

Thermal conduction of titanium implants under CO₂ laser irradiation *in vitro*

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ABSTRACT

Objective: The surgical exposure of dental implants can be performed by means of scalpel, punch, or, with less bleeding, by means of CO₂ laser. Possible overheating of the peri-implant bone tissue should be avoided. The goal of this study was to examine the temperature changes on implants under CO₂ laser irradiation (Luxar CO₂ 20 SP laser from POLYMED, Glattbrugg, Switzerland). **Study design:** Straumann® implants were irradiated with continuous wave (cw), continuous wave with super-pulse (cw/sp), and pulsed wave (pw). The irradiation power was 4, 5, 6, 7, 8, 9, and 10 W and the irradiation times were 10, 20, 30, and 60 s. Similar temperature changes occurred in cw/sp mode and cw mode, but substantially higher temperatures appeared in pulsed wave mode. **Results:** The quickest temperature changes were observed with cw/sp irradiation (+0.5°C to +41.1°C, depending on the irradiation parameters). Beyond 20 s and 8 W irradiation, a rise exceeding 10°C on the implant surface was found. **Conclusions:** Implant diameter and length as well as the setting parameters of the CO₂ laser (irradiation power, irradiation time, and irradiation mode) are important factors to consider so that risk-free implant exposure can be accomplished. Ignoring these factors causes a risk of pathological heating of the irradiated implants and thus the surrounding tissue, which can result in the loss of an implant.

Keywords: CO₂ laser, titanium dental implant, thermal conduction

INTRODUCTION

After the incorporation phase, various techniques are used to expose submucous implants. Inserted implants can be exposed by means of scalpel, punch, or CO₂ laser.

The CO₂ laser has proved an effective tool for exposing implants.^[1] In this study, thermal stress on the surface of Straumann® implants was measured *in vitro* after CO₂ laser irradiation. The aim was to investigate which irradiation mode, irradiation time, and power is suitable for exposing implants without the critical temperature of 47°C being reached at the implant surface and in the surrounding bone tissue.

MATERIALS AND METHODS

Two implants measuring 3.3 mm/10 mm and 4.1 mm/10 mm in

diameter and length (Standard, SLA) from STRAUMANN® AG Schweiz were used. 1 mm high healing caps were screwed onto the implants.

Plexiglass test pieces (PLEXIGLAS® GS 222) from Center PLAST (Como, Italy) in the form of a cube 5 cm wide, 5 cm deep, and 4 cm tall were fabricated. Four piercing holes 1.8 mm in diameter were drilled into all four walls of the plexiglass test piece at 4 mm intervals to receive special thermocouples. This made it possible to take measurements at two different depths along the inserted implant. Point 1 was 4 mm and point 2 was 8 mm below the roof of the plexiglass test piece [Figure 1].

In addition, a central pilot hole (1.8 mm in diameter) was drilled in the middle of the plexiglass cube so that the appropriate implant could be inserted in that position. The implant was then fitted

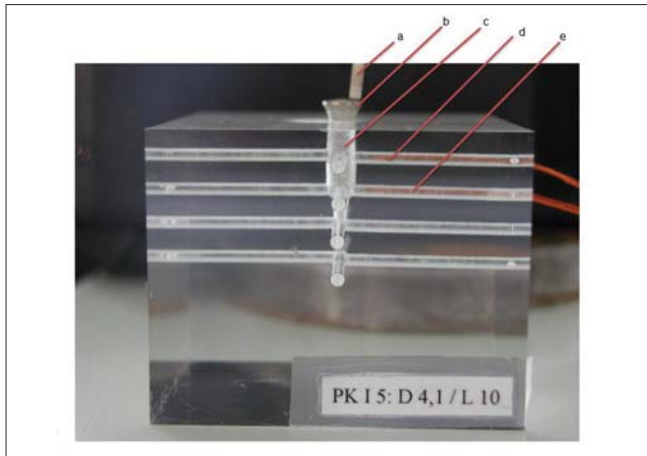


Figure 1: Straumann® implant placed in plexiglass block with thermocouples. (a) Laser cannula, (b) Straumann® implant healing cap (1 mm). (c) Straumann implant 4.1 mm/10 mm. (d) Temperature sensor at 4 mm height. (e) Temperature sensor at 8 mm height

with the healing cap. The pilot holes in the plexiglass test pieces allowed measurements to be taken at four different heights and along a particular plane at four different points on the implant surface. Thus, there was a total of eight measuring points per implant: four points at 4 mm height and four measuring points at 8 mm height of the plexiglass test piece.

