Original Article

An Invitro Study on The Temperature Changes of Dentin, Irradiated by CO_2 and Er: Cr;YSGG Laser

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Introuduction: The aim of this in-vitro study was the evaluation of temperature changes due to irradiation of two different lasers used for the reduction of dentinal hypersensitivity and their effect on the pulp damage. The study was done for two dentin thicknesses.
Material & Methods: Twenty intact extracted third molars were prepared by longitudinal ground sectioning for 1 and 2 mm dentin thicknesses while a thermocouple was positioned at the inner surface of the dentin disk. Thermal evaluation was assessed by a KJT digital thermometer. During the test, the data produced by the thermometer was transferred and logged into a PC via RS232 serial port. CO_2 laser (Ultra pulse, 50W, 100µsec, Spot size: 0.5 mm) and Er,Cr;YSGG laser (Free-running pulse mode,0. 25W, 140µsec, 12.50 milli-joules) irradiations were randomly performed upon the dentin surfaces. The collected data was analyzed by two-way ANOVA test.
Results: The mean temperature rise in 1mm dentinal thickness was 8.57°C which was significantly higher than 3.63°C in 2mm dentin thickness ($P<0.001$) and higher than the threshold temperature for pulp damage; however, no significant difference was noted between the two lasers ($P=0.355$). After removing the CO_2 laser, the temperature decreased to the initial level faster than the time needed for Er,Cr;YSGG laser (44.47°C versus 62.82°C)($P<0.001$). In other words, in both lasers the temperature decrease in 2mm dentinal disc was faster than 1mm dentinal disc.
Conclusion: The temperature rise due to both lasers for 1mm of dentinal thickness was in excess of safe limit for the tissue and it would probably result in pulpal damage. In the case of 2mm dentinal thickness, the temperature rise was not higher than the safe limit and it would not damage the pulp in clinical conditions.

Keywords: Dentin, Temperature, Co_2 lasers, Er,Cr;YSGG, Dental pulp, Dentin Sensitivity

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INTRODUCTION

Dentin Hypersensitivity (DH) is one the most common complications causing discomfort, sharp and severe pain after thermal, chemical or mechanical stimulations in patients. DH is more common in teeth with exposed dentin(1-3). The frequency of DH in several studies has been shown to be from 4% up to 73%(4). Several reasons may cause DH, which all of them are closely related to exposure and patency of dentinal tubules(5). Many theories have been proposed to explain the mechanism of DH, though the most widely accepted theory is the hydrodynamic theory[6-8] which states that the changes in the rate of fluid flow in dentinal tubules cause pain. A number of studies have demonstrated that the tubules are greater in number and diameter in hypersensitive dentin than in non-sensitive dentin thus, sensitivity decreases when these tubules are occluded. Most of the desensitizing procedures or agents are currently used to treat the DH works either by sealing the dentinal tubules or by decreasing the activity of the dentinal sensory nerves, but sometimes they are not completely effective [3]. In the middle of 1980, the use of laser to decrease the level of DH was proposed for the first time. In most of experiments despite the variety in methods and the type of laser, a relative success was described[3, 9, 10]. Because, one of the most important supports of the pulp is the dentin thickness and the interaction of laser with this area liberates heat, investigations to characterize the diffusion of heat across dentin and its effect on pulpal tissue are particularly important.

Laser utilized in treatment of DH are categorized into two groups: "Low power" and " High power" lasers, which have two different mechanisms[11-12]. The main mechanism in high power lasers such as Nd;YAG, CO_2, Er:Cr;YSGG and Diode, is the sealing of the exposed dentinal tubules with melted and re-crystallized dentin which is caused by the photo thermal and occlusive effect of laser. This effect explains the change in structure of the dentinal tubules by melting and fusion of hard tissue [pretubular dentin] which in turn leads to the sealing of the exposed dentinal tubules[13-15].

