Original papers

# Effect of diode lasers with wavelength of 445 and 980 nm on a temperature rise when uncovering implants for second stage surgery: An ex-vivo study in pigs


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## Abstract

**Background.** Many surgical procedures in soft tissue are performed using diode lasers. Recently, a novel diode laser operating at 445 nm wavelength was introduced in dentistry.

**Objectives.** The aim of our study was to evaluate the time of surgery and an increase in temperature of titanium implants during its uncovering using 445 and 980 nm wavelengths.

**Material and methods.** The research included 45 pig mandibles (n = 45). The specimens were randomly divided into 3 groups (n = 15) according to the laser irradiation mode and wavelength; G1 – 445 nm laser, power: 3 W, continuous wave (CW), distance: 2 mm, power density: 7460 W/cm$^2$, fiber: 320 µm, non-contact mode; G2 – 445 nm laser (power: 2 W, CW, power density: 4970 W/cm$^2$, fiber: 320 µm, contact mode; G3 (control) – 980 nm laser, power: 2.5 W, CW, power density: 15920 W/cm$^2$, fiber: 200 µm, contact mode. The temperature was measured with a 2 K-type thermocouples (a P1 at collar and a P2 at mid height of the implant).

**Results.** The mean temperature rises measured by the P1 thermocouple were 16.9°C, 36.1°C and 21.6°C in the G1, G2 and G3 group, respectively. Significant differences in temperature rise were found between the G1 and G2 group ($p = 0.0007$) and the G2 and G3 group ($p = 0.01$). The mean temperature rises measured by the P2 thermocouple were 1.8°C, 1.4°C and 5.6°C in the G1, G2 and G3 group, respectively. Significant differences in temperature rise were found between the G1 and the G2 or G3 group ($p = 0.0001$). The significant differences among the study groups in average time necessary for uncovering the implants amounted to 69.7, 54.4 and 83.6 s, respectively ($p < 0.05$).

**Conclusions.** The application of the 445 nm diode laser in non-contact mode reduced the temperature rise of the implants. The additional pulse intervals during laser irradiation with wavelength of 445 nm when operating in contact mode are needed.



**Key words:** temperature, 445 nm diode laser, 980 nm diode laser, second stage surgery, implant uncovering

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Many in vitro and in vivo studies performed over the last few decades have resulted in improvements in implant design and surface properties, achieving a tight connection between living bone and the implant surface, i.e. osseointegration, no longer poses a challenge. The complication rates in implant osseointegration vary from 0% over a 5-year follow up period to the highest rate in a 10-year follow up period being 29%.[1,2] Furthermore, the 5-year implant survival rates for the implants placed in the mandible and maxilla reached 99.1% and 84.9%, respectively.[3,4] Recent studies showed that sufficient peri-implant bone amount as well as thick soft tissue biotype have a tremendous impact on long term implant survival rates. In recent years, scientific interest in the field of the influence of lasers in reducing postoperative pain and improving healing are being observed.

Many clinical trials have confirmed that using diode lasers reduces pain during surgery and ensures better wound healing, decreasing swelling, edema and scarring, as well as providing better coagulation.[5–7] The treatment protocols by means of semiconductor lasers is effective in removing peri-implant bacteria living on implants, maintaining the sterility of the treatment area and ensuring bio-stimulation, vaporization, coagulation and photo-ablation of the treated tissues.[8]

There are a few different techniques which can be used for second stage implant surgery, e.g. uncovering with a scalpel, tissue punch, thermo-optically powered (TOP) technology or laser.[9–11] However, the use of lasers in second-stage implant surgery in the scientific literature is still limited to cases with sufficient amount of the peri-implant attached gingiva.[12]

Some studies have shown that the Er:YAG laser induced minimal peri-implant temperature increase, has the positive effects for pain decrease and facilitates a prosthetic impression procedure.[13,14] Other studies using a $CO_2$ laser proved its disadvantage: an increase in the titanium implant temperature. There is only one study in the literature, conducted by Fornaini et al., regarding the surgical use of the KTP laser for implant second stage surgery.[15]

Soft tissue vaporization with the use of diode lasers has been widely described in the literature.[5–8] Diode lasers play a significant role in soft tissue vaporization and in the decontamination of infected implant surfaces.[5,13] However, particular attention should be paid to preventing overheating of the bone when applying these devices during surgical procedures.[16] Due to direct bone-implant contact and the special composition of the soft tissue in the implant neck area, the blood flow in this area is reduced, which increases the risk of thermal injuries being transmitted by the implant to the bone tissue. Eriksson et al., in a series of studies, found that increasing the temperature of bone tissue by 10°C for 60 s causes permanent changes in the bone structure.[17,18] Therefore, a tissue temperature gradient (ΔTa) below 10°C should be regarded as optimal and safe.

