Treatment of periodontitis and peri-implantitis with an Er:YAG laser: Experimental and clinical studies

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Abstract

In addition to conventional treatment modalities (mechanical and chemical), the use of different lasers has also been proposed for the treatment of periodontal and peri-implant infections. Preliminary results from both basic studies and controlled clinical trials have pointed to a high potential of the Er:YAG laser. Irradiation with this specific wavelength seems to provide a bactericidal effect against periodontopathic bacteria, a reduction of lipopolysaccharides, and a high ability of bacterial biofilm and calculus removal. Recent clinical results have also indicated that nonsurgical and surgical treatment of periodontitis and peri-implantitis with an Er:YAG laser may lead to significant clinical improvements such as bleeding on probing, probing depth reduction and gain of clinical attachment. The aim of the present review paper is to evaluate, based on the currently available evidence, the use of an Er:YAG laser for treatment of periodontitis and peri-implantitis and to indicate its potential as a new treatment modality.

Keywords: Periodontitis; Peri-implantitis; Er:YAG laser; Therapy; Nonsurgical; Surgical

Introduction

The term “periodontal disease” in its strictest sense refers to both gingivitis and periodontitis [1]. Gingivitis has been defined as an inflammatory condition of the soft tissues surrounding the teeth and seems to be a direct immune response to microbial plaque biofilms building up on teeth. It may be modified by several factors such as smoking, certain drugs and hormonal changes that occur in puberty and pregnancy [2]. Special drug therapies such as nifedipine, and cyclosporine can result in gingival overgrowth in approximately 30% of individuals taking these medications. Chronic gingivitis is seen commonly in individuals with poor oral hygiene procedures for between 10 and 20 days [3]. Periodontitis follows gingivitis and is also influenced by the individual’s immune and inflammatory response. It is characterized as a destruction of the supporting structures of the teeth including the periodontal ligament (PDL), bone and soft tissues, which in turn may cause tooth loss [1]. Similarly, the host response to biofilm formation on implant surfaces includes a series of inflammatory reactions which initially occur in the soft tissue but which may subsequently progress and lead to loss of supporting bone. The presence of bacteria on implant surfaces may result in an inflammation of the peri-implant mucosa, and, if left untreated, it may lead to a progressive destruction of the alveolar bone supporting the implant, which has been named peri-implantitis [4,5]. The prevalence of peri-implantitis in
Potential use of lasers for periodontal treatment

A major goal of periodontal treatment is to resolve inflammation and thereby arrest disease progression [12]. Ideally, periodontal therapy does not only include arresting the disease but also regeneration of the tissues which have been lost due to disease. This includes de novo formation of connective tissue attachment and the regrowth of alveolar bone [13]. The results from controlled clinical studies have shown that nonsurgical (i.e., scaling and root planing using hand instruments) and various types of conventional surgical treatment may lead to a clinically important and statistically significant probing pocket depth reduction and clinical attachment (CAL) level gain [14–16]. However, histologic studies demonstrated that healing following nonsurgical and any type of conventional surgical periodontal therapy is mainly characterized by formation of a long junctional epithelium along the instrumented root surfaces and no predictable regeneration of attachment apparatus [13,17–19,20,21]. In this context, the formation of a smear layer after both mechanical scaling and root planing and ultrasonic instrumentation has been reported to be detrimental to periodontal tissue healing as it may inhibit reattachment of cells to the root surface [22,23]. However, additional root surface conditioning with various substances such as ethylenediaminetetraacetic acid gel (EDTA) at neutral pH, citric- and ortho-phosphoric acids has been shown to be effective in removing the smear layer and exposing the collagenous matrix of dentin [22–25]. In recent years, the use of laser radiation has been expected to serve as an alternative or adjunctive treatment to conventional, mechanical periodontal therapy. Various advantageous characteristics, such as hemostatic effects, selective calculus ablation or bactericidal effects against periodontopathic pathogens might lead to improved treatment outcomes [26–28]. The wavelengths of the lasers most commonly used in periodontics, which include diode lasers, the Nd:YAG laser (neodymium-doped: yttrium, aluminium and garnet), the Er:YAG laser (erbium-doped: yttrium, aluminium and garnet) and the CO₂ (carbon-dioxide) laser, range from 819 nm to 10,600 nm. Due to an excellent soft tissue ablation capacity, CO₂ lasers have been successfully used as an adjunctive tool to deep epithelialize the mucoperiosteal flap during traditional flap surgery [29]. Diode and Nd:YAG lasers were mainly used for laser-assisted subgingival curettage and disinfection of the periodontal pocket with various degrees of success [30–32]. However, several studies reported on thermal side effects, such as melting, cracking or carbonization when CO₂ and Nd:YAG lasers were used directly on root surfaces [33–36]. In case of the CO₂ laser these negative effects could be avoided when irradiation was performed in a pulsed mode with a defocused beam [37]. So far, there is limited information about the effects of diode laser radiation on the surface properties of root surfaces. The results from recent studies showed that this laser may also cause damage to periodontal hard tissues if irradiation parameters are not adequate [38,39]. Furthermore, neither CO₂ nor Nd:YAG nor diode lasers were effective in removing calculus from the root surface [31,32,33]. Since, according to the cause-related concept of periodontal therapy, the main objective of treatment is to remove all calcified deposits from the root surface [40], these types of lasers should only be used as an adjunct to mechanical periodontal treatment. Close attention has been paid to the clinical applicability of the Er:YAG laser with a wavelength of 2.94 μm in the near infrared spectrum. Because of the high absorption of its emission wavelength by water, this laser system provides a capability to effectively remove calculus from periodontally diseased root surfaces without causing thermal side effects to the adjacent tissue [27,39,41]. The absence of thermal damages was most likely due to the optical
characteristics of its wavelength of 2940 nm, since the Er:YAG laser theoretically has a 10 and 15,000–20,000 times higher absorption coefficient of water than the CO₂ and the Nd:YAG lasers, respectively (Fig. 1) [42,43].

