



Intra-pulpal temperature evaluation during diode laser (445 nm) irradiation for treatment of dentine hypersensitivity: in vitro a pilot study

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Abstract

Objective The current study aimed to evaluate the temperature rise in the dental pulp during treatment of dentin with 445-nm diode laser.

Materials and methods Ten single-rooted human premolar teeth were randomly enumerated into 1 to 10. Teeth were embedded in a resin block, and a thermocouple was inserted into the pulp chamber. Cervical third of the crown were irradiated with 1, 1.5, 2, 2.5, and 3 W at time of irradiation of 10, 15, 30, and 60 s (CW, Non-contact mode), while immersed in a 37 °C thermal bath.

Results The maximum mean temperature rise in the dental pulp was 10.6 °C achieved after irradiation with 3 W for 60 s and the lowest temperature increase achieved was 0.3 °C with 1 W for 10 s.

Conclusion Using the 445-nm diode laser, 0.2–1 W, CW up to 60 s; 1.5 W, CW up to 15 s; 2 W, CW, 10 s; and 2.5 W, CW, 10 s are considered biologically safe parameters for the dental pulp during dentine hypersensitivity treatment.

Keywords Diode laser 445 nm · Blue wavelength · Dentine hypersensitivity · Intra pulpal temperature evaluation

Introduction

Dentine hypersensitivity is one of the most common dental problems described as “common cold of Dentistry” by some and “toothbrush disease” by others when it occurs in the presence of gingival recession [1].

Dentine hypersensitivity is defined in the literature as a “pain derived from exposed dentin in response to

chemical, thermal tactile, or osmotic stimuli which cannot be explained as arising from any other dental defect or disease” [2, 3]. It is affecting more than 40% of adults worldwide and more than 40 million people in the USA [4]. In Europe, an average of 27% of the population suffers from dentine hypersensitivity [5], and some studies have reported prevalence levels as high as 68% [6]. Some studies have reported that premolars are the most commonly affected by dentin hypersensitivity [7], while the cervical area of the teeth is the most common site [8].

In the last two decades, a lot of research studies in laser application in medical fields have been introduced [9].

Different laser systems and wavelengths have also been used in a lot of studies for the treatment of dentine hypersensitivity such as Nd:YAG laser which is emitting at 1064 nm; CO₂ laser, 10600 nm; Er, Cr:YSGG, 2780 nm; Er:YAG, 2940 nm; KTP, 532 nm; and diode 980- and 808-nm lasers. These wavelengths are able to melt the dentine surface and also act on crystallization of the inorganic components of the dentine and on coagulation of the dentinal tubules fluids [10].

Diode lasers gave the best results in a lot of clinical studies even in cases of severe dentine hypersensitivity [10].

The existence of the blue wavelength range (445 nm) diode laser shows good energy combined to pigmented cells and

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tissue, with low absorption in water; thus, cutting performance improvement for surgical procedures and deep decontamination for endodontic and periodontal treatment is expected [11].

However, there are no studies reported on the treatment of dentine hypersensitivity by 445-nm diode laser. Furthermore, the safety parameters of 445-nm diode lasers are unknown considering the aforementioned issues.

According to the *in vivo* study done by Zach and Cohen on monkeys, the temperature increase of 5.5°C inside the pulp chamber caused irreversible pulpitis which means the exceeding of the intrapulpal temperature of 42.5°C can result in structurally irreversible pulp tissue damage [12]. Eriksson et al. suggested that duration of temperature increase is an important factor for creating permanent change in pulp tissues. The authors reported that 42°C is a critical temperature when sustained for a 1-min duration [13].

Therefore, the aim of this *in vitro* study is to evaluate the intrapulpal temperature rise during the irradiation with a blue wavelength range 445-nm diode laser as a treatment for dentine hypersensitivity and to show if it will exceed the critical temperature rise of 5.5°C inside the pulp chamber

Material and method

Teeth selection

Ten single-rooted human premolars (extracted for orthodontic reasons) were used in the study. Sound teeth, freshly extracted with completely formed roots, were selected. Carious, broken, previously restored, root canal treated, or any malformation was excluded in the sample teeth. Root canal anatomy was verified radiographically. Teeth were restored in saline solution (sodium chloride 0.9%). Samples were randomly enumerated into 1 to 10.

Sample preparation

The apices of the teeth were dissected 3 mm from the apex of each tooth root using carbide finishing bur, C135U (Jota, Switzerland). Patency was verified with an ISO #10 k-file (NITIFLEX®, DENTSPLY, Switzerland). The root canals were prepared and enlarged by performing the conventional mechanical preparation starting from the apex by using endodontic k-files ISO #15,20,25,30,35 (NITIFLEX®, DENTSPLY, Switzerland) to allow the insertion of the thermocouples through the root canals into the coronal pulp chamber. Normal saline solution (sodium chloride 0.9%) has been used for the irrigation of the root canals during root canal preparation.

