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The Temperature Changes in the Pulp Chamber During Cavity Preparation with the Er:YAG Laser Using a Very Short Pulse

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Abstract

Objective: The aim of this study was to examine the temperature changes in the pulp chamber during cavity preparation with the Er:YAG laser (2940 nm) with a very short pulse (VSP).
Materials and Methods: Nine groups of 10 intact molars each were used. One root of each sample was amputated and a thermocouple was inserted into the chamber. Class V cavity preparation in enamel was performed, and then preparation was performed in dentine. The enamel was lased with 400, 360, and 320 mJ in contact mode using a VSP with a duration of 100 μsec. The diameter of the fiber tip was 950 μm. Frequencies of 10, 12, and 15 Hz were used, and the total time of irradiation was 10 sec. The dentine was irradiated with 340, 280, and 200 mJ at 10, 8, and 5 Hz for 7 sec. Cooling was done with a water spray (73 psi and 50 mL/min). The differences were tested by MANOVA and the Bonferroni *post hoc* test.
Results: The highest rise in temperature in the pulp was achieved after enamel irradiation with 400 mJ and 15 Hz (1.99 $\pm$ 0.28°C), and the lowest was after irradiation with 320 mJ and 10 Hz (0.70 $\pm$ 0.18°C). In dentine the highest temperature increase was achieved with 340 mJ and 10 Hz (1.37 $\pm$ 0.42°C), and the lowest was with 200 mJ and 5 Hz (0.43 $\pm$ 0.18°C). Two-way analysis of both enamel and dentine showed that the influence of energy on temperature increase was stronger than that of frequency.
Conclusion: Cavity preparation with an Er:YAG laser using VSP mode *in vitro* did not cause significant increases in temperature in the pulp chamber of human molars.

Introduction

The damage to the pulp after cavity preparation is often a consequence of the temperature increase in the chamber during drilling,[1] making impressions with thermoplastic materials,[2] or curing of composites.[3] Heat build-up during the various types of laser procedures done on teeth is of great concern. Thermal injuries to pulp can be examined *in vivo* using histological studies, microscopy, laser Doppler flowmetry,[4] or via a thermocouple inserted into a tooth to be extracted.[5] *In vitro* studies are performed on extracted teeth using a thermocouple[6] or infrared video systems.[7]

Due to its wavelength (2.94 μm) and absorption characteristics by hydroxyapatite and water, the Er:YAG laser is one of the most commonly used lasers for cavity preparation and caries removal.[8,9] Its reported bactericidal effects[10,11] are related to the vaporization of the moisture in bacterial cells as a result of the high energy absorption by water of this laser wavelength.

Although the efficiency of ablation of hard dental tissues by the Er:YAG laser is increased in comparison with other lasers,[12] it is still slower than conventional drilling.[13] Recently, new technology that enables changes in pulse duration has been introduced. It is reported that shorter pulse rates (100 μsec) considerably increase the ablation rate of hard dental tissues, in contrast to the commonly used 300-μsec pulses of other erbium lasers. The shorter pulses reach the high ablation threshold of hard dental tissues faster, and consequently less energy is transformed into heat.[14]

The present study was undertaken to examine the temperature changes in the pulp chambers of extracted human teeth during cavity preparation in enamel and dentine with an Er:YAG laser using a very short pulse (VSP), and to de-

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termine the influence of energy settings and frequency on these changes.

Materials and Methods

The laser used in this study was an Er:YAG laser Fidelis model (Fotona, Ljubljana, Slovenia) equipped with variable square pulse technology.

Nine groups of ten intact molars extracted due to impaction or for orthodontic reasons stored in 10% buffered formalin were used in this study. The teeth were obtained with a protocol that was approved by Ethics Committee of the School of Dental Medicine and with informed consent of the donors. The biggest root of each sample was amputated and a thermocouple (Fluke 52; Fotronic, Melrose, MA, USA) was inserted into the chamber. The temperature range of the thermocouple was from –250 to 400°C with an accuracy of ±0.20% (±0.3°C). The thermocouple was fixed by red wax inside the chamber, which also covered the entrance to the chamber (Fig. 1). The wax also isolated the chamber, and prevented the water used for cooling from influencing temperature measurements.

First in enamel, on the buccal surfaces of teeth the class V cavities were prepared with three different energy settings (400, 360, and 320 mJ) in contact mode using an RO7 handpiece. Inside the pulp chamber, the thermocouple was positioned adjacent to the irradiated area. A VSP of 100 μsec in length was used. Each energy level was combined with three different frequencies (15, 12, and 10 Hz). The total period of irradiation was 10 sec, and the diameter of fiber tip was 950 μm. The energy densities for the energy parameters were 14.11, 12.70, and 11.29 J/cm^2.

