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Intrapulpal Temperature during Preparation with the Er:YAG Laser: An *in Vitro* Study

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ABSTRACT

Objective: **This investigation evaluated the variation of the intrapulpal temperature when dentine was irradiated by the Er:YAG laser.** ***Background Data:*** **The effect of preparation with the Er:YAG laser on the intrapulpal temperature is probably the biggest problem in using the laser for preparation of dental hard tissue.** ***Materials and Methods:*** **Seventy-two bovine incisors were studied that had the enamel and dentine of the buccal surface polished to a thickness of 2.0 mm. The teeth were divided into three groups, according to the repetition rate used (Group I = 2 Hz, Group II = 4 Hz, and Group III = 6 Hz), and irradiated, with or without water cooling, using 250, 300, and 350 mJ of energy per pulse. Thermocouples were introduced inside the pulp chamber through the palatine opening of the samples and fixed to the vestibular wall of the pulp chamber using a thermal paste.** ***Results:*** **It was verified that there was a decrease of the intrapulpal temperature for all of the parameters in the Group I irradiated with water cooling and for the parameters of 350 mJ/4 Hz with water cooling. The other irradiations showed an increase of the intrapulpal temperature, varying from 0.03° to 2.5°C.** ***Conclusion:*** **We conclude that the use of the Er:YAG laser promoted acceptable temperature increases inside the pulp chamber. However, we do not recommend this procedure without water cooling because macroscopic observations of the dentine irradiated without water cooling showed dark lesions, suggesting carbonization of this tissue.**

INTRODUCTION

The development of the first laser instrument about 30 years ago was observed by the dental profession with great interest. The desire to pioneer new methods of painless cavity preparation by means of lasers was of special interest. The systems developed at that time had the disadvantage of causing an excessive temperature rise in both the tooth and pulp with only minimal substance removal. Only with subsequent investigations of the interaction between hard tooth tissue and laser beams and with the improvement of laser systems could units be developed that would permit an efficient ablation of substance.

Recently, the main laser used for cavity preparation has been the Er:YAG laser. Although the first research with the Er:YAG laser was in 1988,[1] only in 1997 was this equipment approved by the U.S. Food and Drug Administration (FDA) for cavity preparation and hard tissue management. The 2.94-μm wavelength of the Er:YAG laser falls in an area of the spectrum where both enamel and dentin have absorption peaks.[2] The Er:YAG laser has the ability to remove particles in microexplosions and to vaporize them, a process called ablation.

Great doubt still persists when using the Er:YAG laser on cavity preparation because of the possible occurrence of irreversible pulp damage due to temperature increases that occur. According to Zach and Cohen in 1965, an intrapulpal temperature increase of approximately 5.5°C can promote necrosis in 15% of pulpal tissue.[3] Raising the temperature 11°C will cause 60% necrosis and 100% when raised more than 17°C.[4] This pulpal damage can be avoided or minimized by a suitable choice of laser parameters and adequate use of an air/water spray.

The purpose of this *in vitro* study was to evaluate the intrapulpal temperature during cavity preparation with the Er:YAG

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laser with different pulse repetition rates, and fluences, with or without water cooling.

MATERIALS AND METHODS

Sample preparation

Seventy-two freshly extracted bovine incisors (crack-free) were selected, cleaned with a rotary brush and pumice, and stored in a 0.9% NaCl solution. A coronary opening was made in all samples with a spherical diamond burr (KG Sorensen, No. 4) on a high-speed handpiece (KAVO Super-torque 625) to permit measurement of the dentine thickness between the cavity floor and the pulp chamber, and to allow the positioning of the thermocouples.

On the buccal surface of each tooth, cavities (class V) were prepared with a diamond burr (KG Sorensen, No. 3113) on the same high-handpiece mentioned above, under cooling, to obtain a dentine thickness near 2.0 mm. To reach the dentine thickness used in this study (2.0 mm), the cavities' floors were polished with a heatless wheel stone and plane flat with No. 270, 400, and 600 grit sand paper, respectively. This procedure removed at least 0.3 mm in depth of the dentin surface. The thickness between the pulp chamber and the cavity floor surface was measured on three points of the dentin surface (mesial, medium, and distal) by a specimeter.

Finally, the smear layer created during outer dentin surface preparation was removed by rinsing with a 0.5 M EDTA solution for 2 min.

