposure time influenced the temperature rise. No alterations on the enamel surface were observed when inspected by the digital microscope after undergoing irradiation with the tested parameters.*
Conclusion *From the thermal point of view, under the conditions of the present study the application of an 808 nm diode laser on the outer surface of the tooth at 1W in the continuous mode and at 5W in the pulsed mode for two cycles of 30 s each proved to be safe.*

Keywords *Diode laser; Dental tissues; Laser irradiation; Temperature changes.*

Introduction

Minimal intervention dentistry is a prevailing concept in operative dentistry, which addresses that the amount of enamel and dentin should be maximally conserved through the inactivation/disinfection of carious dental tissue and the stimulation of remineralisation [Mount and Ngo, 2000]. A new technology which might be introduced into this concept is the application of intense near infrared (IR) light as provided by near IR diode lasers to disinfect/sterilise caries in the depth of the dental tissue without precedent cavity preparation, based on the property of near IR light to deeply penetrate into dental tissue [Klinke et al., 1997; Vaarkamp et al., 1995; Odor et al., 1999]. As near IR laser light can penetrate up to 1000 μm into dentin, this property provides a distinct advantage since bacteria can penetrate over 1000 μm into the dentin tubules otherwise unreachable by any other non-invasive inactivation technology [Gutknecht, 2004].

Laser radiation in the near IR range has a bactericidal effect by causing permanent destruction of the bacterial cell membrane. This damage might be enough to stop the growth of the bacterial cells and can be accomplished with small doses of thermal energy [Moritz et al., 1998].

The use of 808 and 980 nm diode lasers has become widespread in clinical dental practice. Recently, an 808 nm diode laser has been marketed for clinical use. This device is extremely compact, cordless, small and very easy to handle. The manufacturer indicates this laser in particular in periodontal pockets for photoactivated disinfection in conjunction with the indocyanin infrared dye (Periogreen®, Elexxion, Germany) by claiming a photothermal effect due to a selective absorption of heat by the infrared dye. However, a photothermal effect leading to bacteria killing, even if less specific, may also be realised by the irradiation with the diode laser without an absorbing dye, just by increasing the energy density of the laser. Such a mechanism would be particularly useful in the treatment of non-cavitated carious lesions, which cannot be penetrated by a light-absorbing dye. Increased energy density of the laser automatically leads to higher thermal load, which might be harmful to the vital tissue, in particular to the dental pulp. Even if the exact temperature is still a matter of controversy, an increase in temperature above 42.5°C may induce irreversible changes in the pulpal tissue according to several authors [Zach and Cohen, 1965; Atai, 2009].

The goal of the present study was to determine by a thermocouple the highest power density settings of the 808 nm diode laser, which would keep the temperature threshold in the pulpal chamber below the critical 42.5°C. As a reference, the temperature at the tooth surface was measured with a second thermal couple. The null hypothesis was that there would be no critical temperature increase caused by the laser radiation.

FIG. 1 Tooth samples mounted on a platform and immersed in 37°C water bath.

Materials and methods

Sixty extracted human single root canal premolars free of restorations or caries and stored at 4°C under 100% relative humidity were used for the study and randomly divided into two groups of 30 teeth each.

In the pulpal chamber group (PG), the root end was cut with the aid of a grinding and polishing machine (Labopol-2, Struers A/S, Denmark) perpendicular to the long axis of the tooth, leaving a defined root length of 10 mm from the cementoenamel junction. Access to the pulpal chamber was prepared through the root canal. The root canal was enlarged with hand files (Dentsply Maillefer, Ballaigues, Switzerland) and 0.70 Gates Glidden drill (Dentsply Maillefer, Switzerland) and both the root canal and the pulpal chamber were cleared of remnant pulpal tissues, cleaned completely and washed with normal saline. Thereafter a 0.6 mm wired mini-thermocouple was inserted through the root canal into the pulpal chamber.

In the subsurface group (SG), a small coronal cavity was prepared by a 0.8 mm round diamond bur (Intensive SA, Grancia, Switzerland) in the mesial occlusal pit. The cavity was approximately 1.5 mm in depth so that the tip of the second wired mini-thermocouple could be fitted and contact the dentine at the subsurface.