To simulate the clinical situation during laser procedures, the samples were embedded in a two-component polyurethane

cast resin (ISO-PUR K 760), having a thermal conductivity (0.6 W/m K) similar to that of bone (0.58–1.2 W/m K) [14].

Temperature measurement

The temperature measurements were recorded using a digital thermometer (OM-USB-TC, Omega Engineering, Inc.), and two thermocouples (K-Type, model OMEGA 5TC-TT-36, 0.13 mm in diameter) were used. One thermocouple was inserted in the root canal until it has been reached inside the pulp chamber of the coronal pulp chamber, while another one was placed in the water bath in order to control the constancy of water temperature at 37 °C. Silicone heat conducting paste (ARCTIC, MX-2) was used to improve heat conduction to the thermocouples. Radiographs were taken to verify the correct placement of the thermocouples.



Laser parameter and settings

All teeth samples were irradiated with blue wavelength 445-nm diode laser (SIROLase blue, SIRONA, Germany). Samples were enumerated from 1 to 10.

The delivery system was an optical fiber tip of 320 μm (EasyTip). Irradiation was performed by introducing the fiber tip on the cervical third of the crown of all teeth.

For samples 1, 2, 3, 4, and 5

The fiber tip was introduced stationary to the cervical third of the tooth, in noncontact mode (the distance between the optical fiber and the irradiated surface was 1 to 2 mm).

While in samples 6, 7, 8, 9, and 10

The fiber tip was continuously moved in both mesial-distal and apical-coronal directions, uniformly covering an area of 4 mm² in noncontact mode and the fiber tip held 1–2 mm from the tooth surface.

Each laser power parameter was delivered for each tooth in four different irradiation times, 10, 15, 30, and 60 s.

The temperature measurements in degrees Celsius had been recorded during irradiation and the temperature rises

Table 1 Laser parameter and protocols for samples 1–5

Sample number	Power and irradiation time	Power and irradiation time	Power and irradiation time	Power and irradiation time	Power and irradiation time
1–5	1 W, 10 s	1.5 W, 10 s	2 W, 10 s	2.5 W, 10 s	3 W, 10 s
	1 W, 15 s	1.5 W, 15 s	2 W, 15 s	2.5 W, 15 s	3 W, 15 s
	1 W, 30 s	1.5 W, 30 s	2 W, 30 s	2.5 W, 30 s	3 W, 30 s
	1 W, 60 s	1.5 W, 60 s	2 W, 60 s	2.5 W, 60 s	3 W, 60 s

The fiber tip (320 μm) was introduced stationary to the cervical third of the tooth, in non-contact mode (the distance between the optical fiber and the irradiated surface was 1 to 2 mm)

above the baseline temperature (37 °C) were described as delta T.

All the laser irradiation procedures were performed by the same person.

All the parameters and protocols are shown in Tables 1 and 2.

Laser irradiation parameter protocols, (Tables 1 and 2)

Results

The temperature rise within the pulp chamber of the teeth was varying according to the power settings and irradiation time used.

Table 2 Laser parameter and protocols for samples 6–10.

Sample number	Power and irradiation time	Power and irradiation time	Power and irradiation time	Power and irradiation time	Power and irradiation time
6–10	1 W, 10 s	1.5 W, 10 s	2 W, 10 s	2.5 W, 10 s	3 W, 10 s
	1 W, 15 s	1.5 W, 15 s	2 W, 15 s	2.5 W, 15 s	3 W, 15 s
	1 W, 30 s	1.5 W, 30 s	2 W, 30 s	2.5 W, 30 s	3 W, 30 s
	1 W, 60 s	1.5 W, 60 s	2 W, 60 s	2.5 W, 60 s	3 W, 60 s

The fiber tip (320 μm) was continuously moved in both mesial-distal and apical-corona directions, uniformly covering an area of 4 mm² (2 mm × 2 mm) in the cervical third of the crown

In teeth samples 1 to 5 where the irradiation procedure was stationary

The minimum temperature increase found was (0.29 °C) with the parameter of 1 W/CW for 10 s while the maximum temperature was found with the parameter of 3 W/CW for 60 s was 74.28 °C; thus, the maximum temperature rise (ΔT max) is 37.28 °C and the maximum mean temperature increase was 10.6 °C in the same parameter (Graph 1).

In teeth samples 6 to 10 where the laser irradiation procedure was with movement

The minimum temperature increase (0.44 °C) was with the parameter of 3 W/CW for 10 s. While, the maximum temperature (46.37 °C) was found with the parameter of 3 W/CW for 60 s. The maximum temperature rise (ΔT max) was 9.82 °C and the maximum mean temperature increase (7 °C) was found in the same parameter (Graph 2).

