# Effect of Nd:YAG, Ho:YAG, Er:YAG, $CO_2$, and GaAlAs Laser Irradiation on Surface Properties of Endosseous Dental Implants

Matthias Kreisler, Dr med dent[1]/Hermann Götz, Dipl-Phys[2]/
Heinz Duschner, Univ-Prof Dr rer nat, Dr med dent habil[3]/Bernd d'Hoedt, Univ-Prof Dr med dent[4]

***Purpose:*** *To analyze potential surface alterations in endosseous dental implants induced by irradiation with common dental lasers.* ***Materials and Methods:*** *Sandblasted and acid-etched, plasma-sprayed, hydroxyapatite-coated, and smooth titanium discs were irradiated using Nd:YAG, Ho:YAG, Er:YAG, $CO_2$, and GaAlAs lasers at various power settings. The specimens were examined by scanning electron microscopy and energy dispersive spectroscopy.* ***Results:*** *In an energy-dependent manner, the pulsed YAG lasers induced partial melting, cracking, and crater formation on all 4 surfaces. Within the energy range applied, the $CO_2$ laser caused surface alterations on the hydroxyapatite and plasma coatings as well as in the acid-etched surface. GaAlAs laser irradiation did not damage any of the surfaces. Energy dispersive spectroscopy revealed an altered chemical compound of the surfaces with regard to titanium, oxygen, and silicon.* ***Discussion:*** *The clinical application of most common dental laser systems can induce implant surface alterations. Relevant factors are not only the laser system and power setting, but also the application system.* ***Conclusion:*** *The results of the study indicate that Nd:YAG and Ho:YAG lasers are not suitable for use in decontamination of implant surfaces, irrespective of the power output. With the Er:YAG and $CO_2$ laser, the power output must be limited so as to avoid surface damage. The GaAlAs laser seems to be safe as far as possible surface alterations are concerned.* (Int J Oral Maxillofac Implants 2002;17:202–211)

**Key words:** *energy dispersive spectroscopy, implant surface alteration, peri-implantitis, scanning electron microscopy*

In addition to undisturbed osseointegration and an adequate prosthetic design, implant maintenance is crucial for long-term prognosis. Bacterial inflammation and infection of the peri-implant tissue induce bone loss and jeopardize clinical success. Most titanium implants feature a rough surface to increase areas of implant-bone contact and anchorage force in alveolar bone.[1] Surface roughness, however, makes elimination of bacteria from implants difficult. Several treatment regimens have been proposed for cleaning and decontamination of implant surfaces. Plastic curettes are probably best for manual removal of peri-implant plaque.[2] Metal curettes, as well as the application of ultrasonic scalers, induce surface alteration in implants and are therefore contraindicated.[3] Bactericidal chemicals such as chlorhexidine digluconate or iodine solutions are useful adjuncts in the treatment of peri-implantitis. Sterilization and cleaning of implant surfaces by means of lasers has been suggested.[4,5] However, the bactericidal potential of some laser systems on roughened surfaces requires considerable scientific investigation. Results published to date are very promising.[6,7] Moreover, dental

[1]Research Assistant, Department of Oral Surgery, Johannes Gutenberg University, Mainz, Germany.
[2]Research Assistant, Institute for Applied Structure and Microanalysis, Johannes Gutenberg University, Mainz, Germany.
[3]Professor and Head, Institute for Applied Structure and Microanalysis, Johannes Gutenberg University, Mainz, Germany.
[4]Professor and Head, Department of Oral Surgery, Johannes-Gutenberg-University Mainz, Germany.

**Reprint requests:** Dr Matthias Kreisler, Department of Oral Surgery, Johannes Gutenberg University, Augustusplatz 2, 55131 Mainz, Germany. Fax: +49-61-31173434.
E-mail: matthiaskreisler@web.de



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lasers have gained some popularity in peri-implant soft tissue procedures involving exposure of implant cover screws (stage II surgery)[8] or contouring hyperplastic gingiva.[9]

This study was part of a research program investigating the possibilities and hazards of laser applications in implant dentistry. The aim of the investigation was the structural analysis of lased implant surfaces by means of scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDX).

## MATERIALS AND METHODS

### Titanium Discs

Test discs made of commercially pure titanium (cpTi) of a thickness of 1.5 mm and a diameter of 10 mm with 4 different surfaces (machine-polished, sand-blasted and acid-etched [SA], titanium plasma–sprayed [TPS], and hydroxyapatite-coated [HA] [Friadent, Mannheim, Germany]) served as substrates. Surface roughness as indicated by the manufacturer was $R_a$= 2.2 µm (SA), $R_a$= 3.41 µm (TPS), and $R_a$= 2.0 µm (HA), with a standard deviation of approximately 20%.

### Lasers

The following laser devices and parameters were used.

