

## Peri-implant care with the CO<sub>2</sub> laser: In vitro and in vivo results

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### Abstract

**Background:** Numerous applications for dental lasers have been proposed for both clinical use and experimental purposes. A new indication might be the sterilization of exposed implant surfaces in order to rehabilitate ailing implants. The purposes of this study were to assess CO<sub>2</sub> laser parameters for the decontamination process in vitro and to evaluate the method in vivo.

**Methods:** In vitro, temperature changes at the bone–titanium implant interface were recorded during use of a CO<sub>2</sub> laser-scanning system (Swiftlase<sup>®</sup>) and the effects of laser irradiation on titanium implants were examined. In vivo, in 6 beagle dogs, a total of 60 implants and bony defects were treated either conventionally by air-powder-abrasive or by laser irradiation or in combination to evaluate if reosseointegration can occur. In 16 patients (41 ailing implants), the reliability of the CO<sub>2</sub> laser-assisted vs. conventional decontamination was tested.

**Results:** Depending on the parameters chosen, melting and other surface alterations could be seen in vitro. In continuous wave mode, mean power output of 2.5 W for a maximum of 10 s is suitable for the decontamination process. In the beagle dog model, histologic examination revealed new direct bone-to-implant contact following laser-assisted therapy. The clinical study showed 4 months after therapy that laser-decontaminated implants and soft tissue resection resulted in statistically significant better radiographic parameters than conventional decontamination plus soft tissue resection.

**Conclusions:** From these results it was concluded that treatment of peri-implantitis can be optimized using CO<sub>2</sub> laser-assisted implant decontamination. Nevertheless, further studies are required in this field.

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**Keywords:** Implant dentistry; CO<sub>2</sub> laser; Peri-implantitis

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## Introduction

During the past years, many applications for dental lasers have been proposed. A new indication might be the sterilization of exposed implant surfaces in order to rehabilitate ailing implants. However, apparently not all laser systems available in dentistry are of value in this regard.

Block [1] reported that the potential exists for Nd:YAG laser irradiation to melt the surface and even to remove the surface layer from plasma-coated titanium implants. From this study it was concluded that the use of Nd:YAG lasers in implant-uncovering procedures or peri-implant gingival surgery should be considered inherently “unsafe” for such procedures [2].

In contrast, carbon dioxide laser energy is not absorbed to any significant extent by metallic surfaces which reduces the potential for damage to the metallic implant surface and for thermal injury to underlying tissues [2,3]. It has also been shown that carbon dioxide laser irradiation has an important potential of sterilization due to its excellent absorption in water [4]. Therefore, the CO<sub>2</sub> laser has also been recommended recently for applications in implant dentistry which include uncovering implants at second stage surgery and decontamination of exposed implant surfaces [2,5].

However, comparatively little is known about the effect of CO<sub>2</sub> laser energy on dental implants or the surrounding tissues when this device is used for the decontamination process. Accordingly, the purposes of this study were to assess CO<sub>2</sub> laser parameters for the decontamination process in vitro and to evaluate the method in vivo.

## Materials and methods

### Dental laser

The CO<sub>2</sub> laser employed was the model 20C manufactured by the DEKA company (Am Lohmühlbach 12a, Freising, Germany). This laser emits a beam of monochromatic light with a wavelength of 10.6 μm. The 20C has a power output range from 1 to 20 W and can be operated in either a continuous, pulsed or superpulsed mode of laser beam delivery. In superpulse mode, mean power is generated by increasing the frequency of pulses; the energy of each single superpulse is 20 mJ. For example, the lowest mean power setting of 0.5 W is generated by 25 pulses of 20 mJ within 1 s. In this mode, maximum wattage output is limited at 7 W. A handpiece with a focus length of 125 mm was used. In the focus, the spot has a diameter of 200 μm [4].

In addition, an accessory system, the Swiftlase<sup>®</sup>-scanner (Opus-Dent, Am Lohmühlbach 12a, Freising,

Germany), was used according to the design of the study. This system was developed for the purpose of reducing tissue carbonization by sweeping a focused CO<sub>2</sub> laser beam in 0.1 s over an area with a diameter of 3.0 mm (resulting in a total of 7.06 mm<sup>2</sup>). As a result, the dwell time on each individual point of this area is less than 1 ms [4].

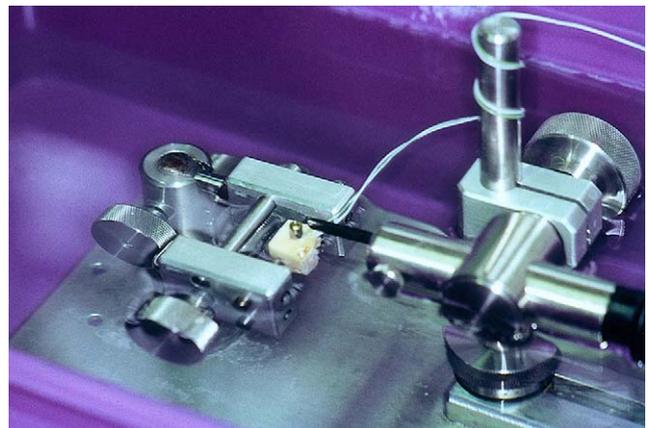
## In vitro studies

### Evaluation of thermal effects

In part one of the in vitro study, an “ailing” implant decontamination protocol was simulated. This was achieved by placing a 11 mm long plasma sprayed Frialit 2 titanium implant (Friadent AG, Mannheim, Germany) in a freshly resected pig mandible [5].