In 1986, Moritz *et al.* reported that 94.5% of patients were free from sensitivity to pain for a period of time more than 12 months after CO_2 laser irradiation over stannous fluoride gel. Intra-pulpal pressure was evaluated before and after treatment; consequently, no significant changes were observed. In the conducted experiment, however, thermal change was not assessed[16]. They performed another study in 2006 and the competence of 0.5W CO_2 laser in desensitization of dentin was validated again[17]. Furthermore, White *et al.* described that intra-pulpal temperature increased as a function of power, frequency and time; on the contrary, it showed a decrease as remaining dentin thickness increased[18].

In 2007, Gholami et al. evaluated and compared the occluding effects of 4 types of lasers on dentinal tubules by LM and SEM in-vitro study. The results showed Nd;YAG, Er:Cr;YSGG and CO_2 were successful in sealing dentinal tubules and decreasing hypersensitivity[19]. Historically, intra-pulpal tissue damage caused by temperature rise has been based primarily on the in-vivo work of Zach and Cohen[16]. They described the demonstrable but reversible pulpal changes with temperature increases of 3.3°C. As temperature increased to 5.5°C, loss of vitality in 15% of teeth was seen. Therefore, in this study 5.5°C is considered as the safety threshold level and the highest temperature limit biologically accepted to avoid pulpal damage.

It is considerable that laser irradiation may increase pulpal temperature above the safety threshold and cause damage[20-22], therefore the aim of this study is to evaluate temperature increase in dentinal thickness which may cause damage under clinical conditions.

There are several studies on the effect of the high power lasers; however our effort is to detect the thermal effects of these lasers with the parameters used in this study.

MATERIAL & METHODS

Specimen preparation

Twenty extracted human third molars were scaled to remove all surface debris from the roots. The samples with caries, restoration or fracture were excluded. For a period of 24 hours, all the samples were stored in distilled water containing 0.1% thymol to inhibit microbial growth. Then each tooth was mounted on self-cure acrylic blocks (Triplex cold, Ivoclar-vivadent, Liechtenstein) according to long axis. While hydrated, dentin slices longitudinally were cut to the size of 1 and 2 mm thickness from buccal and lingual regions by means of a Ground-Section Sutures (Accustom-50, Denmark), dentin slices of 1 and 2 millimeter were cut from each tooth to obtain a total of 40 specimens. The laser treating areas with the dimension of 2×2 millimeter (measuring by a caliper) were prepared on dentinal surface of each disc by means of a high-speed hand piece with air water coolant and a knife-edge diamond bur. The prepared specimen were then stored in isotonic normal saline solution until the time for laser irradiation (less than a week).

Laser Specifications

In this study Waterlase (Biolase, USA) and Lancet-2 (Lancet, Russia) equipments were employed for Er,Cr:YSGG and CO_2 lasers respectively. According to our previous experiment[19], the parameters of laser irradiation for each individual laser type were set as the following:

Er,Cr:YSGG:

Power: 0.25 W
Irradiation mode: Free-running pulse mode
Pulse energy: 12.50 mili-joules
Water percentage: 0%
Air percentage: 34%
Pulse width: 140 microseconds
Duration: 10 seconds
Fiber tip: G6
Distance to target: 0.5 cm

CO_2:

Power: 50 W
Irradiation mode: Ultra-pulse
Pulse width: 100 microseconds
Spot size: 0.5 mm
Duration: 5 seconds
Distance to target: 1.5 cm

Each pre-specified area on dentin disc was randomly exposed to both lasers in a scanning mode (Mesiodistal and Cronoapical movement of light as it shown in Figure 1) and the whole procedure was done by one qualified clinician. After irradiation, the exposed area was marked.