Different diode laser wavelengths are utilized during soft tissue surgery but studies regarding its use for uncovering implants are scarce.[9,19] To the best of the authors' knowledge, this is the first ex-vivo study describing the use of a blue laser wavelength (445 nm) when uncovering implants for second stage surgery.

# Objective

The aim of our study was to evaluate increases in implant temperature, taking into account the different diode laser wavelengths (445 nm and 980 nm) and regarding the contact and non-contact operation modes. In particular, we measured the time it takes for the temperature of an implant to rise by 10°C after 60 s of irradiation and evaluated the laser power settings needed to prevent thermal injury when an implant is being uncovered for second stage surgery. Additionally, the time of the surgical procedure and occurrence of carbonization were assessed.

# Material and methods

## Sample preparation

The research included 45 mandibles (n = 45) of recently slaughtered pigs, of the Złotnicka Biała breed, intended for consumption and which had been obtained from a butcher. The skin of each mandible in the area between the incisor (I1) and the first molar (M1) tooth was cut off. The specimens were randomly divided into 3 groups (n = 15) according to the laser wavelength and operation mode, then were washed under tap water and left for 4 hours before the research commenced. In every specimen, preparation of the soft tissues in the region of the canine (C) and first molar (P1) tooth gave access to the buccal and lingual part of the mandibular alveolar ridge. Ethical approval was not required for this animal ex-vivo study.

## Surgical procedure

In the study area of the mandible, a full thickness soft tissue flap was made by one horizontal and two vertical cuts using a 15C scalpel blade. The soft tissue flap was detached and an implant bed length of 10 mm was prepared by means of a drill, according to the manufacturer's protocol (Dentium Co., Seoul, Korea). A hole (3 mm in diameter) was drilled in each mandible at mid height of the buccal side of the implant bed with a trephine bur so as to place a K thermocouple Probe P2, type TP-02 (Zhangzhou Weihua Electronic Co., Fujian, China). The Superline implants (Dentium Co., Seoul, Korea) made of grade IV pure titanium, 10 mm in length and 4.0 mm in diameter, were placed in touch with the middle part of the implant. Next, a sec-

Table 1. Parameters of lasers used in the study

| Device | Wavelength | Glass fiber diameter | Mode | Frequency | Power (W) | Power density (W/cm²) |
|---|---|---|---|---|---|---|
| Diode laser | 445 nm | 320 µm | non-contact | CW | 3 | 7460 |
| Diode laser | 445 nm | 320 µm | contact | CW | 2 | 4970 |
| Diode laser | 980 nm | 200 µm | contact | CW | 2.5 | 15920 |

W – Watt; nm – nanometers; µm – micrometers; CW – continuous wave; W/cm² – Watt/square cm.

Table 2. Mean temperature gradient and standard deviation measured by TP-01 P1 K-thermocouple after 60 s of laser irradiation during an implant uncovering in the G1, G2 and G3 groups

| Study groups | N | Thermocouple P1ΔTa(°C)(mean + SD) | p-value |
|---|---|---|---|
| Group 1 | 15 | 16.9 + 8.01 | ANOVA analysis, p = 0.0006 |
| Group 2 | 15 | 36.1 ± 18.98 | G1 vs G2, p = 0.0010 |
| Group3 | 15 | 21.6 ± 8.57 | G2 vs G3, p = 0.0100 |
| All groups | 45 | 24.9 ± 15.04 | G1 vs G3, p = 0.5900 |

°C – degrees Celsius; ΔT – temperature gradient; CW – continuous wave; SD – standard deviation; N – number.

ond K-type, P1 temperature probe, type TP-01 (Zhangzhou Weihua Electronic Co., Fujian, China) was placed close to the implant collar and stabilized by a cover screw. The flap was then repositioned and sutured to the soft tissue using a non-absorbable suture (Dafilon®, Braun, Germany). Next, the implants were uncovered using different diode lasers with wavelengths of 445 and 980 nm (Fig. 1).

