The aim of this study is to assess the increase of temperature following laser irradiation with 810 nm, 980 nm, and 1064 nm diode laser wavelengths, of an implant under conditions that more closely replicate those of the human body. A 4 × 14 mm machined surface implant was placed in a porcine rib to replicate the conductivity of heat given by the bone. A peri-implant vertical defect was made that was 2 mm wide and 2 mm deep to simulate bone resorption. Two thermocouples were positioned crestally and apically on the implant surface. The tip of the laser was kept 3 mm away from the surface and continuously moved in an up-and-down and side-to-side fashion, inside the defect for 60 seconds. Initial temperatures and the time needed to reach an increase of 10°C were recorded. The experiment was repeated at room temperature and in a 37°C water bath with the following settings: 0.6 W, 0.8 W, 1 W continuous and repeated in pulsed. A critical increase of temperature of more than 10°C is reached with all lasers at 0.8 W and 1 W in continuous mode at room temperature. Only the 1064 nm diode laser reached the critical increase at 0.8 W in pulsed mode. No critical increase of temperature was registered with other settings and when the bone block was placed in a 37°C water bath. The results of this study suggest that use of these diode lasers does not cause a harmful increase in temperature when used under conditions similar to those of the human body.

Key Words: lasers, dental implants, peri-implantitis, thermodynamics

INTRODUCTION

Fifty years of documented implant practice and research in dentistry have contributed to a wide spread of implantology with an enormous number of implants placed by dental practitioners worldwide. The spread of implant dentistry has brought with it an obvious parallel spread of all the complications related to it, within which peri-implantitis is raising most of the debates in the scientific community. Nothing is clearly defined and commonly accepted, regarding its etiologic and diagnostic features and its management. To date there are different proposed treatments for peri-implantitis, from the resective to the regenerative ones, involving or not involving use of different grafts, membranes, and implantoplasty (mechanical smoothening of the implant surface). What is common among all proposed treatments for peri-implantitis is the necessity of an optimal decontamination of the affected surface that can be done using chemical, antimicrobial, and antibiotic agents, or laser. This latter has shown promising results in in vitro, animal, and human studies, used as is or with the adjunct of photosensitizer dyes (photodynamic therapy). Within all lasers available on the market, the diode laser seems to be the most versatile for its multiple applications, ease of use, relative safety, and low cost.

However, there is still not common agreement regarding safety of the laser device when used on implants. Recent in vitro studies have shown that use of certain types of laser, especially diode, can cause overheating of the implant surface, thus possibly affecting vitality of the surrounding bone when used in a clinical scenario.

The aim of this study is to assess the variation of temperature on the implant surface during irradiation with 3 diode lasers, the 810 nm, 980 nm, and the 1064 nm, used with different settings, under conditions that closely replicate those of the human body.
MATERIAL AND METHODS

A 4 mm × 11 mm (Mk III, Nobelpharma, Yorba Linda, Calif) machined implant was placed into a swine rib that was cut into a block of about 1 cm × 1 cm. An angular bony defect was created prior to implant placement with the dimensions of 2 mm width and 2 mm depth, adjacent to the implant site using a pilot drill to replicate the anatomical situation of the crestal bone resorption caused by peri-implantitis.

A lateral perforation, at the level of the implant apex, was drilled on the side of the bone block for access of the thermocouple. Two calibrated type K thermocouples (Model 710, B&K Precision Corp, Yorba Linda, Calif) were then positioned crestally (at the contact interface between the bone and the implant shoulder, at the opposite side of the irradiation), and apically, on the implant surface (Figure 1).

Three different diode lasers were used in this study: the 810 nm (2.4 G Odyssey, Ivoclar Vivadent, Amherst, NY), the 980 nm (SIROLaser, Sirona Dental Inc, Charlotte, NC), and an experimental 1064 nm (Navigator, Ivoclar Vivadent, Amherst, NY).

The study protocol was designed to closely replicate what was used in the studies from Geminiani15,17 and from Leja16 in which 1 implant was irradiated once per each different setting.

The irradiation was repeated, setting the power at 0.6 W, 0.8 W, and 1 W, first in continuous and then in pulsed mode. The implant was allowed to cool down to the initial temperature in-between 2 consecutive cycles of irradiation. The experiment was done at room temperature (22 ± 8°C) and then repeated in a 37°C water bath with the most coronal part of the sample slightly emerging from the water to replicate as close as possible the actual clinical environment for a total of 36 different irradiation modalities.

