Temperature Generation and Transmission in Root Dentin During Nd:YAG Laser Irradiation for Preventive Purposes

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Abstract—**High-intensity lasers are widely used in dental procedures and the heating produced on the surface is necessary to ensure protective activity against the development of caries and erosion lesions. However, caution should be exercised regarding the spread of heat to the pulp, periodontal tissue and alveolar bone, which can cause harm to these tissues. This study sought to evaluate the generation and transmission of heat in the root dentin and adjacent tissues during irradiation with Nd:YAG laser for preventive activity. For that, 15 lower incisor human teeth had an area of 9 mm^2 of root dentin irradiated with Nd:YAG laser (λ=1.064 µm, 10 Hz, 60 mJ/pulse, 84.9 J/cm^2) for 30s. During irradiations, pulpal temperature was evaluated by fast-response thermocouples, while surface temperature and heat distribution on surrounding tissues were measured by infrared thermography. It was observed a mean surface temperature increase of 293.48±30.6º C in root dentin surface, and 15.85 ± 39.6º C below the irradiated area, 11.72 ± 8.7º C above the irradiated area, 19.77 ± 4.9º C at 1 cm laterally and 7.03 ± 2.7º C at 2 cm laterally to the irradiated area. The mean pulpal temperature augment registered was 6.5±1.4º C. It can be concluded that Nd:YAG laser irradiation promoted surface temperature rises that suggest chemical changes on dentin; however, the temperature increases generated in the adjacent tissues (region of periodontal ligament) and in the pulp chamber may be dangerous in future clinical application considering the irradiation time of 30 s made in this study. Therefore, this laser protocol can be used as long as the irradiation time is reduced in future studies.**

Keywords— **Laser, heat, propagation, root, pulp, ligament.**

I. Introduction

High-intensity lasers are widely used in tooth tissues for different applications. When choosing an irradiation parameter for any clinical application, an important data to be considered is the temperature reached, in order to avoid risks to biological tissues. In addition, the determination of temperature rises on the surface of hard tissues predicts the possibility of the occurrence of different chemical and crystallographic effects. For example, the beginning of carbonate removal occurs after 100º C, while changes in the crystalline phases occur from 800º C [1]. These changes have already been identified with the use of the Nd:YAG laser on enamel and dentin, depending on the energy density applied [2].

Considering the use of lasers for preventing caries, the respect for the temperature limits determined by the classic work of Zach and Cohen (1965) [3] is still imperative for the determination of laser protocols that are safe for pulpal tissue. The effects of these lasers are mostly photothermal and photoacoustic; thus, it is essential to know the transmissibility of this heat generated to the interior of the tooth or to the surrounding tissues. Still, it is important to respect the temperature limits that can be tolerated by periodontal tissues, such as ligaments and alveolar bone, so as not to induce inflammation or necrosis in these tissues [4].

The first factors to be considered in determining secure protocols using high-intensity lasers are those related to the tissue to be irradiated, such as the thickness, the total mass of the tooth and the absorption coefficients for each laser wavelength. In this context, dentin is the tissue of greatest concern, as it is a tissue with low thermal conductivity [5] that offers greater risks to the pulp as it is worked in depth, as the area of the dentinal tubules increases with the depth of this tissue. It is worth mentioning that decayed tissue has more water and less minerals, therefore, the spread of heat becomes easier.

Considering the successful application of the Nd:YAG laser to prevent enamel demineralization, little is known about the parameters that can also be used in dentinal tissue for the same purpose. Thus, an accurate assessment of the generation and propagation of heat from irradiations is imperative. This *in vitro* study evaluated the heat generation in the root dentin during the use of the Nd:YAG laser adjusted with preventive parameters, as well as to quantify the spread of heat to the surrounding tissues, through the simulation of a clinical application, in order to verify the safety of this protocol for dentin, enamel, pulp and periodontal tissues.

II. Material and method

In this study, 15 healthy lower human incisor teeth were used. These teeth were provided by volunteers after approval of this study by the UFABC Research Ethics Committee (CAAE 49456715.0.0000.5594). The teeth were cleaned and the pulp and periodontal tissues were completely removed using endodontic files and manual ultrasonic scrapers, according to the recommended clinical technique. Before use, all teeth were observed using a stereoscopic magnifying microscope, so that those with cracks or any other defects that interfered with the analysis were excluded.

