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Original Article

Temperature Limits during Irradiation in Laser-Assisted Treatment of Peri-Implantitis – Laboratory Research

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Abstract

Introduction: Peri-implantitis is a relatively new and difficult disease that is becoming more common. Of the different therapeutic options to manage this condition, lasers show certain advantages over other therapeutic alternatives because of their antibacterial potential.

Aim: The aim of the present study was to investigate the temperature rise of implant surfaces, soft tissues, and bone during irradiation with diode, CO_2, and Er:YAG lasers.

Materials and methods: Ten implants inserted in biological models were irradiated with three laser systems with different parameters: a diode laser (980 nm) with power levels of 0.75 W and 1.6 W; a CO_2 laser (10600 nm) with power levels of 252 W and 241 W; and an Er:YAG laser (2940 nm) with power levels of 1.5 W, 6.8 W, and 7.5 W. The temperature rise was measured using a specially designed thermal probe (type K thermocouple) with accuracy of ±0.1°C over the range from 20°C to 80°C. The temperature was measured at 5 points – in the implant body, in the mucosa, in the middle part of the implant, in the implant apex, and in the bone around the implant apex. Measurements were obtained at 1 minute working interval.

Results: Diode and CO_2 lasers with both parameters used increased significantly the temperature of more than 46°C, whereas the temperature in the Er:YAG laser group was less than 30°C. There was a statistically significant difference between diode, CO_2, and Er:YAG lasers in favor of the erbium laser.

Conclusions: The Er:YAG laser demonstrates the best thermal properties during irradiation of the implant surface. The three working modes tested – 1.5 W, 6.8 W, and 7.5 W – provide safe intervention on both the soft and bone tissues of the implant interface and on the implant itself.

Keywords

CO_2 laser, diode laser, Er:YAG laser, peri-implantitis, thermal changes, temperature

INTRODUCTION

According to the last Consensus report on the Classification of Periodontal and Peri-Implant Diseases and Conditions, peri-implantitis is "a plaque-associated pathological condition occurring in tissues around dental implants, characterized by inflammation in the peri-implant mucosa and subsequent progressive loss of supporting bone". This condition is not characterized by specific microorganisms and successfully treated by anti-infective methods.[1]

Laser therapy is a modern treatment technique that can be used effectively in addition to conventional mechanical methods for disinfection in peri-implantitis. Various lasers demonstrate antibacterial action against periodontal pathogens which are found to be similar in a peri-implant infection.[2,3] Therefore, lasers, due to their bactericidal action and excellent tissue ablation, are considered as some of the most promising devices to reduce failure rates in dental implantology.[4,5]

Romanos et al. report that ablation of the implant surface with CO_2 laser in continuous mode, power levels of 2–4 W, and noncontact defocused handpiece leads to decontamination of the implant surface and hence effective treatment of the peri-implantitis.[6] Although there is no clinical significance in using diode lasers as an adjunct to peri-implantitis therapy, there are a lot of studies discussing this treatment modality.[7,8] Another laser used very often in the peri-implant therapy is the Er:YAG laser. Takasaki et al. demonstrate that this laser provides effective and safe debridement of the implant surface.[9]

However, laser ablation is a thermal process that could cause an excessive temperature rise in the target and surrounded tissues.[10] Clinicians have to know laser tissue interactions and choose the correct wavelength according to their treatment needs. Heat generation is an important factor for osseointegration and implant survival. Temperature rise over 47°C may cause tissue trauma and further implant loss.[11] Many researchers have tried to measure the heat produced during radiation using devices such as thermocouples and thermal cameras. The cells subjected to a higher temperature have a reduced mineralization capacity. Also, thermocouples are defined as the ideal device for measuring heat during osteotomy in the preparation of the implant site.[12]

However, there is a need to reach a consensus on the standardization of laser-related parameters that could lead to the most favorable results with regard to peri-implant anti-infective therapy.[13]

AIM

Therefore, the purpose of the present study was to determine the temperature changes in and around implants during laser irradiation with Er:YAG, CO_2, and diode lasers by means of integrated digital systems with thermocouples.

