The Use of Lasers in Decontamination of Implant Surfaces and the Treatment of Peri-implantitis – A Mini-Systematic Review

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Abstract:

Introduction: Various implant surface treatments currently available are focusing on decontamination and inhibition of microbial adherence to implant surfaces, thus attempting to prevent peri-implantitis. Laser therapy has shown potential for treating such conditions by safely irradiating titanium surfaces without altering the delicate titanium microstructure, important for osseointegration. The aim of this study was to perform a narrative literature review and analyse current evidence available on the effectiveness of laser decontamination of implant surfaces and treatment of peri-implantitis.

Method: The Electronic databases Medline (via PubMed and OvidSp) and Trip were systematically searched.

Results: Eight studies have been reviewed and treatment outcomes for Er:YAG (Erbium-Doped Yttrium Aluminium Garnet), Carbon Dioxide Lasers (CO2 lasers), Gallium-aluminium-arsenide (GaAlAs) diode lasers, Nd:YAG (Neodymium-doped yttrium aluminium garnet) and photodynamic therapy have been analysed. Despite inconsistencies among studies in terms of study design, positive short-term therapeutic effects have been observed throughout all investigated studies.

Conclusion: Future research needs to focus on longer follow-up periods, synchronizing user settings by implementing guidance on laser power and application, limiting the use of adjunctive interventions and consistent evaluation of clinical outcome variables throughout studies.

Keywords: Laser Treatment Peri-implantitis
Introduction

A variety of laser settings enables employment in various areas of dentistry. One of them is the rapidly evolving area of implantology. Tissue ablation and reduction in bacterial contamination of implant surfaces, soft tissue management and treatment of peri-implantitis (PI) are of special interest to ultimately improve implant longevity.¹

The most common dental implant failure is due to PI and its incidence ranges from 12%-43% of dental implant sites.² Implant removal rates of 8-50% are also attributable to PI.³ PI can be defined as an inflammatory process affecting peri-implant bone post-osseointegration to the functional implant surface, that ultimately results in bone loss.⁴ Its risk factors include plaque, poor oral hygiene, periodontal disease, diabetes, alcohol consumption and smoking.³

Most commercial dental implants are made of titanium or titanium alloys. To increase surface area and enhance osseointegration, a range of surface modifications are available such as sandblasting, plasma spraying and anodizing etching.³ PI was found to occur more frequently around implants with roughened surfaces as this provides microorganisms with a greater surface area to adhere to.⁵ The formation of biofilms on implant surfaces can induce inflammation and ultimately bone loss.³

Current decontamination protocols suggest plastic curettage, chlorhexidine digluconate, iodine as well as local and systemic antibiotics for titanium surface decontamination. The use of ultrasonics and metal instrumentation is contraindicated due to potential induction of surface alterations of the implant surface.² Using certain lasers with appropriate power settings for debridement, avoids mechanical interference and destruction of the micro-texture of the implant surface.⁶
A variety of lasers for the decontamination of implant surfaces are available. These include Nd:YAG (Neodymium-doped yttrium aluminium garnet), Carbon dioxide (CO2), Gallium-aluminium-arsenide (GaAlAs) diode, Chromium-doped yttrium-scandium-gallium-garnet and Erbium-doped yttrium–aluminium–garnet (Er:YAG). However, studies found the Er:YAG to be the most consistent. The Er:YAG laser has proven to be effective in the removal of plaque and calculus on contaminated abutments. This is made possible through emitting a wavelength of 2.94 μm that is highly absorbed in water. Excellent results in periodontal therapy could be achieved in terms of bactericidal and detoxification effects. These results suggest a potential utilisation of the Er:YAG laser in the removal of biofilms and thus PI therapy.

The aim of this study was to perform a comprehensive literature review of the most relevant papers published on the use of lasers in dental implant surface treatment in patients with PI and to determine its effectiveness of decontamination as well as viability of treating PI.

**Materials and Methods**

**PICO:** This is a useful tool for asking a focussed clinical question and is an acronym for: Population, Intervention, Comparison and Outcome. In this mini systematic review, our PICO question was: “For patients suffering from peri-implantitis (P), is laser decontamination of implant surfaces (I), compared to traditional non-surgical periodontal therapy (C), an effective method of decontamination and treatment (O)?”

**Levels of evidence:** Not all evidence is equal and systematic reviews consider the quality of evidence before summarising the evidence within a review. This evidence quality is determined by the methods used to reducing bias within a study design. Studies with the
highest levels of evidence quality are randomised controlled trials, followed by at least one randomised controlled trial on the effectiveness of an intervention. Lower levels of evidence are provided by non-randomised controlled trials and single case studies.

**Search bases:** Electronic databases Medline (via PubMed and OvidSp) and the Trip database were searched by one of the authors (CH) using the following search terms: ‘Lasers and Implants’, ‘Lasers in Implantology’, ‘Peri-implantitis and Lasers’, ‘Peri-implantitis and decontamination’ and ‘Lasers and Biofilm’.