To simulate a standard pulp tissue, a 20% red gelatin solution was inserted into the pulp chamber and root canal through the apical foramen taking into account the similarity of gelatin collagen with the molecule present in pulp tissue, which was posteriorly sealed with photopolymerizable dental composite resin. Afterwards, an opening of 1 mm in diameter was performed on the gingival third of the lingual side of each tooth up to the limit of the pulp chamber (Fig. 1) using a high-speed dental spherical diamond drill under air-water refrigeration, in order to allow the placement of a type K thermocouple (chromel-alumel, NiCr-NiAl, Omega Eng. Inc., USA) in the region of the coronary pulp adjacent to the irradiations. The thermocouple has 127 µm diameter, resolution of 0.2º C and sensibility from 0.1-100° C, and it was kept in place during irradiations with dental wax. The temperature measurements were performed using a NI USB9162 acquisition board (National Instruments, USA), with temporal resolution of 0.05s, and the analysis of temperature variations during and after irradiation was performed using LabView software. Until irradiations, the teeth were kept individually in a humid environment under refrigeration (in sterile cotton and distilled water with thymol) at +4º C. During the experiments, the temperature and humidity of the room was kept constant and controlled.

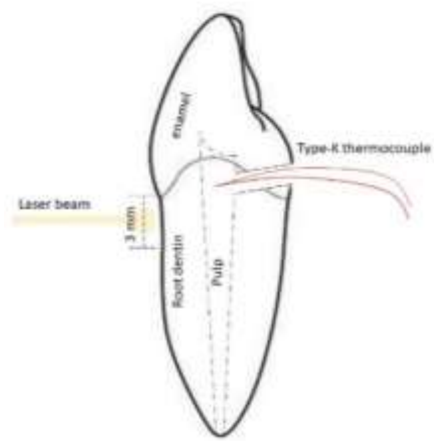


Fig. 1 Scheme of the positioning of the type-K thermocouple and laser irradiation in a tooth

The irradiations were performed using a Nd:YAG laser (Pulse Master 1000 ADT, USA), which operates at wavelength of 1.064 µm, pulse duration of 100 µs, repetition rate of 10 Hz, beam diameter of 300 µm, 60 mJ/pulse and at energy density of 84.9 J/cm^2 [6]. All irradiations were performed after the application of 0.5 mm-thick of a photoabsorber (coal paste, composed of vegetal coal diluted in 50% water and ethanol) [6] in dentin surface, in the absence of refrigeration. The irradiations were performed manually scanning the surface for 30s, keeping the laser fiber focused, at a distance of 1 mm from the surface, which was maintained with the aid of a standardized endodontic file. For irradiations, an area of 9 mm^2 (3 x 3 mm) was delimited with a pencil and a jig, which was totally irradiated with a constant speed of 6 mm/s by a single calibrated operator. During the experiments, the samples were kept static on optical supports (Newport Corp., Irvine, USA) and the energy emitted was verified before irradiation of each sample by a power and energy meter (Coherent FieldMaster GS + Detector LM45; Coherent, USA).

During the irradiations, the surface temperature detection as well as the measurements of heat propagation were performed using an infrared thermographic camera (ThermaCam FLIR SC3000 Systems, Boston, USA). The camera was positioned laterally to the tooth and to the optical fiber of the laser, 10 cm away (Fig. 2), and the images were kept focused through the use of appropriate lenses. The Figure 2 shows an infrared image representative of the placement of a sample in front of the thermographic camera, making it possible to observe the lateral face of the tooth, as well as the head of the laser equipment handpiece and the optical fiber used during irradiations. In addition, it is possible to observe the presence of the photoabsorber paste and the positioning of the thermocouples to measure the intrapulpal temperature.