MATERIAL AND METHODS

Ten titanium DFI implants, size L 13 mm, D 3.75 mm (Alpha Bio Tec®, Israel) are used in the study. They are placed in biological models – pig jaws, prepared for the needs of the study in a licensed slicing factory (**Fig. 1**).

The thermostatic system, as well as the thermosensor, is created for the purpose of this study by Prof. Plamen Zagorchev, Department of Medical Physics, Biophysics and Maths, Faculty of Pharmacy, Medical University of Plovdiv, Bulgaria. The interface dual-channel laboratory data processing system operates with a 13-bit analog-digital converter programmed for parallel communication with a personal computer and ensures temperature tracking with an accuracy of ±0.0250°C. The sampling interval is 500 ms. Data obtained from the collection and averaging of 800 measurements are submitted to the parallel port of the computer for this interval.

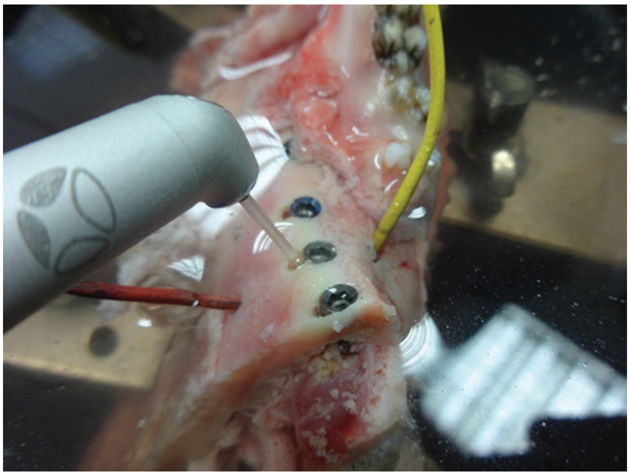

Figure 1. Implants placed in a biological model – a pig jaw.

Control of the temperatures indicated on the computer display is carried out before each measurement and a calibrated Hart 1522 Handheld Standards Thermometers from Hart Scientific Utah, USA, bought with Steinhart-Hart semiconductor thermosensor thermistor polynomial YSI 400, certified with an accuracy of ±0.005°C for the range from 0°C to 50°C.

The system provides the possibility of real-time graphical monitoring of temperature changes in the implant and surrounding tissues, as well as archiving, subsequent data processing, and determination of important thermodynamic parameters.

The samples are placed in a cylindrical microprocessor-controlled ultra-thermostat filled with distilled water at a temperature of 32.50°C±0.05°C, which is stirred intensively during the experiment.

Temperature measurements are carried out with a Fluke 16 digital thermometer (Thermometer, Fluke corporation, USA) stacked with a specially made thermosensor (Type K thermocouples) with an accuracy of ±0.1°C for the range from 20°C to 80°C. The time to establish thermodynamic equilibrium is only 200 ms because of the extremely small mass of the sensor (<5 mg). As a result, the exact temperature reading of each second (per 1000 ms) is achieved.

The thermometer is placed at different points on the surface and inside of the implant body as well as in the soft tissue and bone part of the implant interface as follows:

In – the temperature sensor is inserted into the opening of the implant body;

Middle – the temperature sensor is inserted through an opening in the jaw, made with round bur No 14, to the middle part of the implant;

Mucosa – the thermosensor is placed in the mucosa of implant interface;

Apex – the thermosensor is placed at the implant apex through a hole in the bone;

Bone apex – the thermosensor is inserted into the bone around the implant apex.

For irradiation of the cervical part of the implant surface, we used three types of lasers with different parameters as described below:

1. Er:YAG laser – 2940 nm (Lite TouchTM, Light Instruments, Yokneam, Israel) is used in the study with the following factory preset parameters:
   - Bone remodeling (BR) – power 7.5 W; energy 300 mJ; frequency 25 Hz;
   - Granulation tissue ablation (GTA) – power 6.8 W; energy 400 mJ; frequency 17 Hz;
   - Periodontal pocket debridement (PPD) – power 1.5 W; energy 50 mJ; frequency 30 Hz.
2. CO_2 laser (DS_40UB, Daeshin Enterprise, Seoul, Korea) with a wavelength of 10 600 nm and the following factory preset parameters:
   - Pocket sterilization (PS) – power output 241 W; pulse duration (PD) = 300 µs, relaxation time (RT) = 20 ms;
   - Implant second surgery (ISS) – 252 W; pulse duration (PD) = 200 µs; relaxation time (RT) = 5 ms.
3. Diode laser (LITEMEDICS, Milano, Italy) with a wavelength of 980 nm and two modes of factory settings:
   - Periodontics – power 0.75 W; peak power 2.5 W; frequency 10 Hz;
   - Surgery low – power 1.60 W; peak power 5.0 W; frequency 700 Hz.