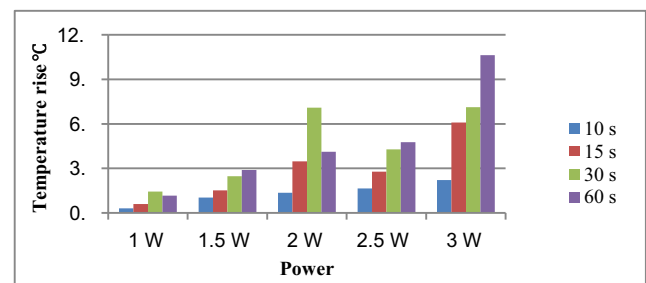
The temperature measurements of the sample teeth after irradiation within four different power settings and irradiation times can be better shown in box plot graphs (Graphs 3 and 4).

Discussion

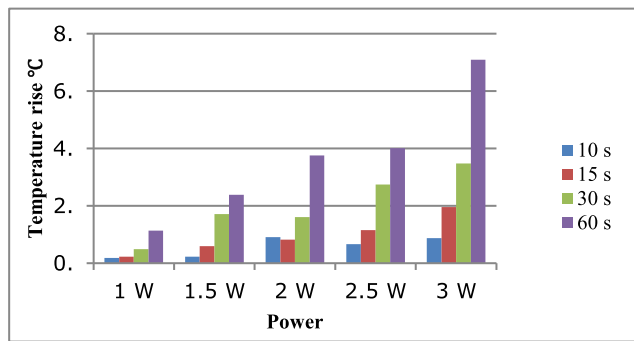
The most important point in the treatment of dentine hypersensitivity is to decrease the pain sensation, which is achieved by either occluding the dentinal tubules or by the blockage of nerve activity safely. A wide variety of the treatment methods have been proposed for the tubular occlusion and nerve activity blockage either by conventional treatment or by laser treatment, especially diode lasers [15, 16].

Most of the articles are concerned with the morphological and thermal changes of the root or dentine surface following the laser application, while only a few research studies considered the temperature measurements within the dental pulp during diode laser irradiation [17, 18]. To the best of our knowledge, this is the first study to evaluate the dental pulp temperature by 445-nm diode laser irradiation.

Liy Y et al. compared the morphological alterations and the thermal effects of 980-nm diode laser in dentine. In their



Graph 1 Stationary irradiation (1 to 5)



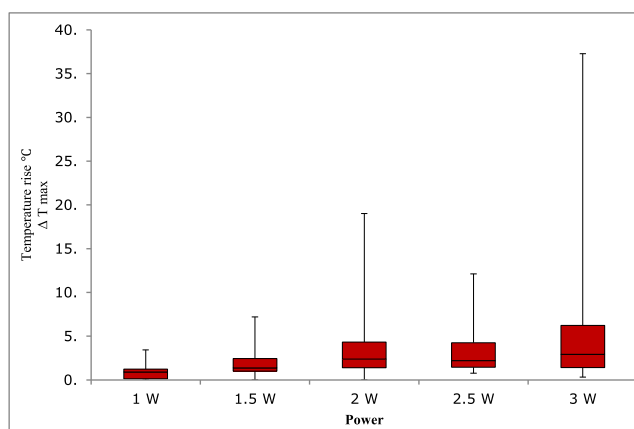
Graph 2 Irradiation with movement (6 to 10)

study, they used 980-nm diode laser with power settings of 2, 3, and 4 W/CW, and the energy density was 166, 250, and 333 J/, respectively.

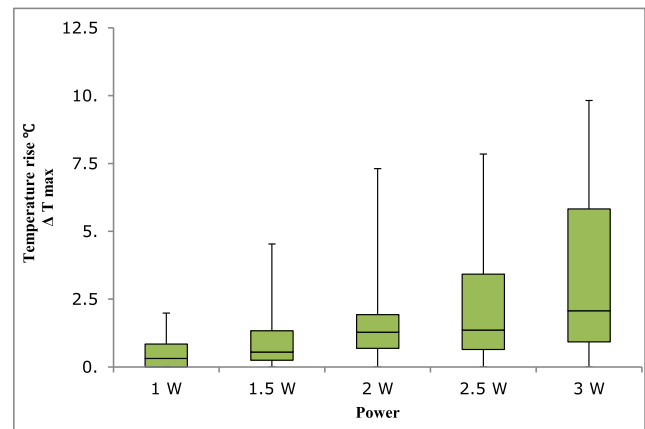
The laser effect on the melting degree of the dentin surface was intensified when the parameters were increased from 2 to 4 W in the continuous mode. And they demonstrated that 2 W/CW (166 J/) was a suitable parameter for a 980-nm diode laser to seal dentinal tubules without excess melting of the dentin as well as its safety in dental pulp tissues. [17, 19].