Plexiglass has thermal conductivity of 0.19 W/m² K and specific heat of 1.47 J/g K. The Luxar CO₂ 20 SP laser (POLYMED, Glattdbrugg, Switzerland) was used for the study.

Type K flexible thermosensors with a diameter of 1.3 mm (Fisher Scientific AG, Wohlen, Switzerland) were used to measure temperature. These sensors have a temperature measuring capacity of -250°C to +400°C and a response time of 0.5 seconds. In addition, two Logger Digi-Sense thermometers with a measuring capacity of -40°C to +150°C and accuracy of ±0.03°C were used to record the measured results [Figure 2].

The Luxar CO₂ 20 SP laser, two temperature gauges with thermocouples, and two Straumann® implants were used in each plexiglass block for the test series.

The CO₂ laser power settings were 4, 5, 6, 7, 8, 9, and 10 W, in keeping with the clinical situation, and the healing cap firmly screwed onto the implant was irradiated with each of these power settings in the following three modes:

1. continuous wave with super-pulse irradiation (cw/sp),
2. continuous wave irradiation (cw), and
3. pulsed wave irradiation (pw)

To measure the temperature at two points on an implant simultaneously, a thermosensor was used at a 4 mm and 8 mm height. The baseline temperature was between 19.0°C (measurements taken in September) and 24.8°C (measurements taken in August). The temperature values thus corresponded to the temperature increases based on initial room temperature. The temperature was measured at 4 mm height twice per implant and the arithmetic mean was calculated from these measurements.



Figure 2: Type K flexible thermosensor

The laser cannula had a diameter of 0.8 mm and was fixed to a holder so that the same irradiation angle (10°–20°) and distance (1 mm) from laser cannula to implant healing cap could be applied. The CO₂ laser was recalibrated after each test.

The results of 84 measurements per implant were included in the statistical analysis, which gave a total of 168 data for two implants [Table I].

The statistical analysis was carried out in relation to the material (3.3 mm and 4.1 mm), the irradiation modes (cw/sp, cw, and pw), the irradiation power, and irradiation time. The level of significance was set at $P < 0.05$. Linear data were subject to multivariate analysis (linear mixed effect model) using System R (R Foundation for Statistical Computing, Vienna, Austria; www.R-project.org).

RESULTS

All the measurements revealed power-dependent temperature increases. Gradual differences emerged as a result of using the different irradiation modes. The degree of heating was always proportional to the irradiation power. The highest values were for continuous wave mode with super-pulse (cw/sp). The lowest values were recorded in pulsed wave (pw) irradiation mode.

The implants were irradiated for 10 seconds with 4, 5, 6, 7, 8, 9, and 10 W in all three operating modes (cw/sp, cw, and pw) without a temperature increase of more than +10°C taking place. The mean temperature rise in the thinner implant (3.3 mm) was roughly twice as high at 8 W as at 4 W [Figures 3 and 4]; in the thicker implant (4.1 mm), the increase at 8 W [Figure 5] was five times higher than at 4 W.

After 20 seconds, there was a temperature rise exceeding +10°C in cw/sp and cw modes above 8 W in the 3.3 mm implant. Pulsed wave mode did not produce a temperature increase exceeding +10°C [Figure 4].

