The Application of Photodynamic Therapy in the Treatment of Periodontal and Peri-Implant Infections

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Running title: Photodynamic therapy in periodontal and peri-implant therapy
Abstract
Antimicrobial photodynamic therapy (PDT) has lately attracted much attention among clinicians for the treatment of pathogenic biofilm associated with periodontitis and peri-implantitis. However, at present, the data from randomized controlled clinical studies (RCTs) are still limited and, to some extent, controversial which makes it difficult to provide appropriate recommendations for the clinician. Therefore, the aims of the present study were: a) to provide an overview on the current evidence from randomized controlled clinical studies evaluating the potential clinical benefit for the additional use of PDT to subgingival mechanical debridement (i.e. scaling and root planing (SRP)) alone in nonsurgical periodontal therapy and b) to provide clinical recommendations for the use of PDT in periodontal practice. Based on the available evidence from RCTs the following conclusions can be drawn:

- In patients with chronic periodontitis (ChP) the combination of SRP and PDT may result in substantially higher short-term clinical improvements evidenced by probing depth (PD) and/or bleeding on probing (BOP) reductions compared to SRP alone.
- In patients with aggressive periodontitis (AgP) the use of PDT cannot replace the systemic administration of amoxicillin and metronidazole. Due to lack of data, no conclusions can be made to what extent PDT may replace the use of systemic antibiotics in patients with ChP.
- Limited evidence from one study indicates that PDT may represent a possible alternative to local antibiotics in patients with incipient peri-implantitis.

Key Words: Photodynamic therapy, chronic periodontitis, aggressive periodontitis, peri-implantitis, antibiotics, bacterial biofilm
Biological rationale

Periodontitis is a multifactorial disease which is associated with loss of the supporting tissues (i.e. periodontal ligament and alveolar bone) around the tooth. A major objective of periodontal therapy is to remove soft and hard, supra- and subgingival deposits from the root surface in order to stop disease progression. Numerous studies have reported significant improvements of clinical and microbial parameters following nonsurgical periodontal therapy.

Despite the fact that non-surgical periodontal treatment may result in significant clinical improvements in the great majority of cases, evidence indicates that none of the currently available instrumentation techniques are effective in completely eliminating subgingival bacterial biofilm. These limitations may be attributed to several factors such as the complex anatomy of teeth (i.e. furcation involvements, root invaginations), presence of intrabony defects, etc., mechanical limitations related to the size of instruments or invasion of periodontal pathogens into the surrounding soft tissues or possible recolonization of periodontal pockets from other diseased sites or intraoral niches. Power-driven instruments (i.e. sonic and ultrasonic scalers) have been introduced to further enhance the effectiveness of scaling and root planing (SRP). However, findings from clinical studies have also shown comparative outcomes following power-driven and manual instrumentation.

Thus, the current evidence indicates that nonsurgical periodontal treatment may result in substantial clinical improvements in the great majority of cases, but none of the currently available instrumentation techniques are able to completely eliminate subgingival bacteria and calculus.

