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ORIGINAL ARTICLE

A comparative study of temperature elevation on human teeth root surfaces during Nd:YAG laser irradiation in root canals

D. Strakas · R. Franzen · A. Kallis · L. Vanweersch · N. Gutknecht

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Abstract The purpose of this study was to evaluate the temperatures on the root surfaces during Nd:YAG laser irradiation in root canals using pulse durations of 180 and 320 μs. Thirty extracted human teeth were used in this study. The teeth were enlarged up to ISO 40 (multi-rooted) or up to ISO 60 (single-rooted) by conventional technique using K-files. Then the teeth were placed into a water bath with a constant temperature of 37 °C and then irradiated with an Nd:YAG laser having an output power of 1.5 W, a frequency of 15 Hz, using an optic fiber of 200 μm diameter. The temperature on the root surface was measured by means of attaching thermocouples in three areas (coronal, mesial, and apical regions) of the root canals. The thermographic study showed that the average temperature elevation for both pulse durations on the root surfaces was less than 9 °C. There was no significant difference in the observed temperatures in coronal and mesial areas. Though a higher increase of temperature was observed in the apical region when the pulse length of the Nd:YAG laser was 320 μs. The results of the study showed that the temperature rises during Nd:YAG laser irradiation with parameters used in this study minimal to cause damage on bone and periodontal tissues. Moreover, it was suggested that in order to have lower temperature in the apical region, an Nd:YAG laser with a pulse length of 180 μs is preferred than one with a pulse length of 320 μs.

D. Strakas (✉) · A. Kallis
Aachen Dental Laser Center, RWTH Aachen University,
Private Clinic, Sp. Spiridi 28, Volos,
38221 Volos, Greece
e-mail: dimitris.strakas@gmail.com

R. Franzen · L. Vanweersch · N. Gutknecht
Klinik für Zahnerhaltung und Parodontologie,
Universitätsklinikum Aachen,
Aachen, Germany

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Introduction

The importance of sterilizing a root canal

The primary target of an endodontic therapy is to remove the organic material from the root canal, then to shape the root canal in order to introduce the filling material in it and then to fill the root canal with this material in order to seal it from the surrounding oral tissues [1, 2]. The most critical point in the procedure is to obtain "sterile" root canals since microorganisms are one of the major causes of the development of endodontic disease. That means that the target of a "microbe-free" root canal is crucial for a successful therapy [3–5].

The smear layer

It has been shown that the smear layer is not beneficial to the overall success of the treatment because it is responsible for leakage between the canal walls and the filling materials and should be removed prior to the root filling. It has been also shown that this layer contains microorganisms, which if the canal cannot be completely sealed, can result in subsequent pathologic conditions [6]. Conventional procedures in endodontics are focusing in removing debris and microorganisms from the root canal with hand instrumentation, sometimes in combination with motor-driven files, or with ultrasonic instruments [7].

Chemical irrigants are also recommended to dissolve debris and smear layer. Solutions such as ethylenediaminetetraacetate are used. However, both irrigants are unable to remove smear layer effectively and they are not able to reach the bacterial colonizations harbored in the dentinal tubules. Kouchi et al. could demonstrate that bacteria are capable of invading the dentine up to a depth of 1.100 μm [8]. On the other hand, chemical irrigants penetrate no more than 130 μm into the dentine as indicated by Lindhe [9].

The introduction of lasers in endodontic therapy

In order to achieve a high bactericidal effect, lasers were introduced in 1971 in endodontic treatment, and different types of lasers since then have been investigated for their efficacy in root canal sterilization [10, 11]. Experiments like those of Gutknecht et al. demonstrate that Nd:YAG laser irradiation has bactericidal effects in depths of 1.000 μm and more [12].

Numerous studies have been performed using Nd:YAG lasers [7, 13, 14, 15, 16]. It is the most popular laser used in the root canal sterilization due to its fiber optic delivery system which enters the narrow root canals, its high absorption in pigmented tissue (bacteria), and its high transmission through dentine walls [17–21].

High-power pulsed Nd:YAG lasers are mostly used in the field of sterilizing a root canal due to its high bactericidal effect. In the investigation performed by Gutknecht, Conrads, and Sievert, an average of 99.91 % of the bacteria examined (*Enterococcus faecalis*) could be eliminated [13].

The heat produced by the lasers has become a great factor for clinical acceptance in endodontic treatment. The American Association of Endodontists has warned that the temperature increase inside the root canal by the laser could potentially damage the periodontal tissues. The magnitude of heat generated depends on a number of variables, such as the type of the laser, the power settings, the mode of energy delivery, the presence of water, and the type of the target tissue [22–24].