As shown in Figure 1, all teeth were mounted on an acrylic platform, which was specially formed (2 mm × 7 mm × 17 mm) to fit on top of the chamber of a water bath (Grant Optima™ T100, Cambridge Ltd., United Kingdom). The purpose of this procedure was to provide a steady base for the dental crown to be irradiated and to keep the root of the tooth immersed into 37 °C water bath during the irradiation to simulate *in vivo* conductivity and diffusibility of heat.

After complete filling of the pulpal chamber with a thermal conductor paste (Cooler Master HTK-002), an ø 0.6 mm coated Type K wired mini-thermocouple (Greenlee Textron Inc., USA) was positioned in a way that its bare tip (0.3 mm x 1.5 mm) was in direct contact with the surface of the inner pulpal wall. The apical root opening where the wire entered the root canal was sealed with light-cured resin composite (Gradia Direct, GC, Tokyo, Japan) stabilising at the same time the thermocouple.

For temperature measurements at the tooth subsurface, the small coronal cavity was filled with the thermal conductor paste and the tip of the mini-thermocouple was inserted into the cavity so that it contacted the dentine directly under the tooth surface to be irradiated. The wire was stabilised with light-cured resin composite (Gradia Direct).

Sixty min before performing the temperature measurements the samples were retrieved from the 4°C solution and immersed into five-litre water bath (Grant Optima™ T100), which was kept at a constant temperature of 37.0°C. An 808 nm +/- 10 nm Class 4 GaAIAs diode Laser (Claros Pico, Elexxion AG, Radolfzell, Germany) was used for the study. Laser irradiation and temperature measurements were performed with the following parameters.:

1. 5.0 Watt, pulsed mode, pulse length 26 µs, frequency 16,000 Hz, fiber diameter 300 µm.
2. 5.0 W, pulsed mode, pulse length 26 µs, frequency 16,000 Hz, fiber diameter 600 µm.
3. 1.0 W, continuous wave (CW), fiber diameter 600 µm.

The laser fiber applicator tip was connected to the handpiece in order to deliver the laser energy by scanning a surface zone of approximately 9 mm^2 for two cycles of 30 s with a pause interval of five seconds.

The applicator was held at an angle of approximately 60° to the tooth surface, and there was slight contact between the enamel surface and the tip. The applicator was moved at a speed of approximately 1.5 mm/s. The experimental set-up is presented in Figure 2.

The thermocouples were connected to a digital data-logger (Voltcraft K202, Conrad Electronic GmbH, Pratteln, Switzerland). Temperature changes during irradiation were recorded every 5 s for a recording period starting 5 seconds before laser irradiation and up to about 10 s after the end of irradiation, until the temperature started to decrease. The collected data, which was available in both tabular and graphic form, was monitored in real time and transferred to a computer.

For digital microscope analysis of the treated tooth surface (Keyence VHX-S500E, Osaka, Japan), two

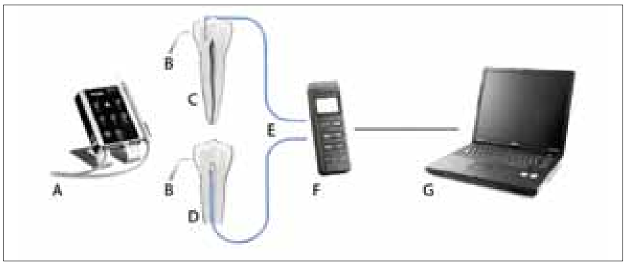

FIG. 2 Schematic representation of the set of appliances used: 808 nm Diode laser (A), fiber application tip (B), sample for subsurface placement (C), sample for pulpal chamber placement (D), K-type thermocouple fixed in a coronal cavity in SG, and within the pulp in PG (E), digital data logger (F), computer (G).