- Carbon dioxide ($CO_2$) laser (λ = 10,600 nm) (Sharplan 20c, Sharplan, Allendale, NJ). The power output set for this experiment varied between 1.0 and 4.0 W in the pulse mode at 50 pulses per second (pps). Pulse frequency was fixed in this mode of operation. A microchip varied the pulse width according to the power output. Energy fluence was between 15.2 and 60.8 $Jcm^{-2}$ per pulse. The laser light with a beam diameter of 200 µm was delivered by the articulated arm and a special application tip designed for use in periodontics and implant dentistry allowing subgingival irradiation.
- Gallium-aluminum-arsenide (GaAlAs) laser (λ = 809 nm) (ORALASER Voxx, Oralia, Konstanz, Germany). A 400 µm optical fiber was used to transmit the collimated light. Energy fluence was between 1.9 and 26.6 $Jcm^{-2}$ per pulse at a power output of 0.5 to 7 W. Pulse width was 10 ms.
- Erbium:yttrium-aluminum-garnet (Er:YAG) laser (λ = 2,940 nm) (KaVo Key-Laser II, KaVo, Biberach, Germany). This laser system allows variation in the pulse frequency (1 to 15 pps) and the pulse energy (60 to 500 mJ). Frequency was kept constant at 10 pps. Energy fluence, as measured at the end of the application tip, varied between 6.6 $Jcm^{-2}$ and 28.0 $Jcm^{-2}$. Pulse width was between 250 and 500 µs, as indicated by the manufacturer. The light was delivered by an optic fiber and a 540 µm application tip.
- Neodymium:YAG (Nd:YAG) laser (λ = 1,064 nm) (Duopuls, Quantronix, Darmstadt, Germany).
- Holmium:YAG (Ho:YAG) laser (λ = 2,090 nm) (Duopuls, Quantronix). A laser system with an integrated Nd:YAG and Ho:YAG laser with a 400 µm fiberoptic was used and the light was delivered at 0.5 to 4 W and 5 pps (pulse width: 200 µs) The measured energy fluence was 3.6 to 28.8 $Jcm^{-2}$.

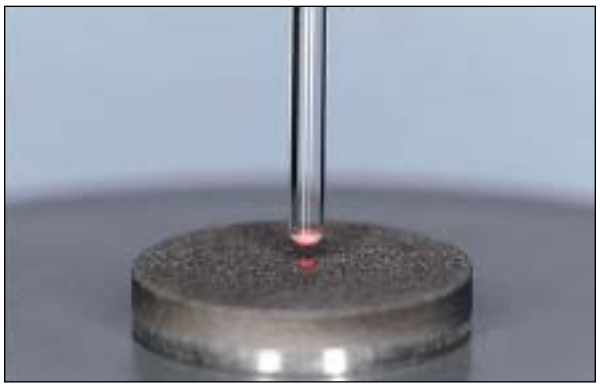

**Fig 1** The optic fiber was positioned at a 90-degree angle to the surface of the specimen at a distance of 0.5 mm.

The distance from the end of the respective delivery system to the surface of the titanium substrate was kept constant at 0.5 mm. The angle of irradiation was 90 degrees (Fig 1). The discs were lased in a single spot for 5 seconds. To ensure comparable test conditions, irradiation was performed without water cooling irrespective of the laser system, although water cooling might cause less damage. Prior to lasing, the average power output of the respective laser system was determined by means of an energy meter (Field Master GS, Coherent, Dieburg, Germany).

### Scanning Electron Microscopy

Subsequent to irradiation, the discs were handled with sterile metal forceps and mounted on a sample holder for SEM. All samples were introduced into the vacuum chamber of a LEO 435 VP SEM (Zeiss-Leica, Oberkochen, Germany) and micrographed with different degrees of magnification. Both secondary and backscattered electrons were detected by means of a standard SE detector and a 4-quadrant backscattered detector (QBSD) (Fig 2).

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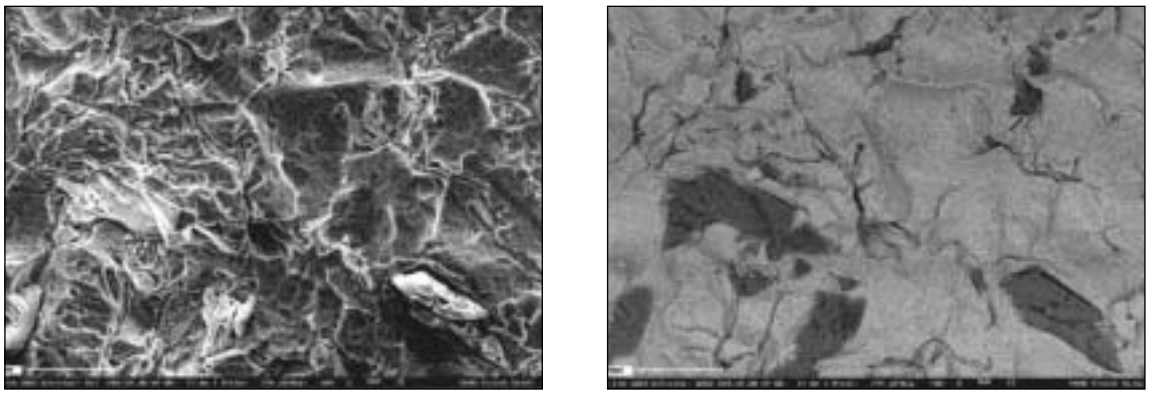

**Fig 2** Scanning electron microscopy of a sandblasted and ecid-etched surface using an SE detector *(left)* and a QBSD *(right)*. The electron-detector image is determined by the topographic contrast. The QBSD-detector image reveals differences in the chemical compound of the surface. Note the aluminum particles *(dark)* in the Ti surface (original magnification ×500).

