Lasers Med Sci (2009) 24:961–970
DOI 10.1007/s10103-009-0676-1

REVIEW ARTICLE

# Laser wavelengths and oral implantology

**George E. Romanos · Norbert Gutknecht · Sandra Dieter · Frank Schwarz · Roberto Crespi · Anton Sculean**

Received: 1 February 2009 / Accepted: 10 April 2009 / Published online: 9 May 2009

**Abstract** In modern implant dentistry there are several clinical indications for laser surgery. Different laser systems have a considerable spectrum of application in soft and hard peri-implant tissues. The literature was searched for clinical application of different laser wavelengths in peri-implant tissues: second-stage surgery of submerged implants, treatment of infrabony defects, removal of peri-implant hyperplastic overgrowths, and, possibly, the preparation of bone cavities for implant placement. This report describes the state-of-the-art application of different laser systems in modern implant dentistry for the treatment of peri-implant lesions and decontamination of implant surfaces. Our study evaluated in vitro examinations, clinical experience and long-term clinical studies. The exact selection of the appropriate laser system and wavelength was dependent on the scientific evaluation of recent literature and the level of changes in implant and tissue temperatures during laser application. The significant reduction in bacteria on the implant surface and the peri-implant tissues during irradiation and the cutting effects associated with the coagulation properties of the lasers are the main reasons for laser application in the treatment of peri-implant lesions and the successful long-term prognosis of failing oral implants. The various applications of lasers in implant dentistry are dependent on the wavelength and laser–tissue interactions.

**Keywords** Implants · Lasers

Although a large number of endosseous implants are being placed and do have a high survival rate [1], the significant annual increase in implant placement is associated with several complications. These are reversible pathological reactions of the peri-implant soft tissues, ‘mucositis’, and ‘peri-implantitis’, progressive destruction of bone around the implant after osseointegration. These reactions are caused by advanced inflammatory changes in the surrounding tissues, so that abnormalities in the tissue around the implant may be the main reason for implant failures. Over a 5-year period, 0–14.4% of dental implants demonstrated peri-implant inflammatory reactions associated with crestal bone loss [2]. Bone complications around the implant may lead to implant failure if no treatment can be established.

Bacterial aggregation begins in the soft tissue around the implant neck, and the bacteria may penetrate the implant–abutment connection. The inflammation spreads apically

---

G. E. Romanos (✉)
Division of Periodontology, Unit of Laser Dentistry,
Eastman Dental School, University of Rochester,
625 Elmwood Ave.,
Rochester 14620 NY, USA
e-mail: Georgios_Romanos@urmc.rochester.edu

G. E. Romanos · S. Dieter
Department of Oral Surgery and Implant Dentistry,
University of Frankfurt (Carolinum),
Frankfurt, Germany

N. Gutknecht
Department of Preventive, Operative Dentistry and Endodontics,
University of Aachen,
Aachen, Germany

F. Schwarz
Department of Oral Surgery, Heinrich Heine University,
Düsseldorf, Germany

R. Crespi
Department of Dentistry, Vita Salute University,
San Raffaele Hospital,
Milan, Italy

A. Sculean
Department of Periodontology, University of Bern,
Berne, Switzerland

and causes vertical and horizontal bone loss. This bacterial infection around the implant is considered to be similar to periodontal disease [3–7], presenting similar microbiological characteristics. Specifically, putative, periodontal pathogens have been detected [8], and *Porphyromonas gingivalis* is found in very high proportions [9–11].

Non-surgical methods of peri-implantitis treatment include mechanical instrumentation and the use of a variety of antibacterial agents. The use of different antimicrobial agents is possible but is only effective when applied during the early stages of the disease [12–14]. Subgingival irrigation with local disinfectants, and local antibiotic therapy with tetracycline fibres, were employed, but neither treatment provided a conclusive therapeutic effect [15]. The systemic administration of antimicrobial agents was tested in the treatment of peri-implantitis; however, the results were limited due to resistant strains of bacteria and ineffective drug dosages [16, 17].

Other recommendations included apically positioned flaps to establish adequate plaque control and polishing threads of implants, especially when wide bony defects are present [18, 19]. However, such therapeutic methods are associated with cosmetic deficiencies in the aesthetic zone. Citric acid and sandblasting [20], sandblasting alone [21–23] or chlorhexidine irrigation [24] has also been recommended. However, these were studies in animals or clinical case reports without long-term data.

There are experimental studies [5, 6] but only two clinical studies [19, 25] demonstrating the surgical treatment of peri-implant infrabony defects. Different therapeutic methods have been recommended to treat peri-implant lesions. Currently, there are no standard treatment protocols to control peri-implant infections, and, therefore, long-term results have to be critically assessed [26]. Lasers may reduce the bacteria and decontaminate the implant surface [27–31], and some articles presented positive effects of laser irradiation to control peri-implant infections.

Moreover, previous in vitro microbiological studies have shown a significant reduction in periodontopathogenic bacteria on implant surfaces when implants are irradiated with different high-intensity (surgical) lasers [30, 31] or low-intensity (soft) lasers using photosensitizers [32]. Even though the inclusion criteria for a review article should be precisely defined, and a meta-analysis or systematic review is necessary, there is no evidence-based therapeutic method today for the treatment of peri-implant defects [26]. Therefore, we also describe in this report a small number of cases, in order to include examples of the clinical application of lasers in implant dentistry.

The paper presents and discusses different techniques of laser usage in the soft tissues around implants and also methods for the treatment of peri-implantitis. A balanced evaluation of the different laser wavelengths and also the advantages and disadvantages of their application in implant dentistry will be presented.

## Laser application to soft tissue during implant surgery

Although therapy for peri-implant mucositis should be based on permanent and systematic plaque control to eliminate the aetiological factors of the disease, the treatment of peri-implant hyperplasias is the excision of the soft tissue around the implant [33].

The second-stage surgery of submerged implants and the surgical removal of hyperplastic peri-implant tissue can be performed with a scalpel, or by electrosurgery or laser [33]. With the scalpel for incision or excision, there may be some bleeding, pain and discomfort during and after surgery. Electrosurgery may damage the implant surface dramatically, disturbing osseointegration and leading to implant failure. Laser surgery is characterized by excellent coagulation, and pain relief for the patient [34].

The carbon dioxide ($CO_2$) laser has been used in the past for excision and vaporization of different soft tissue tumours and peri-implant hyperplasia [34]. The mode of application may be continuous or superpulse, which allows relatively fast excision, adequate coagulation and excellent patient comfort. Patients with implant-supported restorations are able to use their overdentures immediately after surgery, when these prostheses are soft (Fig. 1). Laser fibre systems [i.e., neodymium:yttrium–aluminum–garnet (Nd:YAG), diode lasers] must be used with special care, because of the higher penetration depth, and the possible damage to the bone in direct bone irradiation. Owing to the different interactions between the laser and implant surfaces and the higher absorption by titanium, such lasers may overheat and damage the implant surface.