Laser Mode	Beam ø (μm)	Exposure Time (S)	ΔPT °C (SD)	ΔDT °C (SD)
PWM/5W	300	30	0,7 (0.4)	1.4 (0.3)
		60	1,2 (0,4)	1.7 (0.3)
	600	30	1,6 (0,4)	3,2 (1,3)
		60	2.2 (0.4)	4.3 (1,7)
CWM/1W	600	30	0.9 (0.2)	1.4 (0.4)
		60	1,3 (0,3)	1.7 (0.5)

TABLE 1 Means and standard deviations of pulpal and subsurface temperature rise (ΔPT and ΔDT), where three different laser setting were applied for two irradiation cycles of 30 s each.

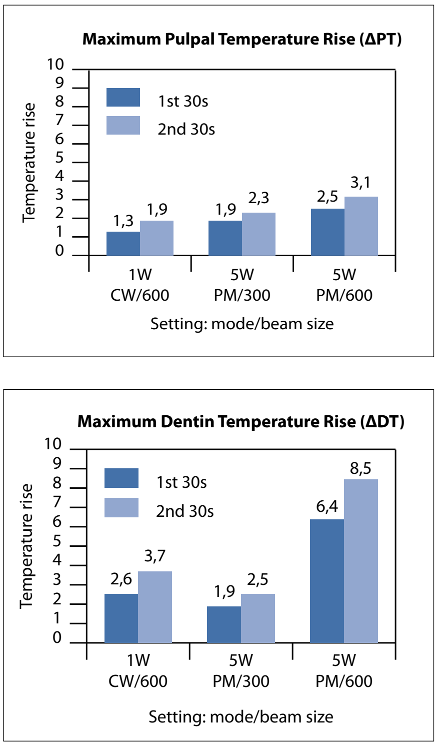

FIG. 3 The maximal recorded pulpal and subsurface temperature rise in two cycles of 30 s of irradiation in different settings.

representative specimens from each group were examined; Photomicrographs (×1000) of representative areas of the specimens were obtained.

The results of testing were entered into a spreadsheet (MS Excel 2010, Microsoft Corp., City State, USA).

Statistical analysis of the data was done with specific software (SPSS V21 for Mac, IBM, USA). To determine the effect of the independent variable (Laser Parameters) on the dependent variable (Temperature Rise) at the pulp chamber and at the subsurface, a 1-way ANOVA and Duncan post hoc test were performed to compare the 6 groups. Then, for the laser parameter that induced the highest heating, differences in temperature rise between pulpal chamber and subsurface were evaluated with an independent t-test. The level of confidence was set to 95%.

Results

Temperature rise, expressed as delta of degrees Celsius (ΔPT) for the pulpal chamber and (ΔST) for the subsurface when treated with the three different laser parameters and for two cycles of 30 seconds each are shown in Table. 1, and Figures 3 and 4.

In the pulpal chamber, one-way ANOVA showed significant differences between the six groups ($p=0.000$). Duncan post hoc test revealed that the highest, significantly different temperature rise (2.2 ± 0.4) was observed when using the following parameters 5W, 16,000 Hz, 600 μm, 2x30 s. The lowest (ΔPT) were observed with 1 W, CW, 600 μm, 30 s (0.9 ± 0.2) and 5 W, pulsed, 16,000 Hz, 300 μm, 30s (0.7 ± 0.4). No significant differences were observed between these two groups.

At the subsurface, one-way ANOVA also showed significant differences between the six groups ($p=0.000$). The highest temperature rise (4.3 ± 0.3) was measured when using the 5W, 16,000 Hz, pulsed, 600 μm, 2x30 s. Significantly, lower (ΔST) was observed when using the following parameters: 1W, CW, 600 μm, 30 s (1.4 ± 0.4); 5 W, pulsed, 16,000 Hz, 300 μm, 30 s (1.4 ± 0.3); 5 W, pulsed, 16,000 Hz, 300 μm, 2x30 s (1.7 ± 0.3); and 1 W, cm, 600 μm, 2x30 s (1.7 ± 0.5). No significant difference could be observed between the last four groups.

The differences in temperature rise between subsurface (4.34 ± 0.3) and pulpal chamber (2.2 ± 0.4), for the laser parameter that induced the highest heating in both measuring spots (5 W, 16,000 Hz, 600 μm, 60 s) evidenced the important thermal insulation potential of dentin due to low thermal conductivity, cutting the ΔoC by half.

Digital microscopy evaluation of the micromorphology of the treated vs untreated surface did not present any noticeable changes (Fig. 5).