The results of Umana et al. confirmed that 810- and 980-nm diode lasers' irradiation at 0.8–1 W for 10 s in continuous mode, laser fiber diameter of 200 μm were able to seal the dentin tubules and these parameters can be considered harmless to the vitality of dental pulp, and may be effective in the treatment of dentinal hypersensitivity, while higher energy densities and power output (1.6–2 W) produce an important destruction of the dentinal surface and hence damage the dental pulp [20].

Their results were comparable to the Kreisler et al. results, where they investigated a 810-nm diode laser and recommended that a power output of 0.5 W for 10 s would be suitable for hypersensitivity treatment in the lower incisors and upper first premolars, while a power of 1 W, also for 10 s is the maximum



Graph 3 Box-plot graphs showing the results of the maximum temperature rise (ΔT_{max}) in all power settings in teeth samples 1 to 5 (stationary irradiation)



Graph 4 Box-plot graphs showing the results of the maximum temperature rise (ΔT_{max}) in all power settings in teeth samples 6 to 10 (with irradiation movement)

output for the other teeth; otherwise, by using more power, the pulp vitality may be jeopardized [17].

The temperature threshold for the survival of the pulp tissue was reported in the classical study of Zach and Cohen, in which the teeth that were subjected to a 5°C increase in the temperature failed to recover in 15 % of the monkey teeth. In recent studies, an increase in temperature of 3°C is assumed to be the maximum ceiling to not produce irreversible pulpal damage [20, 21].

In our study, a diode laser emitting at 445 nm of power settings of 1, 1.5, 2, 2.5, and 3 W in a continuous mode with optical fiber 320 μm at times of 10, 15, 30, and 60 s was used with all previous parameters and applied to all teeth samples 1 to 10.

In the teeth samples 1 to 5 in which the irradiation was stationary, a high increase in temperature was observed in the dental pulp, which exceeded the temperature rise safety limit, compared to the teeth samples 6 to 10, especially with the parameters of 3 W/60s, 2 W/30s, and 2.5 W/30s. This might be due to the carbonization that happened on the tooth surface during laser application resulting in increase of the absorption of the 445-nm diode laser which is highly absorbed in the pigmented tissue. Also, carbonization was observed in most of the teeth samples 1 to 5 where irradiation was starting from the power of 1.5 W at 30 s. Moreover charring and cracking of some teeth samples were noticed. The thickness of enamel and dentine, the quality of the tooth structure, the tooth mass, the heat capacity of the tooth, and the stationary irradiation itself could play a major role in the transmission of laser energy to the pulp which may illustrate the variation of thermal increase inside the pulp chambers.

On the other hand, the teeth samples 6 to 10, where the laser application was delivered with movement, the maximum pulp temperature rise did not exceed the temperature rise safety limit when irradiated with parameters of 1 W up to 60 s. The maximum temperature rise of 1.5 and 2 W laser parameters

was also within the safe limit, when used up to 15 s. No carbonization, charring, or cracking of the tooth was observed, which could be due to the movement of the fiber tip during the laser irradiation. The Umana et al. study concluded that the temperature measurements of 810- and 980-nm diode lasers' irradiation up to 2 W are safe to the pulp tissue when the irradiation parameters were 0.8, 1, 1.6, and 2 W using a fiber diameter of 200 μm and the irradiation time was 10 s. On the other hand, Kreisler et al. concluded that the irradiation with 809-nm diode laser should be limited to 1 W at a maximum irradiation of 10 s in case of a 2-mm minimal mean of dentin layer in the coronal half of the roots. However, in the proximal surfaces of the first maxillary premolars and lower incisors, the output power have to be limited to 0.5 W and the irradiation time to 10 s.

The results of this current study were contradictory to the results of Umana et al. and Kreisler et al. regarding the temperature safety limit to the dental pulp, especially with the irradiation time, where they recommended the use of the same power settings, but with a maximum laser irradiation time of 10 s only. This could be due to the use of different wavelengths and different fiber diameter than in our study.

Conclusion

Within the limitation of this study, it can be concluded that the diode 445-nm laser irradiation 0.2–1 W, CW, up to 60 s; 1.5 W, CW up to 10 s; 1.5 W, CW up to 15 s; 2 W, CW up to 10 s; and 2.5 W, CW up to 10 s are safe parameters for the dental pulp for the treatment of dentine hypersensitivity.

Further temperature evaluation studies are recommended using diode laser 445-nm in the treatment of dentin hypersensitivity on teeth with different morphological variations, furthermore to evaluate its effect on the dentinal tubules and dentine surface structure alterations.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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