**Inclusion criteria:**

Literature which examined the effects Laser decontamination in the treatment of peri-implantitis

Literature available through the University of Bristol

Literature from 2000-2014

Literature in the English language

Literature from any country provided that it was available in the English language

Literature which used any study design type

Both primary and secondary source types were considered

Literature was included irrespective of outcome

**Exclusion criteria:**

There were no further exclusion criteria were applied due to the limited number of publications in this field.
PRISMA flow diagram: A PRISMA flow diagram of the papers selected for review is shown in Figure 1. Forty papers were initially identified and the titles and abstracts of each paper were read by a single author (CH). Thirty-four papers were rejected based on their irrelevance to this review. Bibliographies of these forty papers were also searched for relevant articles and this resulted in two more publications being deemed suitable. Thus, a total of eight articles, published between 2005 and 2014 were selected for analysis (Table 1).

Data capture: Full-text analysis of all included articles was carried out and information was extracted for assessment using data capture sheets which recorded the following data:

a) Primary research studies:

- Study, Year
- Type of study
- Laser investigated
- Control
- Type of Implants
- No. of Implants/No. of patients
- Surgical/Non – surgical intervention
- Adjunctive therapeutics - test and control groups
- Follow up period
- BOP
- Plaque index
- Clinical attachment level (CAL)
- Pocket probing depth (PPD)
- Gingival recession
- Bone levels
- Wavelength
- Tip
- Tip movement
- Tip angulation
- Mode
- Pulse duration
- Power
- Time of application

b) Review papers:

- Publication, Year and laser investigated
- Inclusion/Exclusion criteria
- Studies included in review
- Type of studies
- Clinical outcomes/Decontamination potential

The completed data capture sheets are shown in Tables 2 to 4.

**Bias:** A summary of the risk of bias for all studies included within this review, based upon the Cochrane Collaboration’s tool,⁸ is shown in Table 5.

**Results**

The eight studies selected for review included one Case Report,¹ one Histological Study,⁴ one Clinical Follow-up,⁹ one Pilot Study,¹⁰ two Randomised Control Trials (RCTs),¹¹,¹² one Narrative Review,¹³ and one Systematic Review and Meta-Analysis.⁷
Primary research papers analysed five Er:YAG lasers and one Diode laser and collected data on clinical variables such as bleeding on probing (BOP), plaque index, pocket probing depth (PPD), clinical attachment levels (CAL), gingival recession and bone levels. The reviews assessed decontamination efficacy of five different lasers and in total investigated eleven Er:YAG lasers, seven CO2 lasers, three Nd:YAG lasers, seven GaAlAs diode lasers and one Photodynamic treatment (HELBO).

**Laser therapy in peri-implantitis treatment:** Primary research mostly utilised Er:YAG lasers either as a monotherapy\(^{10,12}\) or adjunctive intervention\(^{2,4,8}\) in the treatment of peri-implantitis, whilst only one study attempted to observe the efficacy of a Diode laser.\(^ {11}\) A total number of 175 implants, with a range of different titanium surfaces, were irradiated to measure clinical outcomes. All studies collected their final data after 6 months post-intervention, apart from one study\(^ {8}\) where the last follow up was scheduled at 24 months.

**Adjunctive treatment:** In most studies\(^ {4,9,10}\) plastic curettage was used as a control whilst one study\(^ {11}\) utilised air-abrasive therapy. Peri- and post-operative medicament adjuncts were used within the control groups, including post-surgery antibiotics\(^ {4}\) and chlorhexidine digluconate 0.2% solution and 0.2% gel.\(^ {10}\) One study\(^ {9}\) used natural bone mineral and collagen membranes within the control group. Additionally, a PERIO-FLOW device was utilised in one study.\(^ {12}\)

Whilst one study\(^ {10}\) did not use any adjunctive therapeutics for the laser test group, one utilised the same post-surgery antibiotics as in their control group\(^ {4}\) but with the addition of 2% chlorhexidine gluconate solution whilst two studies\(^ {9,11}\) used the same adjuncts for their test and control group.

**Surgical versus non-surgical intervention:** Two studies\(^ {4,11}\) used flap surgery for subgingival access, whilst another\(^ {9}\) also used a surgical approach but in conjunction with implantoplasty.
A two-stage treatment protocol was implemented in one study\textsuperscript{2} whereby stage 1 was non-surgical and stage 2 surgical. Two studies\textsuperscript{10,12} used a non-surgical approach for decontamination.

**Laser power settings:** Er:YAG power settings varied between studies, whilst some papers did not report on certain variables. Only two studies\textsuperscript{4,10} used a wavelength of 2.94 µm in contact mode. More similarly, two studies\textsuperscript{10,12} applied a cone-shaped tip with circular tip movement, parallel tip angulation and power at 100mJ/pulse but one\textsuperscript{12} did not report on wavelength and pulse duration. One study\textsuperscript{2} only reported the type of tip, tip movement, angulation and power used, making it more difficult to compare to other studies.

Power settings for the diode laser utilized in one study\textsuperscript{11} only reported on wavelength, mode, power settings and time of application. Only one other study also reported on irradiation time.\textsuperscript{2}

**Effects of Er:YAG on BOP:** One study\textsuperscript{2} reported no bleeding after 3 months of laser treatment, whilst another\textsuperscript{12} observed this in only 31% of cases after 6 months post laser therapy. The remaining three studies recorded a statistically significant reduction in BOP, whilst one study\textsuperscript{4} did not investigate this clinical variable.