Laser device

A pulsed Er:YAG laser system (Key Laser II, KaVo Dental GmbH, Jena, Germany) that emitted at a wavelength of 2.94 μm with a spot size of 0.63 mm was used. Irradiation of a focused beam at dentin with or without fine water mist at 5 mL/min was performed.

Laser irradiation

Before irradiation, samples were randomly divided into three groups, with 24 samples each. The teeth were irradiated with 250, 300, and 350 mJ per pulse, with or without water cooling, as shown at Table 1.

The punctual irradiation was made at only one place. Half of the samples were irradiated under water mist and the other half were irradiated without water mist.

To standardize the focal distance of 12 mm (ideal focal distance to cavity preparation, according to KAVO) , a Hedstrom file was positioned on the superior part of the handpiece 2051 of the Er:YAG laser, as shown at Fig. 1.

At the moment of the irradiation, the samples were positioned on a metallic support, as well as the laser handpiece (Fig. 2).

Temperature measurements

For the measurement of the intrapulpal temperature, a thermocouple (SR lock-in amplifier, Stanford Research System) and a microcomputer (386) were used. The thermocouple cold

TABLE 1. OPERATING LASER PARAMETERS

Group	*Repetition rates (Hz)*	*Energy per pulse (mJ)*	*Fluences (J/cm²)*	*Number of pulses*
1	2	250	80.38	42
		300	96.46	36
		350	112.5	18
2	4	250	80.38	42
		300	96.46	36
		350	112.5	18
3	6	250	80.38	42
		300	96.46	36
		350	112.5	18

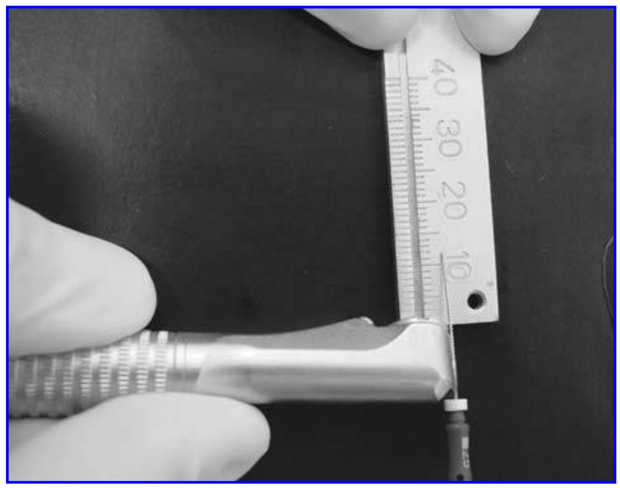

FIG. 1. Standardization of the focal distance (focus, 12 mm).

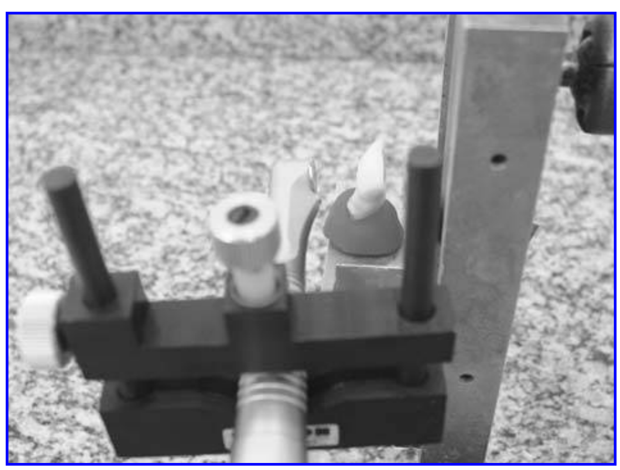

FIG. 2. Sample positioned on a metallic support, as well as the laser handpiece.

junction was carefully isolated. The accuracy of the thermocouple was ± 0.1°C.

Thermocouples were introduced inside the pulp chamber through the palatine opening of the samples. To maximize temperature transference between the thermocouple and the dentinal wall, the pulp chambers were filled with a thermal conducting paste (Implastec-Votorantin, Brazil).

RESULTS

Temperature rises measured during Er:YAG laser preparation in the three groups and with or without water cooling are indicated, respectively, in Table 2 and in Figs. 3 and 4.

The temperature rise measured showed higher temperatures from the samples irradiated without cooling when compared with samples irradiated with water cooling.

In relation to the samples irradiated without cooling, the higher variation of intrapulpal temperature was found in the parameter 6 Hz, 250 mJ, and the smallest value was found when the parameter 2 Hz, 350 mJ was applied. In macroscopic observations, the dentin that was irradiated without cooling showed dark lesions, suggesting carbonization of this tissue.