Temperature evaluation

The dentin discs were fixed by a retainer while the sensor (K-type thermocouple) was connected to one side and the laser irradiation was being performed on the other side. A digital thermometer (KJT thermometer, AZ, Taiwan, Model 8851) was employed to measure the output temperature of the thermocouple. This thermometer is capable of logging the data into a laptop through the serial port (RS-232) and using a data logger provided in the package. For each sample, during laser irradiation and after that, this device evaluated and recorded the temperature changes into two formats: a final graph was produced based on the logged information (X-axis stands for time and Y-axis for temperature) as well as a text file containing temperature/date/time [h/min/s] information. Data was collected in a time zone starting 20 seconds prior to irradiation until 20 seconds after the time scanning of the test area had been completed "Figure 2". This consideration ensured that the temperature returned to the initial levels as it was before the irradiation. Afterwards, the collected data was coded and saved in the corresponding folder regarding each group. Another ability of the provided software was to perform statics. The maximum and minimum temperature and also the mean and standard deviation (SD) of each sample were determined in a columnar graph. Thermocouple was connected to dentin disc at the opposite side of laser irradiation site using a heat-conductive gel to make a more uniform heat transfer on the dentin surface under test.

To evaluate and confirm the maximum temperature change after irradiation, a laser

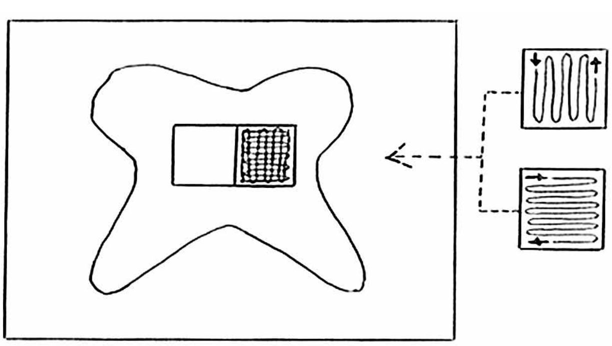

Figure 1. Scanning movement of laser light (RED: Crono-Apical movement, Blue: Mesio-Distal movement) in order to cover the entire dentin surface without missing any point.

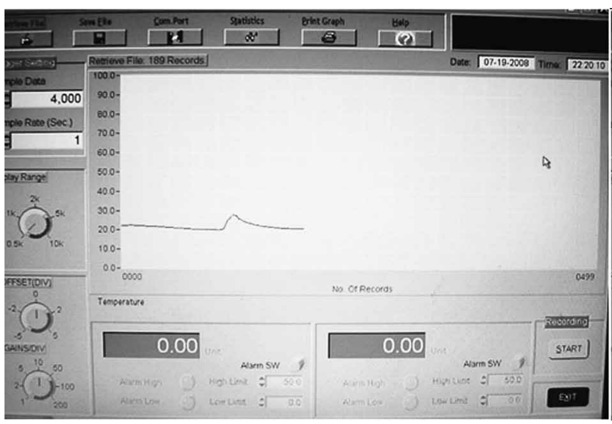

Figure 2. For each sample, during laser irradiation and after that, the software (RS-232) evaluated and recorded the temperature changes into two formats: a final graph was produced based on the logged information (X-axis stands for time and Y-axis for temperature) as well as text file containing temperature/date/time [h/min/s] information. The peak temperature rise and the duration of cooling down process were accurately recorded for each sample.

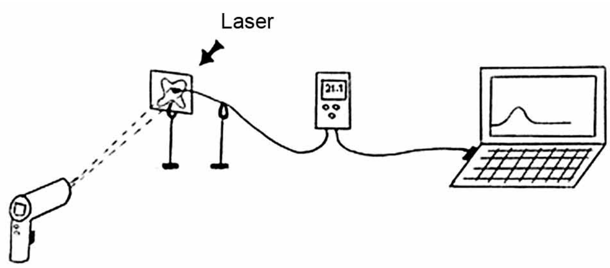

Figure 3. A retainer fixed dentin disc while the sensor (K-type thermometer) was connected to one side and the laser irradiation was being performed on the other side. A digital thermometer was employed to measure the output temperature of the thermocouple. This thermometer is capable of logging the data into a laptop through the serial port RS-232.
Laser targeting infrared thermometer was fixed 40 mm far from the dentin disc in order to totally cover the area of laser irradiation.