QBSD micrographs were taken to demonstrate directly the material conversion at laser-irradiated areas. For comparison of the topographic representation of the SEMs, the microscope parameters were kept constant throughout the examination (high tension 20 kV, probe current 250 pA).

### Energy Dispersive Spectroscopy

Inhomogeneous surface characteristics of lased areas observed by means of the QBSD were submitted to an element analysis. Visualization of the regions of interest and the element detection was done simultaneously by verification of electron beam–induced x-ray radiation. An energy-dispersive spectrometer (Oxford Instrument, Wiesbaden, Germany) was coupled to the LEO 435 VP SEM. The spectrometer is equipped with a Si(Li) detector and a Super-ATW window, which allows the detection of x-rays from elements with an order number higher than 5 (boron). The spectral resolution of the detector is 138 eV at 5.9 kV (MnKα1). The spectra were acquired with a microscope setting of 20 kV high tension, 250 pA probe current, and a working distance of 90 mm. Elements of interest were Ti, O, Si, C, Al, P, and F. The LINK ISIS 300 Software of the EDX system is submitted with a line scan mode, which can demonstrate the alteration of element compound over a long distance of investigation including lased and non-lased areas. X-ray survey spectra, as well as line scans, were taken from the irradiated areas. No obvious interference and peak overlapping appeared, and an evident conformity with the QBSD images was ascertainable.

## RESULTS

### Nd:YAG Laser

SEM showed alterations in all surfaces tested. The scale of the damage was proportional to the power output and was discernible even at the lowest setting possible used in this experiment (3.6 $Jcm^{-2}$). Figure

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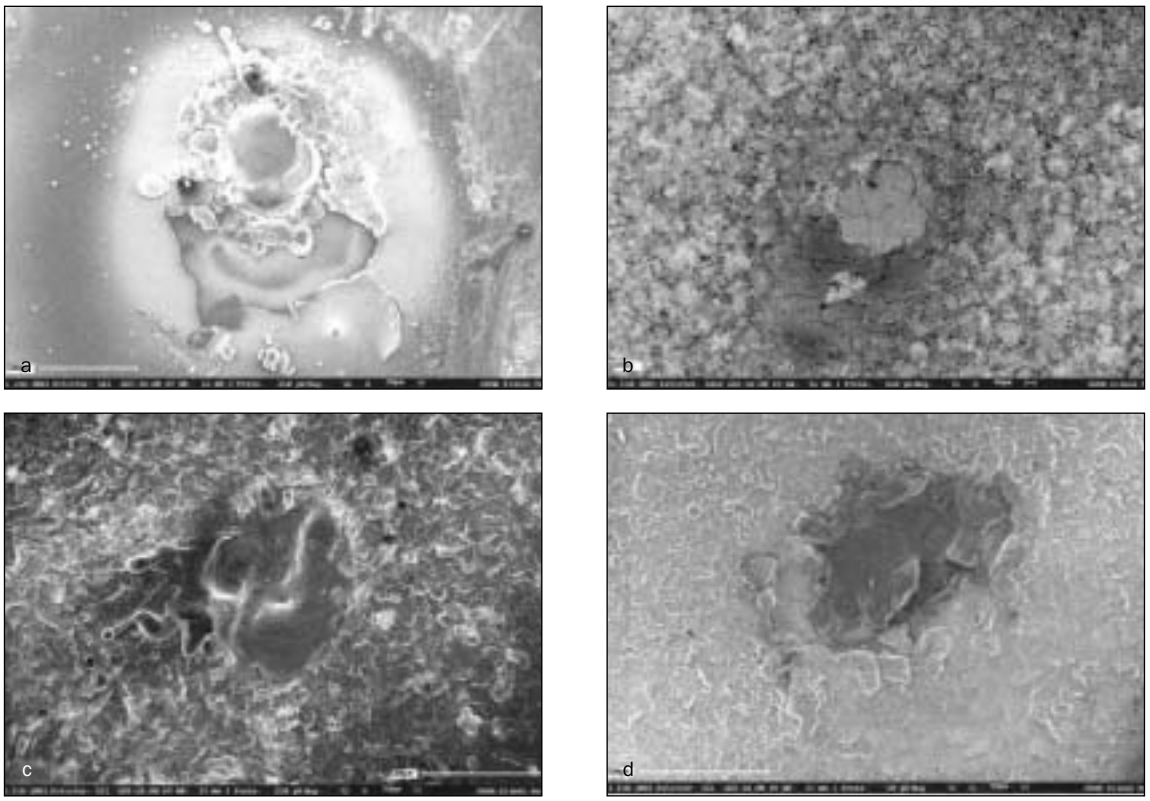


**Fig 3** SEM of Nd:YAG-irradiated (14.4 $Jcm^{-2}$) specimens. (a) Smooth Ti; original magnification ×56; SE detector. (b) TPS surface; original magnification ×75; QBSD. (c) SA surface; original magnification ×75; SE detector. (d) HA-coated disc; original magnification ×75; SE detector.

3 shows a representative image of Nd:YAG-lased surfaces at 14.4 $Jcm^{-2}$. Cracks, melting, and crater formation were the predominant alterations observed. The microscopic appearance, however, varied depending on the respective surface. The HA coating was destroyed on a large scale. EDX revealed an altered chemical compound in the respective surfaces. A remarkable finding was the appearance of high silicon peaks (Fig 4a) and an increased O/Ti ratio in lased areas on the smooth, SA, and TPS surfaces (Fig 4b).