**Effects of Er:YAG on plaque index:** Three studies\textsuperscript{9,10,12} recorded non-significant changes in plaque levels without significant differences between groups. Two studies\textsuperscript{2,4} did not report on this outcome variable.

**Effects of Er:YAG on CAL:** Only two studies by Schwartz et al.\textsuperscript{9,10} reported on clinical attachment levels. The 2012 study\textsuperscript{9} observed a statistically significant reduction in mean CAL values in both groups at 12 months but failed to reach statistical significance after 24 months. Between-group comparisons were of no significance. The 2005 study\textsuperscript{10} however, observed a
statistically significant CAL gain but inter-group comparison did not reach clinical or statistical significance.

Effects of Er:YAG on PPD: Four studies reported significant reductions in pocket probing depths, whilst one study\(^4\) did not record this variable. One study\(^2\) observed a significant reduction in PPD after both, stage 1 (non-surgical) and stage 2 (surgical) treatment. Although, one study\(^9\) reported a significant improvement after 12 months with no notable differences between groups, at 24 months, only the control group remained significant. Compared to other studies, one study\(^10\) observed differences in post- treatment and baseline pocket depths, by categorising the pockets into shallow, moderate or deep pockets. Initially deep pockets showed significant changes in PPD, whilst moderate pockets showed moderate improvements and shallow sites exhibited statistically non-significant changes. One study\(^12\) observed reductions in PPD in both groups but the overall clinical improvement was limited.

Effects of Er:YAG on gingival recession: Three studies reported mild gingival recession\(^2,9,10\) whilst two studies\(^4,12\) did not report on this outcome.

Effects of Er:YAG on bone levels: The main outcome measures in one study\(^4\) was new bone formation, collecting data on new bone height (NBH) and new bone-to-implant contact (NBIC), by using light microscopy and histometrical analysis. An increase in NBH and NBIC were observed in the laser group compared to the curette control group. However, the difference between groups did not reach statistical significance.

Only two studies\(^2,9\) adjunctively utilised synthetic or natural bone. One of these\(^2\) reported bony infill of defects via radiographic evaluation, 6 months after surgery, and no further investigations were carried out in light of laser efficacy and new bone formation in this study. The other\(^9\) also observed an initial increase in bone levels after 12 months but this slightly decreased after 24 months.
Whilst three studies reported some degree of increased bone levels, one study\textsuperscript{12} was the only paper observing a loss in bone levels after 6 months, although not clinically significant. One study\textsuperscript{10} did not report on bone levels.

**Effects of diode laser on clinical outcomes:** One study\textsuperscript{11} reported a significant reduction in BOP at 3 and 6 months after treatment, with no statistically significant difference between groups. Plaque levels saw a continuous reduction between baseline, 3 and 6 months post irradiation. Further statistically significant reductions were observed for CAL at both follow up time points. PPD showed no statistical difference at 3 and 6 months between groups. PPD was decreased at both re-examinations but the second visit did not show any further statistically significant improvements.

**Review of clinical outcomes following Er:YAG, CO\textsubscript{2} and photodynamic therapy:** The review study\textsuperscript{13} observed similar clinical outcomes for CO\textsubscript{2} lasers as with Er:YAG lasers, however Photodynamic therapy did not reach statistical significance for CAL and PPD was of no clinical significance.

**Review of decontamination efficacy following Er:YAG, CO\textsubscript{2}, GaAlAs diode, Nd:YAG laser therapy:** One study\textsuperscript{7} reviewed the decontamination potentials and bactericidal efficacies using various laser systems. All lasers exhibited dose dependant decontamination potentials. CO\textsubscript{2} lasers required higher settings to achieve 100\% decontamination compared to Er:YAG. However, GaAlAs diode lasers reached near complete elimination of microbes at only 2.5W - half of that required for Er:YAG lasers.

**Meta-analysis for Er:YAG laser treatment at the 6-month post-intervention observational interval:** Outcome measures were deemed to be heterogenic enough to evaluate mean outcomes of CAL and PPD by including 3 surgical studies and 1 non-surgical study. Results revealed no statistical significance of CA loss after 6 months for the surgical and non-surgical
group and for all studies. Similarly, PPD was also found to be non-significant for surgical and non-surgical groups and all studies respectively. No evidence for subgroup differences between non-surgical and surgical interventions in CA loss and PPD reduction treatments were identified.

Discussion

The basis of successful treatment of PI disease is a healthy periodontium that requires excellent patient education on oral hygiene, constant re-enforcement and motivation. Thus, patient compliance is vital after decontamination. Despite that, some studies failed to record plaque levels, leading to inconsistencies in results. One study reported a decrease in plaque levels post-laser treatment, however, this kind of outcome may be confounded by patient’s improved oral hygiene regime. It is therefore hard to evaluate whether this was down to laser efficacy or patient factors. Regular follow up visits to monitor and maintain oral hygiene is of paramount importance. The serious confounding factor of smoking was ignored by all but one study and did not feature in the exclusion criteria. Furthermore, patient’s medical history including systemic disease and medications that could potentially interfere with healing or osseointegration, were not taken into consideration either. Only one study recorded the differences in smoking years and medications between participants but did not exclude subjects on the basis of these variables.