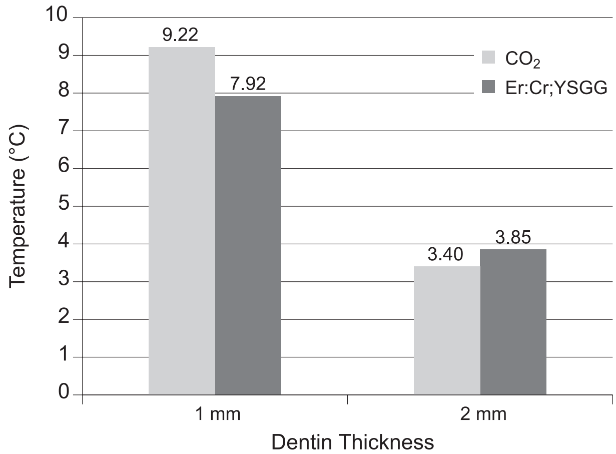

Figure 4. Mean value of temperature rise consistent with dentin thickness.

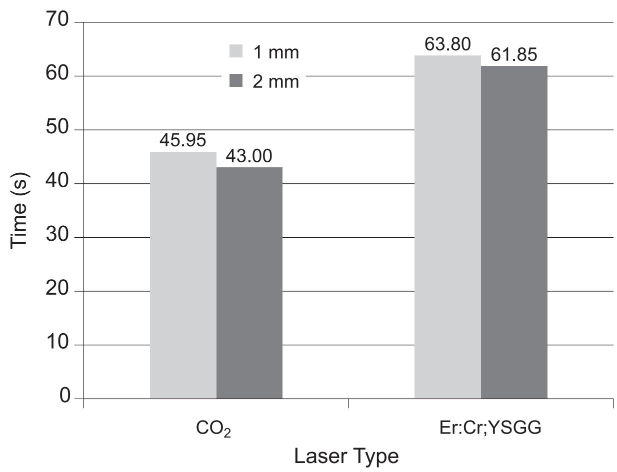

Figure 5. Mean value of cooling time consistent with the laser type.

targeting infrared thermometer (Model 888, AZ, Taiwan) was employed in this study as well. Distance/spot ratio of the device was 10/1 mm and since the coverage area for each laser in our study was 4 mm², the meter was fixed 40 mm far from the dentin slice. For this setting, the opposite surface of the area under irradiation was totally covered by the target point of the meter "Figure 3". Data were normally distributed as Kolmogorov-Smirnov a test revealed and group variances were homogeneous as Levene's test indicated. Moreover, two-way ANOVA test was performed to examine the effect of laser's type and dentin thickness on temperature rise and cooling time of the dentin surface.

RESULTS

1) Effect of Dentin thickness and type of laser on temperature rise

According to figure.1 temperature rise during each laser irradiation was significantly affected by dentin thickness ($P<0.001$). On the contrary, the type of laser did not have an important effect ($P=0.355$) and Temperature rise in 1 mm dentin thickness was higher in both lasers irradiation. "Figure 4"

2) Effect of Dentin thickness and Type of laser on cooling time duration after irradiation

Two-way ANOVA test was performed in this assessment. Statistically speaking, type of laser was effective on the duration dentin discs needed to cool down and reach the stable temperature ($P<0.001$). However, dentin thickness did not make a considerable effect on this process ($P=0.401$). "Figure 5"

DISCUSSION

Many scientific researchers have approved the fact that the exposed dentinal tubules may result in dentinal hypersensitivity[23-24]. Furthermore, by using scanning electron microscope, it has been approved that the number of exposed dentinal tubules in sensitive tooth increases dramatically[11]. The average value for the diameter of the dentinal tubules is significantly higher than the value for the tooth of the control group[25]. Various methods have been previously presented to treat dentinal hypersensitivity; it may be the obstruction or decrease in the diameter of the dentinal tubules and consequently the limitation of their exposure to oral cavity, or it may be the deduction of actuation threshold of neurons by limiting their activity using active ions. These remedies may be implemented by dentists or by patients themselves. While crystal salt, varnishes, and sealants get washed as time passes, laser treatment may be proposed as a reliable and effective solution in this domain[11]. Numerous in-vitro and in-vivo studies have proved the application of different lasers to seal dentinal tubules; each laser source due to the inherent differences in several parameters like laser source, power, frequency, duration, and the mode of irradiation can end in different results[12]. Laser Nd;YAG is the first laser used by Matsumoto et al. in 1985 to treat the increase of dentinal sensitivity[26]. Since then, many experiments have been arranged to check the application and influence of different lasers such as Er:Cr;YSGG, CO_2, Nd:YAG, and Diode to treat dentinal hypersensitivity[19].