### Ho:YAG Laser

Figure 5 demonstrates the effect of Ho:YAG irradiation on the various implant surfaces. Analogous to the findings with the Nd:YAG laser, all surfaces were damaged to a considerable degree in an energy-dependent manner but surface alterations were also discernible at the minimal energy level applied. With rising pulse energy, the diameter of the defects showed an increase. Smooth Ti displayed extensive cracking. On the SA and TPS surfaces, melting was predominant. A large amount of Si and O was found adjacent to the lased area (Fig 6a). The HA coating was practically removed, as demonstrated by the EDX line scan (Fig 6b).

### Er:YAG Laser

Surface characteristics were also influenced by the Er:YAG laser. The respective surface, however, determined the energy necessary to induce surface alterations. Alterations were detected at 8.9 $Jcm^{-2}$ on the TPS surface, 11.2 $Jcm^{-2}$ on the SA surface, 17.8 $Jcm^{-2}$ on the HA-coated surface, and 28.0 $Jcm^{-2}$ on the smooth surface. Figure 7 presents the microscopic appearance of the discs after irradiation at an energy fluence of 28 $Jcm^{-2}$. Melting and glazing were observed on all Ti surfaces. EDX analysis showed a slightly higher O content and reduced Ti content in the irradiated spots (Fig 8). Further considerable changes in the chemical compound of the SA and TPS surfaces could not be

