Thermal Testing of Titanium Implants and the Surrounding Ex-Vivo Tissue Irradiated With 9.3um CO_2 Laser

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Purpose: *To measure the temperature rise and surface damage of titanium dental implants and the surrounding tissue in a pig jaw during 9.3-μm carbon dioxide (CO_2) laser irradiation at various durations of time.*

Materials and Methods: *Thermal analysis tests were performed on 12 implants with the same surface. Twelve implants mounted alone or in pig jaws were laser-irradiated with a 9.3-μm CO_2 laser using 3 different power settings. The temperature of the implant body and the proximal tissues was measured with a J-Type Thermocouple after being laser-irradiated with 3 different power setting for 30, 60 seconds, and 2 minutes. Scanning electron microscope (SEM) and digital microscope images were also taken of the all the implants before and after laser irradiation to detect the presence or absence of surface damage.*

Results: *Temperature analysis showed that in all cases the implant and the proximal tissue temperatures remained around the start temperatures of the implant and tissues with fluctuations of ±3°C but never reached the upper threshold of 44°C, the temperature at which thermal injury to bone has been reported. Digital and SEM images that were taken of the implants showed an absence of surface damage at the cutting speed of 20% (0.7 W); however, cutting speeds of 30% to 100% (1.0–4.2 W) did yield surface damage.*

Conclusions: *Laser irradiation of titanium implant surfaces using a 9.3-μm carbon dioxide laser with an average power of 0.7 W showed no increase in thermal temperature of the implant body and tissue temperatures as well as no evidence of implant surface damage.* (Implant Dent 2019;28:463–471)

Key Words: implant detoxification, implant complication, laser decontamination, thermal testing of implants, peri-implant peri-implantitis

Different treatment modalities for peri-implant disease have been discussed in the literature and are usually recommended based on the amount of bone loss around the implant and defect morphology.[1–3] Surgical debridement of a dental implant affected by moderate to severe peri-implantitis has shown to be unpredictable and highly dependent on the micro and macro surface characteristics of the dental implant.[4] In addition, the morphology of the bone defect surrounding the diseased implant can often impair the ability of the clinician to adequately access and detoxify the implant surface.[5] Various types of laser-assisted implant surface decontamination have been described in the literature with different degrees of success.[6,7] Two lasers in particular, the Erbium:Yttrium–Aluminum-Garnet (Er:YAG) laser and the carbon dioxide (CO_2) laser, have been studied for their ability to assist with peri-implant disease resolution. In a preclinical study, the efficacy of the Er:YAG laser in re-establishing bone-to-implant contact around sites with peri-implantitis was assessed in an animal model and shown to eliminate inflammatory tissue and allow for reosseointegration of the implant surface.[8] Another clinical study investigated the efficacy of a CO_2 laser in the decontamination of failing implants. After a mean follow-up of 27 months, virtually complete bone regeneration occurred in the peri-implant defects.[9] Although these lasers have demonstrated efficacy in bacterial decontamination of diseased implants, a particular concern when using laser therapy can be the

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Table 1. Implants Dimensions

Implant Number	Length [mm]	Diameter [mm]
15_5_2	15	5
15_4.5_1	15	4.5
15_4_1	15	4
13_5_1	13	5
13_5_2	13	5
13_4.5_1	13	4.5
13_4_1	13	4
11_4_1	11	4
9_4.5_1	9	4.5
9_4_1	9	4
7_5.5_1	7	5.5
7_4_1	7	4

increase in implant body temperature leading to possible necrosis of the surrounding tissue.[10] Alterations in implant surface characteristics and tissue temperature have been reported when using lasers with energies exceeding certain thresholds.[11] These alterations have been shown to be proportional to the amount of energy used to decontaminate the implant surface and the type of laser being used.[12] The development of a novel method of implant surface decontamination using a new 9.3-μm CO_2 laser is particularly appealing because of the clinician's ability to control the spot size of the laser focus and percentage of power. In previous laboratory tests, the optimum setting on the 9.3-μm CO_2 SOLEA laser was identified using power and water settings that can be used on dental implants without damaging the surface and causing a temperature increase in the implant and surrounding tissue above the upper safe limit of 44°C established by Erikson et al.[13] The aim of the current study was to replicate this test and results on a larger sample size of implants of the same type but variable sizes. The implant body and the surrounding tissue temperatures were monitored during multiple lasing time-windows of 30, 60 seconds, and 2 minutes.

The ability of the clinician to control the diameter of the laser beam allows the laser to access various sized anatomical challenges. In addition, the cutting speed of this laser can be controlled by a foot pedal rheostat allowing the clinician to easily reduce power if charring of the implant surface is noticed. Finally, control over the water pressure of this laser allows for copious irrigation to cool the implant surface during decontamination, reducing the possibility of damage to the implant surface, increase of implant temperature, and tissue necrosis due to temperature increase.