Discussion

Diode laser could have its place within the clinical methods of dental caries inactivation (DCI) by benefiting

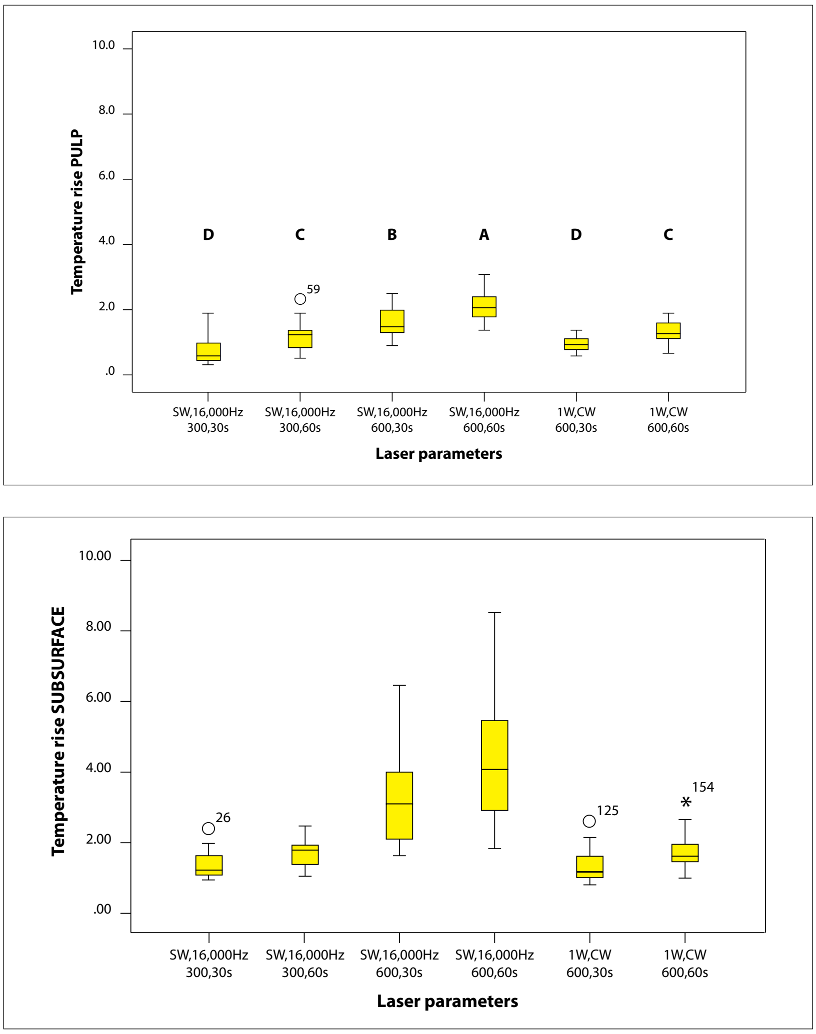

FIG. 4 Box plot of temperature rise (ΔT; °C) in the pulpal chamber and at the subsurface during laser treatment with three different parameters, each for 2×30 s. The highest temperature rise in both locations was observed when using the laser parameters 5 W, 16,000 Hz with a tip diameter of 600 μm and during 60 s. Groups with the same letter are not significantly different ($p < 0.05$).

FIG. 5A

FIG. 5B

FIG. 5 SEM micrography (1000×) of laser irradiated tooth surface (A), and non-irradiated tooth surface (B).

from its antibacterial thermal effect, its capacity for eliminating bacteria that have immigrated deep into the dentin [Gutknecht et al., 2004], and its possible ability of occluding the dentinal tubules [Parirokh and Eghbal, 2007]. Although enamel and dentin have low thermal conductivity [Parker, 2007b; Yazici et al., 2006], the application of high power Diode laser for considerably long duration on the outer surface of the tooth could result in pulp damage.

