Endosseous dental implants are an established treatment alternative for edentulous and partially edentulous patients. Besides undisturbed osseointegration and an adequate prosthetic design, maintenance is crucial for a good long-term prognosis. Clinical implant success can be jeopardized by bacterial infection inducing mucositis or periimplantitis. Most titanium implants feature a rough surface to increase areas of implant-bone contact and anchorage force in the alveolar bone.

Surface roughness, however, makes elimination of bacteria from implants difficult. Sterilization and cleaning of implant surfaces by means of lasers has been suggested. Still, the bactericidal potential of some lasers on roughened surfaces requires considerable scientific investigation. A variety of laser systems (CO₂, Nd:YAG, Er:YAG, Ho:YAG, GaAlAs, argon) are available for different dental applications. Some of the lasers, however, are not suitable for decontamination of implant surfaces, since, even at minimal power settings, considerable surface damage can be observed. Moreover, except for studies carried out with the CO₂ laser, no information about potentially excessive heat generation at the implant-bone interface has been published. Temperatures of 47 to 50°C have been shown to induce tissue damage in the bone. This threshold must not be exceeded during laser application. Clinical guidelines are therefore necessary to ensure a safe treatment protocol when using the laser technique.

Purpose: This study investigated temperature changes at the implant-bone interface during simulated implant surface decontamination with an Er:YAG laser.

Materials and Methods: Step cylinder implants with three different surfaces (titanium plasma sprayed, sandblasted and acid etched, and hydroxyapatite coated) were placed in bone blocks cut from freshly resected pig femurs. An artificial periimplant bone defect with a size of 6 mm² provided access for laser irradiation in the coronal third of the implant. A 540-µm periimplantitis application tip was used at a distance of 0.5 mm from the implant surface. Pulse energy was varied between 60 and 120 mJ at 10 pps. The bone block was placed into a 37°C water bath to simulate in vivo thermal conductivity and diffusivity of heat. K-type thermocouples connected to a digital meter were used to register temperature changes at three levels of the periimplant bone.

Results: The temperature at the implant-bone interface did not exceed 47°C after 120 seconds of continuing laser irradiation. Temperature elevations were significantly higher at the hydroxyapatite-coated implants than in the two titanium surface groups (P < .001).

Conclusion: Decontamination of implant surfaces by means of the Er:YAG laser did not excessively heat the periimplant bone within the energy range investigated. This technique therefore seems clinically safe, at least when used with the surfaces studied.

This study is part of a research program investigating the possibilities and hazards of various laser systems in dental implant applications. The aim of this study was to investigate temperature elevations at the implant-bone interface during simulated surface decontamination by means of a 2,940-nm Er:YAG laser. It was of particular interest whether, at clinically relevant laser power settings, temperature elevations that can induce bone injury occur. Moreover, the influence of different implant surfaces on the heat generation was studied.

Materials and Methods

Stepped cylinder implants (Frialit 2, Friadent) with a diameter of 3.8 mm and a length of 11 mm with three different surfaces (Ti plasma sprayed, sandblasted and acid etched, hydroxyapatite coated) served as substrates.

A 2,940-nm Er:YAG laser (Kavo Key Laser II, Kavo) with a 540-µm perimplantitis application tip and an integrated water cooling system was used. Pulse energy varied between 60 and 120 mJ at 10 pps. During the tests, irradiation was performed alternatively with and without cooling. The temperature of the cooling agent used at time of operation was 23.5°C.

Experimental Setup

Bone blocks of 20 mm × 15 mm × 9 mm were cut from fresh pig femurs. Implant cavities were drilled according to the standard protocol for this implant system.20 Before placing the implants, access holes of 0.5 mm were drilled into the bone to allow thermocouples to contact periimplant bone in the apical, middle, and coronal parts of the implant site. The implants were placed into the block, and a healing abutment was inserted. On one side of the block, a dehiscence in the coronal third was cut to simulate a periimplant bone defect and allow undisturbed irradiation of the implant surface. The size of the defect was 2 mm × 3 mm, corresponding to approximately one sixth of the circumferential area of the implant. The access holes were filled with a thermococonductive paste, and three K-type 0.5-mm thermocouples were inserted and affixed with light-curing resin (Charisma, Heraeus Kulzer).