Irradiation of periodontally diseased root surfaces

In 1994, Aoki et al. [27] have demonstrated that a pulsed Er:YAG laser may be suitable for an effective removal of subgingival calculus from periodontally diseased root surfaces using a glass-fibre tip in contact mode under water irrigation (energy density: 10.6 J/cm²). Aoki et al. [44] also reported on the effectiveness of Er:YAG laser scaling in comparison with ultrasonic scaling in vitro. This laser provided calculus removal on a level equivalent to that provided by an ultrasonic scaler. However, the efficiency of laser scaling was lower than that of the ultrasonic device. Although periodontal treatment with an Er:YAG laser may offer some interesting perspectives to the clinician, some questions are still present and need to be solved. One of them is the extent of the root surface damage after laser application. Histological and scanning electron microscopic (SEM) examinations have shown that under in vitro conditions the Er:YAG laser ablated not only the calculus, but also the superficial portion of the underlying cementum. The surface was left with an acid-etched appearance microscopically [27,39,44–47]. However, this microstructured root surface showed no cracks or thermal effects like carbonization or melting after CO₂- and Nd:YAG laser irradiation [33]. The absence of thermal side effects following Er:YAG laser irradiation of root surfaces has been confirmed by several authors [27,33,39,45–48]. Furthermore, irradiation with this type of laser also failed to alter the intensity of Amide peaks I, II or III, outlining that the chemical structure of the root surface has not been changed [49,50]. However, recently published studies reported a lack of cementum removal when laser instrumentation was performed under in vivo conditions [39,41]. This discrepancy might be explained by a diffusion of heat within the pocket, due to the presence of bleeding that occurs during laser instrumentation under in vivo conditions. Nevertheless, energy settings should be kept to a minimum in order to avoid a removal of underlying sound tissue. Recently, a subgingival calculus detection system with fluorescence induced by 655 nm InGaAsP diode laser radiation has been included in an Er:YAG laser device. Preliminary in vitro results have shown that 655 nm diode laser radiation induces significantly stronger fluorescence in subgingival calculus than in cementum, suggesting that calculus removal may be selectively performed [51–53]. It was assumed that bacteria derived byproducts, such as porphyrine which is released by the periodontopathogenic Porphyromonas sp., may be responsible for the strong fluorescence of subgingival calculus [51,54]. So far, the clinical relevance of this system remains questionable.