Since the introduction of different pulse durations from manufacturers, the heat generation during laser irradiation in the root canal differs. Hence the study measured the temperatures on the root surfaces during Nd:YAG laser irradiation in root canals using pulse durations of 180 and 320 μs. This has not been done so far and we needed to prove that clinicians working with these settings for laser-supported endodontic treatment are on the safe side regarding thermal damage on the periapical tissues.

Materials and methods

Sample preparation

Thirty human freshly extracted non-carious teeth, 15 single- and 15 multi-rooted with straight canals, were used in this study. Only teeth with totally formed roots were selected.

The access cavities were prepared with diamond burs (Shofu, CA, USA). The root canals were cleaned and enlarged with a step-back technique using hand instruments (K-files Dentsply–Maillefer, Ballaigues, Switzerland). The enlargement was up to an apical size of ISO #60 for single-rooted teeth and up to an apical size of ISO #40 for multi-rooted teeth. All the canals were completely cleaned and washed with normal saline. Then, each root canal was dried completely with paper cones.

Laser apparatus

A Fidelis Plus II (Fotona d.d., Ljubljana Slovenia) was used. For this study, we used only the Nd:YAG laser which emits photons at a wavelength of 1,064 nm. This laser is pulsed with three options of pulse width: VSP (100 μs), short pulse (SP) (180 μs), and long pulse (LP) (320 μs). Its maximum frequency is 100 Hz and its maximum output power is 15 W. The delivery system consists of a glass fiber of 200 μm diameter. The aiming laser is a semiconductor diode laser operating at a wavelength of 650 nm.

Experimental procedure

Each tooth was placed in a thermal bath, which was constantly fixed to 37 °C in order to simulate the human temperature in the mouth. On the external surface of the root, three copper–constantan thermocouples (type T 202 KC, Digitron, England) were positioned and attached in order to register thermal changes at the coronal, mesial, and apical third of the root.

Paraffin wax was used to isolate the thermocouple to prevent it being influenced by environmental temperature. The room temperature during the experiment was 25 °C.

To ensure that the 200-μm glass fiber reaches the apex, the working length of each root canal was transferred exactly to the fiber optic waveguide. Using the method described by Gutknecht, the fiber is first positioned in place without activating the laser, and then the fiber is removed from the canal in circular movements from apical to coronal with a rate of 2 mm per second (that means that in a root canal of 20 mm length, the laser irradiation procedure should reach 10 s).

The power settings that was selected were 1.5 and 15 Hz repetition rate which has been proved to be most efficient [7]. Each root canal was first irradiated with SPs (pulse duration 180 μs) and then with LPs (pulse duration 320 μs). Between the two irradiations, adequate time was given for the root canal to return to initial temperature of 37 °C. During the procedure, the highest temperature indicated from each thermocouple (apical, mesial, and coronal) was recorded.

Results

The temperature rise between the two pulse durations in all three points of the tooth can be better seen in the box plot graphs. The chart and the graphs show that mean temperatures for the apical area are the highest, followed by those of mesial and coronal. In accordance, similar results can be seen for the standard deviation, which is also higher for the apical areas.

Comparing the two pulse duration, it shows that the LP gives systematically higher mean values. The difference of the mean values between LP and SP is higher for apical points followed by those of mesial and coronal points.

The temperature distributions seem symmetrical. Using the Kolmogorov–Smirnov tests, it showed that they could be assumed as normal. The results of this study tests can be seen below. All p values were much higher than the formal significance level of 5 %, indicating that the null hypothesis of normality of temperatures is a reasonable assumption.

Statistics

The mean difference in temperature between SP and LP was nonsignificant for coronal areas (mean difference −0.20, $t=-0.073$, $p=0.942$), nonsignificant for mesial areas (mean difference −0.37, $t=-1.34$, $p=0.191$), while in apical points, the mean difference was significant (mean difference −1.29, $t=-2.73$, $p=0.011$) (Table 1). The paired differences of the mean temperatures are high between the three points of the tooth for SP and LP.

For SP, the differences between coronal and mesial were significant ($t=-4.16$, $p<0.001$). Also significant were the differences between coronal and apical ($t=-5.78$, $p<0.001$), and mesial and apical ($t=-2.64$, $p=0.013$). Similar results were drawn for LP and for the differences between coronal and mesial ($t=-5.09$, $t<0.001$), coronal and apical ($t=-8.32$, $p<0.001$), and mesial and apical ($t=-3.90$, $t=0.001$).

For reasons of completeness, the corresponding results based on nonparametric tests are shown in the following table. The results confirm the conclusions that were found in the parametric tests (Figs. 1 and 2).