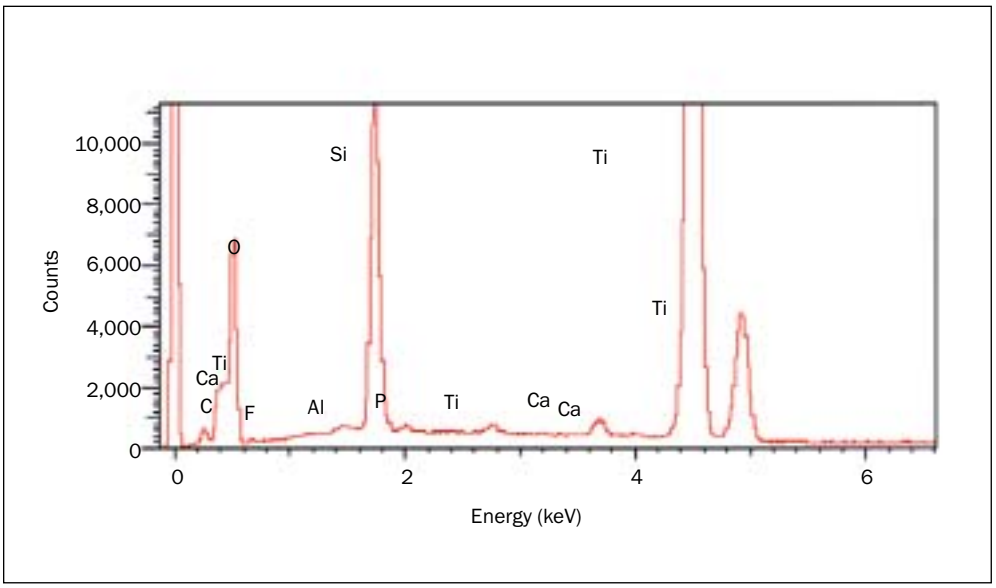


**Fig 4a** EDX spectrum of a smooth Ti surface subsequent to Nd:YAG irradiation. Note the distinct Si peak.

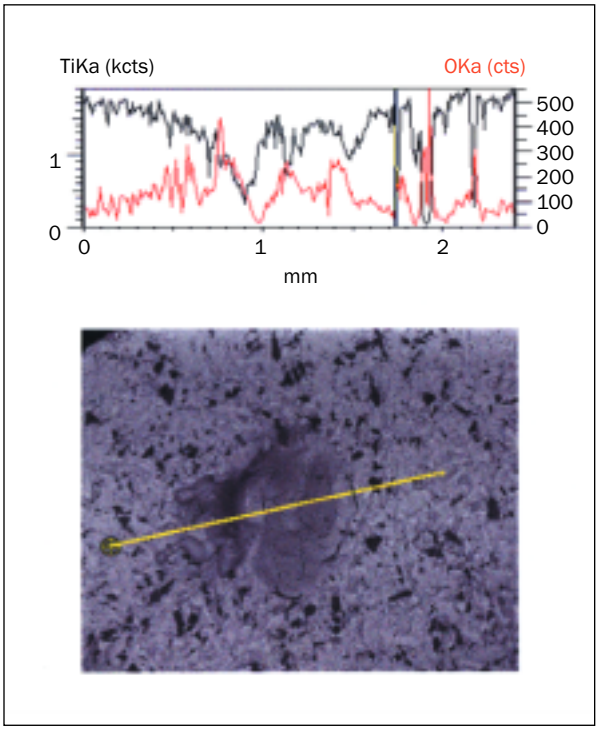


**Fig 4b** EDX line scan of an SA surface. Note the increased O/Ti ratio in the lased area.

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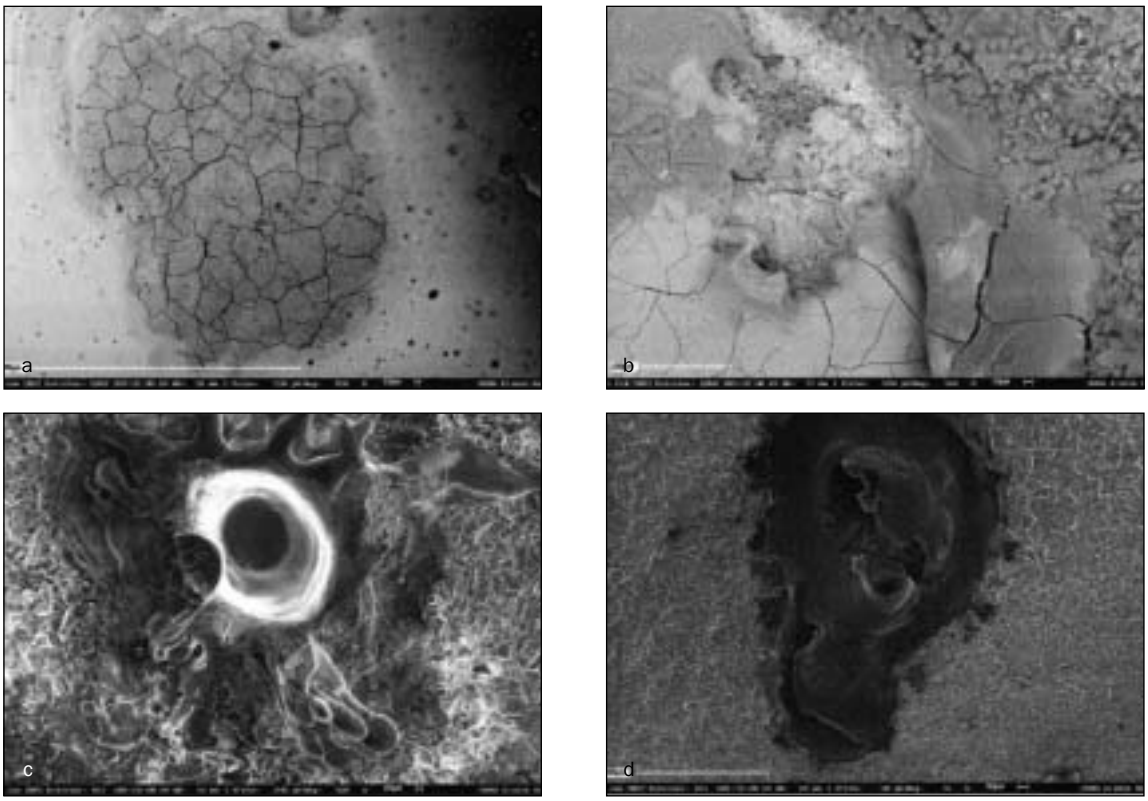


**Fig 5** SEM of Ho:YAG-irradiated (14.4 $Jcm^{-2}$) specimens. (a) Smooth Ti; original magnification ×150; QBSD. (b) TPS surface; original magnification ×250; QBSD. (c) SA surface; original magnification ×130, SE detector. (d) HA-coated disc; original magnification ×75; SE detector.