For an irradiation time of 60 seconds, temperature increases of more than +10°C were recorded in the 3.3 mm implant at power levels above 4 W in cw/sp and cw modes [Figure 3]. In pulsed

Table 1: Overview of measurements in the test series

Implants	Method	Power (Watt)	Time (Sec)	Quantity
3.3 mm	CW/sp	4-10	10, 20, 30, 60	28
3.3 mm	CW	4-10	10, 20, 30, 60	28
3.3 mm	PULS	4-10	10, 20, 30, 60	28
4.1 mm	CW/sp	4-10	10, 20, 30, 60	28
4.1 mm	CW	4-10	10, 20, 30, 60	28
4.1 mm	PULS	4-10	10, 20, 30, 60	28

mode, this did not happen until power was above 8 W [Figure 4]. Temperature increases up to a maximum of +41.10°C (cw/sp) were measured for 60 seconds irradiation with 10 W.

In the case of the 4.1-mm implant, there was a temperature rise exceeding +10°C in all three irradiation modes after 60 seconds irradiation. This was achieved at powers above 4 W in cw/sp and cw irradiation modes and above 8 W in pulsed mode [Figure 5]. The highest measured temperature increase was +34.60°C (cw/sp).

Irradiations in continuous wave (cw) and continuous wave with super-pulse mode (cw/sp) followed a similar course. Pulsed mode was different in that markedly lower temperature rises were measured.

The temperature increase was lower in implants with a larger diameter than in those with a smaller diameter. Irradiation of the 3.3 mm implant by continuous wave with super-pulse (cw/sp) and continuous wave (cw) resulted in a temperature increase exceeding +10°C beyond 20 seconds irradiation time and 8 W of power [Figure 4]. The 4.1-mm implant showed a temperature rise exceeding +10°C after 20 seconds irradiation time at 10 W of power in cw/sp and cw modes. In pulsed wave mode all the increases recorded were below +10°C [Figure 5].

Figures 3 to 5 clearly show the temperature increase graphs at two points (4 mm and 8 mm) in both implants during and after irradiation in all three modes (cw/sp, cw, and pw). The higher the wattage, the steeper the temperature rise and the faster the implant heats up. The temperature increase at both measuring points follows a similar course, but the pulsed mode results in slower cooling in the lower lying sensor (8 mm) after the end of irradiation. The temperature increase is still above +10°C 120 seconds after the end of irradiation with 8 W in cw/sp and cw modes.

DISCUSSION

The thermal stress on the surface of Straumann® implants of different diameters as a result of CO₂ laser irradiation was investigated in this study. Unlike other studies, which have examined only a narrow range of different settings of the CO₂ laser, an attempt was made in this study to find laser setting parameters at which thermal stress and overheating of the implants could be reduced or ruled out. The temperature increase and heat build-up was found to differ in relation to the diameter. The measurements revealed that implant diameter, irradiation power, irradiation time, and irradiation mode are important parameters determining thermal stress caused by implant exposure by CO₂ laser.

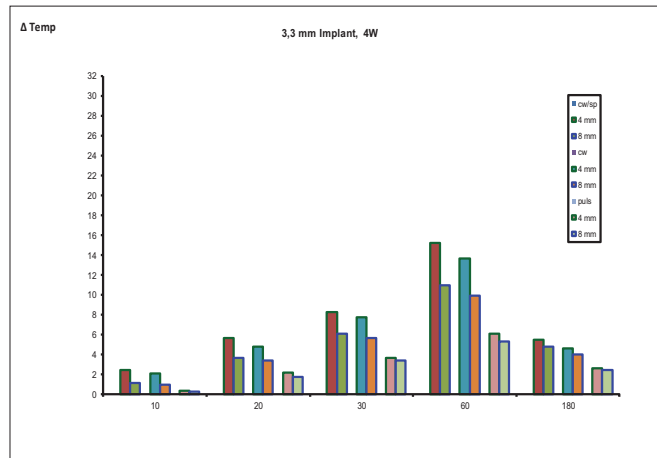


Figure 3: Temperature cooling over 120 seconds with 4 W irradiation power. Temperature graph at 4 mm (green) and 8 mm (blue) measuring point for the 3.3 mm implant after 10, 20, 30, and 60 seconds irradiation time and 120 seconds after end of irradiation in cw/sp, cw, and pw modes with 4 W irradiation power