A T-type thermocouple (University of Technology, Department of Electronic Techniques, D-Munich), measuring 0.5 mm in diameter, was positioned 1 mm underneath the marginal level of the bone in the interface and allowed to contact bone and implant simultaneously. Along the implant surface, the lased zone ended 1 mm above the marginal rim of the bone. The implant bearing bone was fixed in a 37 °C water bath. The model system was stabilized at room temperature prior to beginning the irradiation procedure. Temperature changes were recorded using a personal computer connected to the thermocouple (Fig. 1).

Power and exposure time were varied according to the following experimental design: Irradiations were performed in both a continuous mode and in superpulse mode. In both modes, exposure times of 5 and 10 s were tested. The power raised in 0.5 W steps up to the maximum wattage. At each step, only the mean temperature of three measurements was used.



**Fig. 1.** Experimental set-up in vitro. The implant-bearing bone is fixed in a water bath at 37 °C. The level of immersion could not reach the marginal rim of the bone with the thermocouple in the implant–bone interface.

Regarding the lased area of 3.0 mm in diameter, the mean power densities in continuous mode ranged from  $7 \text{ W cm}^{-2}$  to a maximum of  $283 \text{ W cm}^{-2}$  and in super-pulse mode from 7 to  $99 \text{ W cm}^{-2}$ . However, in super-pulse mode, maximum power spikes of 250 W were available due to the very short pulse duration of 80  $\mu\text{s}$ .

At an exposure time of 5 s, the fluences (i.e. the energy densities) in continuous mode ranged from  $35 \text{ J cm}^{-2}$  to  $1.4 \text{ kJ cm}^{-2}$  (and from  $70 \text{ J cm}^{-2}$  to  $2.8 \text{ kJ cm}^{-2}$  at an exposure time of 10 s). In superpulse mode, the energy densities ranged from 35 to  $99 \text{ J cm}^{-2}$  at an exposure time of 5 s (and from 70 to  $198 \text{ J cm}^{-2}$  at an exposure time of 10 s).

### Scanning electron microscopy

In part two of the *in vitro* study, new standard 15 mm plasma-sprayed implants with a diameter of 3.8 mm (Frialit 2, Friadent AG, Mannheim, Germany) were removed from their containers and lased at those power levels which had caused a rise in temperature up to  $47^\circ\text{C}$ . The samples were examined in a scanning microscope (JEOL, USA, Peabody, Mass.) to visualize the entire surface of the lased implants.

### In vivo studies

#### Experimental set-up

Six 2-year-old female beagle dogs from the same pedigree were used in this study. Five 11-mm-long titanium plasma-spray-coated Frialit-2 implants (Friadent AG, Mannheim, Germany) with a diameter of 3.8 mm were placed bilaterally in the premolar and molar region of the mandibles, overall 60 implants. The implants were uncovered 3 months after placement. After 4 weeks of oral hygiene, cotton floss ligatures were positioned around the implants [6]. Gross plaque accumulation around the implants was undisturbed for 3 months, which resulted in circumferential peri-implant bone defects.

Surgical treatment consisted of granulation tissue removal, including decontamination of the implant surface with three different methods. Twenty implants (group 1) were decontaminated conventionally by an air-powder-abrasive [3,7,8], the Prophy-Jet<sup>®</sup>, for 60 s. Another 20 implants (group 2) were decontaminated by laser treatment alone (continuous wave, 2.5 W, duration of 6 times 10 s). The last 20 implants, group 3, were treated conventionally by the Prophy-Jet<sup>®</sup> for 60 s and then lased with the specified parameters for another 60 s.

In each hemi-mandible, only one mode of treatment was performed. Consequently, one treatment method was carried out in 4 hemi-mandibles, resulting in a total of 20 implants per group.

To evaluate the effects of augmentative means, in each group, three non-resorbable membranes of the

same type were positioned (Gore-Tex<sup>®</sup> Augmentation Material Oval 4, W.L. Gore & Associates, USA-Flagstaff/Arizona). Since each group consisted of four hemi-mandibles, each hemi-mandible received one membrane whereas the 4th hemi-mandible, selected randomly, did not.

### Histology and histometry

After a 4-month healing period, the animal heads were fixed by vascular perfusion with 2% glutaraldehyde following a carotid artery “cut-down” procedure. The mandibles were block resected and the undecalcified histologic sections were prepared and analyzed according to the technique of Donath and Breuner [9]. The initial section thickness of 300  $\mu\text{m}$  was reduced to approximately 20  $\mu\text{m}$  with the Exakt grinding unit (Exakt Cutting-Grinding System, Exakt Apparatebau, Norderstedt, Germany). Ground sections were stained with toluidine blue. This stain is particularly well suited to identify bone regeneration and destruction. Mature bone stains pink to purple; newly regenerated immature bone takes on a dark blue color [4].