Another important observation was the lack of a smear layer formation on the root surface after Er:YAG laser instrumentation [55,56]. As mentioned above, the formation of a smear layer after mechanical root surface debridement with hand or ultrasonic instruments has been reported to be detrimental to periodontal tissue healing as it may inhibit cell migration and attachment [25,57]. In this context, it is important to point to the results from previous studies which have shown that the surface structure of previously diseased roots after Er:YAG laser instrumentation seemed to offer better conditions for the adherence of PDL fibroblasts than scaling and root planing with hand instruments [58–61]. However, a recent histological study, evaluating human intrabony defects following access flap surgery with root surface and defect debridement using an Er:YAG laser, revealed that healing was predominantly characterized by formation of a long junctional epithelium along the instrumented root surface. Formation of a new connective tissue attachment (i.e. new cementum with inserting collagen fibres) was only observed occasionally [62]. Finally, several studies have reported antimicrobial effects against periodontopathic bacteria and the removal of lipopolysaccharides by Er:YAG laser radiation from root surfaces in vitro [26,28,63,64]. However, preliminary clinical data failed to demonstrate any additional bactericidal effects following Er:YAG laser irradiation of periodontal pockets when compared to scaling and root planing using hand instruments [41,65,66]. In this context, it must be emphasized that a bacterial recolonization of the periodontal pocket occurs after 3 months [67,68].

Nonsurgical and surgical periodontal treatment

Controlled clinical trials [65,66,69] and case report studies [70,71] have indicated that nonsurgical periodontal treatment with an Er:YAG laser may lead to significant clinical improvements as evidenced by probing depth (PD) reduction and gain of CAL. In particular, in a clinical case report study evaluating the clinical assessments of an Er:YAG laser for soft tissue surgery and scaling, a total of 38 patients with moderate to advanced periodontitis were treated [71]. Each subject was evaluated on the day of laser application and after 1, 2, 3 and 4 weeks. Mean PD was reduced from 5.6±2.0 to 2.6±0.9 mm. These results were statistically and clinically significant compared to baseline.
However, no further details concerning the development of gingival recessions (GR) and CAL were given. Schwarz et al. [70] have treated 15 patients, suffering from chronic periodontitis, with an Er:YAG laser. The postoperative healing was uneventful in all cases. No complications such as abscesses or infections were observed throughout the study period of 6 months. Subsequent to instrumentation, mean CAL was statistically significant improved when compared to the baseline scores. In a first controlled clinical study, Er:YAG laser irradiation was compared to conventional scaling and root planing using a split-mouth design in 20 patients [66]. Periodontal pockets of 110 teeth exhibiting subgingival calculus with moderate to advanced periodontal destruction were treated under local anesthesia with either the Er:YAG laser or hand instruments. Laser treatment was performed using chisel typed contact tips (1.10 × 0.5 mm, or 1.65 × 0.5 mm) under water irrigation (Fig. 2). The laser treatment was performed from coronal to apical in parallel paths, with an inclination of the fibre tip at 15–20° to the root surface [72]. The laser treatment required shorter time than the control treatment. At 6 months following treatment, both treatment approaches resulted in significant CAL gains; however laser treatment seemed to be superior at initially deeper pockets (>7 mm). In both groups, CAL gains obtained following treatment could be maintained over a 2-year period [65]. Furthermore, Schwarz et al. [69] investigated the necessity of adjunctive scaling and root planing after Er:YAG laser treatment. However, it was observed that the combined treatment Er:YAG laser and scaling and root planing did not seem to additionally improve the outcome of the therapy compared to laser treatment alone. Most recently, Sculean et al. [73] compared the effectiveness of an Er:YAG laser to that of ultrasonic instrumentation for nonsurgical periodontal treatment. Twenty patients with moderate to advanced periodontal destruction were randomly treated in a split-mouth design with a single episode of subgingival debridement using either an Er:YAG laser device combined with a calculus detection system with fluorescence induced by 655 nm InGaAsP diode laser radiation, or an ultrasonic instrument. At 6 months following treatment, mean values of bleeding on probing (BOP), PD and CAL improved statistically significant in both groups. However, no statistically and clinically differences in the improvements of investigated parameters were observed between both treatment modalities. Preliminary clinical results have also demonstrated that treatment of deep intrabony periodontal defects with the use of an Er:YAG laser alone or in combination with the application of an enamel matrix protein derivative may lead to a clinically important and statistically significant gain of CAL [74,75] (Tables 1 and 2).