METHODS AND MATERIALS

An institutional review board approval was not required for this study because it was a benchtop study performed at Convergent, Needham, MA. Thermal tests were conducted on 12 titanium implants of the same type (Neoss Inc., Woodland Hills, CA) of assorted sizes (Table 1) in 2 configurations, both during lasing of the CO_2 laser: (1) Recording the temperature of the implant itself as it was mounted on the bench. (2) Recording the temperature of the surrounding tissue as the implant was mounted in the pig jaw.

Configuration 1

The hollow part at the cap end of each implant was filled with thermal paste (OMEGATHERM, OT-201-2; Omega, Biel/Bienne, Switzerland), and the tip of a J-Type Thermocouple (TC) (SC-TT-J-36–36, Omega) was inserted and situated in that space. The other end of the TC was connected to a temperature logger (HH806U, Omega), logging in 1-second increments. The implant was then mounted such that the cap end was held with a clip and protected with an electrical tape, leaving the body of the implant available to be irradiated by the laser (Fig. 1). The starting temperatures were ambient, in the range of 17 to 22°C.

The SOLEA system (SN K482) was set to the proposed nonaltering settings of low power using spot size 1.25 mm, at 20% cutting speed (Average power = 0.7 W) and at 100% mist (13 mL/min) on software SW 3.2. Using the contra-angle handpiece, each implant was irradiated with the laser on the grooved sides for 30 seconds continuously, and the temperature was logged. After 30 seconds, the laser irradiation was terminated, and the implant was left to return to its baseline temperature. Once the baseline temperature was reached, the process was repeated on a different area of the implant surface for a lasing time-window of 60 seconds and then again for 2 minutes. High magnification images of representative implant surfaces were taken with a digital microscope at ×35, ×140, and ×700 (Hirox digital microscope RH-2000, HIROX-USA, Inc., Hackensack, NJ) before lasing and after each lasing time-windows of 30, 60 seconds, and 2 minutes (Fig. 2, A–L). The above was repeated for all 12 implants.

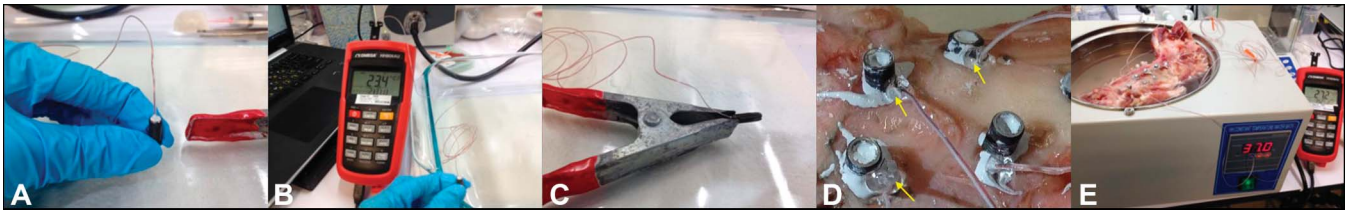

Fig. 1. (**A**–**E**) The hollow space of the implant was filled with thermal paste, and the tip of a thermocouple was inserted into that space. (A) The other end of the thermocouple was connected to a temperature logger. (**B**) The cap end of the thermocouple was held with a clip and covered with an electrical tape to prevent the mist from getting to the thermocouple. The body of the implant was left exposed and available to be irradiated with the laser. (**C**) Holes were drilled into the pig jaw using the SOLEA laser and filled with thermal paste. Each implant was placed into a hole, and the tip of a thermocouple was situated in the space between the tissue and the thermocouple. A second adhesive covered was used to protect the thermocouple from the mist. (**D**) The pig jaw was placed in a 37°C water bath (yellow arrows) (**E**).