The specimens were photographed (magnification  $\times 2$ , Ektachrome 100 HC daylight, Kodak, Rochester, USA). The resulting slides were scanned at  $5\times$  magnification (Sprint Scan 35, Polaroid, Munich, Germany) using the Micrografics Picture Publisher 4.0 (Microsoft, Munich, Germany) and stored as bit-map data on a personal computer (INTEL 80486 DX 2/66 16 Mbyte). A 15-inch-monitor (Nokia, Bochum, Germany) was connected to the personal computer which provided a resolution of  $800 \times 600$ . A special software (Adobe Photoshop<sup>®</sup> 5.0., Adobe Systems Inc., Edinburgh, GB) allowed for computer-based histomorphometric analyses with a zoom of 2.5 [10].

Measurements were recorded from the mesial and distal aspects of each implant to evaluate the amount of repositioned bone. Thus, the length of implant embedded in new bone was determined by measuring the distance between the most apical level of new bone in direct contact with the implant surface to the most coronal level of new bone in direct contact with the implant surface. Distances of areas without direct contact to the bone were then measured and subtracted. Since the lengths of the implants were known, the distances measured could be easily converted to their actual dimensions in millimeters.

### Determination of titanium

Fresh specimens of oral mucosa, regional lymph nodes, spleen, liver, lung and kidney were obtained for both histologic and chemical analysis. For the histologic evaluation, standard procedures for soft tissue examination were used.

The titanium concentration in the fresh specimens was determined chemically by the inductively coupled

plasma atomic emission spectroscopy technique [11]. Tissue samples were freeze-dried, mixed with 1 ml of a suprapure solution of HNO<sub>3</sub> and then incinerated to ash in a quartz tube at a temperature of 170 °C for 8 h. Finally, the contents of titanium determined were converted to concentrations of the fresh tissue (µg Ti/g fresh weight).

## Clinical study

Between February 1999 and February 2002, 16 patients were incorporated in this study with a total of 41 ailing implants (progressive vertical bone loss, probing depth (PD) ≥ 5 mm, bleeding on probing). Presurgical treatment consisted of chlorhexidine application (0.3%) for 3 weeks (*T1* = beginning of hygiene phase). Antibiotics were not administered. All patients were allowed to choose either the conventional or the laser-assisted decontamination protocol.

In the control group (group 1 = conventional decontamination with an air-powder-abrasive, Prophy-Jet<sup>®</sup>, Dentsply, USA-York), 6 patients were included with a total of 19 implants (17 IMZ, 2 Frialit 2) and in the laser group (group 2), 10 patients with 22 implants (13 IMZ, 4 Frialit 2, 2 Branemark implants, 3 ITI-screw implants).

After raising full thickness flaps, surgical treatment consisted of granulation tissue removal and implant decontamination (*T2* = surgical intervention). In both groups, implant surfaces were treated with the air-powder-abrasive for 60 s. However, in the laser group, the implants were laser-irradiated, in addition, with the specified parameters (cw 2.5 W, 12 × 5 s). After the decontamination procedure, the full thickness flaps were carefully resected, redraped and sutured.

In all cases, healing was uneventful after surgery. Clinical and radiologic follow-ups were carried out 4 months after therapy (*T3*) and in June 2002 (*T4*). Mean follow up in June 2002 was 17 months (6 months minimum, 38 months maximum). For the radiographic evaluation, standardized orthopantomograms were used (Oralix multiscan, Fa. Gendex).

The following clinical parameters were identified: Oral hygiene was evaluated with the sulcus-bleeding index and the approximal plaque index [12]. The PD [13] was measured with the periodontal probe PCP 11 (Aesculap AG, D-Tuttlingen) between the marginal rim of the mucosa and the bottom of the sulcus. The distance between the implant shoulder and the marginal mucosa (DIM) [13] was measured similarly. Consequently, the value for the attachment level (AL) was the sum of the PD and the distance from the implant shoulder to the marginal rim (DIM): AL = PD + DIM.

In the radiographs, evaluation of the distance between implant and bone (DIB) was carried out according to the method described by Buser et al. [13] on the mesial

and distal aspects of the implants. The DIB value over time provided information on resorption of the peri-implant marginal bone. The measurements were made with calipers on a back-lit screen in a darkened room. For conversion to the original dimensions, the distance from the implant upper edge to the tip of the implant was used as the reference length.

## Statistic analysis

Statistical analysis was performed using a commercial computer program (Microsoft Excel<sup>®</sup>, version 97, Munich, Germany). Data are presented as means ± standard deviation or as counts or proportions.

In the beagle dog study, two-tailed Student's *t*-tests permitted comparison of the repositioned bone in the three treatment groups. A *P*-value less than 0.05 in the two-tailed test was considered to indicate statistical significance.

In the clinical study, two-tailed Student's *t*-tests permitted comparison of the clinical and radiologic parameters in the two treatment groups. Again, a *P*-value less than 0.05 in the two-tailed test was considered to indicate statistical significance.

## Results

### Results of the in vitro studies

#### Thermal effects

Table 1 shows the temperature changes that incurred when the implant was subjected to laser energy. In continuous wave irradiation, a power of 2.5 W could be used without thermal damage to the surrounding bone. Considerably higher temperature increases were observed at all power levels with superpulse irradiation.