Table 1 One-sample Kolmogorov–Smirnov test

	Kolmogorov–Smirnov *Z*	Asymp. Sig. (two-tailed)
SP_coronal	.778	.581
SP_mesial	.659	.777
SP_apical	.710	.695
LP_coronal	.793	.555
LP_mesial	.937	.344
LP_apical	.518	.951

Test distribution is normal. Calculated from data

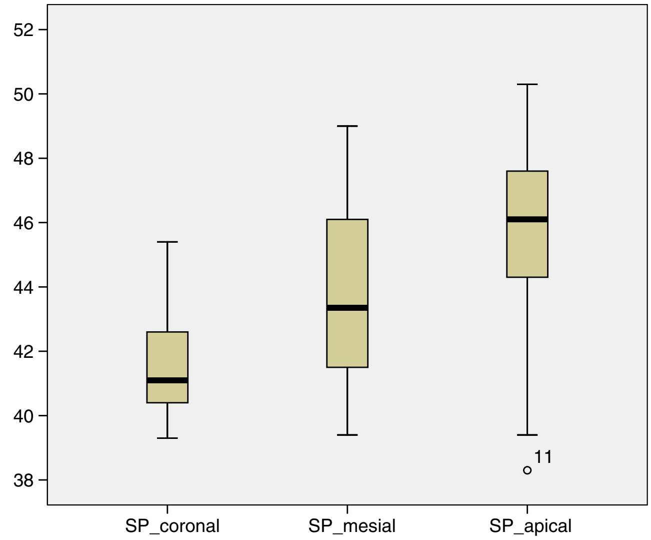

Fig. 1 Box plot graph for SP

Discussion

From the analysis, it was shown that the temperatures do not differ between SP and LP for the coronal and mesial points. These mean differences remain statistically nonsignificant even if one-sided tests are used, mainly in case where information from the experiment exists as to the direction of the mean difference of temperatures. In apical points though, the mean differences were statistically significant.

Statistically significant were also the paired differences between the three points of the tooth either in SP or LP. This study was aimed to compare the temperature elevation on human tooth surface induced by a pulsed Nd:YAG laser with same power settings but different pulse duration.

It is clear that the most susceptible area for thermal damage is the apical part of the root where there is only a thin layer of dentine and cement between the root canal and periodontal ligaments and surrounding alveolar bone.

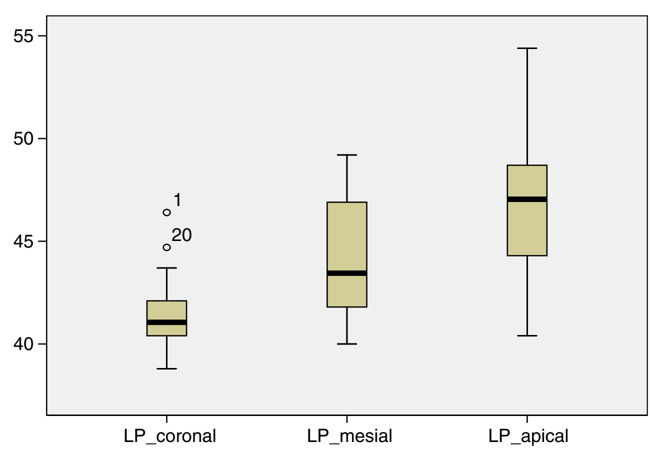

Fig. 2 Box plot graph for LP

Several reports have attempted to find a safe limit that would allow lasers to be used without causing thermal injury. Most studies resulted that the in vitro temperature rise after laser-assisted root canal therapy is between 47.3 and 51.4 °C and that higher temperatures than 53 °C will result in bone necrosis [25].

In this study, it was shown that the highest temperature rises were observed in the apical point of the root either using short pulses or long pulses. The mean temperature measured for SP was 45.5 °C and for LP was 46.8 °C. That is a mean temperature elevation of 8.54 °C for SP and 9.83 °C for LP taking under consideration that the experiment was done under stable temperature condition of 37 °C.

This temperature rise is only present for the minimal time of the pulse duration, so it is impossible to produce thermal damage on the apical region of the root canal. We must also consider that the blood vessels of the area will accelerate the heat conductivity in an in vivo situation, and thus helping the periodontal tissues to cool down faster and the expected temperature elevation will be even smaller [26].

Conclusion

Based on the conditions of this study, the Nd:YAG laser application in the root canal will not increase the temperature of surrounding tissue more than 10 °C which is the threshold for the occurrence of evident bone tissue damage according to the study of Eriksson and Albrektsson [27], since there is only a mean temperature elevation of 8.54 °C for SP and 9.83 °C for LP in apical points.

There was no significant difference in the observed temperatures in coronal and mesial areas. The results of the study demonstrated that the temperature rises during Nd: YAG laser irradiation at the parameters used in the study are minimal to cause damage on bone and periodontal tissues.

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