The results are processed and analyzed by the Kruskal-Wallis method. The values are exported to determine a statistically significant difference between the dimensions in the groups at a level of significance <0.05.

RESULTS

Results from the study are presented in **Figs 2–6**. **Fig. 2** demonstrates temperature changes in the implant body during laser irradiation. Diode and CO_2 lasers with both parameters used lead to a significant increase of the temperature of more than 46°C, whereas the temperature in the Er:YAG laser groups is less than 30°C.

When measured in the middle part of the implant through a hole in the bone, high temperatures were registered in the diode laser groups – more than 44°C using 0.75 W power and more than 60°C using 1.6 W power. In the CO_2 laser groups, the temperature was less than 38°C and in the Er:YAG laser group – less than 32°C **(Fig. 3)**.

The temperatures we measured in the mucosa of the implant interface were similar to those in the middle part of the implant – in the diode laser groups they were the highest (44.3±1.41°C for 0.75 W and 59.9±1.15°C for 1.6 W), in the CO_2 laser groups they were less than 38°C and in the Er:YAG laser groups they were the lowest (30.29±0.82°C for 1.5W, 31.5±0.97°C for 6.8 W and 30.1±0.88°C for 7.5 W) **(Fig. 4)**.

In the apical part of the implant body, the temperatures reached at 1 minute are shown in **Fig. 5**. In the diode and CO_2 laser groups, the temperature was more than 38°C whereas in the Er:YAG laser groups it was less than 32°C. The highest temperatures were measured at irradiation with the 1.6 W diode laser (51±1.05°C) and with the 252 W CO_2 laser (45.5±1.08°C).

The temperature found in the bone around the apex of the implant body was less than 47°C in all treatment groups. However, in the diode and CO_2 laser groups, it was more than 36°C whereas in the Er:YAG laser groups it was less than 32°C.

The data for the temperature amplitudes in all treatment groups are shown graphically in **Fig. 7**.

The statistical significance for the Er:YAG laser is presented in **Table 1**. There is a statistically significant difference for all tested sites between the Er:YAG laser and the diode and CO_2 lasers in favor of the Er:YAG laser. For all significant differences found in the study, please, contact the authors.

DISCUSSION

The main laser-material (tissue) interactions are reflection, transmission, absorption, and scattering. The interaction between laser light and metal surfaces is determined mainly by the degree of absorption and reflection. Each metal has a certain ability to reflect, which depends on the specific wavelength of the laser. The reflection coefficient of titanium when irradiated with the Er:YAG laser is around 70% and for the CO_2 laser it is as high as 96%.[14]

Absorbed energy leads to frequency-dependent processes of fluorescence, photothermic, and thermal effects. Due to the extremely poorly represented transmission and depth absorption, it focuses primarily on the reflection capacity of the titanium implant. It seems very important for the observed thermal effects and explains at first glance the weak absorption of infrared (thermal) laser radiation both in the volume of the implant and in its adjacent tissue (Nachkov et al., 2018). Measuring the thermal effects during laser exposure in therapeutic procedures in the maxilla-facial region is a key point for the result and prognosis of the treatment in the long term.

The basic methods for determining temperature changes in biological tissues are either through an infrared thermal chamber or through a thermometric system with thermocouples. Generally, the thermocouple is more strongly influenced by the surrounding factors and must be fully immersed and in appropriate contact with the environment in which the temperature is measured. In the present study, we conduct that the experiment closely resembles the real conditions in the oral cavity due to its tempering to the physiological temperature.