The study designs varied widely, including the use of different surgical and non-surgical treatments with the addition of adjunctive therapies between studies as well as within test-and control groups. This further complicates the comparison of outcome variables, hence relative laser efficacy assessments cannot be made. Not all studies recorded the same clinical parameters, including p-values, making a reliable inference impossible.
Small sample sizes in some studies might be skewing outcome data and statistical significance cannot be obtained. Power calculations to estimate an acceptable number of patients and/or implants needed to obtain a positive therapeutic outcome are required.

Potential operator bias could not specifically be identified but most studies did not mention the number of operators or their skill level, causing possible inter-study discrepancies.

Most studies selected to treat acute PI, but no universal definition was used throughout the studies, potentially shifting some outcomes to look more favourable compared to others. Although, some studies reported on suppuration, this was not a consistently reported variable.

One of the biggest inconsistencies between studies was noted in terms of laser settings and application. Whilst some variables were left unreported, others varied widely, in spite of research showing that energy levels have a significant effect on decontamination of implant surfaces. Future research needs to address the implementation of protocols and guidance for laser application to enable evaluation of the relative effectiveness of lasers on implant decontamination and safety. This will become particularly important with the introduction of new high pulse repetition rates, increasing the risk of thermally altering the implant surface morphology. Thus, some current lasers are deemed unsuitable for implant decontamination due to reports of cracking, crater formation and melting of titanium surfaces following the use of Nd:YAG and holmium-doped:YAG lasers. CO2 lasers are commonly used to irradiate implant surfaces, however, there is increased risk of heating the titanium implant and surrounding bone. One study investigated the Er:YAG laser for visible irradiation damage and reported no changes of titanium under 50 mJ/pulse (energy density 17.7 J/cm2) and constant water spray using contact mode. Furthermore, a second study investigated microstructural changes when irradiation parameters were set to 12.7 J/cm2 and 10 Hz
energy density, whilst cooling the implant surface with water, but no alterations in surface structure could be observed either. Thus, research accepts the safe use of Er:YAG laser systems for implant surface decontamination.

A 2008 Cochrane systematic review concluded that only very little reliable evidence currently formulates an effective intervention for treating PI, further confirming the need for future research, including laser therapy.\textsuperscript{18}

\textbf{Conclusions}

The research question “For patients suffering from peri-implantitis, is laser decontamination of implant surfaces, compared to traditional non-surgical periodontal therapy, an effective method of decontamination and treatment?” has not been answered by this mini-systematic review. The use of lasers in dental implant surface treatment requires further high quality RCTs to be undertaken and would greatly benefit from prioritising the implementation of standards for laser parameters and applications. Most studies focused on Er:YAG lasers, but it would be interesting to see future research investigating more treatment outcomes of CO2 and Diode laser therapies. The use of adjuncts needs to be limited to evaluate true laser efficacy. Detailed patient selection, Plaque indices and severity of PI needs to be uniformly reported throughout research papers as well as the same outcome variables to allow comparison. Positive outcome measures have been obtained after 6 months, suggesting an effective initial response to laser decontamination, however, results generally tailed off at 24 months in the one study that obtained records at this time point. Hence, re-examinations up
to at least one year following treatment with intermittent visits for general implant maintenance, oral hygiene and vital patient motivation, need implementing.

Based on the limited amount of information available, the implications for clinicians at this point in time is to follow manufacturers recommended laser settings, whilst using their clinical expertise and judgement when carrying out laser therapy in patients with PI.

Conflicts of Interest:

The authors have no conflicts of interest.

References:

5. Esposito M, Grusovin MG, Worthington HV. Interventions for replacing missing teeth: treatment of peri-implantitis (Review). *Cochrane Database of Systematic Reviews* 2012; **1**


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**Table 1**: The studies included within this review

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of study</th>
<th>Laser type</th>
<th>Control</th>
<th>Follow up period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badran <em>et al.</em>, 2011</td>
<td>Case report</td>
<td>Er:YAG</td>
<td>N/a</td>
<td>3 and 6 months</td>
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<tr>
<td>Takasaki <em>et al.</em>, 2006</td>
<td>Histological study</td>
<td>Er:YAG</td>
<td>Plastic curettes</td>
<td>24 weeks</td>
</tr>
<tr>
<td>Schwarz <em>et al.</em>, 2012</td>
<td>Clinical follow up</td>
<td>Er:YAG</td>
<td>Plastic curettes</td>
<td>12 and 24 months</td>
</tr>
<tr>
<td>Schwarz <em>et al.</em>, 2005</td>
<td>Pilot study</td>
<td>Er:YAG</td>
<td>Plastic curettes and chlorhexidine digluconate 0.2%</td>
<td>3 and 6 months</td>
</tr>
<tr>
<td>Papadopoulos <em>et al.</em>, 2014</td>
<td>RCT</td>
<td>Diode laser</td>
<td>Plastic curettes</td>
<td>3 and 6 months</td>
</tr>
<tr>
<td>Study</td>
<td>Type</td>
<td>Laser Types</td>
<td>Air-abrasive Therapy</td>
<td>Duration</td>
</tr>
<tr>
<td>-----------------------</td>
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</tr>
<tr>
<td>Renvert et al., 2011</td>
<td>RCT</td>
<td>Er:YAG</td>
<td>-</td>
<td>6 months</td>
</tr>
<tr>
<td>Kotsakis et al., 2014</td>
<td>Systematic Review</td>
<td>- CO₂ laser, Er:YAG, Photodynamic treatment (HELBO)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kamel et al., 2014</td>
<td>Narrative Review</td>
<td>- GaAlAs diode, CO₂, Nd:YAG, Er:YAG</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 1: PRISMA flow diagram of the studies included within the review