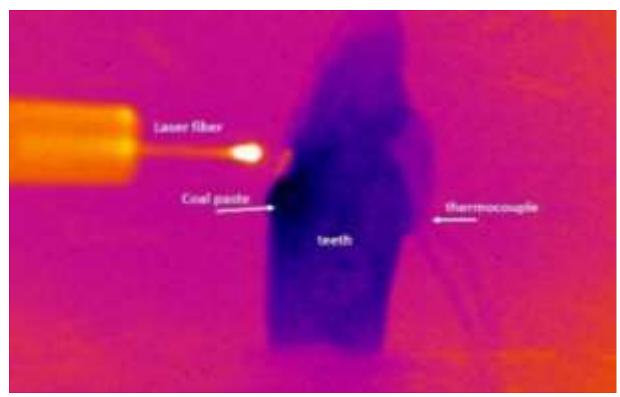
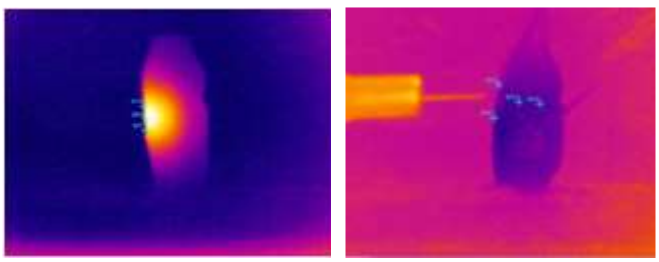


Fig. 2 Infrared image taken from the positioning of the laser fiber, teeth and thermocouple

The experiments were carried out at a controlled temperature of 21.5º C, 70% relative humidity and considering the tooth emissivity equal to 0.91. The infrared images were obtained with a resolution of 0.01º C, using a recording rate of 300 Hz. The monitoring of the temperature both by the thermocouple and by the thermographic camera started 5s before and ended 3min after the laser irradiation so that not only the temperature rise was observed, but also the time needed to return to the initial condition.

For the analysis of the temperature on the surface of the root dentin, three points on the dentin surface were selected (Fig. 3a), namely SP01 (inferior border of the irradiated area), SP02 (superior border of the irradiated area) and SP03 (center of the irradiated area). For the analysis of the temperature propagation to the adjacent tissues, 4 points were analyzed (Fig. 3b): SP01- 1 cm below the irradiated area; SP02- 1 cm above the irradiated area; SP03- 1 cm in depth of the irradiated area, and SP04- 2 cm in depth of the irradiated area. Such analyzes were performed using the software ThermaCam Researcher 2001 (FLIR Systems, USA).

All temperature data obtained, both from the surface and from the pulp, were transported to Microsoft Excel, so that the average curves with their respective standard deviation values were plotted.



a b

Fig. 3 Stablished points on the root dentin surface (a) and surrounding areas (b) for temperature analysis in infrared images

III. Results

Figure 4 shows a representative sequence of infrared images obtained during irradiations. It is noticed the ejection of the coal paste at the beginning of the irradiation, as well as the generation and spread of the heat generated by the adjacent areas, reaching pulp, enamel and periodontal tissue. Still, it is possible to observe the cooling of the tooth after the end of the irradiation.

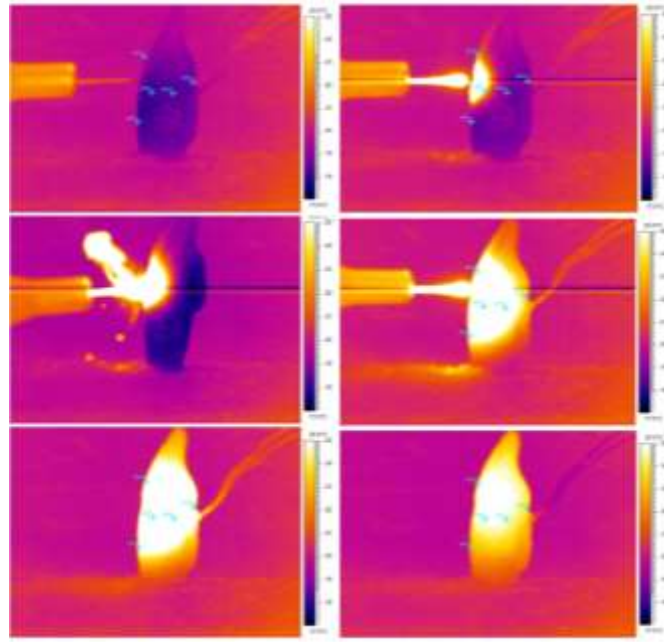


Fig. 4 Representative sequence of infrared images obtained at irradiations

The analysis of the superficial points of the root dentin immediately below the irradiated area showed an average temperature increase of 293.48 ± 30.6º C in the center of the irradiated area, and 299.92 ± 106.8º C in the inferior border (Table 1). These values were calculated by subtracting the initial temperature of each tooth detected by the camera. In these same analyzes, temperature peaks of up to 407.7º C were detected.