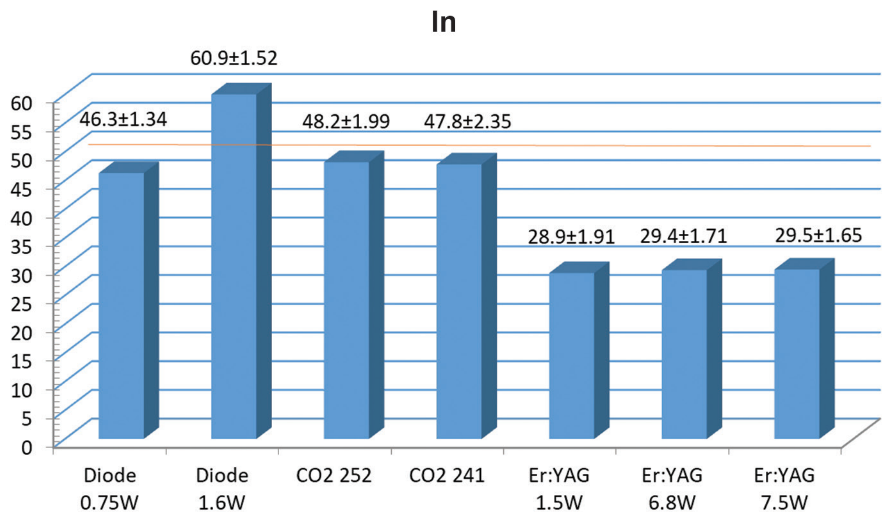

Figure 2. Mean values of the temperature (in °C) in the implant body during irradiation with all tested lasers and parameters.

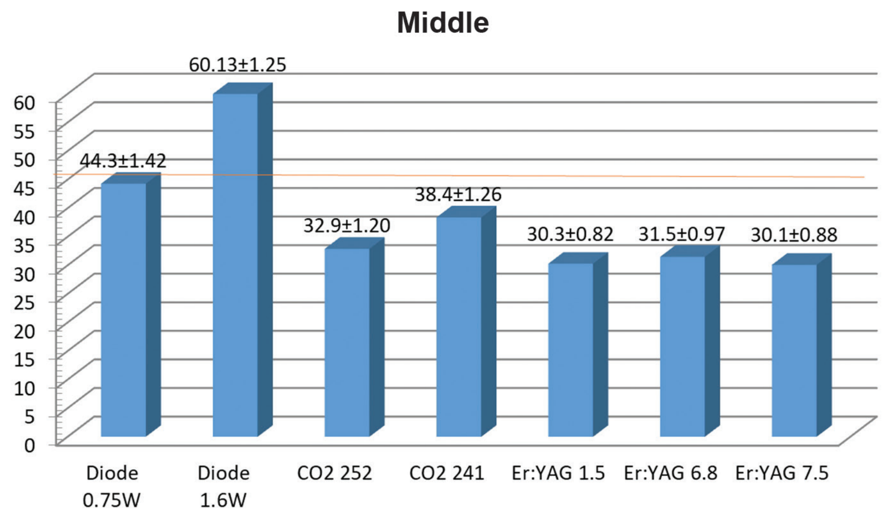

Figure 3. Mean values of the temperature (in °C) in the middle part of the implant body, tested through a bone hole, during irradiation with all tested lasers and parameters. The red line is at 47°C.

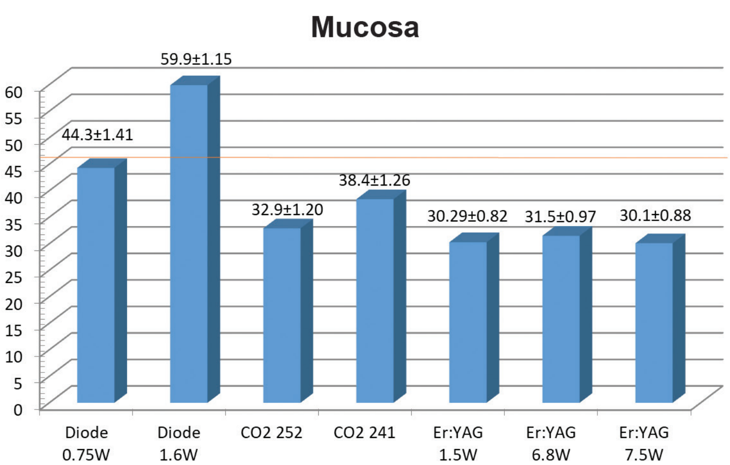

Figure 4. Mean values of the temperature (in °C) in the mucosa during irradiation with all tested lasers and parameters. The red line is at 47°C.