## Measurement procedure

The specimens were placed in a container with water at a temperature of 22°C for 20 min and the temperature was monitored with a Medicare Clinical Products (MCP) Gold mercury thermometer (Medicare Products Inc., New Delhi, India). The temperature of the implant was measured by means of a calibrated digital Thermometer CHY802W (CHY Firemate C0., Tainan City, Taiwan) with the two temperature probes of the K thermocouple probes , TP-02 and TP-01 type (Zhangzhou Weihua Electronic Co., Fujian, China). The measurement error was 0.3°C. The temperature was measured in a continuous manner by means of probes attached to the collar and at mid height of the implant. The thermocouples were covered by a thermo-conductor paste ART.AGT-057 (AG Termopasty, Sokoły, Poland ) to ensure good thermal flow. The thermal conductivity of the paste was 0.243 Cal /g K. The results in temperature rise after 60 s of laser irradiation were recorded (if the time of the surgical procedure was below 60 s, the irradiation of the implant was continued to reach the target time of 1 min). The time of the peri-implant soft tissue incision was measured with a sports stopwatch SP17 XL-009A (Fuzhou Swell Electronic Co., Ltd , Fujian, China).

## Study groups

The study specimens (n =45) were divided into 3 groups: G1 (n = 15), G2 (n = 15) and G3 (n = 15).

Group G1: Diode laser, 445 nm (SIROLaser Blue, Dentsply Sirona, Germany), operation mode: continuous wave (CW), power: 3 W in non-contact mode, distance: 2 mm, power density: 7460 W/cm², tip angle set at 90°, fiber: 320 µm.

Group G2: Diode laser, 445 nm (SIROLaser Blue, Dentsply Sirona, Germany), operation mode: continuous wave (CW), power: 2 W in contact mode, distance: 0 mm, power density: 4970 W/cm², tip angle set at 90°, fiber: 320 µm.

Group G3: Diode laser, 980 nm (SmartM, Lasotronix, Polska), operation mode: continuous wave (CW), power: 2.5 W in contact mode, distance: 0 mm, power density: 15920 W/cm², tip angle set at 90°, fiber: 200 µm (Table 1).

## Statistical analysis

The outcomes obtained were subjected to statistical analysis by means of STATISTICA v. 12 (StatSoft®, Tulsa, USA) software. The mean increase in temperature of the implants was assessed using the one-way ANOVA test. Pair comparisons were carried out based on the Tukey post-hoc test at significance levels $p = 0.05$.

# Results

The analysis of the temperature rise after 60 s of laser irradiation measured by P1 thermocouple revealed a significantly lower temperature for G1 – 445 nm diode laser operating in non-contact mode (mean 16.9°C, $p = 0.0007$) or G3 group – a 980 nm diode laser operating in contact mode (mean 21.6°C, $p = 0.01$) as compared to G2 group, a 445 nm diode laser operating in contact mode (mean 36.1°C). The difference in the mean temperature rise among groups G1 and G3 was insignificant ($p = 0.59$) (Table 2).

The analysis of the temperature rise measured by the P2 thermocouple revealed significantly higher temperature for group G3 (mean 5.6°C) as compared to G2 (mean

Fig. 1. Surgical and measurement procedure used in the study. A) The study area in the pig's mandible. B) An alveolar ridge C) The implant bed preparation. D, E) The implant placement. F) Thermocouples attached to the implant. G) Reposition of the flap prior to a laser irradiation. H) The unveiling of the implant using diode laser