However, Arnabat-Dominguez et al. [35] described second-stage surgery of submerged healed implants using the erbium:yttrium–aluminum–garnet (Er:YAG) laser with successful results, except on implants located where aesthetic considerations were important or in areas with insufficient width of keratinized mucosa surrounding the implants (Table 1).

## Laser applications in peri-implantitis therapy

There is no doubt that, In the case of peri-implantitis, the implant surface is contaminated with soft tissue cells, bacteria and other bacterial by-products [36]. Micro-irregularities of the implant surface support bacterial adherence and, in cases of contamination, wound healing is compromised. Furthermore, endosseous implants with rough surfaces [sandblasted, titanium plasma sprayed (TPS)

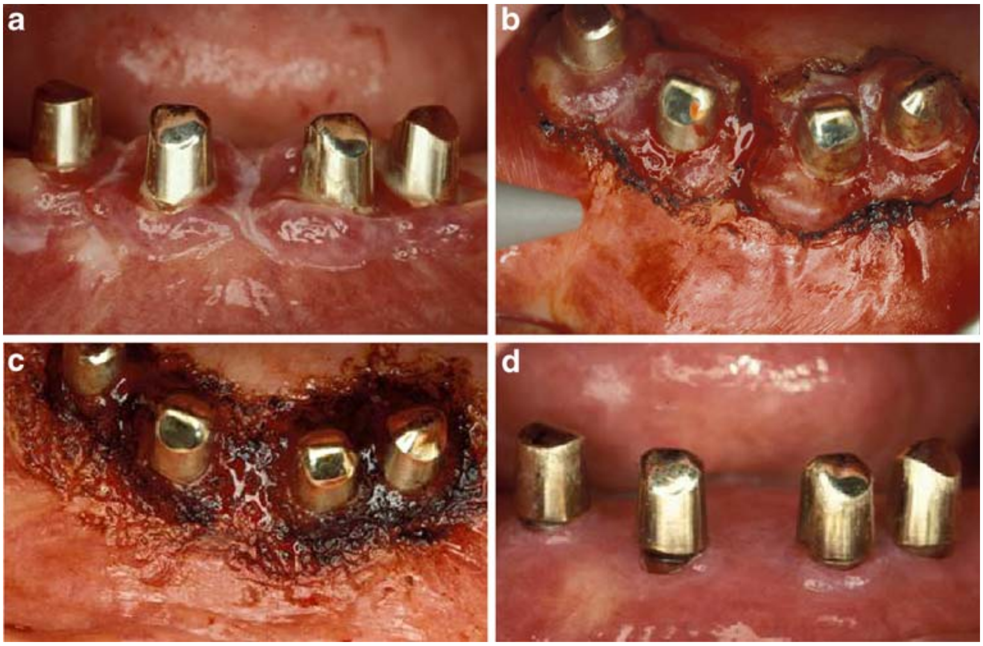

**Fig. 1** **a** Hyperplastic soft tissue around the implant immediately before $CO_2$ laser-assisted excision. **b** $CO_2$ laser-assisted excision of the hyperplastic peri-implant soft tissue. **c** Coagulation and sufficient carbonization of the peri-implant soft tissue during laser irradiation. **d** Final result 1 year after laser excision

**Table 1** Effects of lasers on implant surface (*Er,Cr:YSGG* erbium,chromium:yttrium–scandium–gallium–garnet)

| Study | Laser wavelength | type of study | effects |
|---|---|---|---|
| Block et al. [27] | Nd:YAG | In vitro | Melting, sterilization |
| Kato et al. [28] | CO2 | In vitro | Bacterial reduction |
| Bach et al. [29 | Diode (810 nm) | Clinical | Pocket reduction |
| Romanos et al. [30] | CO2 | In vitro | Bacteria reduction |
| Kreisler et al. [31] | Diode (810 nm) | In vitro | Bacteria reduction |
| Haas et al. [32] | Photodynamic therapy | In vitro | Bacteria reduction |
| Arnabat-Dominguez et al. [35] | Er:YAG | In vivo | Second-stage surgery |
| Romanos et al. [47] | Diode (980 nm) | In vitro | No surface modifications |
| Romanos et al. [47] | Nd:YAG | In vitro | Significant melting |
| Romanos et al. [48] | CO2 | In vitro | No surface modifications |
| Deppe et al. [51] | CO2 | In vitro | No surface modifications |
| Deppe et al. [56] | CO2 | In vivo (dogs) | New bone formation |
| Oyster et al. [54] | CO2 | In vitro | No significant temperature rise |
| Romanos and Nentwig [55] | CO2 | Clinical | Peri-implantitis therapy |
| Deppe et al. [58] | CO2 | clinical | Peri-implantitis therapy |
| el-Montaser et al. [69] | Er:YAG | In vivo | No thermal damage |
| Kesler et al. [73] | Er:YAG | In vivo | Better osseointegration |
| Sasaki et al. [75, 76] | Er:YAG | In vitro | Minimal surface changes |
| Lewandrowski et al. [77] | Er:YAG | In vivo | Better healing than the drill |
| Pourzarandian et al. [78] | Er:YAG | in vivo | Initial faster bone healing |
| Schwarz et al. [79] | Er:YAG | In vivo | Safe (but not better) healing when compared with the control |
| Romanos et al. [80] | CO2, Er,Cr:YSGG | In vitro | Attachment of osteoblasts |
| Schwarz et al. [81] | Er:YAG | In vitro | Reduction in bleeding on probing |
| Takasaki et al. [82] | Er:YAG | In vivo | Re-osseointegration |
| Mouhyi et al. [84] | CO2 | In vitro | No significant temperature rise |
| Rechman et al. [85] | Er:YAG | In vitro | Surface changes |

and hydroxyapatite (HA)-coated] are characterized by better anchorage to the alveolar bone, but, when such implant surfaces are contaminated, it is very difficult to prevent the peri-implant inflammation.

Different modes of peri-implantitis therapy and implant decontamination have been reported [19–24]. Guided bone regeneration (GBR) techniques have been used for the treatment of bone defects around the implant [19, 25]. These are precise surgical techniques requiring excellent surgical skills. There can be complications, such as exposure of the non-resorbable (expanded polytetrafluoroethylene) membranes [24, 37], which requires the earliest possible removal of the membrane [37]. An increase of bone was reported in these studies, re-osseointegration around all types of implants was not ideal [24], and this procedure had limited predictability in daily practice [38–40]. In general, peri-implant bone defects are characterized by poor bone regenerative capacity adjacent to contaminated implant surfaces [37]. Currently, there are no clinical studies or case series documenting successful regenerative procedures in peri-implant bone lesions. Some case series demonstrated limited bone fill after GBR procedures [39]. To enhance results, reduce bone loss due to peri-implantitis, and to attain bone regeneration around implants, investigators suggested that it would be necessary to decontaminate ailing implant surfaces [11, 13, 39].