#### Scanning electron microscopy

The surface sections of all cw-irradiated plasma-sprayed titanium implants maintained the typical structure of the plasma spray layer without any sign of thermal damage. Accordingly, continuous wave irradiation does not appear to exert adverse effects on the

**Table 1.** Effect of continuous (cw) and superpulse (sp) laser beam on implant temperature

Power (W)	0	0.5	1.0	1.5	2.0	2.5	3.0
cw 5 s ( $\Delta T$ , °C)	0	0.5	1.3	2.7	4.1	5.7	7.9
cw 10 s ( $\Delta T$ , °C)	0	0.5	2.8	5.1	7.9	10.1	13.2
sp 5 s ( $\Delta T$ , °C)	0	0.5	2.1	3.7	5.1	7.5	9.0
sp 10 s ( $\Delta T$ , °C)	0	0.6	3.4	6.6	9.6	12.5	15.6

Relative temperature response as a function of variations in wattage (0–3 W) and exposure time (5 and 10 s).

surface properties. Superpulse irradiation, however, resulted in sufficient heat accumulation at the surface of the implant to melt the plasma-sprayed titanium, thereby reducing or eliminating the surface porosity with resultant microfracturing.

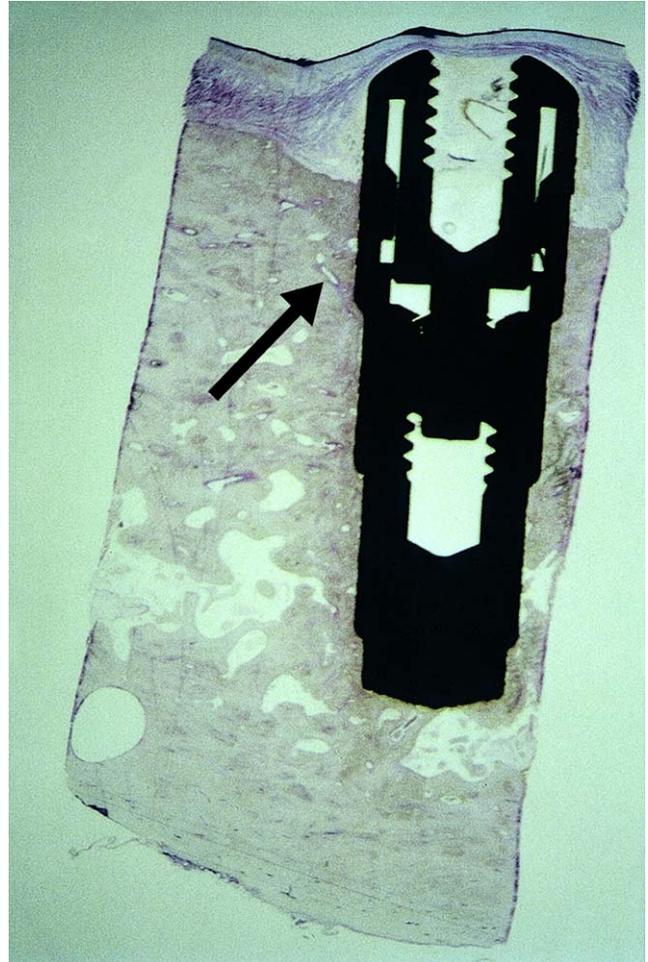
## Results of the animal study

### Histologic observations and histometry

In group 1 (conventional decontamination), minimal new bone formation was observed (Fig. 2). The specimens of laser-assisted groups 2 and 3 demonstrated large amounts of rapidly formed lamellar bone with active bone formation still occurring. Some areas of the previously contaminated implant surfaces showed evidence of new direct bone-to-implant contact without an intervening band of connective tissue (Figs. 3 and 4). In the 40 laser-treated implants, no signs of thermal damage to the surrounding bone could be found. In the histometric evaluation, however, no statistically



**Fig. 2.** Implant after conventional therapy (group 1): Minimal new bone formation indicated by an arrow. Toluidine blue, magnification  $\times 5$ .



**Fig. 3.** Implant after laser-assisted therapy (group 2): Large areas of newly formed bone in direct implant contact (new bone stained darker than old bone; arrow). Toluidine blue, magnification  $\times 5$ .

significant differences could be detected between the three therapy groups (Table 2).

Almost complete filling of the defects was seen in implants additionally treated with submerged membranes [4] (Fig. 5).