**Potential use of lasers for the treatment of peri-implant infections**

Today, there is considerable evidence to support a cause–effect relationship between microbial colonization and the pathogenesis of implant failures [76–78]. The presence of bacteria on implant surfaces may result in an inflammation of the peri-implant mucosa, and, if left untreated, it may lead to a progressive destruction of the alveolar bone supporting the implant, which has been named peri-implantitis [4,5]. Therefore, the removal of bacterial plaque biofilms is a prerequisite for the therapy of peri-implant infections [4]. In recent years, several maintenance regimens and treatment strategies (i.e. mechanical, chemical) for failing implants have been suggested [79–85]. Mechanical debridement is usually performed using specific instruments made out of materials less hard than titanium (i.e. plastic curettes, polishing with rubber cups) in order to avoid a roughening of the metallic surface which in turn may favour bacterial colonization [79,81,84,86]. Since mechanical methods alone are insufficient in the elimination of bacteria on roughened implant surfaces, adjunctive chemical agents (i.e. irrigation with local disinfectants, local or systemic antibiotic therapy) were examined clinically and proven to enhance healing following treatment [80,82,85]. Although air-powder-flow was also successfully used for implant surface decontamination in vitro [79,87], there are limitations in the application because it can lead to microscopically visible alterations of the implant surface and be associated with an increased risk of emphysema [83,87,88]. Recently, in addition to these conventional tools, the use of different laser systems has also been proposed for treatment of peri-implant infections. As lasers can perform excellent tissue ablation with high bactericidal and detoxification effects, they are expected
### Table 1. Clinical studies: nonsurgical periodontal treatment with an Er:YAG laser

<table>
<thead>
<tr>
<th>Study/observation period</th>
<th>Laser device</th>
<th>Laser parameters</th>
<th>n</th>
<th>Groups</th>
<th>BOP(0) (%)</th>
<th>BOP(1) (%)</th>
<th>PD(0)</th>
<th>PD(1)</th>
<th>CAL(0)</th>
<th>CAL(1)</th>
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<tbody>
<tr>
<td>Watanabe et al. [71]/4 weeks</td>
<td>ML22, HOYA Co., Japan</td>
<td>32 mJ/pulse, 10 Hz 11.3 J/cm²</td>
<td>25</td>
<td>Laser</td>
<td>—</td>
<td>—</td>
<td>2.9 ± 1.3</td>
<td>2.5 ± 1.4</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Schwarz et al. [70]/6 months</td>
<td>KEY2®, KaVo, Germany</td>
<td>120 mJ/pulse, 10 Hz 14.5 J/cm²</td>
<td>10</td>
<td>Laser</td>
<td>59</td>
<td>19</td>
<td>4.7 ± 0.7</td>
<td>3.1 ± 0.6</td>
<td>6.1 ± 1.1</td>
<td>4.6 ± 1.0</td>
</tr>
<tr>
<td>Schwarz et al. [66]/6 months</td>
<td>KEY2®, KaVo, Germany</td>
<td>120 mJ/pulse, 10 Hz 14.5 J/cm²</td>
<td>20</td>
<td>Laser</td>
<td>56</td>
<td>13</td>
<td>4.9 ± 0.7</td>
<td>2.9 ± 0.6</td>
<td>6.3 ± 1.1</td>
<td>4.4 ± 1.0</td>
</tr>
<tr>
<td>Schwarz et al. [65]/12 months</td>
<td>KEY2®, KaVo, Germany</td>
<td>120 mJ/pulse, 10 Hz 14.5 J/cm²</td>
<td>20</td>
<td>Laser + SRP</td>
<td>58</td>
<td>18</td>
<td>5.2 ± 0.8</td>
<td>3.2 ± 0.8</td>
<td>6.9 ± 1.0</td>
<td>5.3 ± 1.0</td>
</tr>
<tr>
<td>Schwarz et al. [69]/24 months</td>
<td>KEY2®, KaVo, Germany</td>
<td>120 mJ/pulse, 10 Hz 14.5 J/cm²</td>
<td>20</td>
<td>Laser</td>
<td>56</td>
<td>20</td>
<td>4.9 ± 0.7</td>
<td>3.3 ± 0.9</td>
<td>6.3 ± 1.1</td>
<td>4.9 ± 1.0</td>
</tr>
<tr>
<td>Sculean et al. [73]/6 months</td>
<td>KEY3®, KaVo, Germany</td>
<td>120 mJ/pulse, 10 Hz 14.5 J/cm²</td>
<td>20</td>
<td>Laser</td>
<td>24</td>
<td>11</td>
<td>—</td>
<td>—</td>
<td>Gain: 1.1 ± 0.6</td>
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n = number of patients; BOP = bleeding on probing; PD = probing pocket depth; CAL = clinical attachment level; SRP = scaling and root planing (0) = baseline examination; (1) = last examination.