Table 1 Average (±SD) of maximum and variation of temperature detected on surface of root dentin during irradiations

Temperature (º C)	Center	Superior border	Inferior border
Variation	293.48 ± 30.6	276.8 ± 52.9	299.92 ± 106.8
Maximum	312.77 ± 30.6	296.17 ± 52.9	319.21 ± 106.8

The temperature variation curves detected during the irradiations (Fig. 5) show a rapid increase in the beginning of the irradiations, with some peaks and valleys characteristic of the interaction of the laser pulses with the tissue. The exponential decay is observed immediately after the end of the irradiations, whose return to the initial temperature takes approximately 200 seconds.

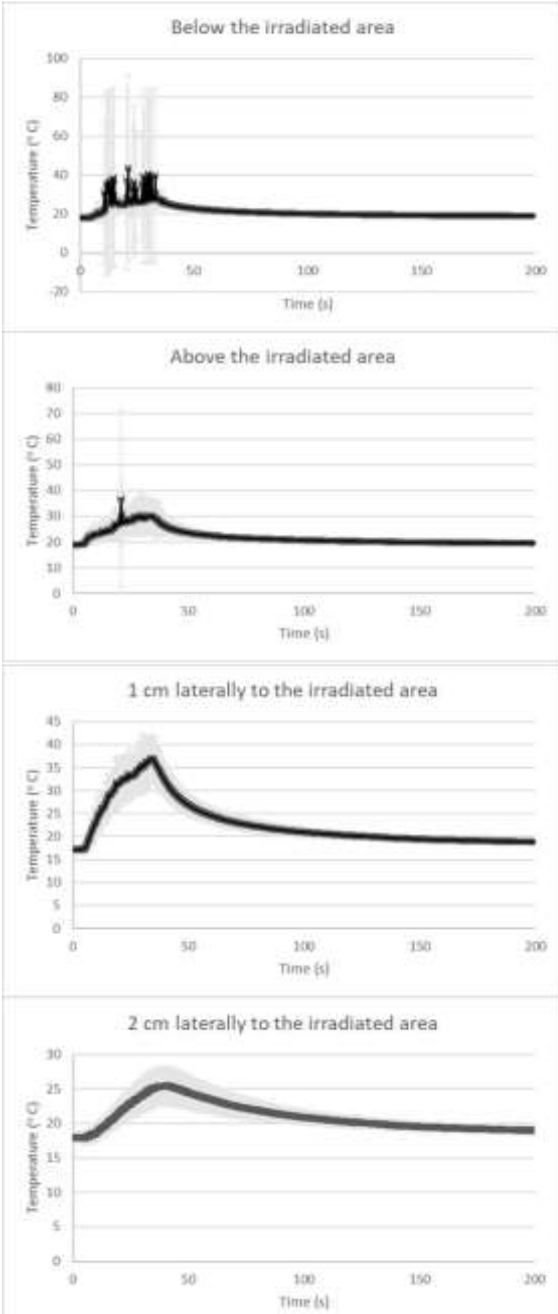


Fig. 5 Temperature variation curves detected during the irradiations below, above, 1 cm and 2 cm laterally to the irradiated region. The shaded areas represent standard deviation

At points adjacent to the irradiated area, it was evidenced an average elevation of 15.85 ± 39.6° C below the irradiated area, 11.72 ± 8.7° C above the irradiated area, 19.77 ± 4.9° C at 1 cm laterally and 7.03 ± 2.7° C at 2 cm laterally to the irradiated area (Table 2). In these regions, temperature peaks of 166.39° C, 53.33° C, 47.28° C and 30.3° C were observed, respectively.

Table 2 Average (±SD) of maximum, minimum and variation of temperature detected on the different regions during irradiations

Temperature (° C)	Peak	Minimum	Variation
Below the irradiated area	36.44 ± 39.2	20.59 ± 3.9	15.85 ± 39.6
Above the irradiated area	30.54 ± 8.7	18.82 ± 0.5	11.72 ± 8.7
1 cm laterally to the irradiated area	36.92 ± 4.5	17.15 ± 1.0	19.77 ± 4.9
2 cm laterally to the irradiated area	25.42 ± 2.8	18.39 ± 0.8	7.03 ± 2.7

Figure 6 shows the average pulpal temperature variation curve measured by the thermocouple. An average increase of 6.15±2.4° C was observed. However, it was possible to detect a maximum peak of 10.71° C during the measurements.