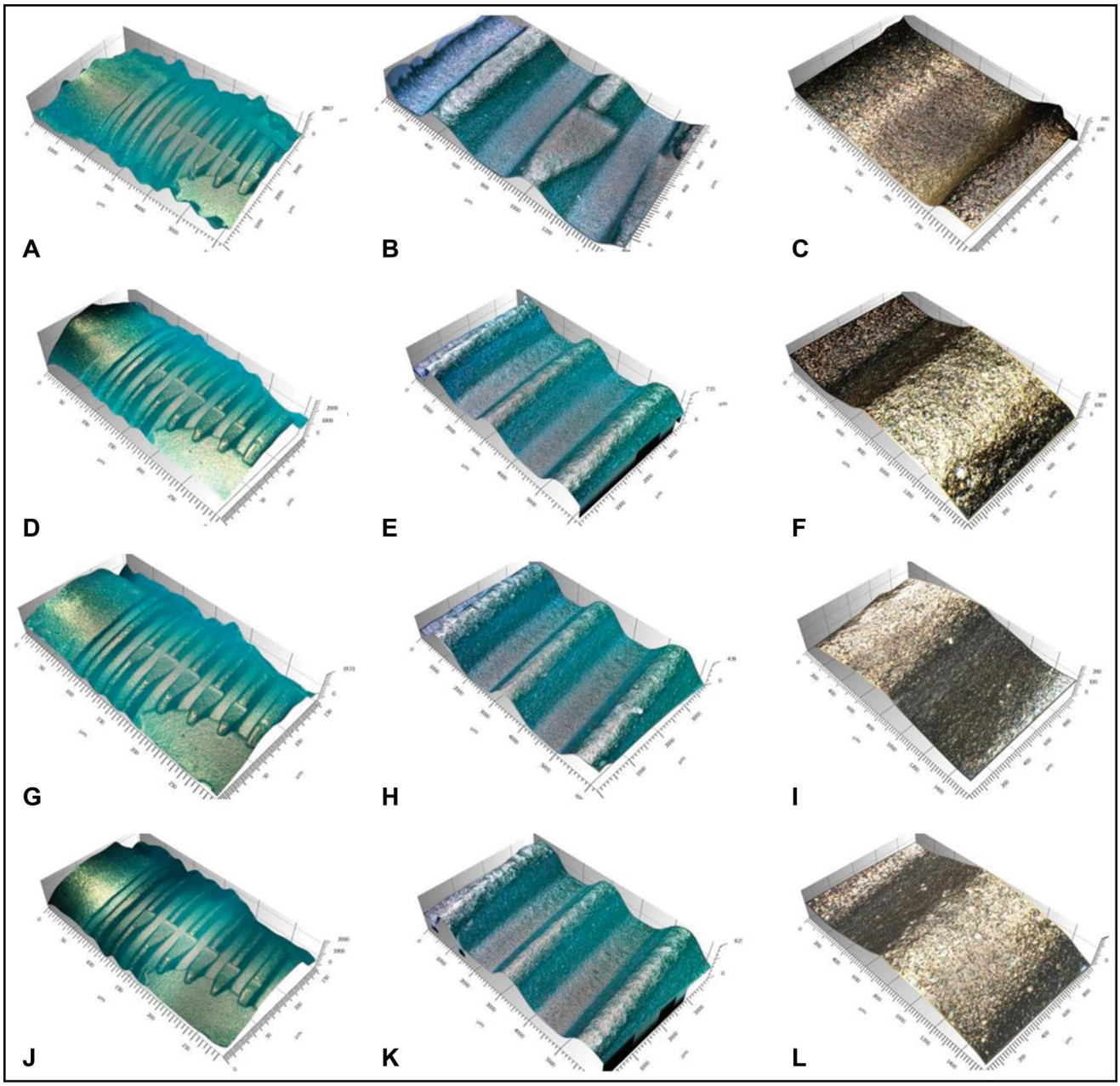

Fig. 2. (**A**–**L**) Digital microscope images at ×35, ×140, and ×700 magnifications of implant no. 7_4 _2. (**A**–**C**) Not irradiated. (**D**–**F**) Irradiated for 30 seconds with the nonaltering settings. (**G**–**I**) Irradiated for 60 seconds with the nonaltering settings. (**J**–**L**) Irradiated for 2 minutes with the nonaltering settings. All cases show similar surface to the control, nonirradiated sample.

Configuration 2

Two halves of previously frozen pig jaws were obtained from a local farm. Each half was used to hold 6 implants, spaced apart at a distance >5 mm. To place each implant, a hole was drilled in the jaw using the SOLEA laser. The hole was filled with the OMEGATHERM thermal paste, and the implant was then inserted into the hole and having 2 to 4 threads of the implant protruding from the jaw's surface. The tip of a Type-J TC was placed in the paste-filled gap between the implant and the tissue and connected to a temperature logger logging in 1-second increments. A second adhesive (Loctite 3092; Henkel, Düsseldorf, Germany) was applied to the location where the TC was inserted to create

Table 2. SOLEA Settings—Low Power 1.25 (SW3.2)

	20% Cutting Speed*	30% Cutting Speed	100% Cutting Speed
Pulse duration (μs)	20	28	90
Average power (W)	0.7	1.0	4.2
Mist (%)	100	100 and 0	100

*Represents the cutting speed that is recommended by the authors.

Fig. 3. A–C Digital microscope images of implant no. 13_5_7 irradiated with 30% cutting speed and 100% mist for 10 seconds exhibiting damage on the surface of the implant.