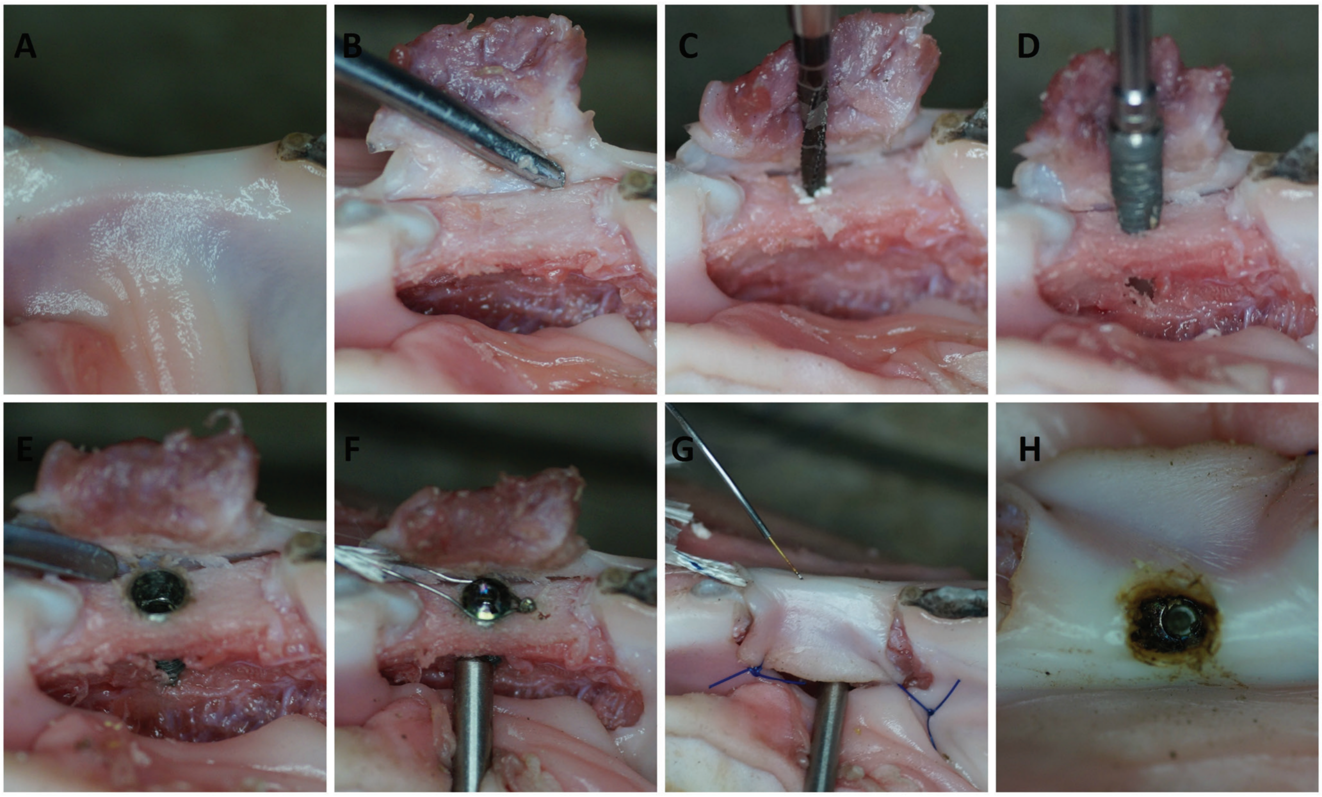
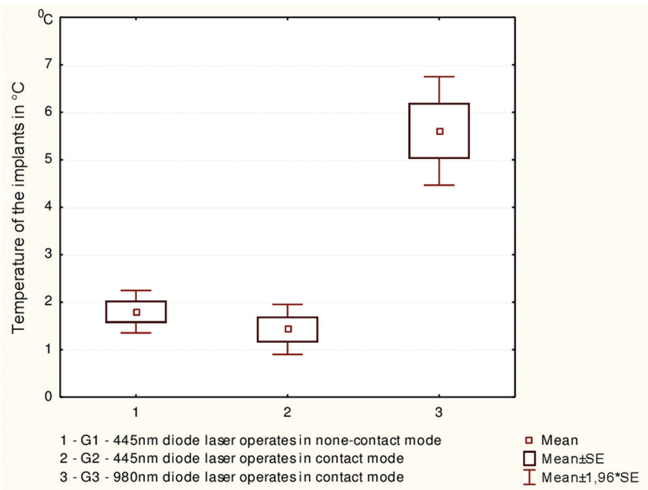
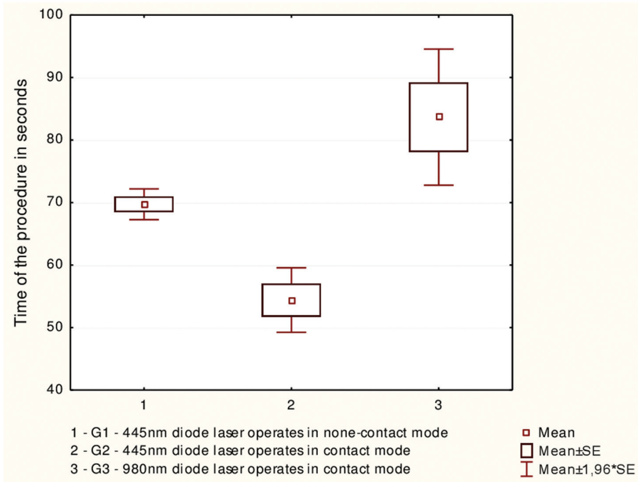