Hussey et al. [1995] have reported that the pulp might be endangered by temperature rise. While Zach and Cohen [1965] showed that 15% of teeth undergoing an intrapulpal temperature rise of 5.5 °C were irreversibly damaged. Nowadays, an increase in temperature of 3.5°C is deemed to be the maximum ceiling to not produce irreversible pulpal damage [Krmek et al., 2009]. Similarly, the laser energy absorbed by the dentin generates heat within the dentin, which might, if it is excessive, result in structural changes and damage to the dental hard tissue [Schuchard, 1975; Sato, 1983].

In this *in vitro* study, all samples experienced a measurable temperature increase either within the pulp chamber or at the subsurface. The maximum temperature rises observed were 3.1 °C in the pulp, and 8.5 °C at the subsurface. Thus, there is no significant risk on the dental structures when the teeth were irradiated with an 808-nm diode laser in 1W continuous mode or 5W pulsed mode.

In laser dentistry, most previous studies on the thermal effects of laser either utilised other types of laser or observed other clinical applications [Alfredo et al., 2008; İşman et al., 2014; Kreisler et al., 2002].

Thus, and considering the great diversity of the existent laser systems each with different properties, as well as the variety of parameters that can be adopted, it becomes complex to extrapolate our study to other ones. In the present study, statistically significant differences in temperature rise were found between the measurements of the 1W/ CW mode and those of the 5 W/pulsed mode as the latest presented higher ΔPT and ΔST. This is explained by greater wattage and high frequency (16,000 Hz) of the adopted pulsed mode. Similarly, the maximum ΔPT and ΔST were reported in the second cycle of irradiation. These results are in accordance with what reported in the literature related to the interaction of dental laser with the dental hard tissue [Coluzzi and Convissar, 2011].

Similarly, there were increases in ΔPT and ΔST with the increase of beam size. These results agree with the studies of Yu et al. [1993] who evaluated the effects of beam size, energy density, and wattage on the maximum pulpal temperature elevation. However, Parker [2007a] reported that the result of using a smaller beam spot size increases the thermal transfer from the laser to the target tissue. This contradiction could be explained by the low absorption coefficient and less interaction between dental hard tissue and near-IR laser in comparison to the studies of Parker who evaluated the interaction between Co_2 laser and oral soft tissues.

Measurements were preformed while the teeth roots were immersed into 37°C water bath. This procedure ensured complete hydration of the tooth structure during lasing. It was also an attempt to mimic the cooling effect of the blood circulation in the periodontal ligament and adjacent jawbone.

Contact was avoided between the water and the bare tip of the thermocouple by filling the root canal with a conductor paste and sealing the apical aperture with composite. This corresponds with the consideration of Ramsköld [1997] who stated in his study that the thermal bath is less similar to the pulpal *in vivo* situation due to the freely circulating water and large volume of cooling liquid available in the water bath.

Single-rooted premolars were chosen for this experimental design. Yu [1993] reported in his study on different types of laser that a thinner enamel/dentin section will have a higher pulpal temperature change. It can be concluded that ΔPT and ΔST should be lower in multiple rooted teeth and higher in Incisors and deciduous teeth. Therefore, decision was made to irradiate the proximal side of the samples as it presents the least thickness and hence is susceptible to greater rise in temperature.

In order to simulate a real access to the proximal surface of the tooth, we applied the fiber tip with an angle of 60°. However, difficulty was observed to achieve regular continuous scanning the tooth surface using hand control delivery system and the surgical fiber tip. This problem would necessitate further development of the fiber tips, which should be more adaptable for handling and scanning the tooth surface.

Beside the necessity to investigate the effectiveness of 808 nm diode laser on dental caries bacterial decontamination, the results obtained in the present study open perspectives to new investigations considering the parameters that provide sufficient temperature increase within the safety limits of tooth structures and surrounding tissue.

Conclusions

Within the limits of the present in vitro investigation, it can be concluded that all laser parameters tested for the irradiation of outer surface of teeth with the 808 nm diode laser used in this study produced a temperature increase in the pulpal chamber, which was below the critical threshold for the vitality of the pulpal tissue. Subsurface temperatures were about 50% higher, but still acceptable and no micromorphological enamel changes such as melting, crack formation, or burning were detected by SEM observations on the enamel surface.

Thus, the null hypothesis expecting no critical temperature increase caused by the laser radiation was confirmed by this in vitro study.

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