### Titanium concentration of tissues

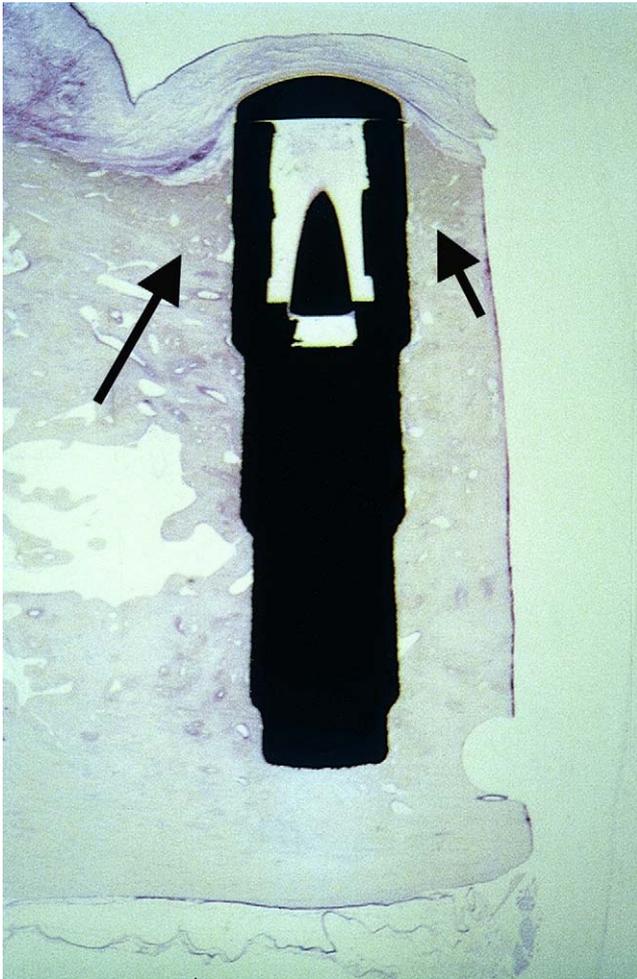
Mean values of titanium concentrations in various tissues of all six dogs were evaluated. As can be seen in Table 3, the maximum concentration was found in the spleen, followed by liver, oral mucosa, kidney, regional lymph nodes and lung. This order was the result of an extremely wide range of the titanium concentrations in the spleen. It should also be noted that wide ranges were also found in all other tissues [11].

### Results of the clinical study

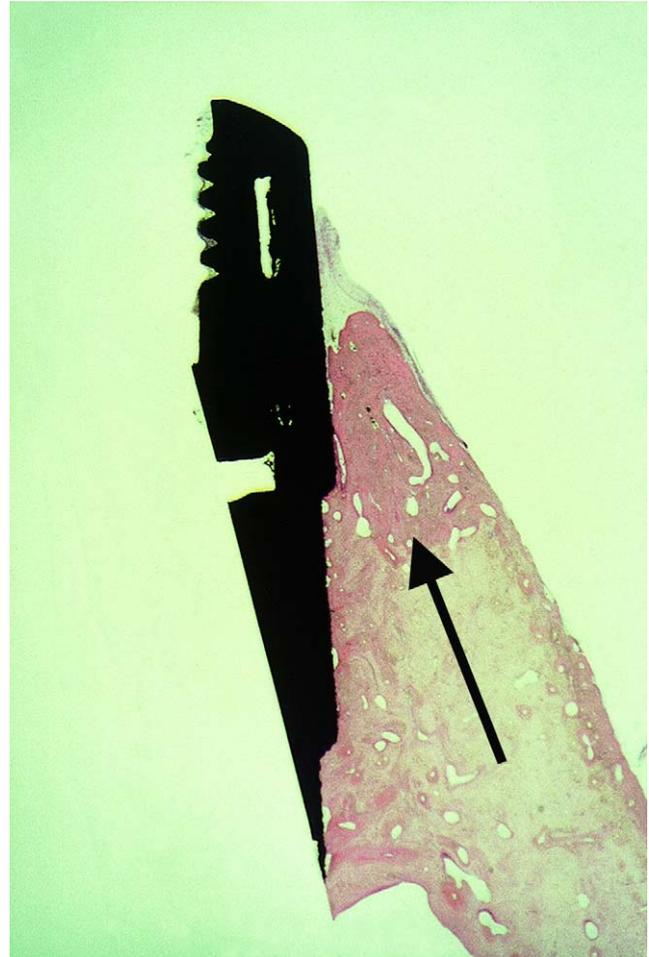
Four months after therapy, implants treated with laser decontamination and soft tissue resection showed

statistically significant better clinical ALs than implants treated with conventional decontamination followed by soft tissue resection (Figs. 6–8, Tables 4–6). On the opposite, at the end of the study (T4), there was no more statistically significant difference between these two groups. Radiographic evaluation 4 months after therapy (T3) revealed that there was no statistically significant

difference concerning DIB values, but existed at the end of the study (Tables 4, 5 and 7). However, three implants were lost due to progressive bone loss as well in the laser group as in the conventionally treated group. Nevertheless, from these results it was concluded that treatment of peri-implantitis could be optimized using a laser-assisted decontamination.



**Fig. 4.** Implant after combination treatment (group 3): Also, large amounts of new bone formation (arrow) in direct contact to the formerly contaminated implant surface. Toluidine blue, magnification  $\times 5$ .



**Fig. 5.** Section of an implant after combination treatment (group 3), concomitantly treated with a non-resorbable membrane: new bone formation up to the level of the cover screw. Repositioned bone (arrow) even on the smooth surface of the implant surface. Toluidine blue, magnification  $\times 5$ .