Several studies showed the dramatic changes that curettage and ultrasonic instrumentation can make on the implant surfaces [41–43]. The application of air–powder abrasive instruments also may affect the surface of HA-coated implants [44], and there is an enhanced risk of air emphysema when deep alveolar bony defects are treated [45, 46]. The removal of bacterial plaque and endotoxins by mechanical instrumentation is difficult, between the threads of the implant when the surfaces are rough, and bacteria and lipopolysaccharides can remain on the implant surfaces after mechanical antimicrobial therapy.

Various reports have shown some changes in the implants' surface textures as a function of the type of laser and wavelength that was used [33, 34, 47–51]. In addition, the lasers' characteristics are important, because of the different reactions they can produce on the implant surfaces (Table 1). Specifically, the physical properties of the $CO_2$ laser and the surgical effects of its wavelength allow soft tissue removal in areas around the implant, as well as decontamination of implant surfaces. Continuous wave $CO_2$ lasers do not appear to have adverse effects on the surface chemistry, but the superpulse mode seems to have a significant influence on the surface chemistry, which is not desirable for decontamination of failing implants [51]. A previous study reported that continuous wave (cw) $CO_2$ laser irradiation at up to 6.0 W power does not modify sandblasted, titanium plasma sprayed or HA-coated implant surfaces [48]. Other authors recommend a 5.0 W power $CO_2$ laser to remove bacterial contaminants from the implant surfaces without any damage to the implant surface structure [28]. In contrast, Deppe et al. [51] showed that there was no implant alteration to the surface of TPS-coated implants, and excellent sterilization was demonstrated when the power setting was very low (2.5 W).

Romanos et al. [30] investigated the bactericidal effect of the continuous wave $CO_2$ laser (at a low power output of 2 W) on sandblasted titanium implant surfaces contaminated with *Porphyromonas gingivalis* and also showed a significant reduction in *P. gingivalis* after $CO_2$ laser irradiation of implant surfaces. This is comparable to the results of Coffelt et al. [52], who demonstrated an ablation threshold energy density of 11 J/cm$^2$ on root surfaces.

Kato and colleagues [28] showed that the $CO_2$ laser may have a significant bactericidal effect, reducing periodontopathogenic bacteria.

Encouraging results were reported when $CO_2$ laser was used as a decontamination device to improve re-osseointegration [51] in dogs. The study suggested that this laser system may be an effective therapeutic modality in the treatment of peri-implantitis.

Based on scanning electron microscopy (SEM) studies, many authors have demonstrated that the $CO_2$ laser does not change the implant surface or the type of implant surface pattern (sandblasted/HA-coated and TPS) [48–54]. It was also reported that the use of the low power $CO_2$ laser (2–4 W, cw or 6 W pulse mode at a frequency of 20 Hz and width of 10 ms) induced only a small temperature increase, but below the threshold levels [54].

In a clinical study Romanos and Nentwig [55] demonstrated the successful treatment of peri-implant defects using the $CO_2$ laser in combination with bone grafting with autogenous or xenogenic grafts. The augmented areas were covered with a resorbable barrier based on GBR principles. Follow-up examinations showed significant reduction in the pocket probing depth. No inflammatory reactions around the implant (e.g., bleeding or suppuration) were noted during the entire observation period. Complete bone fill was observed radiologically in all infrabony defects after the use of xenogenic materials in all sites treated with autogenous bone grafts, and at least two-thirds of the bony defect had filled with bone due to some bone graft resorption over time (Fig. 2). The authors attributed the bacterial reduction in the very deep bony lesions and the surrounding bone to the reflection and transmission of the laser light by the implant material during irradiation.

Histological observations in animal studies demonstrated significant new bone formation after $CO_2$ laser irradiation around implants with peri-implantitis-induced bone defects. The laser seemed to be able to decontaminate the implant surface and to re-osseointegrate ailing implants with TPS