Initial and final temperatures were recorded as well as the time needed to reach a critical threshold of 10°C increase. The change in temperature was monitored until it cooled down to the initial values. Temperatures were registered at every 10-second time point to allow for a graphical representation of the heat generated over the time of irradiation. Output values were expressed as differential temperature (ΔT = final temperature – initial temperature) and expressed in °C.

RESULTS

Results of the heating test are summarized in the tables (Tables 1 and 2).

Table 1 shows the maximum temperature reached by the thermocouple under each condition. The ΔT values over the 10°C threshold are in bold; values that are in italics are those that are less than 1.5°C below the threshold.

Analyzing the results, it seems that a critical increase of temperature of more than 10°C is reached at room temperature...
only with the 810 nm laser at 0.8 W and 1 W in continuous mode, with the 980 nm laser at 0.8 W and 1 W in continuous mode, and with the 1064 nm laser at 0.8 W in both continuous and pulsed mode and 1 W only in continuous mode. The 980 nm laser reached an increase of 9.8°C at 1 W in pulsed mode and an increase of 9.6°C at 0.6 W in continuous mode both on the cervical area. These values are very close to the critical threshold. The critical temperature was never reached when the lasers were used in pulsed mode except with the 1064 nm laser when used at 0.8 W.

When the bone block was placed in a 37°C water bath, a critical increase of temperature was never registered with any setting.

The highest increase of temperature registered was 23.6°C, registered at the cervical point when the 1064 nm laser was used at 1 W in continuous mode at room temperature.

The hottest peaks of temperature always were registered, as expected, at the cervical point, which was the closest to the laser application, whereas, at the apical thermocouple, the values were in a safety range most times.

In summary, the \( \Delta T \) values ranged between 4.4°C and 10.8°C for the crestal thermocouple and 2.9°C and 12.1°C for the apical thermocouple with the 810 nm diode laser at room temperature.

When the 980 nm diode laser was used, the \( \Delta T \) values ranged between 3.5°C and 19.4°C for the crestal thermocouple.
and 5.2°C and 13.7°C for the apical thermocouple at room temperature, and between 0.9°C and 5.3°C for the crestal thermocouple and 0.2°C and 4.4°C for the apical thermocouple in the 37°C water bath.

The ΔT values ranged between 7.5°C and 23.6°C for the crestal thermocouple and 1.2°C and 5.7°C for the apical thermocouple with the 1064 nm diode laser used at room temperature, and between 2.1°C and 5.8°C for the crestal thermocouple and 0.6°C and 1.6°C for the apical thermocouple in the 37°C water bath with the same laser.

The crestal thermocouple reached the critical threshold in 51.91 seconds when the 810 nm diode laser was used at 1 W continuous at room temperature, and the apical one reached the threshold in 42.3 seconds with same laser used at 0.8 W continuous under the same conditions.

When the 980 nm laser was used at room temperature, the crestal thermocouple reached the critical temperature in 42.46 seconds when used at 0.8 W continuous and in 18.75 seconds when used at 1 W continuous, whereas the apical thermocouples reached the threshold, respectively, in 47.99 and 32.75 seconds.

The crestal thermocouple passed the critical temperature very rapidly when the 1064 nm diode laser was used at 0.8 W and 1 W in continuous, reaching the threshold in 5.99 and 7.43 seconds, respectively. When the 1064 nm diode laser was used at 0.8 W pulsed, an increase of 10°C was obtained after 31.81 seconds of irradiation.

**DISCUSSION**

In this study we tested the heating potential of 3 diode lasers, one of which is an experimental prototype not on the market used at different power and wave settings on an implant/bone interface.

Generally, the maximum temperature increases were recorded at the crestal thermocouple with the power set at 0.8 W and 1 W and in continuous wave. The time to critical threshold, when reached, was faster when the laser was used in continuous wave. The 1064 nm diode laser was the fastest with the highest temperatures reached, whereas the 810 nm, when a critical 10°C increase was achieved, was the slowest.