**Table 2.** Results of the beagle-dog study

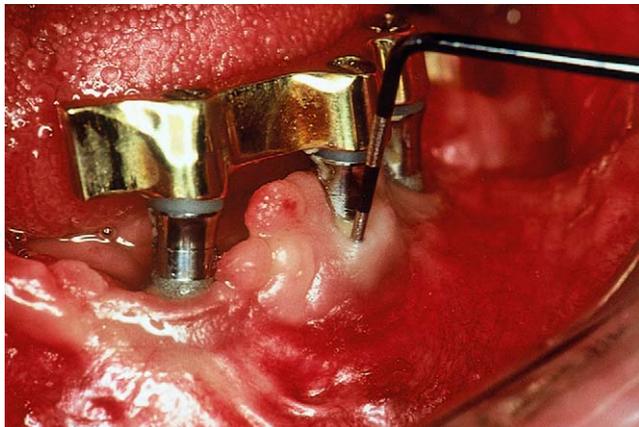
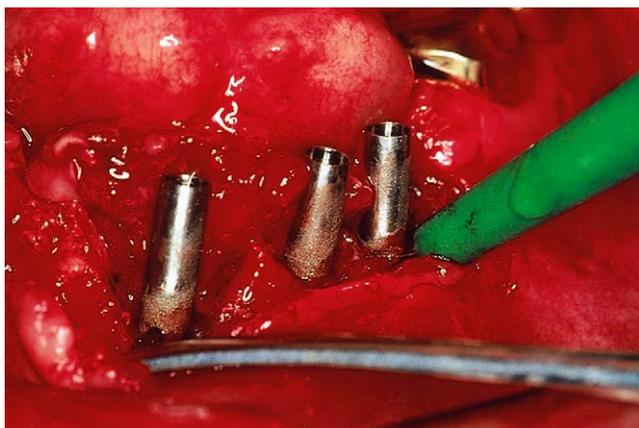
Average defect depths and average reapposition of regenerated bone												
	Group 1				Group 2				Group 3			
Parameter	Average	SD	Min	Max	Average	SD	Min	Max	Average	SD	Min	Max
Depth of defects	1.7	0.8	0	2.9	1.7	0.9	0.1	3.7	1.7	0.5	0.9	3.3
Bone gain in histometry (mm)	0.64	0.68	0	2.2	0.62	0.58	0	2	0.75	0.52	0	2.2

Average defect depths and average reapposition of regenerated bone in all three groups (mean values, standard deviation, maxima and minima). Group 1: Conventional therapy with an air-flow powder instrument for 60 s. Group 2: Laser-assisted treatment (cw, 2.5 W, 12 times 5 s). Group 3: Decontamination first with an air-powder-abrasive and then lasing with the specified parameters.

**Table 3.** Results of the beagle-dog study

	OM	LN	Spleen	Liver	Lung	Kidney
Mean ( <i>n</i> = 6)	1.83	1.78	4.14	2.01	1.48	1.30
Min.	0.11	0.17	0.16	0.32	0.64	0.1
Max.	8.78	4.77	15.7	7.37	5.08	7.41
SD	2.68	2.01	7.7	2.72	1.76	2.51

Titanium concentration in  $\mu\text{g/g}$  fresh weight. Mean values, minima (Min.), maxima (Max.) and standard deviation (SD) of different tissues of all six animals. Local tissues (OM oral mucosa, LN regional lymph nodes) showed now higher titanium concentrations than visceral organs. Highest titanium concentration in the spleen, lowest in kidney.

**Fig. 6.** Severe peri-implant bone loss.**Fig. 7.** Surgical intervention: CO<sub>2</sub> laser-assisted implant decontamination.

## Discussion

The purpose of this study was to determine whether (1) CO<sub>2</sub> laser-assisted decontamination of exposed implant surfaces has adverse effects on the reosseointegration of so-called ailing implants in the dog model, (2) CO<sub>2</sub> laser irradiation might enhance the amount of

**Fig. 8.** Clinical result 4 months after therapy. Peri-implant tissues free of inflammatory reaction.

titanium release of dental implants, (3) to assess the reliability of CO<sub>2</sub> laser-assisted implant decontamination vs. a conventional decontamination procedure in humans.

(1) In the beagle dog model, laser-assisted decontamination of exposed implant surfaces had no adverse effects on the reosseointegration of so-called ailing implants. In contrast, previously contaminated implant surfaces showed evidence of reosseointegration. However, based on the results of the *in vitro* study, it can no longer be stated that, in general, carbon dioxide laser irradiation is safe when applied to titanium implants. Consequently, superpulse irradiation cannot be recommended for peri-implant care. This observation is in agreement with the most current literature. Rechmann and coworkers [3] reported that dental implants, subjected to pulsed CO<sub>2</sub> laser irradiation, showed no signs of ablation (energy fluences were unfortunately not reported). Nevertheless, the authors assumed that higher spike pulse powers may also alter the surface in accordance with the results of this study.

The results of the beagle dog study, however, emphasize that the laser parameters chosen for the decontamination can be considered “safe” for such procedures and for the regeneration capacity of the surrounding bone. However, on comparison of the three therapy groups, the results of the histometric analysis showed no statistically significant difference. Nevertheless, the present study provides histologic evidence of the potential for bone regeneration after CO<sub>2</sub> laser irradiation.