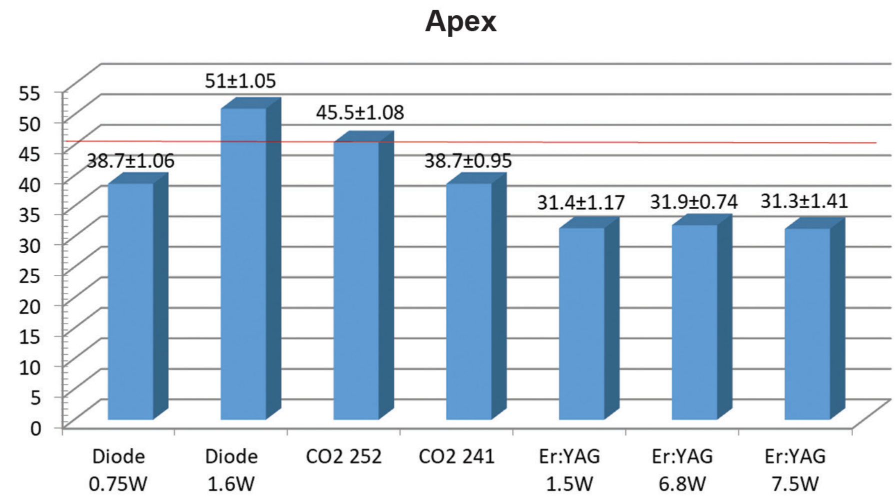

Figure 5. Mean values of the temperature (in °C) in the apex of the implant body, tested through bone hole, during irradiation with all tested lasers and parameters. The red line is at 47°C.

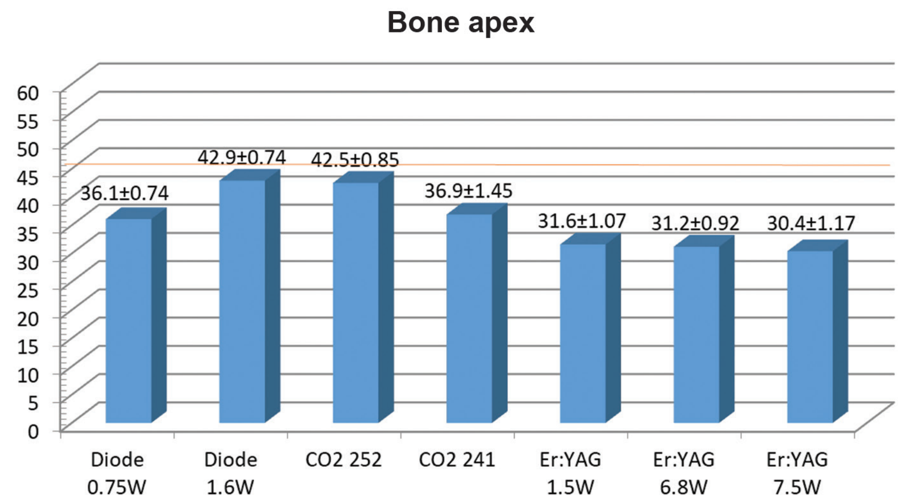

Figure 6. Mean values of the temperature (in °C) in the bone around the apex of the implant body during irradiation with all tested lasers and parameters. The red line is at 47°C.