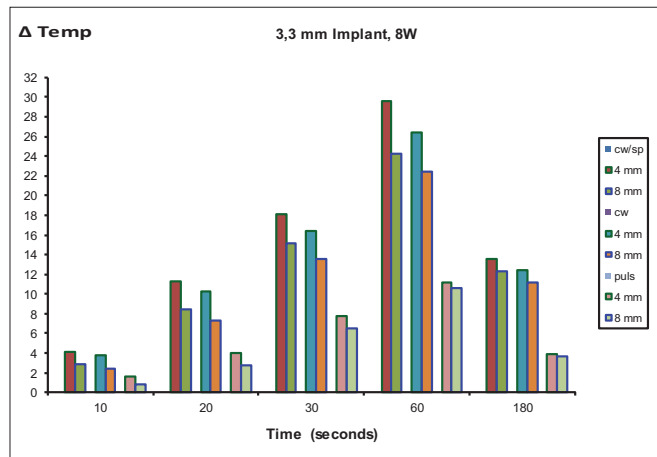


Figure 4: Temperature cooling over 120 seconds 8 W irradiation power. Temperature graph at 4 mm (green) and 8 mm (blue) measuring point for the 3.3 mm implant in cw/sp, cw, and pw modes after 10, 20, 30, and 60 seconds irradiation time and 120 seconds after end of irradiation with 8 W irradiation power

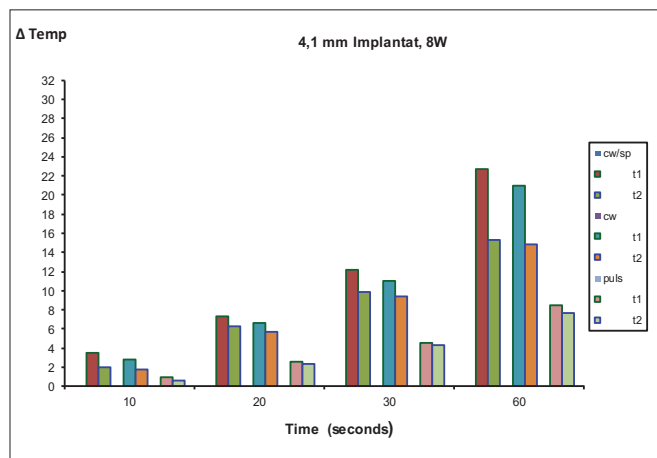


Figure 5: Temperature cooling over 120 seconds 8 W irradiation power. Temperature increase in the 4.1 mm implant in cw/sp, cw, and pw modes after 10, 20, 30, and 60 seconds irradiation time and 8W irradiation power

The temperature increases were higher in smaller diameter implants than in larger diameter implants. The consequences of the continuous wave irradiation mode with or without super-pulse were similar. The implants heated up more quickly and to a greater extent when irradiated with super-pulse.

In pulsed wave mode, the temperature increase in the implants was so small that a critical level (+10° C) was only reached with high irradiation power (above 8 W) or a long irradiation time (60 seconds).

Temperatures above 47°C on the bone tissue lead to coagulation and denaturation of collagen and bone proteins and to impairment of osteoneogenesis.^[2] This is why in this study +10°C was chosen as the critical temperature increase in implants (body temperature 37°C). In cw/sp and cw modes, a temperature rise of more than +10°C occurred in the 3.3-mm implant irradiated with 8 W for 20 seconds. When the irradiation time increased, the critical level was reached with 4 W in cw/sp and cw modes.

Cooling of the implants follows a different course, depending on the irradiation mode. The quickest cooling was recorded after irradiation in cw/sp mode, followed by cw and pulsed modes. The higher the irradiation power, the faster the cooling. Measurements at two different heights (4 mm and 8 mm) of the implant surface revealed differences. Cooling was slower apically than coronally.

