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Measurement of temperature changes during cavitation generated by an erbium, chromium: Yttrium, scandium, gallium garnet laser*

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ABSTRACT

Aim: The present study evaluated the magnitude of temperature changes in the tooth during cavitation produced by an Er,Cr:YSGG laser. Methods: The root canal of a single extracted maxillary canine was enlarged to a size 30/.02 file. Four thermocouples were attached to the tooth: one to the surface of the root and three inserted into the canal at 3, 9, and 15 mm from the apical foramen, respectively. The tooth was placed in a plastic container at room temperature around 25˚C. The tooth was processed as follows. In the EDTA condition, the tooth was irrigated with 17% EDTA; in the NaOCl condition, the tooth was irrigated with 3% NaOCl; and to analyse the effect of different thicknesses of dentin, the tooth was irrigated with tap water. In all conditions, the irrigants were activated at 2 W for 120 seconds. Results: The mean temperature was 25.2˚C to 27.1˚C and the temperature ranged from 25.0˚C to 29.6˚C. The temperature elevation measured during cavitation generated by the laser didnot exceed 5˚C. Conclusions: The magnitude of the temperature changes in the root canal and at the surface of the tooth did not exceed 5˚C when laser-driven irrigation was used to produce cavitation in the root canal.

Keywords: Cavitation; Heat; Laser-Driven Irrigation; Temperature Changes

1. INTRODUCTION

Shaping of the root canal has improved with advances in metal technology. However, owing to the anatomical complexity and irrigurarity of teeth, cleaning of the canal still relies heavily on the adjunctive use of chemical rinsing and soaking solutions [1]. The irrigation procedure is a very important part of root canal treatment. However, hand irrigation is not sufficiently effective in the apical third of the root canal, or in oval extensions, isthmuses, and anastomoses [2]. Vapour lock that results in trapped air in the apical third of the root canal may also hinder the exchange of irrigants and decrease the efficacy of debridement [3].

To enhance the dispersal of the irrigant and to activate it, sonic and ultrasonic techniques have been investigated and developed. The use of lasers has been proposed as an alternative to conventional approaches to cleaning and disinfection [2]. Both ultrasound and pulsed middle infrared lasers cause cavitation and pressure waves within the root canal space [4]. Various types of laser (such as Diode, Nd:YAG, Er:YAG or CO_2) have been investigated in an attempt to develop improved treatment methods, and the performance of lasers that are used in the field of dentistry has been improving [5].

In a previous study, evaluation by scanning electron microscopy (SEM) revealed that the laser-driven irrigation system under evaluation had the ability to remove the smear layer at the root tip [6]. This capacity could be attributed to the ability of the laser-driven irrigation system to create cavitation. Cavitation is defined as the formation of vapor or a cavity that contains bubbles inside a fluid [7]. In water, the use of a laser at ablative settings can result in the formation of large elliptical bubbles. These vapor bubbles can cause expansion to 1600 times the original volume of the water [8]. This process can allow the irrigant to access the apical third of the canal more easily, which might assist in the cleaning of canals of irregular shape. In addition, cavitation bubbles expand, become unstable, and then collapse in what is termed implosion [9]. The implosion will have an impact on the surfaces of the root canal, causing shear forces, surface deformation, and the removal of surface material [10]. Using cinematic holography, Ebeling and Lauterborn observed shock waves that emanated from

*The authors deny any conflicts of interest related to this study.

the collapsing bubbles that were generated by a laser pulse [11]. These laser-generated pressure waves moved at high speed and appeared to enhance the action of endodontic irrigants in the removal of the smear layer [12].

It is possible that the heat that is generated by laser-driven irrigation within the root canal could have a deleterious effect on the periodontal tissues. An increase in temperature of any solution inside a root canal is considered desirable in principle [13], because it enhances the chemical reactivity and hence the disinfecting potential of the solution [14]. However, any increase in temperature on the outer root surface beyond 47˚C is harmful to the periodontal ligament and bone [15] and can have catastrophic consequences [16].

The purpose of the study reported herein was to measure the magnitude of the temperature changes inside the root canal and at the external root surface that occured during laser-driven irrigation using a continuous flow of irrigant. The influence of the thickness of the dentin, which is a poor insulator, was also investigated.

2. MATERIAL AND METHODS

2.1. Preparation of the Tooth and Thermocouple Assemblies

A single human permanent canine that had been stored in saline solution was selected. The length of the tooth was 20 mm, with an intact clinical crown. The tooth had been extracted for reasons unrelated to the present study. The tooth was not decoronated and the intact crown served as a reservoir for the irrigation solution. After preparing conventional access to the tooth, the working length (WL) was determined by inserting a size 8 C+ file passively into the canal until it was visible at the apex, and then retracting the file by 1 mm. To simulate the conditions within the root canal, the apex of the tooth was sealed with sticky wax. The canal was instrumented using stainless steel K-type files (Dentsply Maillefer, Ballaigues, Switzerland). The specimen was shaped using hand instruments up to a size 30/.02 file. During instrumentation, the canal was irrigated with 3 mL of 3% NaOCl and 3 mL of 17% ethylenediaminetetraaceticacid (EDTA) alternately between every change of instrument.