Carrying the experiment using the model here described was essential to investigate the heat transfer and dispersion on an implant when it is surrounded by osseous tissue. This model, to our knowledge, was used in only 3 other studies investigating laser heat transfer: Matys et al.\(^ {18}\) used pig ribs, Leja et al.\(^ {16}\) used a bovine rib, and Monzavi et al.\(^ {19}\) used a sheep mandible. All other studies used polysiloxane, resin, Plexiglas, or titanium disks.\(^ {15,17,20-22}\)

An important improvement that we added to our study

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Extended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure Time (seconds)</td>
<td>Protocol of Irradiation</td>
</tr>
<tr>
<td>10, 20, 30</td>
<td>Noncontact at 1 mm distance</td>
</tr>
<tr>
<td>20</td>
<td>In contact</td>
</tr>
<tr>
<td>60</td>
<td>Crestal noncontact at 4 mm distance</td>
</tr>
<tr>
<td>15</td>
<td>Nonspecified</td>
</tr>
<tr>
<td>60</td>
<td>Crestal noncontact at 3 mm distance (moving)</td>
</tr>
<tr>
<td>10, 20, 30, 60</td>
<td>Crestal noncontact at 1 mm distance (steady)</td>
</tr>
<tr>
<td>60</td>
<td>Crestal noncontact at 3 mm distance (steady)</td>
</tr>
</tbody>
</table>
| 60 | Crestal noncontact at 3 mm distance (steady) | Crestal and apical | Room temperature | Critical with CO\(_2\) 2 W continuous and 4 W pulsed, and with Er:YAG when irrigation was not used and slightly when used ay 250 mJ on coronal
model is the 37°C water bath to replicate the human body temperature. Only in another study in the literature was the irradiation performed while the sample was kept in this device; however, in that study, another type of laser, the Er:YAG, was used. In a different study by Matys et al,18 the sample was kept in water at 37°C but irradiated out of the water. From our experience we have observed that, when out of the water bath, the drop of temperature starts immediately, thus causing an inconstant environmental temperature during the time of irradiation.

The 10°C critical threshold of temperature increase was decided, according to Eriksson et al,23–25 based on studies that showed that an increase of more than 10°C over the body temperature could be harmful for the bone vitality.

The power settings that we chose for our experiment were 0.6 W, 0.8 W, and 1 W. Other studies use even higher wattages; however, it is not recommended to use the diode laser at power settings higher than 1 W. Pilot studies conducted in our laboratory showed that these higher wattages can cause harmful histologic changes in the tissues.26,27

The fiber optic tip was held 3 mm away from the irradiated surfaces and moved continuously over the target area. The distance was decided according to our clinical laser decontamination protocol, and the continuous movement was performed to reflect the actual clinical application. The studies present in the literature are very heterogeneous regarding the tip distance, varying from 1 mm to 4 mm and, in some cases, the tip is kept in contact with the surface. Studies performed by our group have shown that the fiber optic tip of a diode laser, kept in contact with an implant surface, will modify the surface characteristics.28 Continuous movement will help dissipating some of the heat transfer from the laser and, to our knowledge, has been performed only in one other study present in the literature.16

The studies available are generally extremely variable in terms of study model, power settings, time of application, use of the pulsed wave, mode of irradiation, and type of laser employed. The results of all these studies are also variable, ranging from different degrees of harmful increase of temperature recorded to no critical increases under any condition (Table 3).

Of the 8 studies we found, 4 applied a diode laser. The study by Matys et al18 does not report any critical increase of temperature with the 980 nm diode laser applied on the implants placed in pig ribs and wet in 37°C water; however, although the power was set to 4 W, irradiation lasted for no more than 30 seconds.

Kushima et al20 reported negative results using a 808 nm diode laser set at 1 W; however, irradiation was performed at room temperature and, most importantly, with the laser tip in contact with the surface.

In the study performed by Geminiani et al15 with a 810 nm laser, ranging from different degrees of harmful increase of temperature recorded to no critical increases under any condition (Table 3).

In conclusion, use of diode lasers with any wavelength is safe for the use on dental implant surfaces, provided that they are used with certain cautionary measures, namely a 3 mm distance from the surface, a continuous movement of the fiber optic tip over the surface, a power of maximum 1 W and, preferably, a pulsed wave mode.

REFERENCES

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