It should be noted that the maximum temperature increase reached at the end of irradiation was higher in cw/sp than in cw mode, which in turn produced larger temperature increases than pulsed mode.

The reason for the slower cooling with pulsed mode presumably lay in the accumulation of energy, arising from the summation of impulses during pulsed irradiation.

Comparable to von Wooten *et al.*, we also found in our measurements that the temperature increase at the implant surface is directly linked to the exposure time and irradiation power, as is the temperature increase in cw/sp and cw modes.^[3] However, the course and maximum temperature levels reached were different in pulsed and cw/sp modes. The effect of the CO₂ laser on implants is not hazardous: the CO₂ laser beam can cause fusion at the implant surface^[4,5] or heat build-up.^[3,6-13]

95% of the energy of the laser beam was absorbed by the peri-implant tissue and converted into heat.^[8] It is therefore safe to apply the CO₂ laser to dental implants at an irradiation power of less than 4 W in cw mode, 8 W in pulsed mode (0.05 seconds), and for an exposure time of less than 4 seconds.^[8]

It became clear in our study that, depending on implant type, a temperature exceeding +10° C could only be measured in pulsed mode when irradiation power was above 8 W and irradiation time over 60 seconds.

This critical level was reached with the continuous wave and continuous wave with super-pulse irradiation modes on laser settings of 8 W and 20 seconds. Irradiation of different diameters resulted in different temperature increases. Hence, the irradiation

parameters need to be adapted to the implants to be exposed.

The thermal conductivity of titanium is 21.9 W/mK.^[5] As in several other studies,^[3,5-13] we also found that titanium conducts the heat and that the effect of the CO₂ laser on dental implants correlates with local heat build-up and temperature increase, which vary depending on the setting of the irradiation parameters. The thermal conductivity of the plexiglass used in our study, at 0.19 W/mK, is far lower than that of titanium (21.9 W/mK). Thus, the temperature increase recorded at both measuring points after implant irradiation is mainly conducted by the implant.

A small gap in the micron range forms between healing cap and implant, depending on the torque applied at closure.^[14,15] The size of the microgap has little relevance because thermal conduction of the fluid, cell remnants, and micro-organisms contained in the gap also needs to be taken into account. Scanning electron microscopic images of a longitudinal section of the implant with healing cap should be taken in order to locate the gap accurately. It is possible that a small amount of heat may be insulated by this minimal gap in terms of thermal conduction and result in a slight decrease in the measured value, but this is of even less clinical relevance.

In peri-implantitis treatment, the CO₂ laser can be used for short exposure times and at low irradiation power settings without causing any thermal damage to the peri-implant bone tissue.^[2,5,16-21]

Implant exposure by means of CO₂ laser has several advantages, such as bloodless exposure and consequently a clean operating field, the possibility of immediate impression-taking for prosthodontic treatment, a disinfectant effect, and rapid wound healing.

All three irradiation modes (cw/sp, cw, and pw) can be used, taking into account the specific mode, irradiation time, and power, without causing thermal damage. Irradiation of implants with all three modes (cw/sp, cw, and pw) and power settings of between 4 and 10 W is safe for an exposure time of less than 10 seconds.

For implant exposure, we recommend continuous wave mode because it is more effective than pulsed mode but causes a lower temperature increase than super-pulsed mode.

The irradiation parameters, power, time, and mode play a key role in implant exposure and must be adapted to the implant being exposed. This is the only way to avoid unnecessary overheating of the implants and thereby reduce the risk of necrosis in the surrounding tissue. The consequence would be loss of an implant. When exposing implants *in vivo*, it must be remembered that they lie below the mucosa and this is made up of around 90% water. Consequently, the majority of the heat is absorbed by the mucosa. Hence, there is considerably less heating of implants *in vivo*.

Further *in vivo* studies are required to allow direct comparison of the results of this study. However, the results recorded in the study should be seen as a guideline and should help clinicians consistently avoid causing thermal trauma when exposing implants by CO₂ laser.

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