T type (copper-constantan) thermocouples were made by twisting together one end of each of two wires (0.1 mm). The joint was silver soldered to prevent the wires from unwinding under the influence of cavitation and to enhance electrical contact between the two wires. Spaghetti-type plastic insulation was placed over each wire to within 3 mm of the solder joint. This 3 mm section of wire was coated with a flowable compomer restorative material (Dyrect flow, Dentsply) to keep the wires separated and to facilitate handling. Four thermocouples were attached to the tooth: one was attached to the root surface and three were inserted into the root canal at 3, 9, and 15 mm from the apical foramen, respectively (**Figure 1**). The free ends of the wires were attached to a data recorder (LogoScreen 500 cf; Jumo, Fulda, Germany) running PCA 3000 software (Jumo, Fulda, Germany). The accuracy of the temperature measurements was verified to be 0.1˚C in a pilot study, in which results from a thermocouple submerged in water at room temperature were compared with calibrated thermometer readings.

The tooth, together with the attached thermocouples, was mounted individually in an opening in the lid of a plastic container so that the root was submerged in water (at approximately 25˚C) to the level of the cementoenamel junction. The temperature of the room was regulated such that the temperature measured by both the internal and external thermocouples was stabilized at 25˚C ± 0.3˚C. After the temperature had stabilized, the integrity and insulation of the thermocouples was confirmed by irrigating the canal with 5 ml of tap water at 20˚C. The units were judged to be satisfactory if an initial drop in temperature was followed by a slow return to room temperature. This procedure served as a control for the study.

To measure the effects of the thickness of the dentin wall on the temperature at the root surface, the walls of the tooth were prepared with a fissure bur to give thickness of 1 mm and 2 mm at the cervical areas (mesial and distal, respectively); subsequently thermocouples were

Figure 1. Each test specimen was constructed by placing three thermocouples inside the root canal; in addition, one thermocouple was attached to the surface of the root canal.

attached to both sides.

In the EDTA condition, the tooth was irrigated with 17% EDTA. In the NaOCl condition, the tooth was irrigated with 3% NaOCl. To analyse the effect of different thickness of dentin, the tooth was irrigated with tap water. All experiments were carried out five times.

2.2. Laser Parameters

An erbium chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) dental laser (Waterlase MD, Biolase, San Clemente, CA) was used at panel settings of 2 W average power and 35 Hz and was focused through a plain fiber (quartz) tip (MZ6) with a diameter of 600 µm and length of 14 mm. The true power output of the system was determined with a laser power meter that was placed at a distance of 10 mm from the terminus of the fibre; according to the laser power meter, 2 W was equivalent to 1.2 W. The difference in power between the panel setting and the power measured with the laser power meter can be explained by the loss of energy from the fiber tip during transmission, which was in line with the manufacturer's specifications. The fiber tip was fixed in the hand piece of the laser, which was activated for a period of 120 seconds. The pulp chamber served as a reservoir for the irrigation solution. The fiber tip was submerged in the solution and made to hover above the orifice of the pulp chamber. The co-axial water spray and air were switched off.

2.3. Statistical Analysis

The temperatures recorded during the periods before deposition of the irrigant and activation of the laser were averaged and served as baselines. The data were compared using two-way analysis of variance (ANOVA) and the Bonferroni post-hoc test.

3. RESULTS

The results obtained are shown in **Tables 1** and **2**, and **Figures 2-4**. A total of 100 temperature measurements was obtained for each irrigation condition tested. Baseline temperatures were stable in the range of 25.0˚C ± 0.3˚C before deposition of the irrigation solution and agitation by the laser. The standard deviations are presented as an estimate of the uncertainty of the experiments.

3.1. Irrigation with EDTA

The mean (standard deviation) root canal temperature at 0, 30, 60, 90, and 120 seconds after application of the 2 W laser in the presence of EDTA irrigant was: 25.16 (0.11), 26.36 (0.54), 26.45 (0.91), 26.89 (1.08), and 27.24 (1.10)˚C, respectively.

Table 1. Changes in temperature in the root canal during cavitation (mean ± standard deviation).

Duration (seconds)	EDTA		NaOCl	
	Mean	SD	Mean	SD
0	25.17	0.11	25.22	0.09
30	26.00	0.83	26.08	1.04
60	26.46	0.91	26.12	0.90
90	26.90	1.08	26.00	0.69
120	27.25	1.10	26.30	0.96

Table 2. The minimum and maximum temperatures of the tooth during cavitation for all conditions.