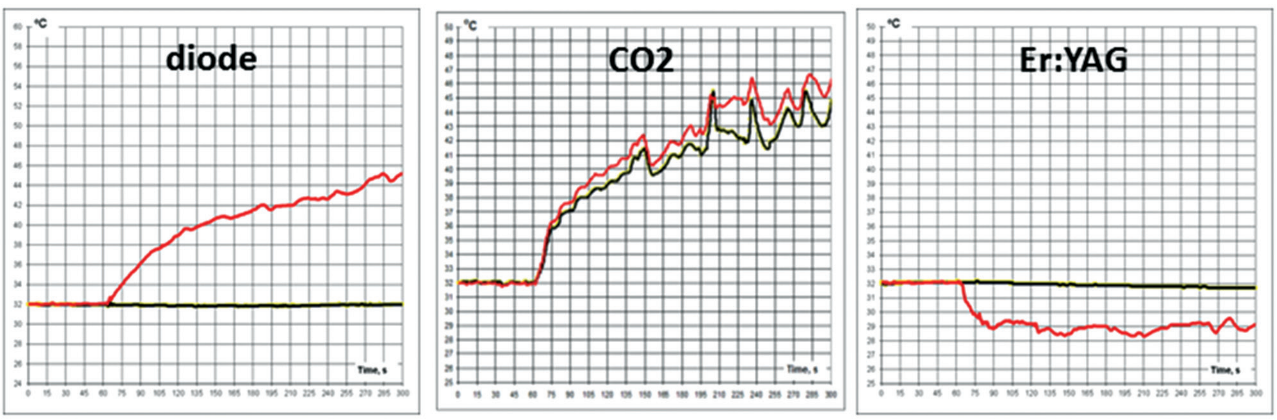

Figure 7. Summary data of the temperature amplitudes registered for diode, CO_2, and Er:YAG laser irradiation.

Table 1. Statistically significant results in the comparison between Er:YAG laser and diode and CO_2 lasers

Dunn's multiple comparison test	χ^2	*p*
In		
Diode L 0.75 W vs. Er:YAG 1.5 W	58.20	<0.001
Diode L 0.75 W vs. Er:YAG 6.8 W	54.40	<0.001
Diode L 0.75 W vs. Er:YAG 7.5 W	48.20	<0.01
Diode L 1.6 W vs. Er:YAG 1.5 W	104.6	<0.001
Diode L 1.6 W vs. Er:YAG 6.8 W	100.8	<0.001
Diode L 1.6 W vs. Er:YAG 7.5 W	94.60	<0.001
CO_2 252 W vs. Er:YAG 1.5 W	69.25	<0.001
CO_2 252 W vs. Er:YAG 6.8 W	65.45	<0.001
CO_2 252 W vs. Er:YAG 7.5 W	59.25	<0.001
CO_2 241 W vs. Er:YAG 1.5 W	66.35	<0.001
CO_2 241 W vs. Er:YAG 6.8 W	62.55	<0.001
CO_2 241 W vs. Er:YAG 7.5 W	56.35	<0.001
Middle		
Diode L 0.75 W vs. Er:YAG 1.5 W	73.50	<0.001
Diode L 0.75 W vs. Er:YAG 6.8 W	59.00	<0.001
Diode L 0.75 W vs. Er:YAG 7.5 W	79.00	<0.001
Diode L 1.6 W vs. Er:YAG 1.5 W	91.50	<0.001
Diode L 1.6 W vs. Er:YAG 6.8 W	77.00	<0.001
Diode L 1.6 W vs. Er:YAG 7.5 W	97.00	<0.001
CO_2 252 W vs. Er:YAG 7.5 W	38.50	<0.05
CO_2 241 W vs. Er:YAG 1.5 W	55.50	<0.001
CO_2 241 W vs. Er:YAG 6.8 W	41.00	<0.05
CO_2 241 W vs. Er:YAG 7.5 W	61.00	<0.001
Mucosa		
Diode L 0.75 W vs. Er:YAG 1.5 W	73.50	<0.001
Diode L 0.75 W vs. Er:YAG 6.8 W	59.00	<0.001
Diode L 0.75 W vs. Er:YAG 7.5 W	79.00	<0.001
Diode L 1.6 W vs. Er:YAG 1.5 W	91.50	<0.001
Diode L 1.6 W vs. Er:YAG 6.8 W	77.00	<0.001
Diode L 1.6 W vs. Er:YAG 7.5 W	97.00	<0.001
CO_2 252 W vs. Er:YAG 7.5 W	38.50	<0.05
CO_2 241 W vs. Er:YAG 1.5 W	55.50	<0.001
CO_2 241 W vs. Er:YAG 6.8 W	41.00	<0.05
CO_2 241 W vs. Er:YAG 7.5 W	61.00	<0.001
Apex		
Diode L 0.75 W vs. Er:YAG 1.5 W	48.25	<0.001
Diode L 0.75 W vs. Er:YAG 6.8 W	41.75	<0.05
Diode L 0.75 W vs. Er:YAG 7.5 W	47.25	<0.01
Diode L 1.6 W vs. Er:YAG 1.5 W	92.50	<0.001
Diode L 1.6 W vs. Er:YAG 6.8 W	86.00	<0.001
Diode L 1.6 W vs. Er:YAG 7.5 W	91.50	<0.001
CO_2 252 W vs. Er:YAG 1.5 W	74.50	<0.001
CO_2 252 W vs. Er:YAG 6.8 W	68.00	<0.001
CO_2 252 W vs. Er:YAG 7.5 W	73.50	<0.001