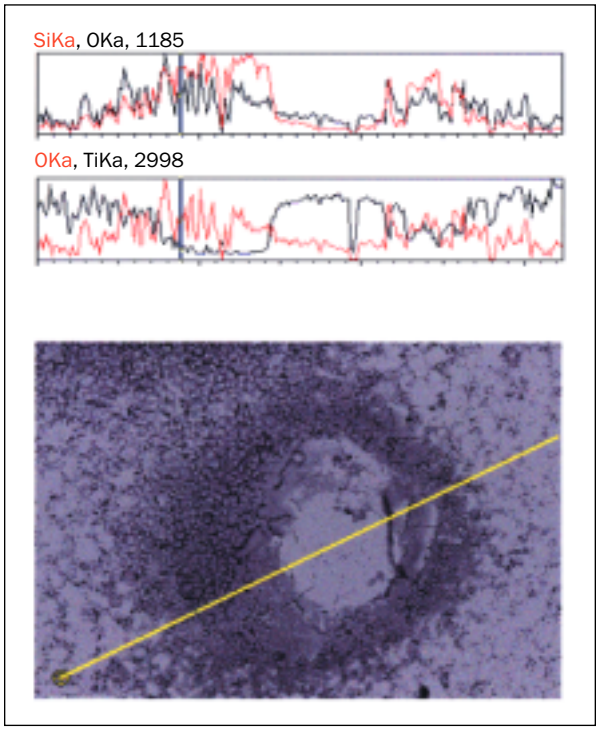


**Fig 6a** EDX line scan of a TPS surface. Note the increase of SI and O around the lased area.

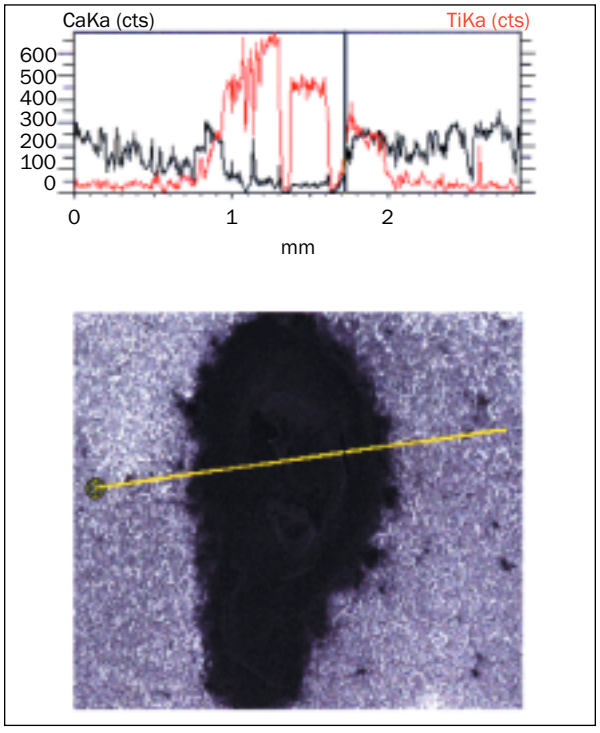


**Fig 6b** EDX line scan of an HA-coated surface. Note the displaced HA coating in the lased area and the exposure of the Ti body.

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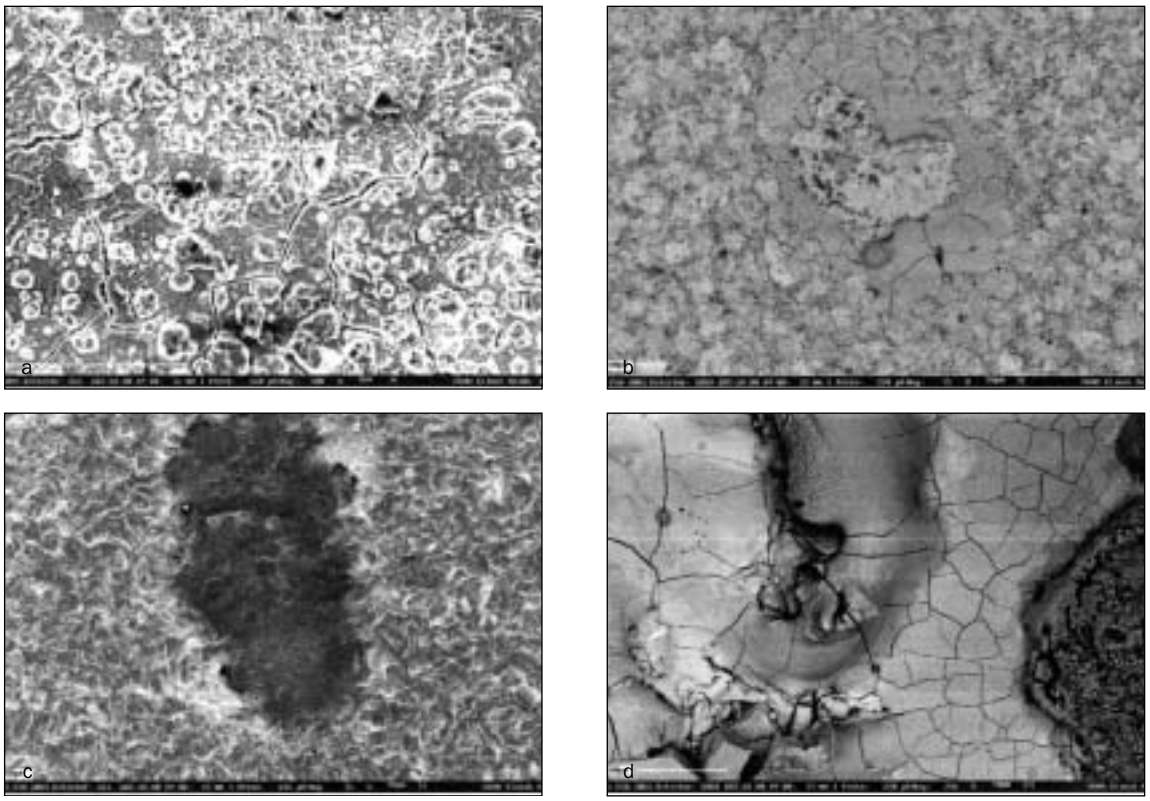


**Fig 7** SEM of Er:YAG-irradiated (28.0 $Jcm^{-2}$) specimens. (a) Smooth Ti; original magnification ×500; SE detector. (b) TPS surface; original magnification ×75; QBSD. (c) SA surface; original magnification ×75, SE detector. (d) HA-coated disc; original magnification ×250; SE detector.

detected. Single Al spots were found in the lased area, which must be attributed to the fabrication process of the discs and which were uncovered by irradiation. Si contamination was minimal. The HA coating was totally removed and the Ti beneath was cracked.

### $CO_2$ Laser

Alterations in the machine-polished surface at the laser parameters applied could be detected neither by SEM nor EDX analysis. At energy fluences above 30 $Jcm^{-2}$, the surface of the TPS and SA specimens appeared glazed. The HA coating was affected by laser irradiation at a fluence of 15.2 $Jcm^{-2}$ (Fig 9a). EDX analysis detected a higher O/Ti ratio in the lased areas. HA particles were melted and the Ti body of the discs was partially exposed as demonstrated by the line scan (Fig 9b). No Si could be detected.

### GaAlAs Laser

No surface alteration was found by means of the methods applied. This was true even after energy fluence was increased to 26.6 $Jcm^{-2}$ at 50 pps and at the maximum power output of the laser device.