For the samples irradiated with water cooling, the higher variation of intrapulpal temperature was found in the parameter 6 Hz, 300 mJ, and the smallest value was found when the parameter 2 Hz, 250 mJ was applied. On the contrary, the samples irradiated without cooling did not show macroscopic signs of carbonization.

The student *t*-test revealed statistical significant differences ($p \leq 0.05$) in the intrapulpal temperature rise between the three groups.

DISCUSSION

The major purpose of this study was to verify the variations on intrapulpal temperature during cavity preparation with the Er:YAG laser.

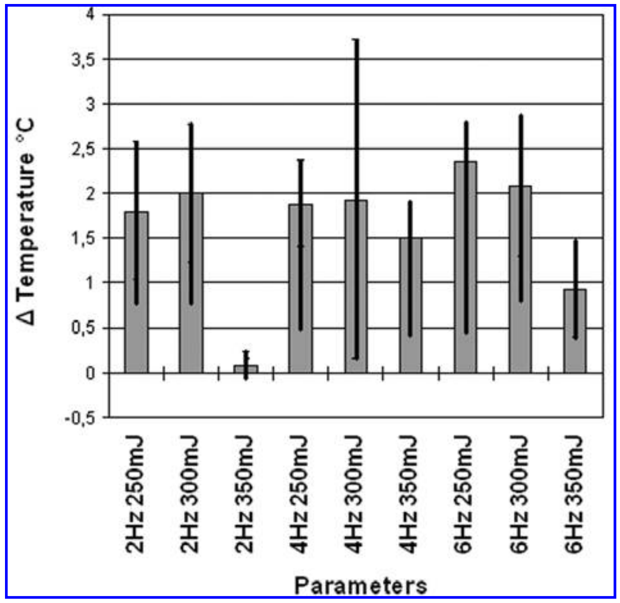

FIG. 3. Temperature increases without spray (means and standard deviations).

It is possible that accidental or intentional exposure of dentin surfaces to laser energy may cause pulpal damage if temperatures rise sufficiently high. Zach and Cohen[3] reported that pulp temperature rises of 5.6°C caused loss of pulpal vitality in 15% of teeth tested. Temperature rises in excess of this value are unacceptable because of the potential for loss of pulpal vitality.

The data from this study indicate a relation between the repetition rates and the variation of the intrapulpal temperature. This condition can be observed in the samples irradiated with 250 mJ, with or without cooling, where the same numbers of pulses were applied. In this case, the intrapulpal temperature is higher when 6 Hz is used, following 4 and 2 Hz. The same occurred with the samples irradiated with 300 and 350 mJ, both

TABLE 2. MEANS OF INTRAPULPAL TEMPERATURE AND STANDARD DEVIATIONS

Groups	*Repetition rates (Hz)*	*Energy per pulse (mJ)*	*Temperature rises (°C ±SD)* *No cooling*	*Water cooling*
		250	1.80 (±0.77)	−1.65 (±1.70)
1	2	300	2.00 (±0.77)	−0.48 (±0.65)
		350	0.08 (±0.15)	−0.18 (±0.24)
		250	1.88 (±0.48)	0.03 (±0.33)
2	4	300	1.93 (±1.78)	0.58 (±0.30)
		350	1.50 (±0.41)	−0.08 (±0.15)
		250	2.35 (±0.44)	0.05 (±0.10)
3	6	300	2.08 (±0.79)	1.45 (±0.64)
		350	0.93 (±0.54)	0.00 (±0.00)

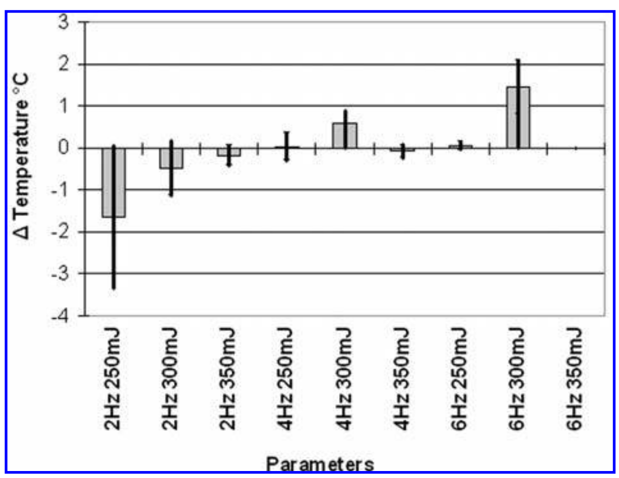

FIG. 4. Temperature increases with spray (means and standard deviations).