*Follow-up study.*
to be one of the most promising new technical modalities for treatment of failing implants [89–91]. The interaction between laser light and metal surfaces is mainly determined by the degree of absorption and reflection. Each metal features a certain spectral reflection capacity, which is dependant on the specific wavelength of the laser. The reflection capacity of titanium for the Er:YAG laser with its wavelength of 2940 nm in the near infrared spectrum is 71% and rises up to 96% for the CO₂ laser at 10,000 nm [92]. In this situation, the implant surface does not absorb the irradiation and subsequently there is no temperature increase, which would damage the implant surface. Indeed, recent in vitro studies have demonstrated that, in an energy dependent manner, only the CO₂ laser, the diode laser and the Er:YAG laser may be suitable for the irradiation of implant surfaces, since the implant body temperature did not increase significantly during irradiation [89–91,93–95]. Regarding the effect of lasers on titanium, the Nd:YAG laser is not suitable for implant therapy, since it easily ablates the titanium irrespective of output energy [90]. So far, bactericidal effects on textured implant surfaces in vitro were only reported for the CO₂- and Er:YAG laser [87,93,94]. Since, neither CO₂ nor diode lasers were effective in removing plaque biofilms from root surfaces or titanium implants, both types of lasers were only used adjunctive to mechanical treatment procedures [32,35,96]. In contrast, as described above, several investigations have reported on the promising ability of the Er:YAG laser for subgingival calculus removal from periodontally diseased root surfaces without producing major thermal side-effects to adjacent tissue [27,41].

**Er:YAG laser device and fibre tip for nonsurgical irradiation of implant surfaces**

Recently, a cone-shaped quartz glass fibre tip (diameter: cylinder 1 mm; conical tip 0.5 mm), emitting an axial and radial laser beam, has been particularly designed for nonsurgical instrumentation of peri-implant pockets. The specific pattern of radiation was generated in order to enable even irradiation of screw-typed dental implants (Fig. 3). However, the axial and radial components of radiation may also unintentionally damage the adjacent alveolar bone during laser instrumentation. Indeed, the results of a recent cell culture study have shown that mitochondrial activity of SaOs-2 osteoblasts was significantly reduced after Er:YAG laser irradiation using a cone-shaped glass fibre tip at energy settings of 40, 60, 80 and 100 mJ at 10 Hz (energy densities of 5.08, 7.62, 10.16 and 12.7 J/cm²) [97]. Each energy setting was used at a distance of 1, 2 and 3 mm between the application tip and the bottom of the

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<tr>
<td>Schwarz et al. [74]/6 months</td>
<td>KEY²®, KaVo, Germany</td>
<td>120 mJ/pulse, 10 Hz, 23 Laser</td>
<td>14.5 J/cm²</td>
<td>SRP+EDTA+EMD</td>
<td>57 31 8.1 0.8 4.0 14.5 J/cm²</td>
<td>SRP+EDTA+EMD</td>
<td>57 31 8.1 0.8 4.0 14.5 J/cm²</td>
<td>SRP+EDTA+EMD</td>
<td>57 31 8.1 0.8 4.0 14.5 J/cm²</td>
<td>SRP+EDTA+EMD</td>
<td>57 31 8.1 0.8 4.0 14.5 J/cm²</td>
<td>SRP+EDTA+EMD</td>
<td>57 31 8.1 0.8 4.0 14.5 J/cm²</td>
<td>SRP+EDTA+EMD</td>
<td>57 31 8.1 0.8 4.0 14.5 J/cm²</td>
<td></td>
</tr>
<tr>
<td>Sculean et al. [75]/6 months</td>
<td>KEY²®, KaVo, Germany</td>
<td>120 mJ/pulse, 10 Hz, 23 Laser</td>
<td>14.5 J/cm²</td>
<td>SRP+Ultrasound device</td>
<td>44 18 7.8 0.8 4.6 10 J/cm²</td>
<td>SRP+Ultrasound device</td>
<td>44 18 7.8 0.8 4.6 10 J/cm²</td>
<td>SRP+Ultrasound device</td>
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<td>SRP+Ultrasound device</td>
<td>44 18 7.8 0.8 4.6 10 J/cm²</td>
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</table>