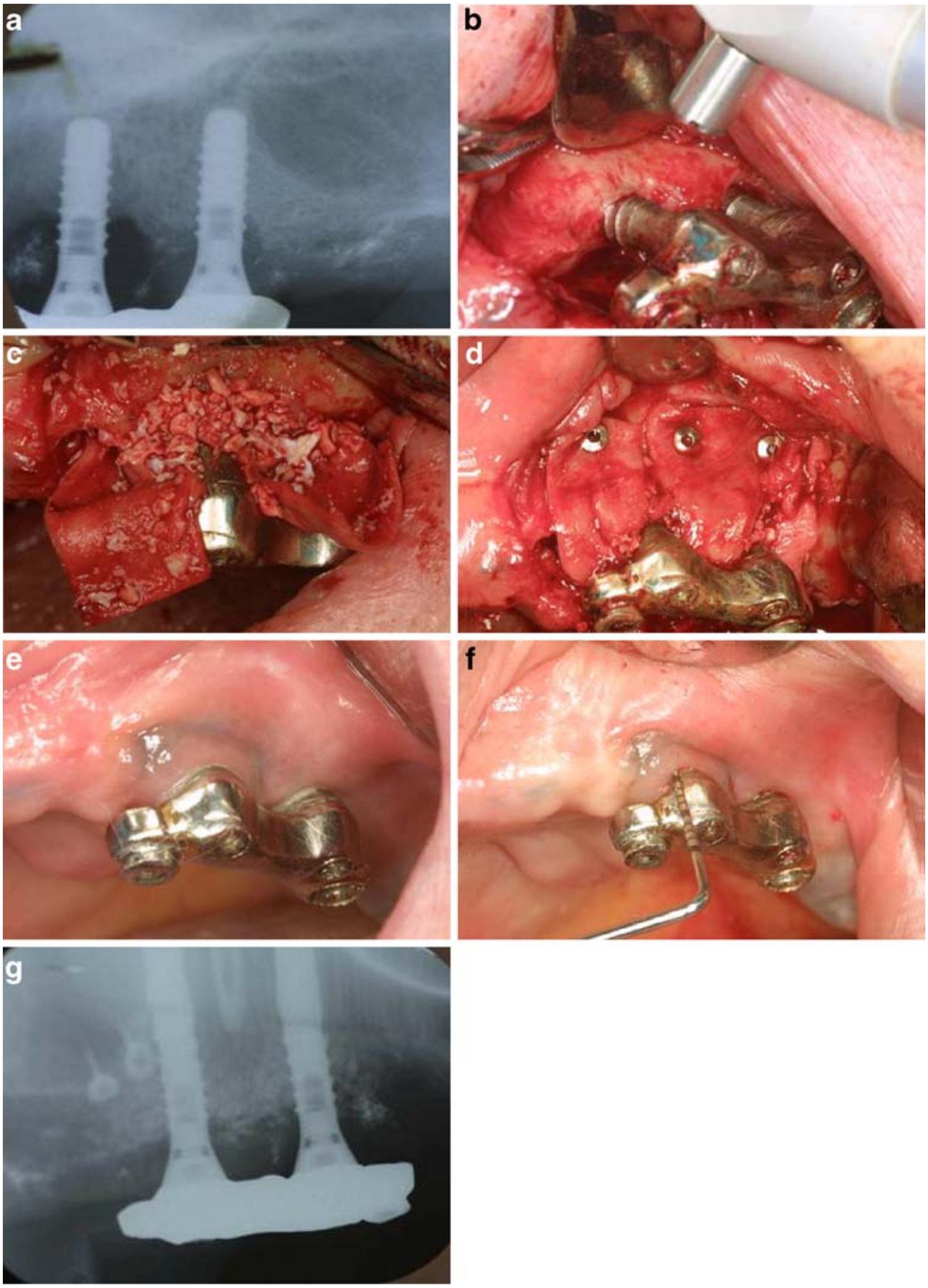

**Fig. 2** **a** Radiograph showing crestal bone loss around the two implants. **b** Implant decontamination with a defocused $CO_2$ laser immediately before augmentation. **c** Augmentation with bovine grafting material immediately after implant decontamination. **d** Coverage of the augmentation sites with a collagen membrane. **e** Clinical result 8 months after peri-implantitis therapy. **f** Clinical result 8 months after peri-implantitis therapy, showing the shallow peri-implant pockets. **g** Radiological examination 8 months after peri-implantitis therapy shows the new bone formation around the failing implants and the stable result

rough surfaces [56, 57]. Based on these experimental data Deppe et al. [58] demonstrated the clinical safety and efficacy of the $CO_2$ laser when applied with beta-TCP for the treatment of peri-implantitis.

The diode laser should be an alternative option to the $CO_2$ laser for decontamination of implant surfaces after flap elevation. Diode lasers are advantageous for the general practitioner because the units are small and reliable [59].

Significant antimicrobial effects were demonstrated in an in vitro study, in which peri-implant pockets were irrigated with toluidine blue and the peri-implant defects were irradiated with a diode low-intensity laser (905 nm for 1 min) [32]. However, there were no histomorphometric data showing new bone formation and re-osseointegration after the use of this laser wavelength.

An in vitro study with different implant surfaces [47] has shown that 980 nm diode lasers using high-power settings (10 W) do not damage titanium surface texture. Further, clinical indications for diode laser can be the removal of peri-implant overgrowths as well as decontamination of implant surfaces before augmentative surgical procedures; however, the use of a diode laser with an 810 nm wavelength in a high-power setting adversely changes the implant surface, and, for that reason, such lasers have to be applied with special care in order to treat peri-implantitis efficiently [29]. High-power diode lasers (810 nm) have excellent coagulation properties that are similar to those of the Nd:YAG laser [53, 60] and are characterized by the superficial tissue absorption with penetration to the underlying tissues [61, 62].

In contrast to the promising results of the $CO_2$ laser and diode lasers in studies investigating irradiation of implant surfaces, the application of a contact Nd:YAG laser leads to sufficient decontamination, in terms of sterilization of the implant, but also significant changes (melting and crater-like formation) of the implant surface [27, 48]. Furthermore, a significant temperature increase during laser irradiation has also been reported [63]. For these reasons the application of the contact Nd:YAG laser for the treatment of peri-implantitis, and for other soft tissue surgical procedures such as treatment of hyperplastic mucositis and second-stage surgery in submerged endosseous implants, is contraindicated.

Recent technological advances have led to an increase in the treatment options for dento-alveolar surgery. The traditional therapeutic techniques for bone removal using high-speed and low-speed rotary instruments, bone chisels and bone files were compared with the use of laser in bone surgery. Since there is no need to exert pressure on the bone, lasers may be superior to mechanical drilling [64, 65]. Several studies have demonstrated that the Er:YAG laser cuts bone precisely, with minimal thermal damage of 10–15 µm [63–67]. The laser removes a fixed amount of material per pulse, making precise control of cutting depth possible [68–72], and the low average power provides holes comparable to those obtained with mechanical drills. A previous study using a rabbit tibia model reported delayed healing of laser osteotomies compared with conventional saw osteotomies [64]. To date, few comparative studies of osseointegration of titanium implants in Er:YAG laser-prepared bone have been performed [69–73]. When lasers are used for bone surgery, careful histological and histomorphometric evaluation of bone and percentages of bone-to-implant contact after healing are required. Kesler et al. [73] compared the osseointegration of titanium alloy implants placed in the tibiae of rats, when bony cavities were created by Er:YAG laser and mechanical drill. Er:YAG laser was used with a regular non-contact handpiece, metal tip and water irrigation. The parameters used were 2 mm spot size on focus, 500–1,000 mJ per pulse, 400 ms pulse duration, and an energy density of 16–32 J/cm$^2$. The authors removed a bone volume of 1.4 mm$^3$ per pulse. Based on the results of this study, it may be assumed that Er:YAG laser can definitively be used clinically for implant site preparation with subsequent osseointegration and bone healing, with a statistically significant higher percentage of bone-to-implant-contact than with the conventional methods. In addition, collateral bone damage was less than in the bur-prepared bone. Perhaps because of the difficulty of applying sufficient coolant between the bone and the drill bit, the bur may cause necrosis, despite the use of low bur speed. By external irrigation of the bone with saline solution during the laser treatment, it was possible to reduce carbonization of the bone and enhance healing of the implant site. There is no doubt that laser irradiation should be avoided close to anatomical structures of importance, such as nerves, in order to avoid damage due to overheating. The Er:YAG laser allows the removal of the cortical part of the bone, penetrating to a depth of 3–4 mm, and insertion of the implant is possible, especially in weak bones. However, it is not possible at the moment to create the entire osteotomy in the total length and diameter with the Er:YAG laser or any other laser. In addition, it is not possible to have sufficient cooling during laser irradiation at the osteotomy site, and there is a need for further development.