40 potentially relevant studies identified through electronic database search

34 studies omitted based on title or abstract

6 studies deemed relevant for detailed review

2 studies found via bibliography search

8 studies selected for analysis
<table>
<thead>
<tr>
<th>Study</th>
<th>Type of study</th>
<th>Laser type</th>
<th>Control</th>
<th>Type of implant</th>
<th>No. of implants/no. of patients</th>
<th>Surgical/Non-surgical intervention</th>
<th>Adjunctive therapeutics for test group</th>
<th>Adjunctive therapeutics for control group</th>
<th>Follow up period</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badran et al., 2011</td>
<td>Case report</td>
<td>Er:YAG</td>
<td>N/a</td>
<td>Not reported</td>
<td>1 implant/1 patient</td>
<td>Stage 1: non-surgical; Stage 2: surgical</td>
<td>Surgical ultrasonic debridement; bone curettes, synthetic bone substitute (BCP)</td>
<td>N/a</td>
<td>3 and 6 months</td>
<td>Increase in new bone height and new bone-to-implant contact, compared to the control group, although not statistically significant</td>
</tr>
<tr>
<td>Takasaki et al., 2006</td>
<td>Histological study</td>
<td>Er:YAG</td>
<td>Plastic curettes</td>
<td>Sand-blasted large grit acid-etched (SLA) surface implants (solid screw Ø 3.3 x 10 mm standard plus, ITI® Dental implant system, Straumann AG, Waldenburg, Switzerland)</td>
<td>16 implants/Four 1-year-old beagle dogs</td>
<td>Peri-implant flap surgery</td>
<td>2% Solution of Chlorhexidine gluconate; Antibiotics for 3 days post-surgery</td>
<td>Saline solution irrigation; Antibiotics for 3 days post-surgery</td>
<td>24 weeks</td>
<td></td>
</tr>
<tr>
<td>Schwarz et al., 2012</td>
<td>Clinical follow up</td>
<td>Er:YAG</td>
<td>Plastic curettes</td>
<td>Implant systems: ANK, AST, BRA, CAM, ITI, KSI, REP, TSV, XIV, NI*;</td>
<td>26 implants/24 patients</td>
<td>Flap surgery; Implantoplasty</td>
<td>Natural bone mineral and collagen membrane</td>
<td>cotton pellets; sterile saline; natural bone mineral and covered with a collagen membrane</td>
<td>12 and 24 months</td>
<td>Reductions of BOP, PPD and CAL were significant at 12 months, however, only the reduction in BOP remained significant after 24 months</td>
</tr>
<tr>
<td>Schwarz et al., 2005</td>
<td>Pilot study</td>
<td>Er:YAG</td>
<td>Plastic curettes and chlorhexidine gluconate 0.2%</td>
<td>Titanium implants (Straumann) Screw type; SLA; TPS</td>
<td>32 implants/20 patients</td>
<td>Non-surgical</td>
<td>No adjuncts used</td>
<td>chlorhexidine digluconate 0.2%; subgingival application of CHX gel 0.2 %</td>
<td>3 and 6 months</td>
<td>Reductions of BOP, PPD and CAL were significant, despite unchanged plaque levels</td>
</tr>
<tr>
<td>Papadopoulos et al., 2014</td>
<td>RCT</td>
<td>Diode laser</td>
<td>Plastic curettes</td>
<td>Titanium Implants</td>
<td>16 implants/16 patients</td>
<td>Flap surgery</td>
<td>Plastic curettes, sterilized gauzes soaked in saline</td>
<td>Plastic curettes, sterilized gauzes soaked in saline</td>
<td>3 and 6 months</td>
<td>Reductions in BOP, PPD and CAL 6 months after treatment; However, diode laser irradiation did not deem to add any additional benefits clinically</td>
</tr>
<tr>
<td>Renvert et al., 2011</td>
<td>RCT</td>
<td>Er:YAG</td>
<td>Air-abrasive therapy</td>
<td>Not reported</td>
<td>100 implants/42 patients</td>
<td>Non-surgical</td>
<td>No adjuncts used</td>
<td>PERIO-FLOW® device</td>
<td>6 months</td>
<td>Reduction of BOP was significant, however, reduction in PPD was not</td>
</tr>
</tbody>
</table>