under water cooling. The same results were found by Hibst and Keller, who stated that the repetition rate was the most important parameter determining the accumulated heat.[5,6]

As repetition rates, fluence, and exposure times increase, the pulpal temperature also increases to levels that may cause detrimental pulp effects.[7,8] The present study used exposition times varying from 3 to the 20 s, depending on the energy per pulse and repetition rates applied. For these short exposition times, the intrapulpal temperatures do not reach critical levels. These conditions, together with the poor thermal conductivity of the dentin,[9] suggest that the use of high (but acceptable) repetition rates and fluences, but short exposition times, reduce the risks of promoting pulp damage.

Regarding the dentin thickness, it is known that this thickness has a decisive role in the generation of the intrapulpal temperature; in other words, with thinner dentin heating inside the pulp chamber will be higher.[7,10] Because one cannot directly measure the remaining dentin thickness *in vivo,* it is important that the operator choose adequate laser parameters to ablate a sound or a carious tissue. The operator must judge the dentin thickness and adjust the laser settings based on clinical experience and other factors, such as size of the tooth and the area to be treated.

This research also verified the importance of using an air/water spray on laser ablation to reduce the intrapulpal temperature. According to our results, the means of intrapulpal temperature when the samples were irradiated under water cooling were significantly lower than those obtained in irradiations without cooling. In some cases (2 Hz, 250 mJ), the irradiation with cooling presented an intrapulpal temperature mean of −1.65°C while the same parameter, but without cooling, showed 1.80°C intrapulpal temperature mean, a difference of 3.45°C between them. This may be verified in other parameters used in this study.

In our experiment, the volume of water was regulated to keep the tooth moistened. If the volume was too high, vaporization of water occurred without dentin ablation. If the volume was too low, dentin ablation was inefficient and heating of the tooth became more significant.

The water film reduces the heat effect, both for single and multiple pulses. Because the surface is dry after the laser pulse, a temperature decrease for single pulses might be due to shielding the tooth surface against the nonablating outer parts of the beam. Thus heat production is lessened in the outer part of the laser spot, enhancing the radial heat flow. For multiple pulses, the surface is covered by a water layer again, with additional cooling of the surface. Thus, the temperature decrease by water is more pronounced for multiple pulses, compared to single shots.[11]

The fact that water might inhibit the ablation depths because of high absorption of the Er:YAG laser radiation in water is of concern.[12] Visuri *et al*.[13] evaluated the effects of water spray during Er:YAG laser irradiation on dental hard tissues and found that the water minimally reduced the ablation efficiency. Burkes *et al*.[14] showed that when dental hard tissues were irradiated by an Er:YAG laser accompanied with fine water mist, not only could the temperature be suppressed, but the cutting efficiency could also be increased.

When teeth are irradiated with water mist, neither carbonization nor melting in the cavities or its surrounding tissues are found.[12] However, when teeth are irradiated without water mist, carbonization is easily recognized at the margins of the cavities, as shown in Fig. 5. Therefore, water mist is necessary during the Er:YAG laser irradiation. Water plays an important role in initiating the ablation of dental hard tissues[12] and prevents the intrapulpal temperature from reaching critical levels. In our experiment, the time of exposure was too short to promote critical increases in intrapulpal temperature. Even so, irradiation without cooling cannot safely be performed, because the dentin irradiated without water mist showed dark lesions, suggesting carbonization of this tissue. However, the values of larger relevance are those found in the cases in which the irradiation was accompanied by cooling, because they prove the clinical safety of use of the Er:YAG laser for cavity preparation, in the parameters here used.

FIG. 5. Carbonization promoted by irradiation with the Er:YAG, without cooling.

Further *in vivo* studies should be performed using the real time to prepare cavities, because the factor time interferes directly with the temperature values found in this type of study.

CONCLUSIONS

In the conditions of the present study, we conclude that the use of the Er:YAG laser promoted acceptable temperature increases inside the pulp chamber. The values of temperature variation found for some samples irradiated under water cooling became negative, indicating that there was a decrease in temperature inside the pulp chamber during the irradiations. We do not recommend this procedure without water cooling because macroscopic observation of the dentine irradiated without water cooling showed dark lesions, suggesting carbonization of this tissue.

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