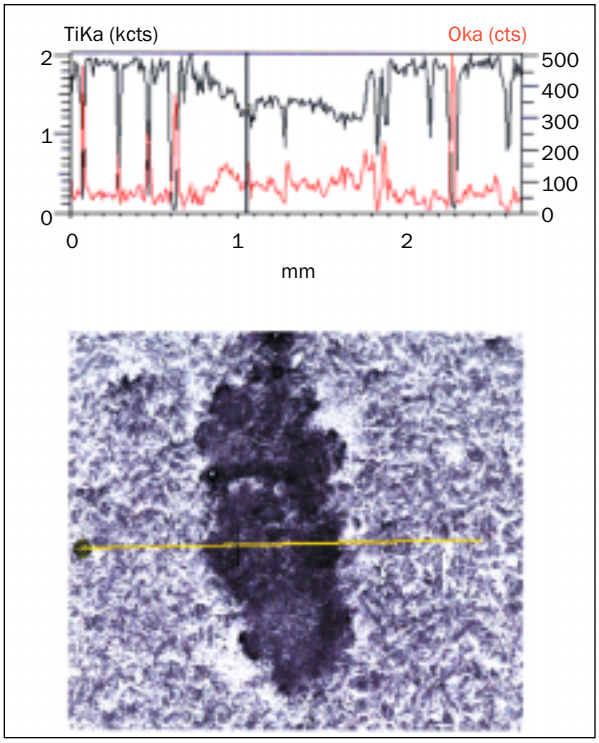


**Fig 8** EDX line scan of an SA surface. Note the increase of O/Ti ratio in the lased area.

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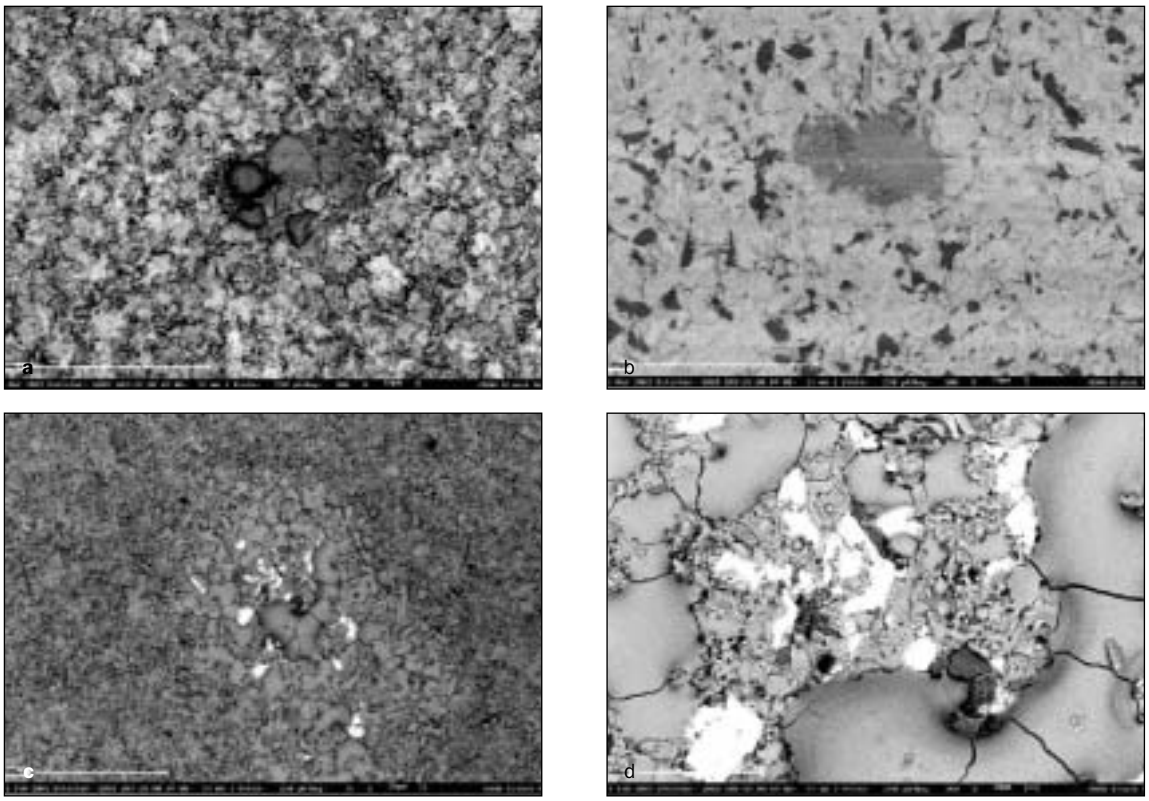


**Fig 9a** SEM (QBSD) of $CO_2$ laser–irradiated (60.8 $Jcm^{-2}$) specimens. (a) TPS surface; original magnification ×100. (b) SA surface; original magnification ×100. Note the glazed surface. (c) and (d) HA-coated specimens; original magnification ×75 and ×350. Note the melted HA.