CO_2 241 W vs. Er:YAG 1.5 W	46.75	<0.01
CO_2 241 W vs. Er:YAG 6.8 W	40.25	<0.05
CO_2 241 W vs. Er:YAG 7.5 W	45.75	<0.01
Bone apex		
Diode L 0.75 W vs. Er:YAG 1.5 W	38.00	<0.05
Diode L 0.75 W vs. Er:YAG 6.8 W	39.75	<0.05
Diode L 0.75 W vs. Er:YAG 7.5 W	50.50	<0.001
Diode L 1.6 W vs. Er:YAG 1.5 W	78.00	<0.001
Diode L 1.6 W vs. Er:YAG 6.8 W	79.75	<0.001
Diode L 1.6 W vs. Er:YAG 7.5 W	90.50	<0.001
CO_2 252 W vs. Er:YAG 1.5 W	74.50	<0.001
CO_2 252 W vs. Er:YAG 6.8 W	76.25	<0.001
CO_2 252 W vs. Er:YAG 7.5 W	87.00	<0.001
CO_2 241 W vs. Er:YAG 1.5 W	42.50	<0.05
CO_2 241 W vs. Er:YAG 6.8 W	44.25	<0.01
CO_2 241 W vs. Er:YAG 7.5 W	55.00	<0.001

Only three types of lasers of the infrared range are suitable for treatment procedures in implantology: CO_2 (carbon dioxide), diode, and Er:YAG (erbium: yttrium-aluminum garnet) due to their specific interaction with the titanium implant.[15]

Currently, all data in the literature show that reaching the upper limit of 47°C at 1 minute leads to irreversible changes in the surrounding implant bone. Determination of the parameters of the temperature during prophylactic and healing procedures is of utmost importance for the creation of predictable protocols and successful results.[11]

A challenge for modern periodontology and implantology is determining the thermal effects during laser irradiation on the titanium implant body and the implant interface in laser-assisted peri-implantitis therapy.

In the present study, the diode laser (1.6 W) made the temperature increase at 1 minute above the biological threshold of 47°C in the implant body, in the middle part of the implant body, in the mucosa, and in the apex of the implant. This would have adverse consequences in clinical conditions – denaturation of proteins, necrosis of soft and hard tissues, and impaired osteointegration. In addition to the titanium implant loss, complications of a local and general nature can occur. Similar results are reported by Geminiani et al., who used the same laser wavelength (980 nm) for 1 minute irradiation time and concluded that the critical threshold of temperature rise of 10°C could be reached just for 12 sec when using the continuous mode of irradiation and for 23 sec when using the pulsed mode.[16] These results demonstrate that the diode laser does not have the appropriate wavelength for implant irradiation.

The CO_2 laser can operate contactless, in pulse mode, and under air cooling. However, it generates high temperatures in and around the implant that reach the thermal limit of 47°C. Interestingly, the temperature rise when irradiating with CO_2 laser is the highest in the implant body (more than 47°C), in the implant apex (more than 38°C), and in the bone around the implant apex (more than 37°C). In the mucosa around the implant and in the middle part of the implant body, the temperature is between 32°C and 38°C. Probably, there is an accumulation of heat along the implant body, which results in higher temperatures around the apex in comparison to the middle part of the implant and the mucosa of the implant interface. Mouhyi et al. obtained similar results.[17] They advise irradiation of wet implant surfaces because the temperature rise in these circumstances is significantly less. The time tested in their study is extremely short – only 5 seconds.