Photodynamic therapy (PDT), also called photoradiation therapy, phototherapy, photochemotherapy, photo-activated disinfection (PAD), or light-activated disinfection (LAD), was introduced in medical therapy in 1904 as the light-induced inactivation of
cells, microorganisms or molecules and involves the combination of visible light, usually through the use of a diode laser and a photosensitizer.\textsuperscript{10} The photosensitizer is a substance that is capable to absorb light of a specific wavelength and transform it into useful energy. Each factor is harmless by itself, but when combined they can produce lethal cytotoxic agents that can selectively destroy cells.\textsuperscript{11} Thus, PDT has been proposed as a modality to reduce bacterial load or even to eliminate periodontal pathogens.\textsuperscript{12, 13} The action mechanism of PDT has been extensively described previously.\textsuperscript{14} Briefly, upon illumination the photosensitizer is excited from the ground state to the triplet state. The longer lifetime of the triplet state enables the interaction of the excited photosensitizer with the surrounding molecules. It is anticipated that the generation of the cytotoxic species produced during PDT occurs while in this state.\textsuperscript{15, 16} The cytotoxic product, usually singlet oxygen ($^{1}$O$_{2}$), cannot migrate at a distance more than 0.02 $\mu$m after its formation, thus making it ideal for local application of PDT, without endangering distant molecules, cells or organs.\textsuperscript{16} In vitro studies have revealed that light from a Helium/Neon (HE/Ne) laser or a Gallium-Aluminum-Arsenide (GaAlAs) laser, in combination with appropriate photosensitizers, can achieve a significant reduction in the viability of both aerobic and anaerobic bacteria in a solution of subgingival plaque from patients with chronic periodontitis.\textsuperscript{17, 18} Dobson & Wilson (1992) have shown that bacteria associated with periodontal disease can be killed through photosensitization with Toluidine Blue – O (TBO) and irradiation with a He/Ne soft laser.\textsuperscript{19} Subsequent studies in animals have shown PDT was distinctly advantageous in reducing the periodontal signs of redness and bleeding on probing, and significantly suppressed \textit{P. gingivalis}.\textsuperscript{20}
During the last decade, a considerable interest has evolved in evaluating the use of PDT in the treatment of periodontal and peri-implant infections. However, despite the relatively abundant literature, the data on the clinical relevance of PDT when used in conjunction with mechanical therapy are still controversial and difficult to interpret for the clinician.

Therefore, the aims of this review article are: a) to provide an overview of the current evidence from randomized controlled clinical studies (RCTs) evaluating the potential clinical benefit for the additional use of PDT to mechanical debridement alone in nonsurgical periodontal therapy and b) to provide clinical recommendations for the use of PDT in periodontal practice.

**Use of PDT as adjunct to nonsurgical periodontal therapy in patients with untreated chronic periodontitis (ChP)**

A total of 18 RCTs have compared the potential additional benefit of PDT to SRP with the use of SRP alone in untreated periodontitis patients (Table 1). Eight out of the 18 studies have reported statistically significantly higher improvements in probing depth (PD) reduction and/or clinical attachment (CAL) gain following SRP + PDT compared to SRP alone,\(^{21-28}\) while the rest of 10 studies have failed to reveal statistically significant differences in these parameters.\(^{29,30-38}\) An additional improvement for the reduction of bleeding on probing (BOP) following the use of PDT was reported in 5 out of the 19 papers.\(^{22, 26, 28, 31, 32}\) Changes of microbiological parameters were evaluated in 8 of 18 studies. Four studies have found a statistically significant effect of the additional use of PDT on the reduction of periodontal pathogens,\(^{28, 35, 37, 38}\) while 4 studies have failed to reveal any differences between the treatments groups.\(^{31, 33, 36, 39}\) Three out of the 18 studies have also evaluated the
changes in terms of various inflammatory markers. All three studies have revealed statistically significantly higher reductions in the investigated inflammatory markers following the additional use of PDT (Table 1).

Use of PDT as adjunct to nonsurgical periodontal therapy in patients with Aggressive Periodontitis (AgP)

Two RCTs have compared treatment with SRP + PDT to treatment with SRP alone, and another study has compared SRP alone to PDT alone (i.e. without any mechanical debridement). (Table 2). While one study has found in deep pockets (PD ≥ 7 mm) statistically significant improvements in terms of PD reduction and CAL gain and significantly less periodontal pathogens of the red and orange complex and IL-1β/IL-10 ratio following treatment with PDT, the other study has failed to reveal any statistical significant differences in the evaluated clinical and microbiological parameters between the treatments (Table 2).

Use of PDT as adjunct to nonsurgical periodontal therapy in maintenance periodontitis patients

Eight RCTs have evaluated the potential additional benefit of PDT to SRP as compared with the use of SRP alone in maintenance patients (Table 3). Two out of the 8 studies have reported statistically significantly higher improvements in PD reduction and CAL gain following SRP + PDT compared to SRP alone. An additional improvement for the reduction of BOP was reported in 5 out of the 8 studies.
While three studies have found a statistically significant effect of the additional use of PDT on the reduction of periodontal pathogens,\textsuperscript{46-48} three other studies have failed to reveal statistically significant differences between the treatment groups.\textsuperscript{49-51} Three out of the 8 studies have also evaluated the changes in terms of inflammatory markers.\textsuperscript{47, 50, 52} Two studies have revealed statistically significantly higher reductions in the investigated inflammatory markers following the use of PDT,\textsuperscript{47, 50} while one study detected no differences\textsuperscript{52} (Table 3).