Fig. 2. The mean temperature rise in Celsius (°C) measured by TP01 Ps k-thermocouple at mid height of the implant during its uncovering in G1, G2, G3 groups




**G1 vs. G2: p= 0.7811**
**G1 vs. G3: p= 0.0001**
**G2 vs. G3: p= 0.0001**

Fig. 3. The mean time in seconds required to an implants uncovering by means of a Diode lasers with a different parameters



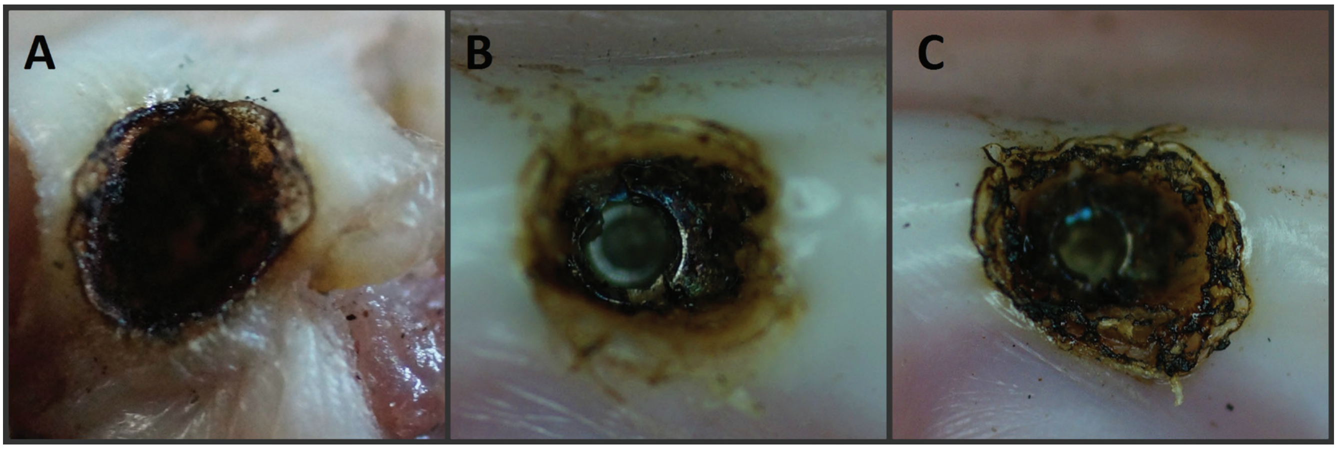

**G1 vs. G2: p= 0.0126**
**G1 vs. G3: p= 0.0252**
**G2 vs. G3: p= 0.0001**

1.4°C) and G1 (mean 1.8°C) (p = 0.0001). However, there was no differences in temperature increase between groups G1 and G2 (p = 0.78) (Fig. 2).

The time required for implant uncovering during irradiation using a 445 nm diode laser operating in contact mode (mean 54.4 s) was significantly shorter as compared to a 445 nm diode laser operating in non-contact mode (mean 69.7 s, p = 0.0126) and a 980 nm diode laser (mean 83.6 s, p = 0.0252). Furthermore, our findings show that there also is significant difference between groups G2 and G3 (p = 0.0001) (Fig. 3).

We also observed greater signs of carbonization occurrence during soft tissue cutting by means of a diode laser with a wavelength of 445 nm operating in contact mode as compared to a 980 nm laser or a blue laser operating in non-contact mode (Fig. 4).