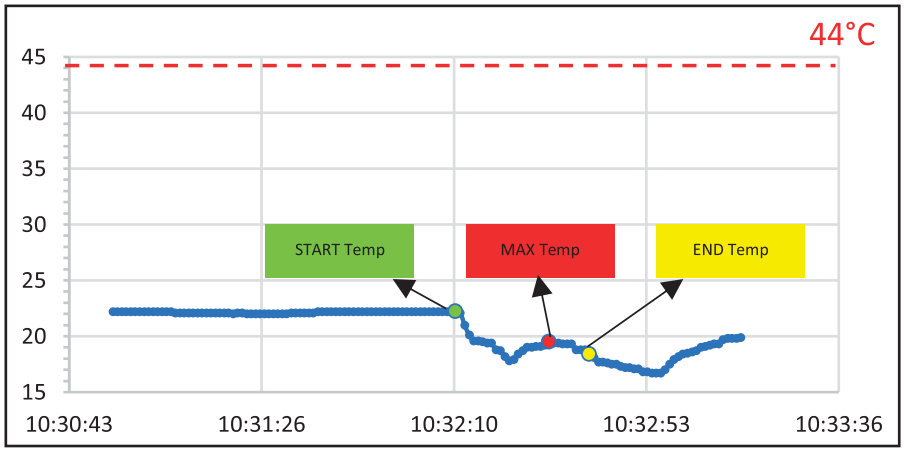

Fig. 4. Just Implant 13_5_2—30 seconds—Config 1.

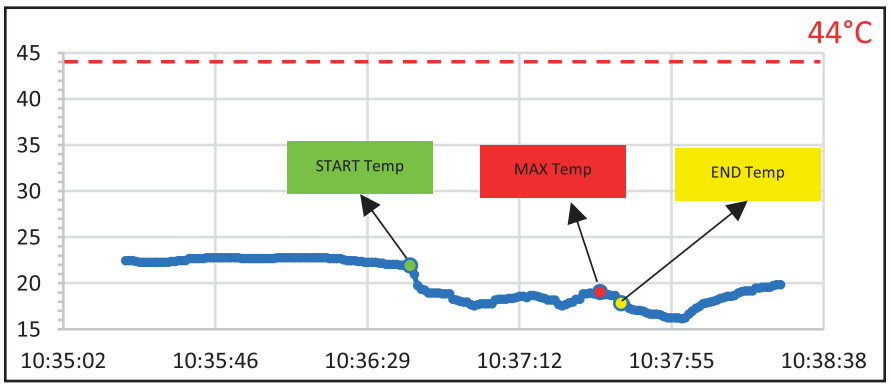

Fig. 5. Just Implant 13_5_2—60 seconds—Config 1.

a seal and prevent water from getting into the space with the TC. The jaws were placed in a water bath at temperature at 37°C. The thermocouples were allowed some time to reach a temperature of 25 to 33°C.

The SOLEA system was set to the proposed nonaltering settings of low-power 1.25 mm, 20% speed (average power = 0.7 W), and 100% mist (13 mL/min). Using the contra-angle handpiece, the implant was laser-irradiated on top for 30 seconds continuously during which the temperature was logged. After 30 seconds, the laser irradiation was terminated, and the TC was allowed some time to return to its baseline temperature. Once the baseline temperature was reached, the process was repeated for a lasing time-window of 60 seconds and then again for 2 minutes. The aforementioned steps were repeated for the additional implants. Table 2 summarizes SOLEA settings used in this study (Table 2).

A 1-sample *t* test was used to determine whether the observed temperatures were statistically different from the 44°C threshold. A digital microscope (RH-2000; Hirox) and a scanning electron microscope (SEM) were used to acquire images from nonirradiated implants (controls) and implants irradiated for 30, 60 seconds, and 2 minutes of time durations with the nonaltering settings. In addition, images were acquired from implants irradiated with surface-altering settings of low-power 1.25-mm spot size, 30% and 100% cutting speed (average power ~1.0 and 4.2 W, respectively) with 0% and 100% mist. The purpose of this was to show the altered surface of the implant as a result of laser irradiation with power settings higher than recommended (Fig. 3, A–C).

RESULTS

In all cases, the temperature of the implants and surrounding tissue never reached the upper threshold of 44°C. In Configuration 1, the temperature fluctuated during the irradiation time

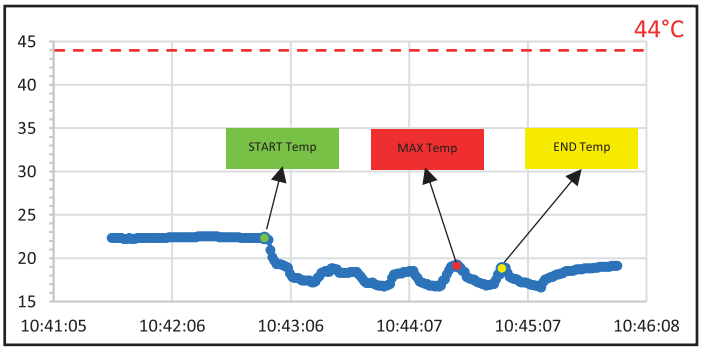

Fig. 6 . Just Implant 13_5_2—2 minutes—Config 1.