(2) Since titanium is known to be a very reactive metal, under atmospheric conditions, laser irradiation could generate a thickened layer of titanium oxides on the implant. These oxides, again, are less resistant to mechanical stress [11], thereby possibly imposing

**Table 4.** Results of the clinical study. Means and standard deviations at various times of evaluation after conventional decontamination (group 1) and soft tissue resection. “*n*” = numbers of implants evaluated at time *T1*–4.

Time	PI	SBI	PD	DIM	AL	DIB
<i>T1</i> ( <i>n</i> = 19)	1.8 ( $\pm$ 1.2)	2.7 ( $\pm$ 0.9)	6.6 ( $\pm$ 1.8)	1.1 ( $\pm$ 1.2)	7.7 ( $\pm$ 1.3)	7.8 ( $\pm$ 1.6)
<i>T2</i> ( <i>n</i> = 19)	0.7 ( $\pm$ 0.8)	0.7 ( $\pm$ 0.8)	5.1 ( $\pm$ 1.3)	1.9 ( $\pm$ 1.1)	7.0 ( $\pm$ 0.9)	7.6 ( $\pm$ 1.4)
<i>T3</i> ( <i>n</i> = 15)	0.6 ( $\pm$ 0.7)	0.9 ( $\pm$ 0.5)	3.2 ( $\pm$ 0.9)	3.1 ( $\pm$ 1.4)	6.3 ( $\pm$ 1.1)	7.2 ( $\pm$ 1.9)
<i>T4</i> ( <i>n</i> = 16)	0.8 ( $\pm$ 0.9)	1.2 ( $\pm$ 1.1)	4.2 ( $\pm$ 1.2)	2.6 ( $\pm$ 1.3)	6.8 ( $\pm$ 0.8)	7.9 ( $\pm$ 1.5)

**Table 5.** Results of the clinical study. Means and standard deviations at various times of evaluation after laser decontamination (group 2) and soft tissue resection. “*n*” = numbers of implants evaluated at time *T1*–4.

Time	PI	SBI	PD	DIM	AL	DIB
<i>T1</i> ( <i>n</i> = 22)	1.4 ( $\pm$ 0.9)	2.8 ( $\pm$ 1.2)	5.7 ( $\pm$ 1.4)	1.5 ( $\pm$ 1.8)	7.2 ( $\pm$ 1.5)	7.4 ( $\pm$ 1.1)
<i>T2</i> ( <i>n</i> = 22)	0.7 ( $\pm$ 0.8)	0.6 ( $\pm$ 0.3)	6.1 ( $\pm$ 1.6)	0.8 ( $\pm$ 1.2)	6.9 ( $\pm$ 0.8)	7.2 ( $\pm$ 1.3)
<i>T3</i> ( <i>n</i> = 20)	0.8 ( $\pm$ 0.6)	0.7 ( $\pm$ 0.6)	2.1 ( $\pm$ 1.3)	3.4 ( $\pm$ 0.8)	5.5 ( $\pm$ 0.9)	6.9 ( $\pm$ 1.4)
<i>T4</i> ( <i>n</i> = 17)	0.9 ( $\pm$ 1.2)	1.7 ( $\pm$ 1.0)	3.5 ( $\pm$ 1.6)	3.2 ( $\pm$ 1.5)	6.7 ( $\pm$ 0.6)	6.8 ( $\pm$ 0.8)

**Table 6.** Analysis of clinical attachment levels: At *T3*, laser-assisted therapy (group 2) shows a statistically significant better result than conventional decontamination (group 1). On the opposite, at *T4*, there is no more statistically significant difference at the 0.05 level between these two methods.

Attachment level	Mean $\pm$ SD	<i>n</i>	<i>t</i> -value	Difference significant?
<i>T3</i> : Group 2/Group 1	5.5 ( $\pm$ 0.9)/6.3 ( $\pm$ 1.1)	20/15	–3.87	Yes ( $p \leq 0.002$ )
<i>T4</i> : Group 2/Group 1	6.7 ( $\pm$ 0.6)/6.8 ( $\pm$ 0.8)	17/16	–2.28	No

**Table 7.** Analysis of radiographic DIB values: At *T3*, there is no statistically significant difference between laser-assisted decontamination (group 2) and conventional decontamination (group 1). On the opposite, at *T4*, laser-assisted therapy is more of value than conventional decontamination.

DIB values	Mean $\pm$ SD	<i>n</i>	<i>t</i> -value	Difference significant?
<i>T3</i> : Group 2/Group 1	6.9 ( $\pm$ 1.4)/7.2 ( $\pm$ 1.9)	20/15	–0.91	No
<i>T4</i> : Group 2/Group 1	6.8 ( $\pm$ 0.8)/7.9 ( $\pm$ 1.5)	17/16	–4.80	Yes ( $p \leq 0.002$ )

a higher titanium load on the tissues. In another study in beagle dogs, titanium concentrations of almost all organs were under the detection limit ranging from 0.01 to 0.21  $\mu\text{g/g}$  [14]. However, titanium was found in 12 of 19 regional lymph nodes with concentrations between 0.16 and 9.0  $\mu\text{g/g}$  [14]. In the present study, titanium concentrations in the visceral organs ranged from 0.14 to 7.41  $\mu\text{g/g}$ , the concentrations of the regional lymph nodes from 0.11 to 8.78  $\mu\text{g/g}$ . Thus, these results are very similar to those of Weingart concerning titanium levels in the lymph nodes, but exceed those of the visceral organs [14]. Nevertheless, these levels are still lower than those determined by Schliephake in the mini-pig which had resulted just from placing dental implants alone without any decontamination procedure [15,16].