Radiographs were taken to verify the position of the thermocouples close to the implant-bone interface. The entire block was placed into a water-filled heating circulator (Julabo MWB, Julabo Labortechnik), with only the area to be lased not being submerged. The optic fiber was positioned perpendicular to the implant surface at a distance of 0.5 mm (Fig 1). Prior to irradiation, the system was stabilized at a temperature of 36.5 to 37.0°C to simulate in vivo thermal conductivity and diffusivity of heat. Irradiation time was 120 seconds. Temperature changes during irradiation were recorded using a multichannel digital meter (Omega Engineering) connected to the thermocouples. Recordings were performed simultaneously at three measuring points (MP 1 to 3) every second for an 8-minute period. Between two laser treatments, the system was allowed to cool to the initial temperature (Fig 2).

Statistical Analysis

A total of 360 measurements with and 360 without water cooling were performed. The statistical analysis was carried out with a statistics package (SPSS for Windows, release 10.0.5, SPSS). The differences in temperature prior to irradiation and after 120 seconds of laser application were calculated. The box-plot design21 was chosen to present the results. Data were shown separately for each implant surface. Group comparison at each pulse energy and measuring point, respectively, was performed by means of the Mann-Whitney U test, and differences were considered to be significant when $P < .05$.

Results

When irradiation was performed without water cooling, temperature increases were observed. Figures 3 to 5 show the temperature elevations related to the
various pulse energies used, determined at three different measuring points. Temperature elevations increased with rising pulse energy and decreased with greater distance from the spot of irradiation to the respective measuring point. The values in the hydroxyapatite group were significantly higher than in the plasma-sprayed and sandblasted groups. Differences between the two titanium surfaces were predominantly not significant. Only at MP 2 at a pulse energy of 120 mJ were significantly higher temperature elevations measured in the sandblasted implants. Starting irradiation at the baseline temperature of 36.5 to 37°C, lasing did not result in temperature increases over 47°C after 120 seconds.

The application of the water cooling system during irradiation resulted in a temperature decrease at the implant-bone interface (Fig 6). As a mean, the temperature fell by 2.7°C (60 mJ), 2.3°C (80 mJ), 1.6°C (100 mJ), and 1.3°C (120 mJ) after a lasing time of 120 seconds (values for MP 1 in the titanium plasma-sprayed group). Differences between the measuring points were below 1°C. The values were comparable to those obtained at the other surfaces studied.

**Discussion**

According to the results of the present study, Er:YAG laser irradiation of implant surfaces at pulse energies between 60 and 120 mJ did not induce excessive heat generation in the periimplant bone. The maximum temperature elevations presented were determined after a continuing irradiation of 120 seconds without the application of a cooling agent. Even after this relatively long period, a temperature of 47°C was not exceeded.

This indicates that water cooling is not really necessary when irradiating ailing implants with an Er:YAG laser. Using the integrated cooling system, the treatment of contaminated implants would not require the consideration of heat generation, even at longer irradiation periods, or probably even at higher pulse energies. It has not yet been investigated, however, whether a water film on the laser-treated titanium or hydroxyapatite surface might adversely influence the decontamination process, since laser light of 2,940 nm is very well absorbed in water. Therefore, decontamination was simulated with and without water cooling. The laser system studied allowed variation of the pulse energy between 60 and 250 mJ. The decision to limit the energy to 120 mJ was based on investigations showing that higher pulse energies can result in structural damage of commonly used implant surfaces.

In vitro investigations have provided proof that lasers are an effective tool for the elimination of periodontitis- and periimplantitis-relevant pathogens. It seems, therefore, that the application of lasers might be an adequate treatment alternative for ailing implants. Under standardized in vitro conditions, the Er:YAG laser op-
erated at pulse energies of 60 to 120 mJ guarantees a significant bacterial reduction on Ti plasma-sprayed, acid-etched, and hydroxyapatite-coated implant surfaces.30 The application of high-energy lasers in dentistry, however, requires special consideration regarding potential risks of inadvertent tissue and material damage. With regard to the treatment of periimplantitis, this refers to possible implant surface alterations and excessive heat generation in the perimplant bone. Temperatures of 47 to 50°C during implant surgery significantly reduce bone formation, resulting in potential implant failure.19 Although the biologic effect of excessive heat generation in already osseointegrated implants has not yet been investigated, it must be taken into consideration that this process might impair bone remodeling or even induce implant deintegration.