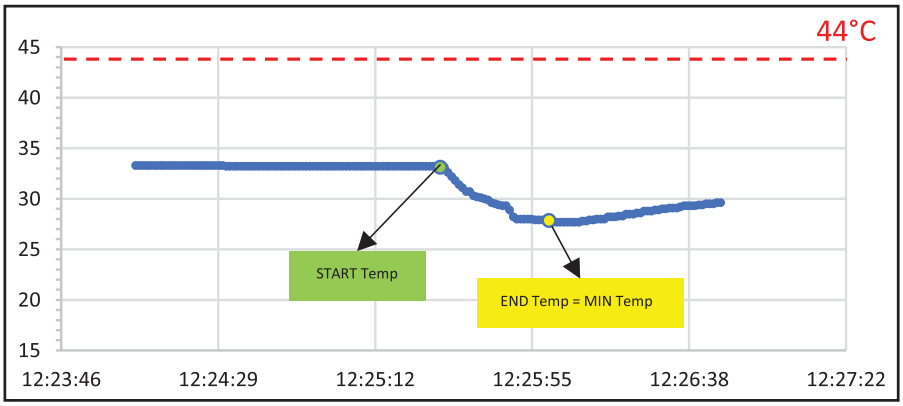

Fig. 7. Implant in pig jaw 13_5_2—30 seconds—Config 2.

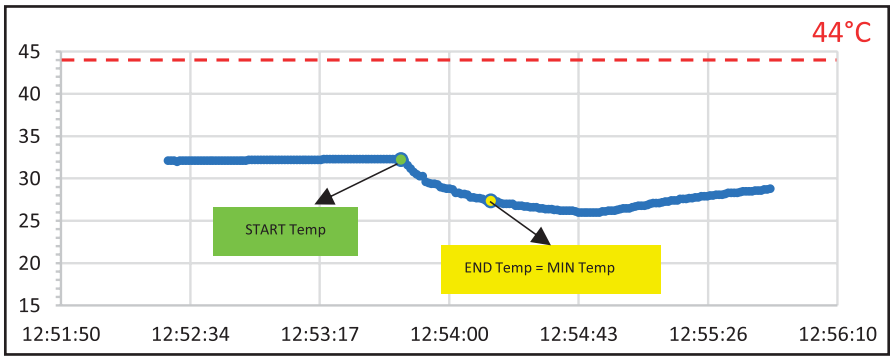

Fig. 8. Implant in pig jaw 13_5_2—60 seconds—Config 2.

but maintained an average temperature consistent with the initial temperature. The temperature fluctuated within ±3°C as a function of the proximity of the laser spot to the TC location. The tip of the TC was embedded in the thermal paste and inside the hollow space of the implant, reaching a few millimeters into the implant's body (from the cap end). As the laser spot was getting closer to that region, the temperature exhibited an increase, and as it was moved further away (toward the base of the implant), the temperature decreased. However, because of the cooling effect of the mist, the maximum temperature was still lower or only slightly higher compared with the start temperature.

In Configuration 2, the start temperature was higher as the pig jaw was kept in the 37°C water bath. In this case, the cooling effect of the mist was more pronounced, resulting in an initial decrease in temperature followed by a monotonically decreasing trend for the entire duration of laser irradiation. No temperature increase was observed for any of the samples, regardless of the proximity of the laser spot to the TC. Figures 4–9 are representatives of each of the aforementioned behaviors. Tables 3 and 4 summarize per each test configuration the start temperature, max/min temperatures, and the delta from the 44°C threshold (Tables 3 and 4).

The delta calculations were obtained by measuring the difference in temperature (an increase or a decrease) from the 44°C mark and are presented in Tables 3 and 4 for both configurations (Tables 3 and 4). For Configuration 1, the maximum temperature during the irradiation duration was considered for the delta calculations. For Configuration 2, because the temperature was only decreasing, the minimum temperature was considered for the delta calculations.

A one-sample *t* test was used to determine whether the observed temperatures were statistically different from the 44°C threshold. In all cases, the delta in temperature difference (increase or decrease—form the 44C) was statistically significant, with $P < 0.0001$.

In Figure 10, A and B are the microscope images and corresponding SEM images for a sample of implants showing no difference in the surface of the implants before/after laser irradiation, as well as implants with an altered surface (Fig. 11, A–E).