Therefore, the titanium levels after CO<sub>2</sub> laser decontamination cannot be regarded as increased even though rough plasma-sprayed implants were used in this study.

- (3) The results of the clinical study indicated that, early after treatment (*T3*), laser-assisted decontamination plus soft tissue resection results in very similar bony ALs as conventional decontamination plus soft tissue resection (DIB 6.9 ( $\pm$ 1.4) vs. DIB 7.2 ( $\pm$ 1.9), Tables 4 and 5). In contrast, over the long term (*T4*), ongoing bone resorption occurred in the conventionally decontaminated group 1, not following laser decontamination (DIB 7.9 ( $\pm$ 1.5) vs. DIB 6.8 ( $\pm$ 0.8), Tables 4 and 5). Nevertheless, due to the small sample size, it is not yet clear whether CO<sub>2</sub> laser decontamination is indeed more of value in the treatment of peri-implantitis in humans.

However, there are several positive reports in the literature on use of laser decontamination in general. Application of a diode laser ( $\lambda = 810 \text{ nm}$ ) resulted in recurrence rates of less than 7% [17]. In a another clinical study, Haas and coworkers reported on use of photodynamic therapy with toluidine blue plus diode laser light ( $\lambda = 906 \text{ nm}$ ) in a total of 24 ailing implants [18]. This method resulted in a mean bony reapposition of 2 mm ( $\pm 1,90 \text{ mm}$ ) after a 9.5-month period. Schwarz and Coworkers [19] have demonstrated clinically that also the wavelength of the Er:YAG laser ( $\lambda = 2,94 \mu\text{m}$ ) is of value in the treatment of peri-implant infections. Therefore, many laser wavelengths seem to have advantages in the treatment of ailing implants, alone or in combination with conventional methods. However, bone reappositions have only been demonstrated histologically for the  $\text{CO}_2$  laser [4].

## Conclusion

From these results it may be concluded that  $\text{CO}_2$  laser decontamination has no adverse effects on the osseointegration of ailing implant, neither in the beagle dog nor in humans. Over the long term, clinical and radiographic parameters indicated that the decontamination process with use of the  $\text{CO}_2$  laser can stop the progression of inflammatory bone resorption very effectively. However, the success of any laser treatment is based on good education. Nevertheless, there are also several limits in the laser therapy, especially in mobile implants. In such cases, explantation is indicated. Therefore, laser treatment of ailing implants ought to be of noticeable interest for qualified laser centers or practitioners. Further studies are required in this field to identify a gold standard in the treatment of ailing implants.

## Zusammenfassung

### Periimplantitis-Therapie mit dem $\text{CO}_2$ -Laser: Ergebnisse in vitro und in vivo

**Einleitung:** In den letzten Jahren wurde eine zunehmende Zahl von Indikationen für den Einsatz von Dentallasern genannt. Eine neue Anwendung könnte in der Dekontamination freiliegender Implantatoberflächen bestehen. Ziel dieser Untersuchungen war, geeignete Laserparameter in vitro und in vivo zu identifizieren und die Methode am Patienten zu überprüfen.

**Material und Methode:** In vitro wurden die Temperaturanstiege am Titan-Knochen-Interface während  $\text{CO}_2$  Laser-Bestrahlung unter Verwendung eines Scanners gemessen und die Auswirkungen auf die Implantatmorphologie untersucht. In einer tierexperimentellen Studie

wurden insgesamt 60 periimplantäre Defekte konventionell, durch Laserbestrahlung bzw. in Kombination therapiert und histologisch untersucht, inwieweit knöcherne Reappositionen möglich sind. Ziel einer klinischen Studie an 16 Patienten bzw. 41 Implantaten war es, die Laser-gestützte Dekontamination im Vergleich zum konventionellen Vorgehen zu evaluieren.

**Ergebnisse:** Abhängig von den Parametern waren Aufschmelzungen der Implantatoberfläche zu erkennen. Im cw-Betrieb waren dagegen mittlere Leistungen bis zu 2,5 W für bis zu 10 s Bestrahlungszeit applizierbar, ohne die kritische Temperatur am Interface zu überschreiten. Im Tiermodell zeigten sich nach 4 Monaten knöcherne Reappositionen an vormals kontaminierten Implantatoberflächen. In einer klinischen 3-Jahres-Studie waren nach Lasertherapie bessere röntgenologische Parameter nachweisbar als nach konventioneller Dekontamination.

**Konklusion:** Aufgrund dieser Ergebnisse wurde die Schlussfolgerung gezogen, dass die  $\text{CO}_2$ -Laser-assistierte Implantatdekontamination die Therapie periimplantärer Entzündungen optimieren kann. Weitere Studien sind erforderlich, um ein gesichertes Behandlungsprotokoll für die Periimplantitistherapie erstellen zu können.  
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**Schlüsselwörter:** Implantologie;  $\text{CO}_2$  Laser; Periimplantitis

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