**Use of PDT as an alternative to systemic or local antibiotics**

An extremely important aspect which needs to be kept in mind when considering the use of PDT, is the lack of bacterial resistance which gains even more importance in the light of the worldwide increase in bacterial resistance against antibiotics.\textsuperscript{53} Thus, its repeated application in conjunction with mechanical debridement may represent a valuable future option for treating periodontal and peri-implant infections.\textsuperscript{11, 54} At present, there is however limited evidence on the possibility of PDT to replace systemic or local antibiotics.

A recent RCT study has evaluated the treatment of patients with AgP by means of nonsurgical periodontal therapy in conjunction with either systemic administration of amoxicillin and metronidazole or two-times topical application of PDT.\textsuperscript{55, 56} The results have shown that both treatment protocols resulted in statistically significant improvements in PD reduction, gain of CAL and improvement in BOP compared to baseline. The systemic use of amoxicillin and metronidazole yielded however, at both 3 and 6 months, statistically significantly higher reductions in mean PD compared with the treatment using PDT.\textsuperscript{55, 56} The most important clinical finding was the change in the total number of pockets ≥ 7 mm following both treatment protocols. In the PDT group, the total number of pockets ≥ 7 mm was reduced from 137 to 45 with the
corresponding values of 141 and 3 in the amoxicillin and metronidazole group. Moreover, compared to the results at 3 months, at 6 months, an additional decrease in the number of pockets ≥ 7 mm was measured.\textsuperscript{55, 56} On the other hand, the use of PDT has also led to statistically and clinically significant improvements compared to baseline, although the number of residual pockets needing further therapy was substantially higher compared with the use of systemic antibiotics (e.g. 45 vs. 3). The changes in clinical parameters were also accompanied by changes in the concentration of matrix metalloproteinases 8 and 9 (MMP-8 and -9) in the gingival crevicular fluid (GCF).\textsuperscript{57} However, while in the antibiotic group, a statistically significant decrease of MMP-8 GCF level at both 3 and 6 months post treatment was observed, these changes were not significant in the PDT group.\textsuperscript{57} Taken together, the available data suggest a rather limited clinical benefit of using PDT in the treatment of patients with AgP.\textsuperscript{40, 42, 43, 56, 57} Thus, at the time being, PDT cannot be recommended as a replacement for systemic antibiotics in patients with AgP. On the other hand, no studies have compared the use of PDT or systemic antibiotics in conjunction with nonsurgical treatment in patients with ChP. Therefore, at present no conclusions can be made regarding this aspect.

The use of PDT as a potential alternative to local antibiotics has been recently evaluated in a RCT study comparing nonsurgical treatment of incipient peri-implantitis (sites with PD 4-6 mm, BOP positive and radiographic bone loss ≥2 mm) by means of mechanical debridement followed by either use of local antibiotics (e.g. minocycline) or application of PDT. The results at six months and at one year have failed to reveal statistically or clinically significant differences between the two treatment protocols, thus suggesting that PDT may represent a valuable alternative to local antibiotics during nonsurgical treatment of incipient peri-implantitis.\textsuperscript{58, 59}
Conclusions

Based on the available evidence from RCTs the following conclusions can be drawn:

- In patients with ChP the combination of SRP and PDT may result in substantially higher short-term clinical improvements evidenced by probing depth (PD) and/or bleeding on probing (BOP) reductions compared to SRP alone.

- In patients with aggressive periodontitis (AgP) the use of PDT cannot replace the systemic administration of amoxicillin and metronidazole. Due to lack of data, no conclusions can be made to what extent PDT may replace the use of systemic antibiotics in patients with ChP.

- Limited evidence from one study indicates that PDT may represent a possible alternative to local antibiotics in patients with incipient peri-implantitis.