*ANK=Ankylos® (cylindrical screw, microrough surface), Dentsply Friadent, Mannheim Germany; AST=Astra Dental Implant System® (cylindrical screw, microthread, nanotype surface), Astra Tech Dental, Mölndal, Sweden; BRA=Astra Dental Implant System® (cylindrical screw, microrough surface), Astra Tech Dental, Mölndal, Sweden; CAM=Camlog Screw Line® (cylindrical screw, microrough surface), Camlog Biotechnologies AG, Basel, Switzerland; ITI,ITI® (cylindrical screw, microrough surface), Institute Straumann AG, Basel, Switzerland; KSI=KSI Bauer Schraube® (conical screw, machined surface), KSI GmbH, Bad Nauheim, Germany; REP=NobelReplace® (tapered screw, microrough surface), Nobel Biocare AB, Goeteborg, Sweden; TSV=Tapered Screw Vent® (tapered screw, microrough surface), Zimmer Dental, Freiburg, Germany; XIV=Xive® (cylindrical screw, microrough surface), Dentsply Friadent, Mannheim, Germany; NI=Non-identifiable implant systems.
Table 3: Laser settings and applications used in included primary research studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Laser type</th>
<th>Wavelength</th>
<th>Tip</th>
<th>Tip movement</th>
<th>Tip angulation</th>
<th>Mode</th>
<th>Pulse duration</th>
<th>Power</th>
<th>Time of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badran et al., 2011</td>
<td>Er:YAG</td>
<td>Not reported</td>
<td>Bevelled</td>
<td>Not reported</td>
<td>10 - 15 degrees</td>
<td>Not reported</td>
<td>Not reported</td>
<td>120 mJ; frequency, 10Hz</td>
<td>Irradiated for 60 seconds</td>
</tr>
<tr>
<td>Takasaki et al., 2006</td>
<td>Er:YAG</td>
<td>2.94 µm</td>
<td>Chisel sapphire glass(P/N 625-8746) with rectangular pointed head of 1.40 x 0.45 mm</td>
<td>Scraping motion</td>
<td>30 - 45 degrees, oblique to implant surface</td>
<td>Contact</td>
<td>30 pps</td>
<td>10.0 J/cm2 (62 mJ/pulse); frequency 20 Hz</td>
<td>Not reported</td>
</tr>
<tr>
<td>Schwarz et al., 2012</td>
<td>Er:YAG</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>11.4 J/cm2, frequency 10 Hz</td>
<td>Not reported</td>
</tr>
<tr>
<td>Schwarz et al., 2005</td>
<td>Er:YAG</td>
<td>2.94 µm</td>
<td>Cone-shaped glass fibre</td>
<td>Circular motion from coronal to apical</td>
<td>Parallel to implant</td>
<td>Contact</td>
<td>10 pps</td>
<td>12.7 J/cm2 (100 mJ/pulse); 85 mJ/pulse</td>
<td>Not reported</td>
</tr>
<tr>
<td>Papadopoulos et al., 2014</td>
<td>Diode laser</td>
<td>980 nm</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Pulsed</td>
<td>Not reported</td>
<td>0.8 W;</td>
<td>Surface irradiated 3 times with 2 min. intervals</td>
</tr>
<tr>
<td>Renvert et al., 2011</td>
<td>Er:YAG</td>
<td>Not reported</td>
<td>Cone-shaped sapphire</td>
<td>Semi-circular motion around the circumferential pocket area</td>
<td>Parallel to implant</td>
<td>Parallel</td>
<td>Not reported</td>
<td>12.71 J/cm2 (100 mJ/pulse)</td>
<td>Not reported</td>
</tr>
</tbody>
</table>
Table 4: Outcome measures recorded in included primary research studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of study</th>
<th>Laser type</th>
<th>BOP</th>
<th>Plaque index</th>
<th>Clinical attachment level</th>
<th>Pocket probing depth</th>
<th>Gingival recession</th>
<th>Bone levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badran et al., 2011</td>
<td>Case report</td>
<td>Er:YAG</td>
<td>No bleeding after 3 months</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Baseline: 5.9 mm; Reduction after 3 months: PPD 2.5 mm, following non-surgical treatment; Additional reduction after 6 months: PPD 0 - 2 mm post-augmentation</td>
<td>Increased by 1 - 2 mm</td>
<td>Bony infill</td>
</tr>
<tr>
<td>Takasaki et al., 2006</td>
<td>Histological study</td>
<td>Er:YAG</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>Schwarz et al., 2012</td>
<td>Clinical follow up</td>
<td>Er:YAG</td>
<td>Reduction after 12 months: 55.0 ± 28.4%; Reduction after 24 months: 75.0 ± 32.6%</td>
<td>Non-significant reduction after 12 months of 0.42 ± 1.0 and 0.2 ± 0.6 (mean ± SD) after 24 months. No significant difference between groups (p &gt;0.05)</td>
<td>Reduced after 12 months: 1.3 ± 1.2 mm; Reduction after 24 months: 1.0 ± 2.2 mm</td>
<td>Reduction after 12 months: 1.7 ± 1.2 mm; Reduction after 24 months: 1.1 ± 2.2 mm</td>
<td>Increased after 12 months by 0.4 ± 0.2 mm; Slight decreases after 24 months: 0.1 ± 0.4 mm</td>
<td>Initially 1 - 3 mm gain in 80% of patients, followed by slight loss after 24 months</td>
</tr>
<tr>
<td>Schwarz et al., 2005</td>
<td>Pilot study</td>
<td>Er:YAG</td>
<td>30% after 3 months; 31% after 6 months compared to 83% at baseline</td>
<td>Non-significant reduction after 3 months from 1.1 ± 0.5 (baseline) to 1.0 ± 0.6 follow by a slight increase after 6 months to 1.1 ± 0.4</td>
<td>Mean gain after 6 months of 0.6 ± 0.3 mm in moderately deep sites; in deep sites 0.9 ± 0.5 mm; shallow sites non-significant</td>
<td>Reduction after 3 months and 6 months of 0.8 ± 0.1 mm; Non-significant increase after 3 and 6 months of 0.1 ± 0.1 mm</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>Papadopoulos et al., 2014</td>
<td>RCT</td>
<td>Diode laser</td>
<td>Significant reduction at 3 and 6 months</td>
<td>4.2% reduction of plaque levels after 3 months with additional reduction of 5.4% after 6 months</td>
<td>Reduction of 0.71 mm after 3 months, with a further reduction of 0.8 mm after 6 months.</td>
<td>Reduction after 3 months of 1.38 mm; Reduction after 6 months of 1.48 mm</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>Renvert et al., 2011</td>
<td>RCT</td>
<td>Er:YAG</td>
<td>No evidence of bleeding in 31% of implants treated after 6 months</td>
<td>Non-significant changes in visible plaque between groups at 6 and 12 weeks and 6 months; Slight reduction after 6 months in control group (p &lt;0.05)</td>
<td>Not reported</td>
<td>Reduction of 0.8 mm (SD ± 0.5) after 6 months with a reduction of &gt; 1.0 mm in 25% of subjects</td>
<td>Not reported</td>
<td>Reduction of 0.3 mm (SD + 0.9) after 6 months</td>
</tr>
</tbody>
</table>