**Table 2. Clinical studies: surgical-/regenerative periodontal treatment with an Er:YAG laser**

- n = number of patients; BOP = bleeding on probing; PD = probing pocket depth; CAL = clinical attachment level; SRP = scaling and root planning EDTA = ethylene diamine tetraacetic acid.
- EMD = enamel matrix derivative.
- (0) = baseline examination; (1) = last examination.
culture plate. Time of exposure was constantly set at 10 s. Non-irradiated cell cultures served as positive controls ($n = 10$). Following irradiation, mitochondrial activity of the cells was measured using a luminescent cell viability assay. This assay quantifies adenosinetriphosphate (ATP) which signals the presence of metabolic active cells and is based on the luciferase-catalysed reaction of luciferin and ATP. After laser irradiation, mitochondrial activity of SaOs-2 osteoblasts was significantly reduced when compared to non-irradiated cells ($P < 0.001$, respectively), irrespective of the used energy setting or distance between the application tip and the bottom of the culture plate. However, mitochondrial activity increased significantly with decreasing energy settings and increasing distances ($P < 0.001$, respectively). Based on these results, detrimental effects of laser irradiation may be reduced by decreasing energy settings on the one hand and increasing the distance between the application tip and alveolar bone on the other hand. However, during nonsurgical instrumentation it may be difficult to estimate depth and width of the intrabony component around dental implants. On the other hand it is important to realize that results obtained by using an in vitro experimental model cannot recreate the complex interactions of cells in vivo. In this context, an issue that has not been determined is the healing pattern of bone following laser irradiation.

**Influence on morphology and biocompatibility of titanium implants**

Recent results from a controlled experimental study have demonstrated that an Er:YAG laser, used with this kind of fibre tip, does not damage titanium surfaces and subsequently does not influence the attachment rate of osteosarcoma derived osteoblasts (SaOs-2) in vitro [39]. A total of 168 titanium discs with 4 different surfaces (sand-blasted and acid etched-SLA, titanium plasma sprayed-TPS, machine polished-MP, and hydroxyapatite coated-HA) were used to evaluate cell attachment. The samples have been equally and randomly assigned to the following groups: (1) Er:YAG laser at an energy level of 100 mJ/pulse and 10 Hz (12.7 J/cm$^2$) using a cone-shaped fibre tip, or (2) an ultrasonic system using carbon fibre tips, or (3) untreated control. The discs were placed into culture plates, covered with a solution of SaOs-2 cells, and incubated for 7 days. The specimens were then washed with phosphate buffer to remove cells not attached to the surface, and the adherent cells were stained with haematoxylin-eosine. Cells were counted using a reflected light microscope and the cell density per mm$^2$ was calculated. Additionally, cell morphology and surface alterations of the titanium discs after treatment were investigated using SEM. All titanium discs treated with the Er:YAG laser demonstrated nearly the same cell density per mm$^2$ as the untreated control surfaces. There was a significant decrease in the number of cells that attached to the implant surfaces treated with the ultrasonic system. The SEM examination showed no visible differences between laser and control titanium surfaces. All surfaces treated with the ultrasonic system showed conspicuous surface damages and debris of the used carbon fibres [39]. So far, there are only few data available describing the effects of an Er:YAG laser on the surface characteristics of differently coated titanium discs [90,98]. In a recent study, Kreisler et al. [38] reported surface alterations, such as melting and glazing, at energy densities of $8.9 J/cm^2$ in TPS surfaces, $11.2 J/cm^2$ in SLA surfaces, $17.8 J/cm^2$ in HA-coated surfaces and $28 J/cm^2$ in smooth titanium surfaces. However, the laser beam was used in non-contact mode without water cooling and the angle of irradiation was $90^\circ$. In a similar study, first micro-morphological changes in sand-blasted and acid etched and titanium plasma sprayed titanium surfaces occurred at an average energy density of $7 J/cm^2$ [98]. The discrepancy noted in these studies might be explained by the fact that the fibre tip was guided in contact mode, parallel to the titanium surfaces under permanent water cooling [39]. In this context, it is important to point to the results of a previous study which have shown that the angulation of the application tip has a strong influence on the amount of root substance removal using Er:YAG laser radiation for periodontal treatment [72]. Furthermore, it should be pointed out that permanent water cooling might cause less damage than irradiation without water irrigation.
Detoxification effects on rough titanium surfaces in vitro