When laser light is absorbed by atoms or molecules, light energy is converted into heat.31,32 The mode of operation (continuous wave [cw] or pulsed) of a laser system is decisive for the resulting temperature gradient in biologic tissues as well as in metals.31,33 When working in the cw mode, the maximum peak energy is relatively low and corresponds to the average energy over the time of laser light emission. A slow but steady warming of the metal body can be observed, and considerable temperature elevations can be recorded, even in remote parts of the object. Pulsed lasers (YAG, CO2) with enormous energy peaks are, eg, capable of generating high surface heating with a steep temperature gradient.31 Because of the short period of laser-metal interaction, thermal diffusion is minimal and high temperatures are, to a large extent, restricted to the area adjacent to the spot of irradiation.10,34

Unfortunately, it is not possible to determine temperatures at the spot of irradiation by means of ther-
mocouples. With regard to the clinical problem, however, it is more important to investigate temperature increases at the periimplant bone. Temperature changes are primarily dependent on the absorption of laser energy. Interaction of laser light with materials can be described in terms of reflection, transmission, scattering, and absorption.\(^8,31,32,33\) Reflection capacity of smooth titanium for light with a wavelength of 3,000 nm is 71%.\(^10\) To our knowledge, data on reflection capacity of different implant surfaces for monochromatic light of 2,940 nm are not available. It must be presumed that it is lower in the hydroxyapatite surface than in the two titanium surfaces, resulting in higher absorption and therefore higher temperature elevations.

Previous studies described temperature elevations in titanium implants during simulated CO\(_2\) laser-assisted stage-two surgery and surface decontamination. Mean temperature elevations from 2.03°C (power output 2 W; cw; irradiation time 2 seconds) to 8.53°C (4 W; cw; 8 seconds) have been reported.\(^14\) In a further study, temperature changes at the implant-bone interface at different output powers, pulse repetition rates, pulse widths, irradiation periods, and implant surface conditions (dry and wet) were studied. The range in temperature elevations was between 1 and 19°C.\(^18\) Because of numerous variable parameters, such as wavelength of the laser system, power output, mode of operation, time of irradiation, distance of the fiber from the specimen, and working angle, it is very difficult to compare results from different investigations. It is crucial, however, to find adequate irradiation parameters for each laser system to ensure reliable implant decontamination without inducing structural changes in the implant surface and jeopardizing bone vitality.

When operated within appropriate irradiation parameters, the Er:YAG laser seems to be suitable for decontaminating various implant surfaces without adverse effects to implants and periimplant bone. Clinical studies are needed to evaluate this laser system in the treatment of periimplantitis.

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References

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Temperature of the implants before and after treatment was detected using a thermocouple. The use of air abrasive and citric acid combination and Er:YAG laser groups was found as the best methods for the decontamination of titanium surfaces of failed implant. When the hand instruments were compared, titanium curette was found better than both the plastic and the carbon curettes which leave plastics and carbon remnants on the titanium surface. The temperature was higher after hand instrumentation when compared to other experimental groups (p < 0.05). Kreisler M, Al Haj H, d'Hoedt B (2002) Temperature changes at the implant-bone interface during simulated surface decontamination with an Er:YAG laser. Int J Prosthodont 15(6):582â€”587. @article{Rios2016TemperatureEO, title={Temperature evaluation of dental implant surface irradiated with high-power diode laser}, author={F. G. Rios and E. R. Viana and G. M. Ribeiro and J. C. Gonçalvez and A. Abelenda and D. Peruzzo}, journal={Lasers in Medical Science}, year={2016}, volume={31}, pages={1309-1316} }. Temperature changes induced by 809-nm GaAlAs laser at the implant-bone interface during simulated surface decontamination. The Er:YAG laser generates the least amount of heat in the bone tissue surrounding the implant. The decontamination mechanism of the lasers is based on their thermal effect, which denatures proteins and produces cell necrosis. Another type of laser with a low thermal effect on the bone and implant surface is the Er,Cr:YSGG, which represents an improvement over the technical properties of the Er:YAG. Further regenerative treatment will depend on the amount of bone loss and the esthetic impact of the implant in question. J Oral Implantol 1992;18: Kreisler M, Al Haj H, d'Hoedt B. Temperature changes at implant bone interface during simulated surface decontamination with an Er:YAG laser. Int J Prosthodont 2002;15: Vol 8, No 2, 8 21. Results: During and after laser therapy, there was no pain or bleeding at the surgical site. At 1 week, the treated gingiva showed fast epithelization with a healthy appearance, but immature healing, in all cases. At 1 month, complete healing with tissue maturation was observed and the gingiva exhibited normal appearance. No post-operative infection or scarring, gingival recession or deformity occurred in any of the patients on rst or subsequent visits. Kreisler M, Al Haj H, d'Hoedt B: Temperature changes at the implantâ€”bone interface during simulated surface decontamination with an Er:YAG laser, Int J Prosthodont 15:582,2002. Moritz A, Schoop U, Goharkhay K, Schaver P, Doertbudak O, Wernisch J, et al. Treatment of periodontal pockets with a diode laser.