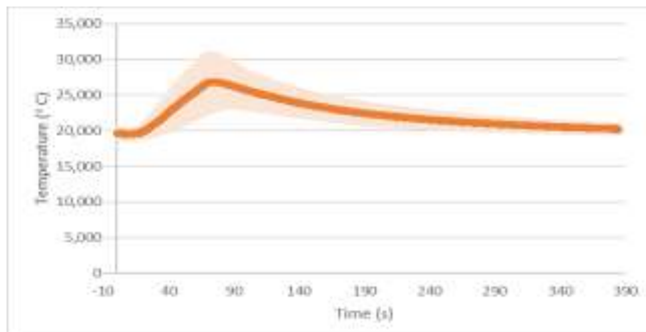


Fig. 6 Average curve of pulp temperature variations detected by the thermocouple. The shaded area represents the standard deviation

IV. Discussion

The Nd:YAG laser is widely used in preventive actions on enamel, and the literature shows promising results in dentin with the same irradiation protocol used in this study [2]. As 1.064 µm photons are not absorbed by any chromophore present in dental hard tissues (absorption coefficient is less than $4x10^{-2}$ cm^{-1})[1], there is a need to apply a photoabsorber, which aims to restrict the generation of heat on the surface and reduce the transmission to deep tissues [6]. Although there have been tests with different photoabsorbers, the coal paste used in this study is still the one that has the best safety in its use, as well as being easily removed after use, which prevents aesthetic damage.

The increase in surface temperature detected in this study (average of 299.92 ± 106.8° C and peaks up to 407.7° C) suggests that the laser radiation chemically modifies the dentin structure, which corroborates previous studies [2]. It is known that the beginning of carbonate removal, water loss and denaturation of the organic matrix begin at temperatures of 100º C, and such actions are important for increasing dentin resistance to demineralization [1]. It is important to consider that the temporal pulse width of the Nd:YAG laser used in this study (100 μs) is less than the recording rate of 300 Hz of the thermographic camera used. Therefore, it is possible that the highest temperature peaks were not detected during irradiations in this study and that these may have been even greater. In fact, this same laser protocol promoted melting and recrystallization of the dentin reported in a previous study [2], which suggests that at least temperatures close to 1000º C have been reached.

In the present work, even with the use of the coal paste [6], there was an average increase in temperature of 15.85±39.6º C in the region immediately below the irradiated area, in the apical direction, which corresponds to the region where periodontal ligaments are found. Temperature increases above 10º C can generate inflammatory changes in periodontal tissues [4]; in this way, the protocol used in this study can be considered dangerous for a future clinical application. In relation to the pulp temperature, it was noticed an average rise of 6.15±2.4º C, which exceeds the limit of 5.5º C that is potentially threatening to pulp vitality [3]. Although the value determined in this study is below the limit for total necrosis of the pulp (16º C)[3], and that the pulp blood circulation can contribute in the dissipation of heat, it is considered that the temperature rise detected in the present study may be unsafe for this tissue.

For future clinical extrapolation, the differences between this *in vitro* and a clinical study must be considered. The model chosen for this study involves the use of a tooth with a small mass, which is more susceptible to heat. The results obtained with this model can be easily extrapolated to other teeth with larger masses, as long as the same irradiation protocol is followed. In teeth with higher masses, it is expected that the heat propagation is less for the pulp; therefore, if a protocol is considered safe in this model, it can certainly be applied to another tooth safely.

The lack of blood circulation, gingival fluid and saliva also contribute to the reduction of heat dissipation, given that periodontal tissues have less thermal conductivity than air [5]. Furthermore, differences in dentin thickness, hydration degree or even in its composition reflect the high values of standard deviation found in all analyzes performed, even when using a large number of samples (15 teeth).

Considering that the energy density employed in the present study has proven benefits in increasing dentin resistance to demineralization and erosion [2, 6], a strategy for future clinical application would be to reduce the irradiation time or fragment it, in order to allow a longer time of thermal relaxation of the dentin. Such an alternative should be evaluated in future studies.

V. CONCLUSION

Nd:YAG laser irradiation promoted surface temperature rises that suggest chemical changes on dentin; however, the temperature increases generated in the adjacent tissues and in the pulp chamber may be dangerous for future clinical application considering the irradiation time of 30 seconds.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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