The authors [73] concluded that the Er:YAG laser could promote the growth of new bone around titanium implants and better osseointegration than with the conventional osteotomies. The results of this study indicated that, in the rat model, the implant sites prepared by laser developed a statistically higher percentage of bone-to-implant contact than that at conventionally prepared sites.

Other studies have reported similar laser-induced stimulation of bone growth [74]. Sasaki et al. [75, 76] demonstrated that surfaces prepared by Er:YAG laser revealed only minimal changes without severe thermal damage, limited to a width of approximately 30 µm, microstructural changes of the original apatites, and reduction of the organic matrix. The typical irregular pattern of irradiated tissue consisted of biological apatites surrounded by organic matrix, and there were no toxic products on the Er:YAG-lased surfaces [75]. Lewandrowski and colleagues [77] also reported that the healing rate following Er:YAG laser irradiation may be equivalent to, or even faster than, that following bur drilling. In addition, the lack of a smear layer and the typical irregular pattern presented by the irradiated tissue may potentially enhance the adhesion of blood elements at the start of the healing process. A further advantage of the faster healing process and laser-induced bone growth may be the earlier function and loading of the implant.

Pourzarandian and co-workers [78] presented a histological and electron microscopy evaluation of bone formation, using the Er:YAG laser, the conventional bur, and the $CO_2$ laser, in the calvarial bone of rats. The initial healing following Er:YAG laser irradiation was faster. In contrast to these studies, Schwarz et al. [79] observed safe healing after Er:YAG laser osteotomy, but the osseointegration of the implants was no better than that in the conventional osteotomy.

For new bone formation and re-osseointegration after treatment of peri-implantitis or in implant site preparation, osteoblast attachment to the titanium surfaces is necessary. Cell culture experiments have become more attractive in recent years in our attempts to understand, control, and direct interfacial interactions at biomaterial surfaces. In particular, cultures of osteoblasts, either primary or from tumour lines, are frequently used to evaluate the effects of surface modifications on cell behaviour and metabolism.

Using scanning electron microscopy, Romanos et al. [80] investigated the attachment of osteoblasts to the titanium surface after laser irradiation of the implant surface. They used four different types of autoclaved titanium disks with machined, HA-coated, sandblasted, or TPS surfaces. The disks were irradiated with a $CO_2$ laser (10,600 nm), with a power output varying between 4 W and 6 W and a frequency of 20 Hz, and an erbium,chromium:yttrium–scandium–gallium–garnet (Er,Cr:YSGG) laser (2,780 nm), with a power of 1.25 W after laser irradiation All the implant surfaces examined were well colonized with osteoblasts. Cell morphology was similar for the irradiated titanium disks and the non-irradiated control group. Cell density in the irradiated test group was similar to that in the non-irradiated disks. The study data showed that laser irradiation of titanium surfaces did not negatively influence osteoblast attachment and cell proliferation. These findings may help to explain the effect of laser irradiation on implant surfaces and support the possibility of new bone formation after implant irradiation.

Recent results from a clinical pilot study have shown that non-surgical therapy using Er:YAG laser was able to reduce bleeding on probing significantly, from 83% at baseline to 31% after 6 months, but it did not significantly reduce the pocket depth and the clinical attachment levels between the laser and control groups [81]. Promising results in the treatment of peri-implantitis have been demonstrated histologically in a study by Takasaki et al. [82]. Experimentally induced peri-implant infections were treated with Er:YAG laser and compared with a curette group. The study showed that there were better results and a tendency to produce greater bone-to-implant contact (re-osseointegration) when the Er:YAG laser was used.

## Conclusions

The increased annual placement of oral implants around the world is also associated with a higher number of complications, such as pathological reactions in the soft tissue surrounding the implant and peri-implant bone defects with continuous loss of supporting bone. Bacterial contamination of implant surfaces is a common reason for implant failure. The modern concepts of clinical treatment for peri-implantitis are not well studied and sometimes do not lead to successful results.

Ideally, bone-to-implant contact should be increased histomorphometrically, and implants should become re-osseointegrated. At present, there is no evidence that anti-infective treatment of implant surfaces prolongs the longevity of an implant [26, 83].

In the past few years a wide spectrum of indications in modern implant dentistry has been proposed for laser systems. In general, lasers can be used in oral implantology for second-stage surgery of submerged implants, surgery to establish the health of soft tissue surrounding the implant, decontamination of titanium implant surfaces, and, experimentally, for implant site preparation. There is a potential interest in the clinical use of the 980 nm diode laser, which has excellent properties of incision, excision and coagulation of the soft tissues. Intraoperative and postoperative clinical findings were excellent, due to its sufficient cutting abilities, precise incision margin, good coagulation effect, and extremely small zone of thermal necrosis in surrounding tissues. [33]

According to recent literature (see Table 1) concerning the application of different laser wavelengths in the treatment of peri-implant lesions, the use of $CO_2$ laser (cw as well as pulsed mode) and diode laser (especially 980 nm) seems to be effective against bacteria without changing the implant surface pattern, as shown by scanning electron microscopy [47, 48]. It has also been noted that irradiation of the implant does not significantly increase the temperature of the implant body [28, 54, 63, 84]. In this respect, Kato et al. [28] noted a slight temperature increase, which did not negatively influence the attachment of fibroblasts or osteoblasts to the implant surface. With regard to the impact of the laser on the tissue surrounding the implant, there is decreased penetration depth due to absorption of the carbon dioxide radiation by the high water content of the mucosa. Both laser systems also showed excellent results in surgical procedures such as excision, incision and coagulation of soft tissues. Laser was advantageous in comparison with conventional methods, such as scalpel or electrosurgery, because of reduced pain and lack of haemorrhage. Furthermore, electrosurgery may damage the implant surface.

The Er:YAG laser also showed a bactericidal effect, which could be used for peri-implantitis therapy [50], although some authors observed modifications of the implant surface after irradiation [85]. Based on the findings in recent literature, the Er:YAG laser may be used clinically for implant site preparation with good results for osseointegration and bone healing, and with a statistically significant higher percentage of bone-to-implant contact than that with conventional methods of site preparation.

The Nd:YAG laser produces sufficient decontamination in terms of sterilization of the implant surface. The application of Nd:YAG laser for treatment of peri-implantitis, hyperplastic mucositis and second-stage surgery of submerged implants is contraindicated, due to the significant increase in the temperature during laser irradiation, the extensive melting of the implant surface and the higher penetration depth of the laser beam.

**Acknowledgements** The authors would like to thank Michael Yunker, D.D.S, for his assistance in the preparation of the manuscript.