**Table Notes:**
- **Study:** The research studies included in the table.
- **Type of study:** The type of study conducted (case report, histological study, clinical follow up, pilot study, RCT).
- **Laser type:** The type of laser used in the studies (Er:YAG, Diode laser).
- **BOP:** Information about bleeding after treatment.
- **Plaque index:** Changes in plaque index after treatment.
- **Clinical attachment level:** Changes in clinical attachment level after treatment.
- **Pocket probing depth:** Changes in pocket probing depth after treatment.
- **Gingival recession:** Changes in gingival recession after treatment.
- **Bone levels:** Changes in bone levels after treatment.

**Outcome Measures:**
- **Badran et al., 2011:** No bleeding after 3 months; Not reported.
- **Takasaki et al., 2006:** Not reported.
- **Schwarz et al., 2012:** Reduction after 3 months: 55.0 ± 28.4%; Reduction after 24 months: 75.0 ± 32.6%.
- **Schwarz et al., 2005:** 30% after 3 months; 31% after 6 months compared to 83% at baseline.
- **Papadopoulos et al., 2014:** Significant reduction at 3 and 6 months.
- **Renvert et al., 2011:** No evidence of bleeding in 31% of implants treated after 6 months.
<table>
<thead>
<tr>
<th>Review article</th>
<th>Type of review</th>
<th>Lasers investigated</th>
<th>No. of studies included</th>
<th>Inclusion criteria/Exclusion criteria</th>
<th>Studies included in review</th>
<th>Lasers investigated</th>
<th>Type of study</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kotsakis et al., 2014</td>
<td>Systematic Review; Meta-analysis</td>
<td>Er:YAG; CO₂ laser; Photodynamic therapy</td>
<td>6</td>
<td>Inclusion criteria:</td>
<td>Deppe et al., 2007</td>
<td>Carbon dioxide laser</td>
<td>Prospective clinical study</td>
<td>- Significant reduction in PD; CAL only significantly reduced in conjunction with adjunctive bone augmentation; - Halting CAL was significantly more successful, compared to conventional treatment, when combined with soft tissue resection</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Exclusion criteria:</td>
<td>Schwarz et al., 2012</td>
<td>Er:YAG</td>
<td>RCT</td>
<td>- Statistically significant reduction in PD at 12 months but not significant after 24 months; - BOP and CAL significantly reduced at 12 months, however, only BOP remained significant after 24 months</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td>Renvert et al., 2011</td>
<td>Er:YAG</td>
<td>RCT</td>
<td>- No significant reduction in PD but a significant reduction in BOP, 6 months post-treatment</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Schwarz et al., 2006</td>
<td>Er:YAG</td>
<td>RCT</td>
<td>- Significant reduction in CAL and PD, 6 months post-treatment but the reduction is not maintained after 12 months (mean reduction in PD and CAL: &lt;1mm); - Reduction in BOP was significantly greater compared to baseline</td>
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<td></td>
<td>Schwarz et al., 2005</td>
<td>Er:YAG</td>
<td>RCT</td>
<td>- Same findings as Schwarz et al., 2006</td>
</tr>
<tr>
<td>Schaefer et al., 2013</td>
<td></td>
<td>Photodynamic treatment (HELBO)</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>RCT</td>
<td>- Reduction in CAL was statistically not significant; Significant reductions in PD after 6 months, but magnitude of reduction was of no clinical significance (0.36mm)</td>
</tr>
<tr>
<td>Review article</td>
<td>Type of review</td>
<td>Lasers investigated</td>
<td>No. of studies included</td>
<td>Inclusion criteria/Exclusion criteria</td>
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<td>Type of study</td>
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<tr>
<td>Kamel et al., 2014</td>
<td>Narrative Review</td>
<td>Nd:YAG; Er:YAG; CO\textsubscript{2} and Diode lasers</td>
<td>18</td>
<td>Inclusion criteria: - English language - Published within the past 20 years, current to 8 February 2012</td>
<td>Goncalves et al., 2010</td>
<td>GaAIAs diode laser; Nd:YAG</td>
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<td>Exclusion criteria: - Clinical studies - Case reports - Case series - Animal studies - Review articles</td>
<td>Haas et al., 1997</td>
<td>GaAIAs diode laser</td>
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<td>Kato et al., 1998</td>
<td>Carbon dioxide laser</td>
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<td>Mouhyi et al., 1998</td>
<td>Carbon dioxide laser</td>
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<td>Kreisler et al., 2002</td>
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<td>Kreisler et al., 2003</td>
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<td>Matsuyama et al., 2003</td>
<td>Er:YAG</td>
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<td>Shibli et al., 2004</td>
<td>Carbon dioxide laser</td>
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<td></td>
<td>Schwarz et al., 2005</td>
<td>Er:YAG</td>
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<td></td>
<td></td>
<td></td>
<td>Nd:YAG</td>
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</tr>
</tbody>
</table>