Fig. 4. Signs of a thermal damage in the soft tissue. A) Diode laser (445 nm) operating in contact mode. B) Diode laser (980 nm) operating in contact mode. C) Diode laser (445 nm) operating in non-contact mode




## Discussion

To the best of our knowledge, no comparison has yet been made ex-vivo in the literature between the effects of blue (445 nm) diode laser irradiation in increasing the temperature of titanium implants for second stage surgery. Nonetheless, the impact of blue lasers on implant temperature has already been analyzed in relation to laser power.[13,19–22] The main objective of this study was to determine effective and safe energy settings for a 445 nm diode laser operating in contact and non-contact mode for implants made from pure titanium (grade IV) in comparison with an infrared wavelength of 980 nm.

In their comparative analysis of temperature increases when uncovering implants for second stage surgery in an animal ex-vivo model, Fornaini et al. stated that 810 nm diode lasers resulted in a higher rise in tissue temperature than Er:YAG and $CO_2$-lasers.[19] Fornaini et al. also emphasized that a diode laser operating in contact mode causes the implant's mean temperature to increase 12.67°C and 21.5°C, as measured by the thermocouple (3 mm below the implant's collar) and by a thermal camera (on a soft tissue level), respectively.[19] The results measured by the thermocouple (mean 12.67°C) are similar to those obtained in our study for a 445 nm diode laser operating in non-contact mode (mean 16.9°C) and are much different as compared to the same laser but operating in contact mode (mean 36.1°C). The differences could be related mainly to the different wavelength but also to the position of the thermocouples. In our study, the probe was placed more superficially than in Fornaini's et al. study.[19] This position of the probe is associated with much more heat accumulation, which implies a greater temperature increase. Furthermore, the mean time of the procedure in the study conducted by Fornaini et al. was 90.8 s.[19] These results are similar to our study in terms of the 980 nm wavelength (83.6 s). In the present study, the mean times of the implant uncovering for the blue diode laser operating in contact and non-contact mode were shorter and amounted to 54.4 and 69.7 s, respectively.

In another in vitro study when thermocouples were placed in a calf tongue, Mergio et al. concluded that a temperature rise by 21°C (ΔTa) could be recorded after diode laser application (808 nm) using a power setting of 3W.[23] Our findings show a similar temperature rise for a 2.5 W diode laser with a wavelength of 980 nm.

In our previous ex-vivo study in a pig model, we conducted the direct irradiation of the implants composed of grade IV titanium by means of a diode laser with a wavelength of 980 nm (3W), which resulted in a temperature rise of 10°C after 17–18 s.[13] In the present work, the temperature gradient was measured in a continuous manner without intervals when uncovering implants for second stage surgery. The heat accumulation by the soft tissue and the light absorption/scattering ratio could be related to peri-implant bone necrosis due to heat transfer. Therefore, the pauses during the laser tissue irradiation seem to be a key factor in preventing thermal injury.[24]

Janda et al., in their study of the assessment of thermal effects on ex-vivo muscle tissue by different medical laser systems (Ho:YAG – 2080 nm, Nd:YAG – 1064 nm and diode lasers – 830 and 940 nm) operating in contact mode revealed large thermal damage at the surface of the tissue for the diode and Nd:YAG lasers.[25] The tissue specimens showed severe carbonization at the surface with only small adjacent coagulation areas after application of the diode laser in contact mode. In our present study, we noted greater carbonization occurrence for a 445 nm diode laser operating in contact mode as compared to the same wavelength but in non-contact mode.

In their recent research, Fornaini et al. compared, on an ex vivo model, the effectiveness of 5 different fiber-delivered laser wavelengths (450, 532, 808, 1064 and 1340 nm) used in bovine tongues to prepare a linear cut of 5 cm in length, at a speed of 5 mm/s.[26] The results of this research showed the best quality of the cut and the lowest temperature increase in the specimens obtained with a 450 nm diode laser (2W, CW, contact-mode). They found an increase in temperature of the bovine's tongues by 8.8–11.6°C for the wavelength of 450 nm. In our present paper, we noted a different value of the temperature rise in the implants probably because of the different laser cut line prepared during soft tissue vaporization. However, our analysis also showed a lower temperature increase in the tissues prepared with a blue diode laser (445 nm) as compared to a near-infrared wavelength (980 nm).