Duration (seconds)	Min	Max
0	25.0	25.3
30	24.2	29.4
60	24.3	28.4
90	24.2	29.2
120	24.4	29.6

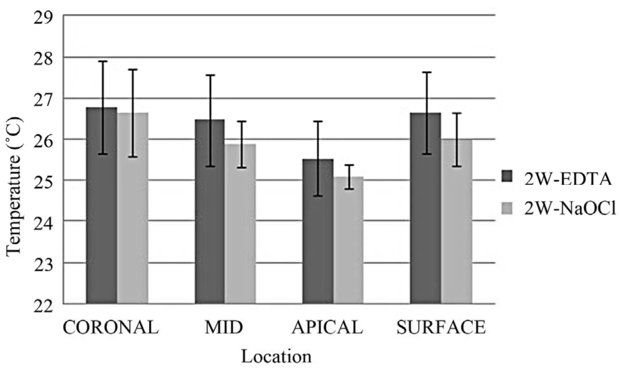

Figure 2. Overall mean temperature in the root canal at each location.

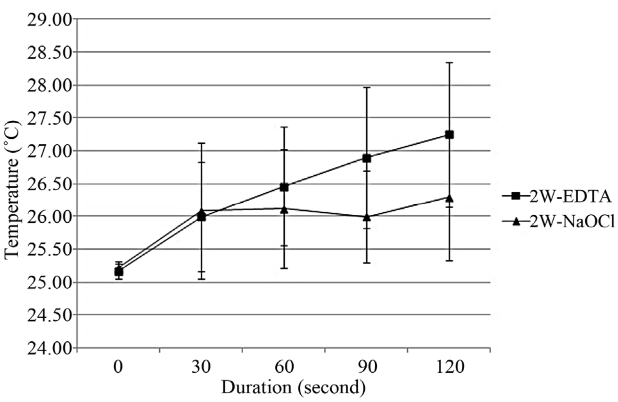

Figure 3. Overall mean temperature in the root canal.

3.2. Irrigation with NaOCl

The mean (standard deviation) root canal temperature at 0, 30, 60, 90, and 120 seconds after application of the 2 W laser in the presence of NaOCl irrigant was: 25.22 (0.09),

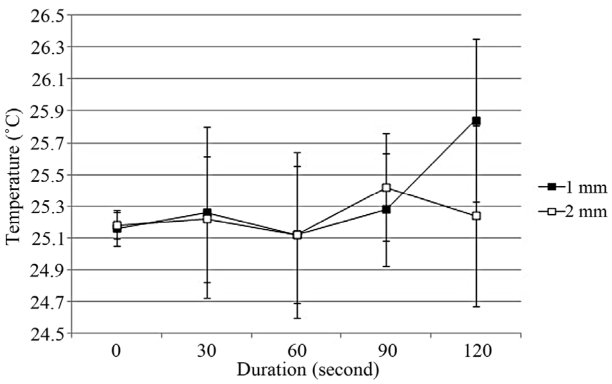

Figure 4. Mean temperature at the root surface for dentin walls of 1 mm and 2 mm thickness.

25.89 (1.06), 26.11 (0.90), 25.99 (0.69), and 26.29 (0.96)˚C, respectively.

3.3. Evaluation of the Effects of Dentin Thickness

The temperature changes at the root surface were lower for the dentin wall that was 2 mm thick than for the one that was 1 mm thick (**Figure 4**); however, the difference was not significant.

4. DISCUSSION

The key use of root canal irrigants is to clean the canal during the enlarging and shaping process. This means that one or more irrigants must be used for the complete debridement of the smear layer and debris from the root canal system (RCS) [17]. Irrigation using a syringe is the standard procedure, but unfortunately syringe irrigation is not effective in the apical third of the root canal [18-20]. As a consequence, acoustic and hydrodynamic methods to activate the irrigant have been developed [21], and these techniques have been shown to increase the efficiency of cleaning. However, the physical mechanisms that underlie these cleaning procedures are not well understood [22]. Laser applications that use different wavelengths have also been proposed as adjuncts to conventional endodontic cleaning procedures [23-26]. The undesirable side-effects that occur with the use of lasers are moderate and within limits this technique is regarded to be safe [23-30]. Previous studies have identified the side-effects that can be caused by the use of lasers in the root canal; they include the creation of ledges at a canal curvature of up to <10˚ [27], carbonization, cracks [5] collateral damage, and apical extrusion of the solution [31].