The results of a recent in vitro investigation have pointed to a high bactericidal potential of the Er:YAG laser on rough titanium surfaces [94]. Commercially available SLA, TPS and HA coated titanium discs were incubated with a suspension of *Streptococcus sanguis* and irradiated at energy settings of 60 and 120 mJ at 10 Hz (7.62–15.24 J/cm²) for 60 s without water irrigation in non-contact mode. Non-irradiated control titanium discs revealed the following bacterial counts: (log): SLA: 6.38 × 10³; TPS: 6.25 × 10³; HA: 2.73 × 10³. Subsequent to irradiation, bacterial counts were significantly reduced (log) to: SLA: 3.13 × 10²; TPS: 2.50 × 10²; HA: 4.38 × 10⁰ (P < 0.001, respectively) at a pulse energy of 60 mJ (7.62 J/cm²), and to: SLA: 5.00 × 10¹; TPS: 3.88 × 10¹; HA: 4.12 × 10⁰ (P < 0.001, respectively) at a pulse energy of 120 mJ (15.24 J/cm²). However, a complete bacterial reduction following laser irradiation could not be observed, irrespective of energy setting. However, at these laser parameters, no excessive temperature elevations (<47 °C), which might have influenced bacterial reduction additionally, or morphological implant surface alterations were detected [94]. Similar results were also observed by Kreisler et al. [87]. Titanium platelets with a SLA surface were coated with bovine serum albumin and incubated with a suspension of *Porphyromonas gingivalis*. Contaminated specimens were randomly irradiated with an Er:YAG Laser (60 mJ/Puls, 10 Hz; 7.62 J/cm²), or treated with an air powder system. After the respective treatment, human gingival fibroblasts were incubated on the specimens. Cell proliferation was significantly (P < 0.05) reduced on contaminated and non-treated specimens when compared to sterile specimens. In both treatment groups, cell proliferation was not significantly different from that on sterile control specimens. However, the air powder system led to microscopically visible alterations of the implant surface whereas laser-treated surfaces remained unchanged [87].

Removal of plaque biofilms from rough titanium surfaces

Preliminary results of an experimental study have shown, that an Er:YAG laser seems to be suitable for the removal of supragingival early plaque biofilms grown on SLA titanium implants [99]. Five volunteers wore acrylic splints with sand-blasted and acid-etched titanium discs for 24 h to build up supragingival plaque. A total of 80 specimens were randomly assigned to the following groups: (1) an Er:YAG laser using a cone-shaped fibre tip (100 mJ/pulse, 10 Hz, 12.7 J/cm²) (Y), (2) an ultrasonic system (U), (3) plastic curettes and rinsing with chlorhexidine digluconate (P), or (4) unworn titanium discs (C). Autoclaved specimens were incubated with SAOS-2 cells for 3 days. The following parameters were measured: treatment time (T), residual plaque biofilm (RPB) and clean implant surface (CIS) areas (%), and mitochondrial cell activity (MA) (counts/second). Statistical analysis within and between groups revealed the following mean scores (± SD): RPB areas: P (61.1 ± 11.4) > Y (36.8 ± 4.5) > U (5.8 ± 5.1); CIS areas: Y (94.2 ± 5.1) > U (63.2 ± 4.5) > P (38.9 ± 11.2); T: Y (5.6 ± 1.2) > U (2.4 ± 0.5) > P (2.3 ± 0.5); MA: C (1.528.636 ± 188.371) > U (831.594 ± 370.228) > Y (678.250 ± 367.902) > P (144.105 ± 120.961). In this context, it is important to realize that a supragingival plaque biofilm, collected artificially after a period of 24 h is non-mineralized, whereas subgingival dental calculus is defined as mineralized dental plaque that is permeated with crystals of various calcium phosphates [100]. However, previous findings from a case report study evaluating the effectiveness of an Er:YAG Laser for the removal of subgingival debris from titanium implants under clinical conditions [101]. This investigation was conducted on eight implants (SLA and TPS) of two patients, considered for explantation due to severe bone loss and inflammation. Immediately before explantation, six implants were instrumented subgingivally with the Er:YAG laser (12.7 J/cm²), while two implants served as a control. All titanium implants were examined using scanning electron microscopy by one calibrated and blinded examiner. In comparison to the untreated control group, nonsurgical instrumentation of titanium implants with an Er:YAG laser resulted in an effective removal of subgingival calculus without leading to any thermal damages. However, all samples of the test group revealed amounts of residual debris which should be taken into account under clinical conditions [101].