After that, all the samples were irradiated again, but the preparation was done in dentine for 7 sec. The energy levels used were 340, 280, and 200 mJ (energy densities of 11.98, 9.88, and 7.06 J/cm^2) combined with frequencies of 10, 7, and 5 Hz.

Cooling during the preparation in both enamel and dentine was done with water spray at a pressure of 73 psi (503 kPa) and a water flow rate of 50 mL/min.

FIG. 1. Experimental model showing the position of the thermocouple inside the pulp chamber. 1 = laser; 2 = thermocouple in pulp chamber; 3 = thermometer.

TABLE 1. SUMMARY OF MEANS AND STANDARD DEVIATIONS FOR TEMPERATURE INCREASES IN THE PULP CHAMBERS AFTER IRRADIATION OF ENAMEL

Energy	*Frequency*	*Mean temperature increase (°C)*	*Standard deviation*
400 mJ	15 Hz	1.9900	.28451
	12 Hz	1.6450	.19595
	10 Hz	1.2250	.34317
360 mJ	15 Hz	1.0400	.31187
	12 Hz	.8700	.30796
	10 Hz	.6850	.44871
320 mJ	15 Hz	.7900	.17137
	12 Hz	.7750	.21975
	10 Hz	.7050	.17911

Mean intrapulpal temperature increases were calculated from the maximum temperature rises seen during and after irradiation.

All data were tested for normality of distribution. MANOVA was used to test the differences between the parameters of energy, frequency, and total energy delivered, with significance set at $p < 0.01$. The post-hoc Bonferroni test was used to determine differences between groups.

Results

The results of temperature measurements for enamel are shown in Table 1, and for dentine in Table 2.

During laser preparation the temperature begins to rise, and the increase continues for a few seconds after irradiation ends. Laser irradiation of enamel by the highest energy level (400 mJ) and frequency (15 Hz) used caused the highest rise in temperature (1.99° ± 0.28°C), while the energy setting of 320 mJ and 10 Hz caused the lowest increase (0.705° ± 0.179°C). Irradiation of dentine caused the temperature to increase in the pulp chamber 1.37 ± 0.42°C with 340 mJ and 10 Hz, and 0.43° ± 0.18°C with 200 mJ and 5 Hz.

Two sets of data were analyzed: temperature readings in enamel and those in dentine. Statistically significant differ-

TABLE 2. SUMMARY OF MEANS AND STANDARD DEVIATIONS FOR TEMPERATURE INCREASES IN THE PULP CHAMBERS AFTER IRRADIATION OF DENTINE

Energy	*Frequency*	*Mean temperature increase (°C)*	*Standard deviation*
340 mJ	10 Hz	1.3750	.42782
	8 Hz	1.0200	.26278
	5 Hz	.9800	.20417
280 mJ	10 Hz	.8850	.33760
	8 Hz	.8200	.26675
	5 Hz	.7900	.24473
200 mJ	10 Hz	.8550	.24165
	8 Hz	.5250	.28447
	5 Hz	.4350	.18144

TABLE 3. RESULTS OF BONFERRONI POST-HOC TESTING FOR FREQUENCY OF LASER IRRADIATION

Frequency	*Frequency*	*Mean difference*	*Standard error*	*Significance*
Enamel	Enamel			
15 Hz	12 Hz	0.1767[a]	0.05236	0.003
15 Hz	10 Hz	0.4017[a]	0.05236	0.001
12 Hz	10 Hz	0.2250[a]	0.05236	0.001
Dentine	Dentine			
10 Hz	8 Hz	0.2500[a]	0.05132	0.001
10 Hz	5 Hz	0.3033[a]	0.05132	0.001
8 Hz	5 Hz	0.0533	0.05132	0.900

[a]Statistically significant difference.

ences in temperatures were found using MANOVA for all of the factors assessed: energy F = 161.34, df = 2; $p < 0.01$, frequency F = 29.56, df = 2; $p < 0.01$, and energy times frequency F = 7.16, df = 4; $p < 0.01$ in enamel. Results were similar for temperature increases in dentine: energy F = 51.62, df = 2; $p < 0.01$, frequency F = 19.91, df = 2; $p < 0.01$, and energy times frequency F = 2.51; df = 4; $p < 0.05$. Results of Bonferroni post-hoc testing are shown in Tables 3 and 4.