## References

1. Albrektsson T, Dahl E, Enbom L et al (1998) Osseointegrated oral implants: a Swedish multicenter study of 8,139 consecutively inserted Nobelpharma implants. J Periodontol 59:287–296
2. Berglundh T, Persson L, Klinge B (2002) A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years. J Clin Periodontol 29:197–212. doi:10.1034/j.1600-051X.29.s3.12.x
3. Mombelli A, van Osten MAC, Schürch E, Lang NP (1987) The microbiota associated with successful or failing osseointegrated titanium implants. Oral Microbiol Immunol 2:145–151. doi:10.1111/j.1399-302X.1987.tb00298.x
4. Lang NP, Brägger U, Walther D, Beamer B, Kornman KS (1993) Ligature-induced peri-implant infection in cynomolgus monkeys. I. Clinical and radiographic findings. Clin Oral Implants Res 4:2–11. doi:10.1034/j.1600-0501.1993.040101.x
5. Lindhe J, Berglundh T, Ericsson I, Liljenberg B, Marinello C (1992) Experimental breakdown of periimplant and periodontal tissues. A study in the beagle dog. Clin Oral Implants Res 3:9–16. doi:10.1034/j.1600-0501.1992.030102.x
6. Schou S, Holmstrup P, Keiding N, Fiehn N-E (1996) Microbiology of ligature-induced marginal inflammation around osseointegrated implants and ankylosed teeth in cynomolgus monkeys (Macaca fascicularis). Clin Oral Implants Res 7:190–200. doi:10.1034/j.1600-0501.1996.070301.x
7. Meffert RM (1996) Periodontitis vs peri-implantitis: The same disease? The same treatment? Crit Rev Oral Biol Med 7:278–291. doi:10.1177/10454411960070030501
8. Mombelli A, Marxer M, Gaberthüel T, Grunder U, Lang NP (1995) The microbiota of osseointegrated implants in patients with a history of periodontal disease. J Clin Periodontol 22:124–130
9. Mombelli A, Lang NP (1998) The diagnosis and treatment of peri-implantitis. Periodontol 2000:63–76. doi:10.1111/j.1600-0757.1998.tb00124.x
10. Renvert S, Roos-Jansaker AM, Lindahl C, Revert H, Rutger Persson G (2007) Infection at titanium implants with or without clinical diagnosis of inflammation. Clin Oral Implants Res 18:509–516
11. Flemmig TF (1994) Infections on osseointegrated implants—background and clinical implications (in German). Implantologie 1:9–21
12. Mombelli A, Lang NP (1992) Antimicrobial treatment of peri-implant infections. Clin Oral Implants Res 3:162–168. doi:10.1034/j.1600-0501.1992.030402.x
13. Zablotzky MH (1993) Chemotherapeutics in implant dentistry. Implant Dent 2:19–25
14. Mombelli A (1997) Etiology, diagnosis, and treatment considerations in peri-implantitis. Curr Opin Periodontol 4:127–136
15. Schenk G, Flemmig TF, Betz T, Reuther J, Klaiber B (1997) Controlled local delivery of tetracycline HCl in the treatment of periimplant mucosal hyperplasia and mucositis. A controlled case series. Clin Oral Implants Res 8:427–433. doi:10.1034/j.1600-0501.1997.080510.x
16. Sbordone L, Barone A, Ramaglia L, Ciaglia RN, Iacono VJ (1995) Antimicrobial susceptibility of periodontopathic bacteria associated with failing implants. J Periodontol 66:69–74
17. Roos-Janssaker AM, Renvert S, Egelberg J (2003) Treatment of peri-implant infections: a literature review. J Clin Periodontol 30:467–485. doi:10.1034/j.1600-051X.2003.00296.x
18. Kwan JY, Zablotsky MH (1991) The ailing implant. J Calif Dent Assoc 12:51–56
19. Jovanovic SA (1993) The management of peri-implant breakdown around functioning osseointegrated dental implants. J Periodontol 64:1176–1183
20. Hanisch O, Tatakis DN, Boskovic MM, Rohrer MD, Wikesjö UM (1997) Bone formation and reosseointegration in peri-implantitis defects following surgical implantation of rhBMP-2. Int J Oral Maxillofac Implants 12:604–610
21. Hürzeler MB, Quinones CR, Morrison EC, Caffesse RG (1995) Treatment of peri-implantitis using guided bone regeneration and bone grafts, alone or in combination, in beagle dogs. Part I: Clinical findings and histologic observations. Int J Oral Maxillofac Implants 10:474–484
22. Behneke A, Behneke N, d′Hoedt B (2000) Treatment of peri-implantitis defects with autogenous bone grafts: six month to 3-year results of a prospective study in 17 patients. Int J Oral Maxillofac Implants 15:125–138
23. Singh G, O′Neal RB, Brenman WA, Strong SL, Horner JA, Van Dyke TE (1993) Surgical treatment of induced peri-implantitis in the micro pig: clinical and histological analysis. J Periodontol 64:984–989
24. Wetzel AC, Vlassis J, Caffessee RG, Hämmerle CH, Lang NP (1999) Attempts to obtain re-osseointegration following experimental peri-implantitis in dogs. Clin Oral Implants Res 10:111–119. doi:10.1034/j.1600-0501.1999.100205.x
25. Hämmerle CHF, Fourmousis I, Winkler JR, Weigle C, Brägger U, Lang NP (1995) Successful bone fill in late peri-implant defects using guided tissue regeneration. A short communication. J Periodontol 66:303–308
26. Klinge B, Gustafsson A, Berglundh T (2002) A systematic review of the effect of anti-infective therapy in the treatment of peri-implantitis. J Clin Periodontol 29 (Suppl 3):213–325. doi:10.1034/j.1600-051X.29.s3.13.x
27. Block CM, Mayo JA, Evans GH (1992) Effects of the Nd:YAG dental laser on plasma-sprayed and hydroxyapatite-coated titanium dental implants: surface alteration and attempted sterilization. Int J Oral Maxillofac Implants 7:441–449
28. Kato T, Kusakari H, Hoshino E (1998) Bactericidal efficacy of carbon dioxide laser against bacteria-contaminated titanium implant and subsequent cellular adhesion to irradiated area. Lasers Surg Med 23:299–306. doi:10.1002/(SICI)1096-9101(1998)23:5<299::AID-LSM10>3.0.CO;2-K
29. Bach G, Neckel C, Mall C, Krekeler G (2000) Conventional versus laser-assisted therapy of periimplantitis: a five-year comparative study. Implant Dent 9:247–251. doi:10.1097/00008505-200009030-00010
30. Romanos GE, Purucker P, Bernimoulin JP, Nentwig GH (2002) Bactericidal efficacy of $CO_2$-laser against bacteria-contaminated sandblasted titanium implants. J Oral Laser Appl 2:171–174