Clinical recommendations

1. In patients with ChP, clinicians may consider the use of PDT in conjunction with subgingival mechanical debridement. However, due to limitations in time and costs, the use of PDT appears to be more suitable in the maintenance phase of therapy.

2. At present, the use of PDT cannot be recommended as an alternative to systemic antibiotics in the treatment of AgP or severe cases of ChP.
**Figures 1 and 2:** Clinical applications of PDT

Figure 1. Application of the phenothiazine chloride dye following subgingival SRP

Figure 2. Application of the low level laser light into the pocket
Tables 1, 2 and 3: Randomized clinical controlled studies, with SRP as control group

Table 1. Photodynamic therapy as initial periodontal therapy in patients with ChP (data of 18 studies reported in 19 publications)

<table>
<thead>
<tr>
<th>Study Author Year Country Type</th>
<th>Diagnosis</th>
<th>Patients Female/male Age Smokers</th>
<th>Study duration</th>
<th>Treatment</th>
<th>Photosensitizer Laser</th>
<th>Laser parameters</th>
<th>Microbiology</th>
<th>Immunology</th>
<th>PD reduction (mm) CAL gain (mm) BOP reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Zahrani &amp; Austah (2011)21 Saudi-Arabia Split-mouth, RCT</td>
<td>ChP</td>
<td>n=17 0/17 41.6 ± 9.6 17 smokers</td>
<td>3 months</td>
<td>Test: SRP + PDT (1x) Control: SRP</td>
<td>Methylene blue (Ondine`s Periowave, Ondine Biopharma, Vancouver, BC) Diode laser</td>
<td>Wavelength 670 nm</td>
<td>Not analysed</td>
<td>Not analysed</td>
<td>Test: PD: from 5.60±0.83 to 3.84±0.85 * CAL: from 6.30±1.44 to 4.70±1.27 * BOP: from 74.50±21.50 to 41.90±22.30 (n.s.) Control: PD: from 5.35±0.46 3.90±0.75 CAL: from 6.18±1.44 to 4.80±1.45 BOP: from 68.00±23.00 to 45.60 to 19.50.</td>
</tr>
<tr>
<td>Alwaeli et al. (2015)22 Jordan Split-mouth, RCT</td>
<td>ChP</td>
<td>N=16 11/5 40.9±13.34</td>
<td>12 months</td>
<td>Test: SRP+PDT Control: SRP</td>
<td>Phenothiazine chloride Diode Lasers (HELBO, Photodynamic Systems, Grieskirchen, Austria)</td>
<td>Wavelength 660 nm, Output power 100mW Application time: 10s/site, 6 sites/tooth</td>
<td>Not analysed</td>
<td>Not analysed</td>
<td>Test: PD: 1.51±1.54* CAL: 1.48±1.89* BOP: 25%* Control: PD: 0.66±1.66 CAL: 0.13±1.7 BOP: 54%</td>
</tr>
<tr>
<td>Andersen et al. (2007)23 England Parallel, RCT</td>
<td>ChP</td>
<td>N=33 22/11 53 (18-75) unclear</td>
<td>12 weeks</td>
<td>Test 1: PDT Test 2: SRP+ PDT Control: SRP</td>
<td>Methylene blue (Periowave) Diode laser (Periowave)</td>
<td>Wavelength 670 nm Energy density 10-20 J/cm² Max. power 150 mW Application time 60s/site</td>
<td>Not analysed</td>
<td>Not analysed</td>
<td>Test 1: PD: 0.67±0.44 (n.r.) CAL: 0.14±0.65 (n.r.) BOP: 73% (n.r.) Test 2: PD: 1.11±0.53* CAL: 0.86±0.61* BOP: 59% (n.s.) Control: PD: 0.74±0.43</td>
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<tr>
<td>Study</td>
<td>Country/Region</td>
<td>Design</td>
<td>N</td>
<td>Age</td>
<td>Treatment</td>
<td>Device Specifications</td>
<td>Outcome Measures</td>
<td>Results</td>
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<tr>
<td>Balata et al. (2013)</td>
<td>Brazil</td>
<td>Split-mouth, RCT</td>
<td>22</td>
<td>43.18 (31-62)</td>
<td>SRP (ultrasonic)+PDT</td>
<td>Methylene blue 0.005% Low power laser (AsGaAl, Photon Laselli, Sao Paolo, Brazil) Wavelength 660nm Output power 100mW Energy density 320 J/cm² Dose 9 J Diameter tip 600 μm Application time: 90s/site</td>
<td>Not analysed</td>
<td>Not analysed</td>
<td></td>
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<tr>
<td>Berakdar et al. (2012)</td>
<td>Germany</td>
<td>Split-mouth, RCT</td>
<td>22</td>
<td>59.3±11.7</td>
<td>SRP+PDT</td>
<td>Methylene blue 0.005% Diode laser (Periowave) Wavelength 670 nm Max. power 150 mW Application time 60s</td>
<td>Not analysed</td>
<td>Not analysed</td>
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<tr>
<td>Betsy et al. (2014)</td>
<td>India</td>
<td>Parallel, RCT</td>
<td>88</td>
<td>39.6±8.7</td>
<td>SRP+PDT</td>
<td>Phenothiazine chloride trihydrate (freshly prepared, Sigma-Aldrich, USA) Diode laser (CNI Opto-electronics Tech., China) Wavelength 655 nm, output power 1W Power density 60 mW/cm² Diameter tip 0.5 mm Application time 60s/site</td>
<td>Not analysed</td>
<td>Not analysed</td>
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<tr>
<td>Braun et al. (2008)</td>
<td></td>
<td></td>
<td>20</td>
<td>11/9</td>
<td>SRP+PDT</td>
<td>Phenothiazine chloride Wavelength 660 nm</td>
<td>Not analysed</td>
<td>Not analysed</td>
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</table>