Two-way analysis of both enamel and dentine showed that the influence of energy level on the temperature increase was stronger than that of frequency (Figs. 2 and 3).

Discussion

The purpose of this study was to determine the influence on temperature increases during cavity preparation with the Er:YAG laser using variable square pulse technology on temperature in the pulp chamber. According to the manufacturer, VSP technology enables the use of active electronic control of laser pulse duration as well as amplitude. This means that changing the pulse duration does not influence the pulse quality, as would occur with ordinary laser technology, for which the form and length of the laser pulse determine the energy density delivered. The shorter pulses used in VSP build up its energy faster, and consequently less energy is transformed into heat, which results in more efficient ablation and less thermal damage to dental tissues.[13–15] Because the tissues are less affected thermally, the manufacturer claims that higher pulse repetition rates up to 50 Hz can be safely used. Thus the very short pulse duration of 100 μsec instead of the traditional 300-μsec pulse should lead to more effective and less harmful ablation of hard dental tissues.

The temperature threshold for the survival of the pulp tissue was established in classical study of Zach and Cohen,[16] in which 15% of monkey teeth subjected to temperature increases of 5°C failed to recover. This increase in temperature of 5°C is considered the maximum temperature that can be withstood by the soft tissue of the pulp.

In this study the highest temperature increase (2.7°C) seen in the pulp chamber was achieved in samples treated with laser parameters of 400 mJ and 15 Hz. All other parameters tested showed smaller temperature increases. In s few cases there was a decrease seen in temperature, probably due to the cooling effect of the water spray. All these results are within the safety limits determined by Zach and Cohen.[16]

Our ablation regimens were defined by the relationship between the laser pulse duration and the laser pulse energy. At high energy levels and low pulse durations, the speed of ablation was faster than the diffusion of heat into the tissue. This kind of ablation is called "cold ablation," meaning that there is no heating of the surrounding tissue. To achieve cold ablation the pulse duration should be shorter than the tissue relaxation time. For enamel the thermal relaxation time is approximately 100 μsec.[15] In our investigation minimal thermal effects were seen on dental tissues, confirming that the VSP mode produced thermal effects near the target values.

Oelgiesser et al.[17] used a conventional Er:YAG laser for class I and class V cavity preparation and for caries removal. They measured the highest intrapulpal temperature rise (4.1° ± 1.29°C) during class I cavity preparation in enamel,

TABLE 4. RESULTS OF BONFERRONI POST-HOC TESTING FOR ENERGY OF LASER IRRADIATION

Energy	*Energy*	*Mean difference*	*Standard error*	*Significance*
Enamel	Enamel			
400 mJ	360 mJ	0.7550[a]	0.05236	0.001
400 mJ	320 mJ	0.8633[a]	0.05236	0.001
360 mJ	320 mJ	0.1083	0.05236	0.120
Dentine	Dentine			
340 mJ	280 mJ	0.2933[a]	0.05132	0.001
340 mJ	200 mJ	0.5200[a]	0.05132	0.001
280 mJ	200 mJ	0.2267[a]	0.05132	0.001

[a]Statistically significant difference.

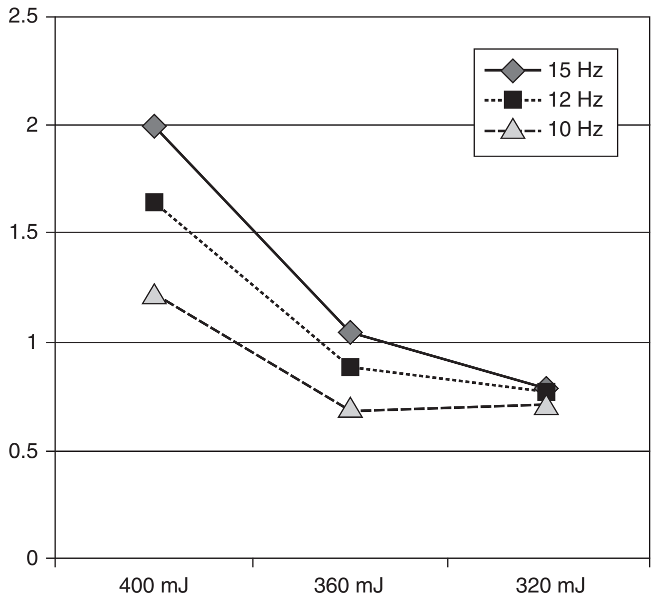

FIG. 2. Two-way analysis for enamel.

and the lowest values were seen during caries removal in dentine.