Fornaini et al. in 2016 also published an ex vivo study which compared the efficacy of four diode laser wavelengths (810, 980, 1470 and 1950 nm) for the ablation of soft tissues in bovine tongue.[27] They recorded the most significant deep temperature increase by the 980 nm diode laser at 4 W (ΔTa = 17.3°). The application of laser light with a wavelength of 980 nm induced a higher thermal rise in the soft tissue, which was also confirmed in our present study in comparison to a blue diode laser.

El-Kholey in his in vivo study of the effects of the use of diode laser on 30 patients (45 implants) showed that the use of a diode laser for second stage implant surgery can minimize surgical trauma, eliminate the need for anesthesia, improve visibility during surgery due to the absence of bleeding, and eliminate postoperative discomfort.[9] During the surgery, a saline drip was applied to the surgical site and the laser irradiation was intermittently stopped every 20–30 s to avoid any increase in temperature of a soft tissue or bone. The only limitation to the use of this technique is a lack of sufficient keratinized tissues around the implant. In our presented paper, laser beam application was done in continuous mode without cooling and pulse intervals that could result in higher heat accumulation in the tissues and implants.

The safe distribution of heat in tissues is a main goal when operating high intensity lasers in bone or soft tissue. According to an in vivo study presented by Augustin et al., the cellular death caused by heat is immediately evident with temperatures above 70°C.[28] However, in line with the conclusions reached by Ericsson et al., an increase in the tissue temperature over 47°C (ΔTa > 10°C) cause irreversible changes in the bone structure.[17,18] Therefore, within the limitations of this ex-vivo study, a temperature gradient below the critical 10°C seems to be safe for using a laser during second stage surgery. Unfortunately, in this study the mean temperature gradient measured for all study groups was over ΔTa = 10°C. The lowest mean temperature value (16.9°C) was obtained by the 445 nm diode laser (non-contact mode, 3W). However, it should be highlighted that the surgical procedure was performed without cooling or pulse intervals, which induces greater heat accumulation in the target tissues. Moreover, our present work was an ex-vivo study with all the typical limitations, e.g. the different chemical composition and biological properties of the "ex-vivo" specimens as compared to "in vivo" tissue, mainly due to the absence of blood circulation.

Nevertheless, we obtained significant differences among the new blue diode laser operating in non-contact (16.9°C, 3W) and contact mode (36.1°C, 2W). Olivi et al. reported that at 2-mm tip-to-tissue distance, fluence decreased by 68% from its level at the tip surface; at 3 mm, it decreased by 78%.[29] Thus, irradiation of the target tissue from a distance could lead to a lower temperature rise due partly to energy loss during laser operations in non-contact mode. In the present paper, we also found a lower mean temperature rise for the 980 nm wavelength (2.5 W) as compared to the 445 nm diode laser (2 W), both operating in contact mode. There is a fundamental difference among absorption and scattering phenomenons depending on the wavelength range. In the visible region of the light spectrum (400–600 nm), both absorption and scattering occur and light penetrates soft tissue to a depth of 0.5–2.5 mm, but in the red to near infrared region (600–1500 nm), scattering prevails and light penetrates to a depth of 8–10 mm.[30] Thus, the lower loss of energy (low scattering) transmitted by a laser with a wavelength of 445 nm as compared to the 980 nm laser (high scattering) could result in greater heat accumulation by the target tissue and a higher temperature rise in the collar part of the implant. Furthermore, the higher temperature increase at the mid implant level for the 980 nm diode laser could be induced by higher scattering and penetration into the tissues by the near infrared wavelength. The use of a diode laser when uncovering implants makes it possible to vaporize soft tissue layer by layer without damage to the bone underneath. Wound healing with low shrinkage makes it possible to take an implant impression in the same session after its uncovering by means of these device.[31,32] However, additional studies using a diode laser with a wavelength of 450 nm are needed to confirm the results of this study in animal and human in vivo models.

# Conclusions

The application of a diode laser with a wavelength of 445 nm in non-contact mode significantly reduced the temperature increase in titanium implants during their uncovering as compared to a 980 nm wavelength diode laser. The use of the 445 nm diode laser in contact mode resulted in the highest temperature rise. It must be taken into consideration to do more intervals during diode laser irradiation with a wavelength of 445 nm when operating in contact mode.

The results of a temperature rise by 10°C seems to be unsafe for clinical use with the parameters utilized in this study when operating diode lasers without irradiation intervals.

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