The results obtained in this thermocouple study demonstrate that the laser with the best physical-biological parameters is the Er:YAG laser. Even during a prolonged operation, this wavelength does not lead to a temperature increase in the implant interface, and in certain areas it decreases slightly (the temperature is less than 30°C in the implant body and around 31°C in the other tested sites). This phenomenon is favored by the water cooling system of the laser and the pulse mode of the beam that allows time for the thermal relaxation of tissues. A similar decrease of about 1-2°C is obtained when irradiating root surfaces with an Er:YAG laser.[18] Kreisler et al. demonstrated that using the Er:YAG laser even without water cooling did not cross the threshold of 47°C for a 120-second irradiation.[14] They used energy levels of 60, 80, 100, and 120 mJ and output temperature of 37°C. When using water cooling there was a decrease in the temperature. Our study demonstrates similar results of temperature decline after 1 minute of irradiation with 50, 300, and 400 mJ energy levels. Similar results have been reported also by other authors.[19] The Er:YAG laser appears to be safe for the surrounding bone tissue because there is no temperature rise after 1 minute of irradiation.[20]

Safe measurements during implant irradiation with Er:YAG laser determine the clinical use of this laser system during peri-implantitis. A recent systematic review of Schwarz et al. shows that the adjunctive use of laser could lead to better results in peri-implantitis therapy.[21]

CONCLUSIONS

Based on these results, we conclude that among the most effective methods that could be included in modern therapeutic protocols in the treatment of peri-implantitis is the Er:YAG laser. The three working modes described – 1.5 W, 6.8 W, and 7.5 W ensure safe intervention on both soft and bone tissues of the implant interface and on the implant itself.

Acknowledgements

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Температурные ограничения во время облучения при лазерном лечении периимплантита – лабораторные исследования

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Резюме

Введение: Периимплантит – относительно новое и сложное заболевание, которое становится всё более распространённым. Из различных терапевтических вариантов лечения этого состояния лазеры демонстрируют определённые преимущества по сравнению с другими терапевтическими альтернативами из-за их антибактериального потенциала.

Цель: Целью настоящего исследования было изучение повышения температуры поверхностей имплантатов, мягких тканей и костей при облучении диодным, CO_2- и Er:YAG-лазером.

Материалы и методы: Десять имплантатов, вставленных в биологические модели, облучали тремя лазерными системами с разными параметрами: диодным лазером (980 nm) мощностью 0.75 W и 1.6 W; CO_2-лазером (10600 nm) мощностью 252 W и 241 W; и Er:YAG-лазером (2940 nm) с уровнями мощности 1.5 W, 6.8 W и 7.5 W. Повышение температуры измеряли с помощью термодатчика специальной конструкции (термопара типа K) с точностью ±0.1°C в диапазоне от 20°C до 80°C. Температуру измеряли в 5 точках – в теле имплантата, на слизистой оболочке, в средней части имплантата, в области верхушки имплантата и в кости вокруг верхушки имплантата. Измерения проводились с рабочим интервалом в 1 минуту.

Результаты: Диодный и CO_2-лазер с обоими используемыми параметрами значительно повысили температуру более чем на 46°C, тогда как температура в группе лазеров Er:YAG была менее 30°C. Наблюдалась статистически значимая разница между диодным, CO_2- и Er:YAG-лазером в пользу эрбиевого лазера.

Заключение: Лазер Er:YAG демонстрирует наилучшие тепловые свойства при облучении поверхности имплантата. Три проверенных рабочих режима – 1.5 W, 6.8 W и 7.5 W – обеспечивают безопасное воздействие как на мягкие и костные ткани интерфейса имплантата, так и на сам имплантат.

Ключевые слова

CO_2-лазер, диодный лазер, Er:YAG-лазер, периимплантит, термические изменения, температура