**Decontamination potentials:**

**Er:YAG:**
- Er:YAG exhibited dose-dependent decontamination, ranging from 59% following irradiation with 80 mJ/pulse at 5 Hz (Tosun et al., 2012) to 99.94% with 120 mJ/pulse at 10 Hz (Kreisler et al., 2002);
- Increased decontamination was observed in very short pulse (VSP) mode at any given power, compared to short pulse (SP) mode.
- However, 100% decontamination could only be consistently achieved at 90 mJ/pulse at 10 Hz in SP mode (Tosun et al., 2012).

**Carbon dioxide laser:**
- CO\textsubscript{2} lasers exhibited a dose-dependent bactericidal efficacy with values ranging from 68% with 2-4 W (10 ms/pulse, 20 Hz) to 100% with 6 W (20 ms/pulse, 20 Hz) (Tosun et al., 2012).
- Streptococcus sanguinis shows greater irradiation resistance than Porphyromonas gingivalis when exposed to 15 to 40 J (Kato et al., 1998); (Hauser-Gerspach et al., 2010).

**GaAIAs diode laser:**
- Dose-dependent decontamination efficacy with decontamination of 45% at 0.5 W to 99.9% at 2.5 W (Kreisler et al., 2003)
- Some studies reported that 100% decontamination cannot be achieved (Kreisler et al., 2003; Sennhenn-Kirchner et al., 2007); others reported 100% decontamination at powers as low as 1 W (Tosun et al., 2012) and bacterial reductions ranging between 94.67 and 100% (Sennhenn-Kirchner et al., 2007). Enterococcus faecalis and S. sanguinis exhibited increased irradiation resistance to GaAIAs diode lasers, compared to P. gingivalis (Goncalves et al., 2010); (Hauser-Gerspach et al., 2010).

**Nd:YAG laser:**
- Powers ranging from 0.3 to 3.0 W exhibited incomplete elimination of microbes in some studies (Giannini et al., 2006); (Block et al., 1992); others showed 100% decontamination using 3.0 W (Goncalves et al., 2010).
- P. gingivalis was easier to eliminate compared to E. faecalis (Goncalves et al., 2010).
<table>
<thead>
<tr>
<th>Authors</th>
<th>Laser Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giannini et al., 2006</td>
<td>Er:YAG</td>
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<td>Schwarz et al., 2006</td>
<td>Er:YAG</td>
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<td>Quaranta et al., 2009</td>
<td>Er:YAG; GaAlAs diode laser</td>
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<td>Sennhenn-Kirchner et al., 2009</td>
<td>Er:YAG; Carbon dioxide laser; GaAlAs diode laser</td>
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<td>Tosun et al., 2012</td>
<td>Er:YAG; Carbon dioxide laser; GaAlAs diode laser</td>
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<td>Block et al., 1992</td>
<td>Nd:YAG</td>
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<tr>
<td>Hauser-Gerspach et al., 2010</td>
<td>Carbon dioxide laser; GaAlAs diode laser</td>
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<tr>
<td>Sennhenn-Kirchner et al., 2007</td>
<td>GaAlAs diode laser</td>
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</table>
Table 5: Summary of risk of bias within the included studies, based upon the Cochrane Collaboration’s tool.\footnote{5}

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of study</th>
<th>Random Sequence Generation</th>
<th>Allocation Concealment</th>
<th>Blinding of Participants and Personnel</th>
<th>Blinding of Outcome Assessment</th>
<th>Incomplete Outcome Data</th>
<th>Selective Reporting</th>
<th>Other Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badran et al., 2011</td>
<td>Case report</td>
<td>N/a</td>
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<tr>
<td>Takasaki et al., 2006</td>
<td>Histological study</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>High</td>
</tr>
<tr>
<td>Schwarz et al., 2012</td>
<td>Clinical follow up</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
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<td>High</td>
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<tr>
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<td>Pilot study</td>
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<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
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</tr>
<tr>
<td>Papadopoulos et al., 2014</td>
<td>RCT</td>
<td>Low</td>
<td>Unclear</td>
<td>Low</td>
<td>Unclear</td>
<td>High</td>
<td>Unclear</td>
<td>Unclear</td>
</tr>
<tr>
<td>Renvert et al., 2011</td>
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<td>Low</td>
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<tr>
<td>Kamel et al., 2014</td>
<td>Narrative Review</td>
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