DISCUSSION

Complete detoxification of a bacterial-contaminated implant surface has been shown to be a critical factor for successful disease resolution around implants affected by peri-implantitis.[14] Many treatment

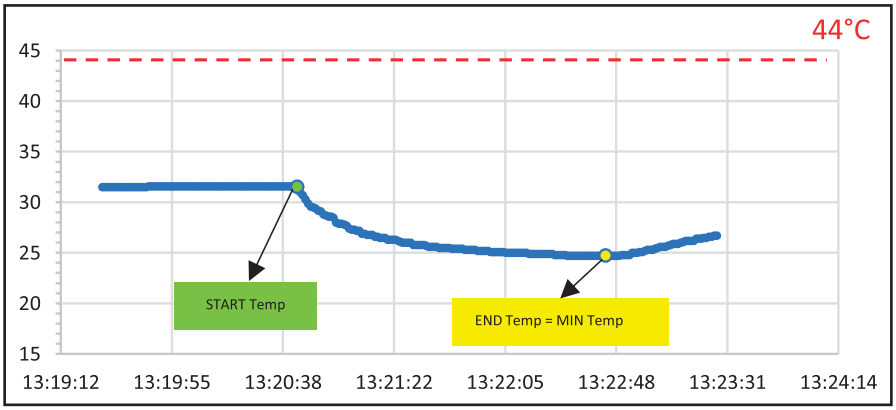

Fig. 9. Implant in pig jaw 13_5_2—2 minutes—Config 2.

modalities have been advocated in the literature with varying degrees of success. The need for predictable methods of surface debridement that do not alter the macrostructure of the implant body are essential for treatment success. Chemical detoxification of commercially pure titanium and titanium alloy implant surfaces has been shown to lead to pitting and corrosion of the implant surfaces.[15] Laser decontamination of bacterial adhesions to the implant surfaces has shown to be a promising method of debridement; however, concerns about increase in implant temperature, surface damage, and tissue necrosis have been reported.[16] Monzavi et al compared different lasers of various wavelengths and their ability to detoxify implant surfaces respective to the elevation of implant body temperature. A total of 60 implants were inserted into a bone block taken from the sheep mandible and placed into a 37-degree Celsius water bath. A 10.6-μm CO_2 laser, Er:YAG laser, Nd:YAG laser, diode laser, and antimicrobial photodynamic therapy were used to irradiate the dental implants at the coronal, middle, and apical aspect of the implant body. The authors found that a 10°C change occurred at the apical aspect of the implant with the Nd: YAG, diode, and 10.6-μm CO_2 lasers with the CO_2 laser causing a statistically significant implant temperature increase.[17] The CO_2 laser has been used in implant dentistry to treat diseased implants because it is minimally absorbed at the implant surface and potentially had a reduced risk of causing temperature-induced tissue damage.[12] In addition, irradiation of titanium surfaces using a CO_2 laser led to increased osteoblast attachment to titanium surfaces, thereby augmenting bone formation and accelerated soft tissue healing around disease implants.[18,19] Park et al examined the effect of laser irradiation of smooth and rough surface implants and compared the Nd:YAG laser with the 10.6-μm CO_2 laser. They found that at high-power settings, both lasers altered both implant surfaces, but the CO_2 laser did not alter either of the implant surfaces at 1 and 2 W.[12] Other studies agree with that study and show that a conventional 10.6-μm CO_2 laser under dry conditions and increased power settings has resulted in charred implant surfaces.[19] Increases in laser wattage of the CO_2 laser has been shown to be correlative to increases in implant surface damage.[20] In addition, heat production as a result of excessive 10.6-μm CO_2 laser application may jeopardize osseointegration.[21] Therefore, an understanding of the relationship between applied laser energy and a clinically relevant, therapeutic effect is crucial for optimal treatment. This study indicates that a new 9.3-μm CO_2 laser has promise in its ability to decontaminate bacterial adhesions without damaging the implant surface or raising thermal temperature of the implant body and proximal tissue. This laser uses a mist that is capable of cooling both the implant body and surrounding tissue during detoxification.

Table 3. Thermal Tests Results—Just Implants—Config 1

Implant Number	Start Temp (°C)	MAX Temp' at 30 s (°C)	Delta From 44°C	Start Temp (°C)	MAX Temp' at 60 s (°C)	Delta From 44°C	Start Temp (°C)	MAX Temp' at 2 min (°C)	Delta From 44°C
15_5_2	22.5	18.6	−25.4	20.5	17.7	−26.3	19.1	18.8	−25.2
15_4.5_1	19.1	18.8	−25.2	18.7	19.1	−24.9	17.4	18.9	−25.1
15_4_1	19.0	19.7	−24.3	17.7	19.0	−25	18	19.3	−24.7
13_5_1	17.8	19	−25	16.9	18.3	−25.7	17.2	18	−26
13_5_2	22.2	19.5	−24.5	21.9	19	−25	22.3	19.1	−24.9
13_4.5_1	20.5	19.8	−24.2	21.2	19.8	−24.2	21.1	20.2	−23.8
13_4_1	19.4	19.9	−24.1	17.9	19.9	−24.1	17.3	19.6	−24.4
11_4_1	19.2	19.6	−24.4	19	19.1	−24.9	19.1	19.1	−24.9
9_4.5_1	19.1	19.3	−24.7	20.3	19.5	−24.5	19.9	19.1	−24.9
9_4_1	20	19.9	−24.1	19.4	19.2	−24.8	19.9	20.3	−23.7
7_5.5_1	19.7	19.8	−24.2	19.5	20.2	−23.8	19.1	19.6	−24.4
7_4_1	23.1	19.4	−24.6	22.8	20.4	−23.6	22.1	20.2	−23.8
Average	20.1	19.4	−24.6	19.7	19.3	−24.7	19.4	19.4	−24.7
STD	1.6	0.4	0.4	1.8	0.8	0.8	1.8	0.7	0.7