31. Kreisler M, Kohnen W, Marinello C, Schoof J, Langnau E, Jansen B, d'Hoedt B (2003) Antimicrobial efficacy of semiconductor laser irradiation on implant surfaces. Int J Oral Maxillofac Implants 18:706–711
32. Haas R, Dörtbudak O, Mensdorff-Pouilly N, Mailath G (1997) Elimination of bacteria on different implant surfaces through photosensitization and soft laser. An in vitro study. Clin Oral Implants Res 8:249–254. doi:10.1034/j.1600-0501.1997.080401.x
33. Romanos GE (2002) Treatment of periimplant lesions using different laser systems. J Oral Laser Appl 2:75–81
34. Catone GA (1997) Lasers in periodontal surgery. In: Catone GA, Alling CC (eds) Laser applications in oral and maxillofacial surgery. Saunders, Philadelphia, pp 181–196
35. Arnabat-Dominguez J, Espana-Tost AJ, Berini-Aytes L, Gay-Escoda C (2003) Er:YAG laser application in the second phase of implant surgery: a pilot study in 20 patients. Int J Oral Maxillofac Implants 18:104–112
36. Quirynen M, Marechal M, Busscher HJ, Waerkamp AH, Darius PL, van Steenberghe D (1990) The influence of surface-free energy and surface roughness on early plaque formation. J Clin Periodontol 17:138–144. doi:10.1111/j.1600-051X.1990.tb01077.x
37. Jovanovic SA, Kenney B, Carranza FA, Donath K (1992) The regenerative potential of plaque-induced peri-implant bone defects treated by a submerged membrane technique: an experimental study. Int J Oral Maxillofac Surg 7:233–245
38. Lang NP, Mombelli A, Tonnetti MS, Brägger U, Hämmerle CHF (1997) Clinical trials on therapies for peri-implant infections. Ann Periodontol 2:343–356
39. Lehmann B, Brägger U, Hämmerle CHF, Fourmousis I, Lang NP (1992) Treatment of an early implant failure according to the principles of guided tissue regeneration (GTR). Clin Oral Implants Res 3:42–48. doi:10.1034/j.1600-0501.1992.030107.x
40. Zablotzky M, Meffert R, Mills O, Burgess A, Lancaster D (1992) The macroscopic, microscopic and spectrometric effects of various chemotherapeutic agents on the plasma-sprayed hydroxyapatite-coated implant surface. Clin Oral Implants Res 3:189–198. doi:10.1034/j.1600-0501.1992.030406.x
41. Thomson-Neal D, Evans GH, Meffert RM (1989) Effects of various prophylactic treatments on titanium, sapphire, and hydroxyapatite-coated implants: a SEM study. Int J Periodontics Restor Dent 9:301–311
42. Fox SC, Moriarty JD, Kusy RP (1990) The effects of scaling a titanium implant surface with metal and plastic instruments: an in vitro study. J Periodontol 61:485–490
43. Rapley JW, Swan RH, Hallmon WW, Mills MP (1990) The surface characteristics produced by various oral hygiene instruments and materials on titanium implant abutments. Int J Oral Maxillofac Implants 5:47–52
44. Augthun M, Tinschert J, Huber A (1998) In vitro studies on the effect of cleaning methods on different implants surfaces. J Periodontol 69:857–864
45. van de Velde E, Thielems P, Schautteet H, Vanclooster R (1991) Subcutaneous emphysema of the oral floor during cleaning of a bridge fixed on a IMZ implant. Case report. Rev Belge Med Dent 46:64–71
46. Brown FH, Ogletree RC, Houston GD (1992) Pneumoparotitis associated with use of an air-powder prophylaxis unit. J Periodontol 63:642–644
47. Romanos GE, Everts H, Nentwig GH (2000) Effects of the diode (980 nm) and Nd:YAG (1064 nm) laser irradiation on titanium discs. A SEM examination. J Periodontol 71:810–815. doi:10.1902/jop. 2000.71.5.810
48. Romanos GE, Everts H, Nentwig GH (2001) Alterations of the implant surface after $CO_2$- or Nd:YAG-laser irradiation. A SEM-examination. J Oral Laser Appl 1:29–33
49. Kreisler M, Gotz H, Duschner H (2002) Effect of Nd:YAG, Ho:YAG, Er:YAG, $CO_2$, and GaAIAs laser irradiation on surface properties of endosseous dental implants. Int J Oral Maxillofac Implants 17:202–211
50. Matsuyama T, Aoki A, Oda S, Yoneyama T, Ishikawa I (2003) Effects of the Er:YAG laser irradiation on titanium implant materials and contaminated implant abutment surfaces. J Clin Laser Med Surg 21:7–17. doi:10.1089/10445470360516680
51. Deppe H, Greim H, Brill T, Wagenpfeil S (2002) Titanium deposition after peri-implant care with the carbon dioxide laser. Int J Oral Maxillofac Implants 17:707–714
52. Coffelt DW, Cobb CM, Mac Neil S, Rapley JW, Killoy WJ (1997) Determination of energy density threshold for laser ablation of bacteria. An in vitro study. J Clin Periodontol 24:1–7. doi:10.1111/j.1600-051X.1997.tb01177.x
53. Rastegar S, Jacques SL, Motamedi M, Kim BM (1992) Theoretical analysis of equivalency of high power diode laser (810 nm) and Nd:YAG laser (1064 nm) for coagulation of tissue: predictions for prostate coagulation. Proc SPIE 1646:150–160
54. Oyster DK, Parker WB, Gher ME (1995) $CO_2$ lasers and temperature changes of titanium implants. J Periodontol 66:1017–1024
55. Romanos GE, Nentwig G-H (2008) Regenerative therapy of deep peri-implant infrabony defects after $CO_2$ laser implant surface decontamination. Int J Periodont Restor Dent 28:245–255
56. Deppe H, Horch H, Henke J, Donath K (2001) Peri-implant care of ailing implants with the carbon dioxide laser. Int J Oral Maxillofac Implants 16:659–667
57. Stübinger S, Henke J, Donath K, Deppe H (2005) Bone regeneration after peri-implant care with the CO2 laser: a fluorescence microscopy study. Int J Oral Maxillofac Implants 20:203–210
58. Deppe H, Horch HH, Neff A (2007) Conventional versus CO2 laser-assisted treatment of peri-implant defects with the concomitant use of pure-phase beta-tricalcium phosphate: a 5-year clinical report. Int J Oral Maxillofac Implants 22:79–86
59. Desmettre TJ, Soulie-Begu S, Devoisselle JM, Mordon SR (1999) Diode laser-induced thermal damage evaluation on the retina with a liposome dye system. Lasers Surg Med 24:61–68. doi:10.1002/(SICI)1096-9101(1999)24:1<61::AID-LSM10>3.0.CO;2-G
60. Wyman A, Duffy S, Sweetland H, Sharp F, Rogers K (1992) Preliminary evaluation of a new high power diode laser. Lasers Surg Med 12:506–509. doi:10.1002/lsm.1900120509
61. Radvar M, MacFarlane TW, MacKenzie D, Whitters CJ, Payne AP, Kinane DF (1996) An evaluation of the Nd:YAG laser in periodontal pocket therapy. Br Dent J 180:57–62. doi:10.1038/sj.bdj.4808976
62. Cobb CM, McCawley TK, Killoy WJ (1992) A preliminary study on the effects of the Nd:YAG laser on root surfaces and subgingival microflora in vivo. J Periodontol 63:701–707
63. Chu RT, Watanabe L, White JM, Marshall GW, Marshall SJ, Hutton JE (1992) Temperature rise and surface modification of lased titanium cylinders. J Dent Res 71144, special issue, abstract no 312
64. Keller U, Hibst R, Mohr W (1991) Experimental animal studies on laser osteotomy using the erbium:YAG laser system (in German). Dtsch Z Mund Kiefer Gesichtschir 15:197–199
65. Hibst R (1992) Mechanical effects of erbium: YAG laser bone ablation. Lasers Surg Med 12:125–130. doi:10.1002/lsm.1900120203
66. Nelson JS, Orenstein A, Liaw LH, Berns MW (1989) Mid-infrared erbium:YAG laser ablation of bone: the effect of laser osteotomy on bone healing. Lasers Surg Med 9:362–374. doi:10.1002/lsm.1900090409