In an earlier study, to avoid some of the side-effects that are associated with the use of a laser, laser-driven irrigation was performed by allowing the laser tip to hover around the orifice of the RCS, instead of placing the tip within the canal itself. During laser irradiation, the root canal was irrigated continuously to maintain the level of hydration. The pulp chamber served as a reservoir for the irrigant [6]. However, heat generation is obvious during dental laser treatment. Water flowing through a tip can feel warm, and the fiber tip of the laser can become too hot to touch. The thermal energy that is generated by the laser can be transferred from the tip of the laser to the irrigation solution. The consequences of this increase in temperature deserve attention: is the rise in temperature safe for bone and periodontal ligament?

Several studies have investigated the temperature at which damage to bone is initiated. Sauk *et al*. found that exposing the periodontal ligament to a temperature of 43˚C resulted in protein denaturation and reported that ankylosis and bone resorption may develop [32]. Matthews and Hirsch discussed the inactivation of bone alkaline phosphatase in vitro at 56˚C and considered this to be the critical temperature for bone injury [33]. In a study that preceded their work on heat-induced bone degeneration, Eriksson *et al*. observed blood that was static in bone 2 days after a 1 minute exposure to a temperature of 53˚C [34]. The follow-up study measured the threshold level required to induce bone injury [15]. Bone injury in two of five rabbits occurred after a 1 minute exposure to 47˚C, whereas the remaining rabbits showed no bone resorption activity that deviated from normal. Damage to fat cells was observed in all the animals. The affected bone and fat tissues were resorbed without signs of subsequent regeneration. Bone healing after thermal injury appeared to induce the formation of connective tissue rather than hard tissue. These results suggest that the critical temperature for bone injury could be as low as 47˚C, which is 10˚C above human body temperature, and that the effect is time-dependent [15].

Regarding the experimental set-up, the experiment was set up at room temperature (25˚C), so that we could observe the magnitude of the temperature changes directly. This system allowed the temperature increases inside and outside the canal to be recorded easily, when irrigant at a temperature of 25˚C was used. In contrast, Cameron [35] and Marco [36] placed the teeth in a water bath at 37˚C to provide a stable temperature for the thermocouples, but used irrigant at 25˚C. As a consequence, the temperature of the teeth was affected by the temperature of the irrigation solution and the magnitude of the increase in temperature due to laser treatment could not be measured directly.

The investigation was performed in the afternoon, so that the heat from the sun did not affect the room temperature, which remained stable at around 25˚C. The room temperature was maintained by an air conditioner that was set to 25˚C. The study used a single tooth because the authors assumed that the data obtained from the same prepared tooth would be comparable. The plastic container filled with water was used to bring the temperature of the four thermocouples close to room temperature, and to prevent excessive conduction of heat away from the tooth.

Given that each thermocouple measured the temperature at a different location, the investigation was started when all of the thermocouples had reached almost the same baseline; the temperatures were not above 25.3˚C. By attaching thermocouples at different positions on the external as well as the internal surface of the root, detailed investigation of changes in temperature could be performed.

An earlier study [6] revealed that laser cavitation resulted in the most effective removal of the smear layer and debris; hence, in the present study we observed the temperature changes produced by a laser at 2 W. The mean temperatures were from 25.2˚C to 27.1˚C and the temperature ranged from 25.0˚C to 29.6˚C. A rise in temperature within this range will not cause pathological damage to periodontal tissues.

Laser agitation in the presence of the EDTA irrigant produced significantly higher temperatures than the NaOCl irrigant ($p < 0.001$) (**Figure 3**). Differences in the physical properties of NaOCl and EDTA might have an effect on the transmission of laser energy by the solution. In fact, during cavitation, more microbubbles formed in the NaOCl solution than in the EDTA solution. The authors assumed that this enhanced formation of microbubbles might have reduced the magnitude of the temperature change. Further research is needed to show which of the physical properties of the NaOCl solution is responsible for the lower rise in the temperature.

Furthermore, there was no significant difference in temperature at the root surface between the wall of 1 mm thickness and that of 2 mm (**Figure 4**). Under the conditions of the study, high temperatures were not recorded in the outer canal, and dentin, which is a poor conductor of heat, insulated the surface of the tooth from the temperature changes within the root canal. The thicker root canal wall was a more efficient insulator, but the difference was not significant.

The temperatures measured coronally were higher than those measured at the middle, apical, and surface positions (**Figure 2**). The thermocouple in the coronal area was located close to the tip of the laser, which might explain why the temperature in the coronal area was high. The results obtained in the study have clinical relevance. Human body temperature is approximately 37˚C. Given that the temperature of the irrigation solution did not increase more than 5˚C during laser cavitation, these experiments demonstrated that the increases in temperature measured in the root canal were far below the critical temperature for damage to the periodontal structures.

5. CONCLUSIONS

On the basis of the results of the present investigation, continuous irrigation during laser cavitation resulted in temperature changes that did not exceed 5˚C, with either EDTA or NaOCl solution (**Tabel 2**). The changes in temperature that were measured inside the root canal and on the outer root surface during cavitation produced by laser were generally acceptable.

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