Table 4. Thermal Test Results—Implants in Pig Jaw—Config 2

Implant Number	Start Temp (°C)	MIN Temp at 30 s (°C)	Delta From 44°C	Start Temp (°C)	MIN Temp at 60 s (°C)	Delta From 44°C	Start Temp (°C)	MIN Temp at 2 min (°C)	Delta From 44°C
15_5_2	29.7	27.3	–16.7	24.7	20.4	–23.6	28.9	24.6	–19.4
15_4.5_1	29.4	25.4	–18.6	28.1	23.7	–20.3	26.1	22.1	–21.9
15_4_1	27.6	21.3	–22.7	27	24.0	–20	25.7	22.5	–21.5
13_5_1	27	25.1	–18.9	24.9	22.7	–21.3	24.8	21.5	–22.5
13_5_2	33.1	27.8	–16.2	32.3	27.3	–16.7	31.5	24.7	–19.3
13_4.5_1	25.4	20.8	–23.2	24.4	20.8	–23.2	24.8	20.4	–23.6
13_4_1	26.2	23.8	–20.2	25	21.1	–22.9	26.4	23.1	–20.9
11_4_1	26.5	24.7	–19.3	25.4	23.6	–20.4	25.9	23.5	–20.5
9_4.5_1	25.4	23.1	–20.9	25.3	22.8	–21.2	25.2	22.3	–21.7
9_4_1	26.1	22.9	–21.1	27	22.4	–21.6	25.8	22.2	–21.8
7_5.5_1	27.2	25.6	–18.4	26.4	24.7	–19.3	26.2	23.7	–20.3
7_4_1	27.8	24.3	–19.7	25.8	22.6	–21.4	25.9	22.6	–21.4
Average	27.6	24.3	–19.7	26.4	23.0	–21.0	26.4	22.8	–21.2
STD	2.2	2.1	2.1	2.2	1.9	1.9	1.2	1.2	1.2

Studies have shown that CO_2 lasers used under wet conditions have less implant surface damage potential than those used under dry conditions.[22] In addition to not causing any implant surface damage when using the appropriate power settings, no increase in implant body and proximal tissue temperature was noted during a lasing period of 2 minutes. Two-minutes of laser irradiation is above and beyond the period of time needed to decontaminate an implant surface affected by peri-implantitis in a clinical setting. A recent review of the laser therapy for the use of peri-implant mucositis and peri-implantitis shows limited results when using lasers as an adjunct to treat diseased implants as compared with conventional instrumentation.[23] This review, however, did not include the 9.3-μm CO_2 laser and was limited in its ability to asses all lasers. Although this study shows promise for the potential of this laser in the treatment of peri-implant disease, further studies are needed to show the efficacy of bacterial decontamination of the implant surfaces under these settings in both an in vitro and in vivo model.

CONCLUSIONS

In this study, the SOLEA 9.3-μm carbon dioxide (CO_2) laser settings, previously found to cause no damage to titanium dental implants, was used to irradiate 12 implants of assorted sizes. Each implant was irradiated for 3 different time durations: 30, 60 seconds, and 2 minutes, both mounted in a pig jaw and separately while mounted on a benchtop outside the pig jaw. The temperature of the implants and surrounding tissue was monitored during the time periods. In all cases, the temperature remained well below the upper limit of the established tissue necrosis temperature of 44°C, averaging 19 and 23°C for the implant alone and the implant in the pig jaw, respectively. A 1-sample *t* test found these differences to be statistically significant with $P < 0.0001$. Digital microscope and SEM images show similar surface characteristics between the control nonirradiated samples and the ones irradiated with the nonaltering settings. Images also showed that when higher than recommended power settings were used during laser irradiation, implant surfaces were damaged. This study demonstrated that using a SOLEA 9.3-μm CO_2 laser with the recommended nonaltering power settings do not cause any surface and thermal damage to the implant itself nor to the surrounding tissue.