67. Walsh JT Jr, Deutsch TF (1989) Er:YAG laser ablation of tissue: measurement of ablation rates. Lasers Surg Med 9:327–337. doi:10.1002/lsm.1900090404
68. Walsh JT Jr, Flotte TJ, Deutsch TF (1989) Er:YAG laser ablation of tissue: effect of pulse duration and tissue type on thermal damage. Lasers Surg Med 9:314–326. doi:10.1002/lsm.1900090403
69. el-Montaser M, Devlin H, Dickinson MR, Sloan P, Lloyd RE (1999) Osseointegration of titanium metal implants in erbium-YAG laser-prepared bone. Implant Dent 8:79–85. doi:10.1097/00008505-199901000-00010
70. el Montaser MA, Devlin H, Sloan P, Dickinson MR (1997) Pattern of healing of calvarial bone in the rat following application of the erbium-YAG laser. Lasers Surg Med 21:255–261. doi:10.1002/(SICI)1096-9101(1997)21:3<255::AID-LSM5>3.0.CO;2-P
71. Kimura Y, Yu DG, Fujita A, Yamashita A, Murakami Y, Matsumoto K (2001) Effects of erbium,chromium:YSGG laser irradiation on canine mandibular bone. J Periodontol 72:1178–1182. doi:10.1902/jop. 2000.72.9.1178
72. Fried NM, Fried D (2001) Comparison of Er:YAG and 9.6-microm TE $CO_2$ lasers for ablation of skull tissue. Lasers Surg Med 28:335–343. doi:10.1002/lsm.1059
73. Kesler G, Romanos GE, Koren R (2006) Use of Er:YAG laser to improve osseointegration of titanium alloy implants—a comparison of bone healing. Int J Oral Maxillofac Implants 21:375–379
74. O'Donnell RJ, Deutsch TF, Flotte RJ, Lorente CA, Tomford WW, Mankin HJ, Schomacker KT (1996) Effect of Er:YAG laser holes on osteoinduction in demineralized rat calvarial allografts. J Orthop Res 14:108–113. doi:10.1002/jor.1100140118
75. Sasaki KM, Aoki A, Ichinose S, Ishikawa I (2002) Ultrastructural analysis of bone tissue irradiated by Er:YAG laser. Lasers Surg Med 31:322–332. doi:10.1002/lsm.10110
76. Sasaki KM, Aoki A, Ichinose S, Yoshino T, Yamada S, Ishikawa I (2002) Scanning electron microscopy and Fourier transformed infrared spectroscopy analysis of bone removal using Er:YAG and $CO_2$ lasers. J Periodontol 73:643–652. doi:10.1902/jop.2002.73.6.643
77. Lewandrowski KU, Lorente C, Schomacker KT, Flotte TJ, Wilkes JW, Deutsch TF (1996) Use of the Er:YAG laser for improved plating in maxillofacial surgery: comparison of bone healing in laser and drill osteotomies. Lasers Surg Med 19:40–45. doi:10.1002/(SICI)1096-9101(1996)19:1<40::AID-LSM6>3.0.CO;2-Q
78. Pourzarandian A, Watanabe H, Aoki A, Ichinose S, Sasaki KM, Nitta H, Ishikawa I (2004) Histological and TEM examination of early stages of bone healing after Er:YAG laser irradiation. Photomed Laser Surg 22:342–350. doi:10.1089/pho.2004.22.342
79. Schwarz F, Olivier W, Herten M, Sager M, Chaker A, Becker J (2007) Influence of implant bed preparation using an Er:YAG laser on the osseointegration of titanium implants: a histomorphometrical study in dogs. J Oral Rehabil 34:273–281. doi:10.1111/j.1365-2842.2006.01704.x
80. Romanos GE, Crespi R, Barone A, Covani U (2006) Osteoblast attachment on titanium discs after laser irradiation. Int J Oral Maxillofac Implants 21:232–236
81. Schwarz F, Sculean A, Rothamel D, Schwenzer K, Georg T, Becker J (2005) Clinical evaluation of an Er:YAG laser for nonsurgical treatment of peri-implantitis: a pilot study. Clin Oral Implants Res 16:44–52
82. Takasaki AA, Aoki A, Mizutani K, Kikuchi S, Oda S, Ishikawa I (2007) Er:YAG laser therapy for peri-implant infection: a histological study. Lasers Med Sci 22:143–157. doi:10.1007/s10103-006-0430-x
83. Esposito M, Hirsch J, Lekholm U, Thomsen P (1999) Differential diagnosis and treatment strategies for biologic complications and failing oral implants: a review of the literature. Int J Oral Maxillofac Implants 14:473–490
84. Mouhyi J, Sennerby L, Nammour S, Guillaume P, van Reck J (1999) Temperature increases during surface decontamination of titanium implants using $CO_2$ laser. Clin Oral Implants Res 10:54–61. doi:10.1034/j.1600-0501.1999.100107.x
85. Rechmann P, Sadegh HM, Goldin DS, Hennig T (2000) On the surface morphology of oral implants after laser irradiation (in German). Dtsch Zahnarztl Z 55:371–376