Nonsurgical treatment of peri-implantitis

Most recently, results of a pilot study have also indicated that nonsurgical treatment of peri-implantitis with an Er:YAG laser may lead to significant clinical improvements [102]. Twenty patients with moderate to advanced peri-implantitis lesions were randomly treated with either (1) an Er:YAG laser using a cone-shaped glass fibre tip at an energy setting of 100 mJ/pulse and 10 Hz (12.7 J/cm²), or (2) mechanical debridement using plastic curettes and antisepic therapy with chlorhexidine digluconate (0.2%) (C). The following clinical parameters were measured at baseline, 3 and 6 months after treatment by one blinded and calibrated examiner: Plaque index (PI), BOP, PD, GR and CAL level. In both groups, there were no signs of any adverse effects
that could be associated with the specific treatment procedure. However, in the control group, one patient with two implants was discontinued from the study due to persisting pus formation 8 weeks after treatment. Mean values of BOP decreased in the laser group from 83% at baseline to 31% after 6 months (P<0.001) and in the control group from 80% at baseline to 58% after 6 months (P<0.001). The difference between both groups was statistically significant (P<0.001, respectively). The laser treated sites demonstrated a mean CAL change from 5.8±1.0 mm at baseline to 5.1±1.1 mm (P<0.01) after 6 months. The C sites demonstrated a mean CAL change from 6.2±1.5 mm at baseline to 5.6±1.4 mm (P<0.001) after 6 months. After 6 months, the difference between both groups was statistically non significant (P>0.05) [88]. In this context, it must be pointed out, that these clinical results were only based on a short-term observation of 6 months and a small study population. However, unpublished data of our working group suggest that nonsurgical treatment of peri-implantitis with an Er:YAG laser may also lead to significant clinical improvements over a period of 12 months (Table 3).

Conclusions

In recent years, the use of laser radiation has been expected to serve as an alternative or adjunctive treatment to conventional, mechanical periodontal therapy. Among all lasers used in the field of dentistry, the Er:YAG laser seems to possess characteristics most suitable for oral treatment, due to its ability to ablate both soft and hard tissues as well as bacterial biofilms and calculus without causing major thermal damage to the adjacent tissue. Indeed, a huge number of experimental and clinical studies have pointed to a high potential of this kind of laser for periodontal treatment, suggesting from a clinical point of view, that the Er:YAG laser may serve as an alternative treatment modality to conventional, mechanical periodontal therapy. These observations, taken together with the finding that peri-implantitis has been classified as a disease process associated with microorganisms known from chronic periodontitis, suggest that the Er:YAG laser may also be used for treatment of peri-implant infections. Indeed, when interpreting the results of the presented studies, it may be concluded that the Er:YAG laser seems to be more suitable for the removal of early plaque biofilms grown on SLA titanium implants than conventional, mechanical treatment approaches. Furthermore, preliminary clinical results suggest, that nonsurgical treatment of peri-implantitis with an Er:YAG laser may lead to significant improvements of all of the investigated clinical parameters. On the other hand, previous case

<table>
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<tr>
<th>Study/Observation period</th>
<th>Laser device</th>
<th>Laser parameters</th>
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<th>Laser parameters</th>
<th>Laser device</th>
<th>Laser parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schwarz et al. [102] / 6 months</td>
<td>KEY3®, KaVo, Germany</td>
<td>85 mJ/pulse, 10 Hz</td>
<td>Laser</td>
<td>Plastic curettes + chlorhexidineglukonat</td>
<td>Laser</td>
<td>Plastic curettes + chlorhexidineglukonat</td>
</tr>
<tr>
<td>6 months</td>
<td>20</td>
<td>83</td>
<td>12.7 J/cm²</td>
<td>31</td>
<td>5.1±0.9</td>
<td>12.7 J/cm²</td>
</tr>
<tr>
<td>6 months</td>
<td>20</td>
<td>80</td>
<td>4.8±1.4</td>
<td>5.5±1.5</td>
<td>5.6±1.4</td>
<td>31</td>
</tr>
</tbody>
</table>

**Table 3.** Clinical study: Nonsurgical treatment of peri-implantitis with an Er:YAG laser

- **n** = number of patients; **BOP** = bleeding on probing; **PD** = probing pocket depth; **CAL** = clinical attachment level; **SRP** = scaling and root planing.
report studies have shown that the use of adjunctive local or systemic antibiotic therapy also had a positive effect on clinical and microbiological parameters. In this context, it must be pointed out, that currently there is still a lack of clinical data evaluating the subgingival microflora associated with peri-implant infections following Er:YAG laser irradiation in vivo. Therefore, further studies are needed in order to compare the effectiveness of this treatment modality on microbiological changes to that of adjunctive local or systemic antibiotic therapy. Another point of interest may be the evaluation of the relative cost-effectiveness of different treatment approaches. From a clinical point of view, it should also be taken into account that a huge number of different implant types and surface characteristics complicate a generalization of the present results.

Zusammenfassung

Therapie der Parodontitis und Periimplantitis mit einem Er:YAG Laser: Experimentelle und klinische Untersuchungen


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Schlüsselwörter: Parodontitis; Periimplantitis; Er:YAG-Laser; Therapie; nichtchirurgisch; chirurgisch

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