Test: PD decrease from 5.11±0.56 to 2.83±0.47 (n.s.) CAL change from 5.49±0.76 to 3.41 ± 0.84 (n.s.) BOP: from 61.58± 15.64 to 36.73±19.72 (n.s.) Control: PD decrease from 5.15±0.46 to 2.83±0.40 CAL change from 5.53±0.54 to 3.39 ± 0.51 BOP: from 62.23± 16.91 to 38.49±20.52
| Country     | Study Design | Control | Treatment 1 | Treatment 2 | Power output | Application time | Wavelength | No significant differences between the groups for | Dose | Not analysed | Not analysed | No significant difference for | Significant higher BOP reduction in both test groups compared to the | PD: 3.6 (0.6, 5.3, 3.2)*  
CAL: 7.04 (1.63, 9.11, 5.33)*  
BOP: 19 (11, 64, 2)*  
Control: Median (inter-quartile range, Max, Min) | PD: 3.7 (0.6, 6.0, 3.4)  
CAL: 7.25 (2.02, 10.09, 5.81)  
BOP: 24 (21, 61, 2)  
Test:  
PD: 0.9±0.3 (n.s.)  
CAL: 0.7±0.3 (n.s.)  
BOP: from 54±16% to 10±5%*  
Control: PD: 0.7±0.7  
CAL: 0.5±0.5  
BOP: from 59±21% to 20±4%*  
Test 1:  
PD: 1.54±0.59*  
CAL: 1.54±1.10*  
BOP: from 88±0.34 to 38±0.49 (n.s.)  
Test 2:  
PD: 2.08±1.02*  
CAL: 2.42±1.14*  
BOP: from 96±0.20 to 42±0.50 (n.s.)  
Control: PD: 1.42±0.88  
CAL: 1.50±0.88  
BOP: from 92±0.28 to 46±0.51 |
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</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Split-mouth</td>
<td>46.6±6.1 no smokers</td>
<td>Control: SRP (HELBO Photodynamic Sys., Austria)</td>
<td>Power output 100 mW Application time 10s/site</td>
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</tbody>
</table>
| Christodoulides et al. (2008) | ChP | N=24  
13/11  
45±8.11  
3 smokers | 6 months | Test: SRP + PDT  
Control: SRP | Phenothiazine chloride (HELBO Blue Photosensitizer)  
Diode laser (HELBO TheraLite Laser) | Wavelength 670 nm  
Output power 75 mW  
Application time 60 s/tooth | No significant differences between the groups for Aa, Pg, Tf, Td, Pi, Pm, Fn, Cr, En, Ec, Cs |  |
| Dilisz et al. (2013) | ChP | N=24  
14/10  
40.7±7.3 no smokers | 6 months | Test1: PDT  
+ SRP  
Control: SRP | Methylene blue 1%  
Diode Laser (Doctor Smile diode, Lambda Scientifica Vincenza, Italy) | Wavelength 808 nm  
Output power 100 mW  
Application time 60 s/site  
Dose 6J  
Fibre tip diameter 300 μm | Not analysed | Not analysed |
| Ge et al. (2011) | ChP | N=58  
28/30  
43±10  
9 smokers | 12 weeks | Test 1: SRP  
+ PDT (once)  
Test 2: SRP  
+ PDT (twice) | Methylene blue 0.01%  
Diode Laser (Periowave) | Wavelength 670 nm  
Output power 140 mW  
Energy density 21 J/cm² | Not analysed | Not analysed | No significant difference for PD reduction and CAL gain.  
Significant higher BOP reduction in both test groups compared to the |