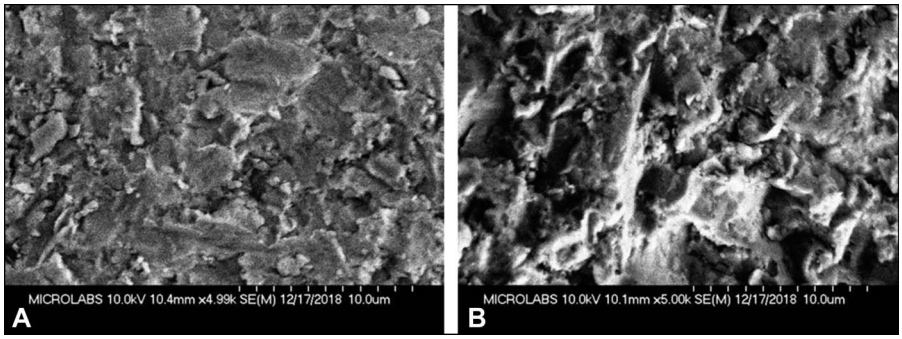

Fig. 10. (**A**–**B**) SEM images of implant no. 13_5_6, irradiated for 2 minutes at nonaltering settings of 20% speed and 100% mist, bottom (**A**) and top (**B**) of the grooves area, ×5000 magnification, showing no damage similar surface to control.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

ROLES/CONTRIBUTIONS BY AUTHORS

S H. Froum: Responsible for the study design and protocol, primary author to write the article. R.-Cantor-Balan: Lead author for the study and protocol implementation, design of experimentation, testing and data analysis. C. Kerbage: Responsible for

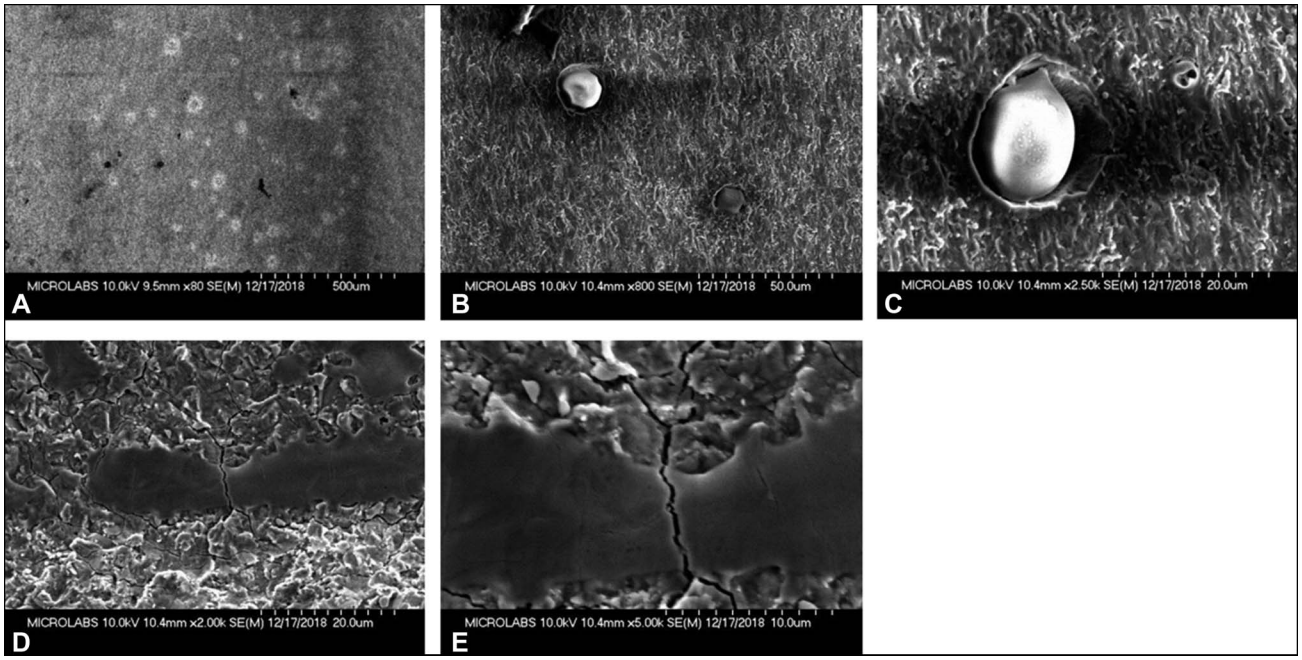

Fig. 11. A–E SEM images of implant no. 13_5_7, irradiated for 10 seconds at surface-altering settings of 30% speed and 100% mist (**A–C**), ×80, ×800, and ×2500 magnifications, respectively, and at 100% speed and 100% mist (**D–E**), ×2000 and ×5000 magnifications, respectively. Both cases show damage of the implant's surface.

oversight of all tests and data analysis. S. J. Froum: Consultant and assisted in reviewing and formatting the article.

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