In contrast to these findings, Glockner et al.[5] saw a temperature decrease in the pulp chamber during preparation with a traditional Er:YAG laser. Only penetration of the pulp chamber and consequently hitting the measuring probe directly with the laser beam caused an increase in temperature. Although it might be expected that the Er:YAG laser with very short pulses we used in our study would cause less heating than the traditional one used in Glockner's study, the cooling effect of water and air should not be overlooked. The possible influence of the temperature of the water used for cooling on the temperature changes seen in the pulp chamber should also be investigated. The influence of different water flow rates and air pressures on the temperatures seen inside the pulp chamber during cavity preparation with a high-speed handpiece was confirmed by Öztürk et al.[1] Comparison of the temperature changes seen in the pulp chamber induced by Er:YAG laser irradiation with those seen with high-speed drilling was done by Raucci-Neto et al.[18] They found that only a high-speed handpiece with a water flow rate of 100 mL/min had lower temperature increases than did Er:YAG laser irradiation at 300 mJ and 3 Hz or 300 mJ and 4 Hz. In addition, a post-irradiated temperature rise was also seen in that study, and to prevent this, Park et al.[19] proposed the use of prolonged water spray cooling after irradiation for 1 or 2 sec. Although insignificant temperature increases inside the pulp chamber during Er:YAG laser irradiation without water cooling ($\leq$2.5°C) were seen by Geraldo Martins et al.,[20] those authors do not recommend performing the procedure without water cooling. Dentin irradiated without water cooling had a darkened surface, indicating that carbonization of the tissue had taken place.

Cavalcanti et al.[21] found an average temperature increase of 2.69°C ($\pm$1.12°) in the pulp chamber during class V preparation with an Er:YAG laser with a pulse duration of 250 μsec, energy level of 350 mJ, and frequency of 10 Hz.

Other lasers used in dentistry such as the CO_2 and Nd:YAG lasers caused considerably higher temperature increases in the pulp than did the Er:YAG laser. In the study of Türkmen et al.[22] 30 sec of lasing of dentine with a CO_2 laser caused temperature increases of 37°C in the pulp chamber, and Nd:YAG lasing increased the pulp chamber temperature by 28°C. Von Fraunhofer and Allen[23] measured temperature increases from 4° to 39°C in the dentinal pulp walls after Nd:YAG laser irradiation (80 mJ at 1, 2, and 3 W) of buccal and lingual teeth surfaces. The importance of the thickness of the remaining dentin in the thermal changes seen in pulp tissue were shown in the study by White et al.,[24] in which Nd:YAG irradiation of teeth in which the dentin was only 0.2 mm thick had temperature increases of 9°C at the energy parameters they used. Although in this study we did not measure the remaining dentin thickness, in the study by Glockner et al.,[5] they demonstrated that heating of the pulp after Er:YAG laser irradiation was not influenced by this parameter.

Conclusion

The findings of this study, together with those of previous studies, of the effectiveness of the Er:YAG laser for caries removal[9] and dentin and enamel ablation,[25] indicate that this type of laser is a modality for cavity preparation and caries removal that does not cause a harmful temperature increase in the pulp chamber.

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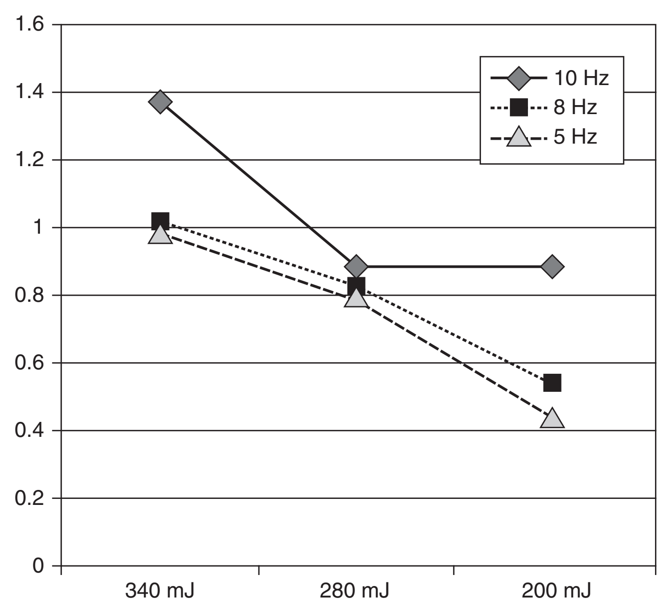

FIG. 3. Two way analysis for dentine.

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