Based on the study conducted by Gholami *et al*. Nd;YAG, CO_2 and Er:Cr;YSGG lasers, set with similar parameters as presented in this study, have shown successful to seal dentinal tubules[19]. Many studies have been performed about Nd:YAG laser; furthermore, it has more superficial absorption than CO_2 and Er:Cr;YSGG; since it may cause more temperature rise in dental pulp, we selected CO_2 and Er:Cr;YSGG for our study. Er:Cr;YSGG also has more benefits in other fields such as enamel removal. It should be noticed that using laser to treat dentin hypersensitivity without considering proper control over its irradiation parameters will lead to thermal damages especially in pulp tissue[11]. According to the prevalence of tooth hypersensitivity in deep cavities and cervical area of teeth which have less dentinal thickness than others, it seems that dentin thickness is effective on pulp damage. As a result, the experiments have been conducted for two dentinal thicknesses of 1 and 2 mm; so that the results have been monitored and stored by digital and infrared thermometers. Type of laser (i.e. CO_2 or Er:Cr;YSGG) does not make any significant difference in the results ($P=0.355$), while for both types, the temperature rise for 1mm dentinal tickness has been reported expressively higher than the case for 2 mm ($P<0.001$).

The experimental results in this study support the direct relation between temperature rise due to laser irradiation and dentinal thickness reported by White *et al.* in 1994[18], Srimaneepomg *et al*. in 2002[27], and Gutkenecht *et al.* in 2005[28].

In current study, the average temperature rise for 1 mm dentinal thickness induced by laser irradiation, has been measured 9.22°C and 7.92°C for Co_2 and Er:Cr;YSGG respectively (Table 1).

Considering the results of an in-vivo study done by Cohen and Zach on monkey tooth regarding the pulp response to external thermal actuations, the safe threshold for temperature rise in pulp has been mentioned 5.5°C[29]. In 15% of cases when the temperature goes above this value, irreversible inflammation and necrosis will be resulted; also, if the temperature rise exceeds 11°C, in 60% of cases, irreversible pulpitis will be expected. Based on the above mentioned facts, the average temperature rise in 1 mm of dentinal thickness, for both types of lasers set by the parameters listed in this study, is higher than the safe threshold tolerable for pulp (i.e. 5.5°C).

As Moritz *et al.* reported a success percentage of 94.5% - 96.5% for adopting 0.5 W CO_2 laser in continuous mode, to treat dentinal hypersensitivity without any side effects[16], a pilot study with the same parameters was conducted in our research. It was observed that the irradiation of a CO_2 laser results in high level of carbonization in dentinal tissue and the temperature rise could be as high as 20°C. To avoid these side effects, the irradiation mode was changed to pulse mode. To justify the difference in the results, the use of stannous fluoride gel on sensitive area before laser irradiation and also the blood circulation in pulp chamber in

Table 1. Temperature rise evaluation according to dentin thickness and type of the laser

Laser	Dentin thickness(mm)	Quantity of samples	Mean value (ºC)	Standard deviation	Min-Max
CO_2	1	20	9.22	0.45	8.31 - 10.12
CO_2	2	20	3.40	0.45	2.50 - 4.30
Er:Cr;YSGG	1	20	7.92	0.45	7.01 - 8.82
Er:Cr;YSGG	2	20	3.86	0.45	2.95 - 4.76

Moritz's study may be considered as the main reasons; however, it needs long term evaluation for better justifications. On the other hand, it was an in-vitro study and in biological situation this tolerable threshold for the pulp may be increased because of blood circulation.