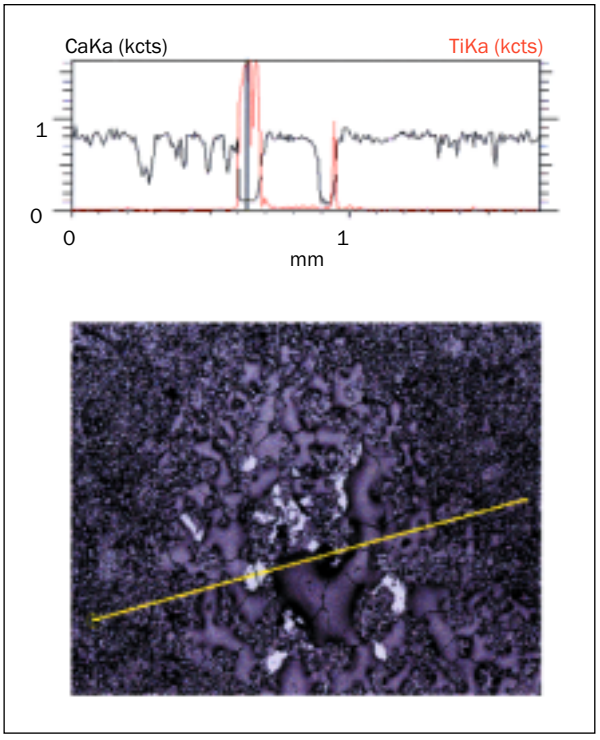


**Fig 9b** EDX line scan of an HA-coated surface. Note the local exposure of Ti.

## DISCUSSION

Interaction between laser light and metals is determined by the energy fluence, the degree of absorption, thermal conductivity, and capacity, as well as the surface composition of the material. Laser light with an energy density beneath $10^6$ W/cm² underlies the laws of linear optics.[10] Each metal features a certain spectral reflection capacity that is, similar to the absorption coefficient, dependent on the wavelength of the laser.[11] Reflection capacity of Ti for near-infrared laser light is between 50% and 60% and rises up to 96% at 10,000 nm. To the authors' knowledge, the influence of different implant surfaces with regard to light reflection has not yet been investigated. At energy densities above $10^6$ W/cm², laws of linear optics do not apply. In the superficial layers of metals (0.1 to 1.0 µm) extreme high temperatures are reached, inducing formation of plasma and alteration of light reflection.[12,13] Locally, a thin channel filled with metallic vapor is formed.[14] The pulsed YAG lasers with extremly short pulse durations of below 500 µs are capable of exceeding energy densities necessary to create plasma. The effect of Nd:YAG laser irradation of titanium implants observed in the present study is comparable to data

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published earlier.[15] Block and coworkers demonstrated that Nd:YAG laser irradiation severely damages TPS and HA-coated implants.[15]

It is not surprising that the same findings apply for smooth or acid-etched surfaces, respectively. The microscopic appearance of the alterations, however, varied with the surfaces investigated. Deppe and associates[16] reported on microscopically visible melting and bluish discoloration of plasma-coated implant surfaces subsequent to $CO_2$ laser irradation at 2.5 W using the superpulse mode. It has been reported that this discoloration stems from thick Ti oxides (250 to 700 Å).[17] In the present study, working in the pulse mode, alterations were detected at a power output above 2 W. Macroscopically, these alterations presented as darkened spots. Microscopically, they turned out to be melted and glazed Ti surface. Bluish discoloration of $CO_2$ laser–irradiated specimens was not observed.

The Si found on Nd:YAG and Ho:YAG laser–irradiated surfaces might be the result of contamination from polishing as suggested by Keller and associates.[18] The fact that no Si was found on $CO_2$ laser–treated specimens supports the hypothesis that, because of the vicinity of the quartz fibers to the specimens, microparticles were detached from the fiber and deposited on the surface of the discs. In contrast to the other laser systems, the light of the $CO_2$ laser is not delivered by a quartz fiber.

Keller and associates investigated the effects of various sterilization processes on surface properties and cellular attachment on commercially pure titanium.[18] The study reported on increased O/Ti ratios and higher thickness of the O subsequent to steam autoclaving and gas sterilization compared to untreated specimens. Furthermore, cell attachment of connective tissue cells was decreased after sterilization. It must be assumed that laser treatment might have a similar effect, since considerable heat generation on the surfaces can be observed when no cooling agent is applied (unpublished data).

The results of the present study indicate that the Nd:YAG and Ho:YAG lasers are not suitable for use in decontamination of implant surfaces irrespective of the power output. When using the Er:YAG and $CO_2$ lasers, the power output must be limited to avoid surface damage. The GaAlAs laser seems to be safe as far as possible surface alterations are concerned.

To standardize test conditions, laser irradiation in this experiment was carried out at a 90-degree angle and a permanent irradiation of a single spot only. The influence of the working angle and surface liquids, such as saliva and blood, on the laser effects, however, require further scientific work.

The findings of the present study may contribute to the understanding of laser-implant interaction. Further research concerning the generation of heat in the implant body and in the adjacent tissues, as well as the potential antibacterial effect of the various laser systems depending on the power output and angle of irradiation, is being carried out to give an overall evaluation of laser treatment of peri-implantitis.

## CONCLUSIONS

The Nd:YAG and Ho:YAG lasers are contraindicated for use in the decontamination of implant surfaces, irrespective of the power output. When using the Er:YAG and $CO_2$ lasers, the power output must be limited to avoid surface damage. The GaAlAs laser seems to be safe within the power settings applied as far as possible surface alterations are concerned.

## ACKNOWLEDGMENTS

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