Based on the results, although the rise of temperature occurs on the dentin surface, a small portion of it will be transferred to pulp. This phenomenon is due to high absorption of laser energy/light in superficial layers of hard dental tissues and low level of its penetrations(11). This fact has been mentioned in the reports presented by Melcer *et al.* They have reported the usage of CO_2 laser, 3W and in continuous mode, to treat the tooth of monkeys and dogs without any damage to pulp(14). However, long-term follow up is necessary to evaluate the side effects precisely.

The experimental results in this study approved that the time needed for the dentin to cool down to its initial value was highly dependent on the laser type ($P<0.001$), while it was somehow the same for different thicknesses ($P=0.401$) (Table 2).

The average cool down time was measured less than 1 minute (44.47 S) for CO_2 laser and a little more than 1 minute (62.82 S) for Er:Cr;YSGG laser. This difference can be justified because of the difference in irradiation time. The irradiation time for laser Er:Cr;YSGG is set to 10 seconds, two times as much as the time for laser CO_2. By this setting, average temperature rise caused by this laser for 1 mm thickness of dentin was measured 7.92°C; while this value for CO_2 laser is as high as 9.22°C. By decreasing the irradiation time for Er:Cr;YSGG laser to 5 seconds, average temperature rise may be halved and even for the case of 1mm it may be safer and less than the damage threshold of pulp. However, some points may not be scanned because of the short time of irradiation. As a practical remedy, to achieve better results, the irradiation can be applied in two periods of 5 seconds with a rest interval of 1 minute.

Considering the fact that average temperature rise for 1mm thickness (8.57°C), regardless of laser type is more than the case for 2 mm (3.63°C) and it is also more than the damage threshold tolerable for the pulp (5.5°C), as well as the fact that residual dentin thickness has no effect on the time that dentin needs to cool down, to decide which sensitive tooth is proper to be treated by laser, the dentin thickness is a main factor to consider. Consequently, the operator's clinical experience estimates the residual dentin thickness, as long as several other factors like Attrition, Abrasion, and Erosion on root surface and also sets the irradiation parameters afterwards. Although, it should be noticed that blood and Lymph circulation in vital pulp tissue will distribute the heat and does not let it concentrate in one single point. This fact may result in less temperature rise in vital pulp tissue. According to the time needed for dentinal discs to cool down, while the parameters for laser irradiation are set as mentioned in this study, one minute as resting interval is recommended between every two successive laser irradiation cycle lasting more than 5 second. Due to technical sensitivity of Co_2 laser and the fact that any minor distance fluctuation between the irradiation source and the target tissue may result in Carbonization, adopting Er:Cr;YSGG laser will be more user-friendly and economical to implement in order to treat dentin hypersensitivity. It is worth reminding, this alternative has more advantages to remove hard and soft tissues comparing with other procedures.

CONCLUSIONS

Major conclusions that can be drawn from this in-vitro experimental study are as follows. The temperature increase induced by the irradiation of laser Er:Cr;YSGG, and CO_2, as characterized in this study, will be more than the breakdown tolerance of pulp and it may cause pulp damage providing the thickness of dentin is 1 mm or less. On the other hand, if the dentin thickness is 2 mm or more, the temperature rise will be less than the

Table 2. Cooling time evaluation according to dentin thickness and type of laser

Laser	Dentin thickness(mm)	Quantity of samples	Mean value (Sec)	Standard deviation	Min-Max
CO_2	1	20	45.95	2.90	40.16 - 51.73
CO_2	2	20	43.00	2.90	37.21 - 48.78
Er:Cr;YSGG	1	20	63.80	2.90	58.01 - 69.58
Er:Cr;YSGG	2	20	61.85	2.90	56.06 - 67.63

breakdown tolerance of dental pulp and it does not cause any conflict or damage for the tissue.

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