| Study                          | Country | Design          | N  | Follow-up | Randomization | Test                              | Control                              | Dose | Application time | Wavelength | Energy density | Fiber tip diameter | Clinical outcomes                                                                 |
|-------------------------------|---------|-----------------|----|-----------|---------------|-----------------------------------|--------------------------------------|------|------------------|-------------|----------------|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------
<p>| Luchesi et al. (2013)³³       | Brazil  | Parallel, RCT   | 37 | 6 months  |                | Test: SRP+PDT                      | Control: SRP+non activated laser     | 60 J | 60 s/site        | 660 nm      | 129 J/cm²       | 600 μm            | Significant decrease in P.g. and T.f. in PDT group, however no significant differences between the groups. |
| Lui et al. (2011)³⁴           | China   | Split-mouth, RCT| 24 | 3 months  |                | Test: SRP+PDT                      | Control: SRP                        | 6 J  | 1 W              | 940 nm      | 4 J/cm²        | 300 μm           | Not analysed No significant reduction of IL-1β at 1 wk in PDT. Significant reduction of GCF at 1 wk and 1 m in favour to PDT. |
| Mettraux &amp; Hüsler (2011)³⁵    | Switzerland | Split-mouth, RCT | 19 | 6 months  |                | Test: SRP+PDT                      | Control: SRP                        | 330 mW | 31 J/cm²        | 670 nm      | 3.1 J/cm²      | 8 mm              | Significant reduction of the total bacterial load in favour to PDT. Significant reduction of T.d. in both groups. No significant differences between the groups. |
| Polansky et al.               |         |                 | 58 | 3 months  |                | Test: SRP + Phenothiazine          |                                      |      |                  |             |                |                  | No significant differences between the groups. Test: PD: 1.59±1.11 (n.s.) CAL: 0.78±1.54 (n.s.) BOP: from 100% to 37.50% (n.s.) Control: PD: 1.50±1.73 CAL: 1.00±1.69 BOP: from 100% to 55% Changes from baseline to 3 m: Test: PD: from 4.7±0.8 to 3.1±0.1 (n.s.) REC: from 0.8±1.2 to 1.8±1.2 (n.s.) BOP from 94±06 to 39±14 (n.s.) Control: PD from 4.5±0.7 to 3.2±0.3 REC from 1.0±1.1 to 1.8±1.3 BOP from 92±10 to 43±12 Test: PD: 2.1±1.4 (n.s.) CAL: 1.5±1.3 (n.s.) Control: PD: 1.5±1.6 CAL: 0.9±1.7 |</p>
<table>
<thead>
<tr>
<th>Study (Year)</th>
<th>Country</th>
<th>Design</th>
<th>N</th>
<th>Age</th>
<th>Sex Ratio</th>
<th>Duration</th>
<th>Test</th>
<th>Control</th>
<th>Treatment Details</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sigusch et al. (2010)</td>
<td>Parallel, RCT</td>
<td>ChP</td>
<td>24</td>
<td>17/7</td>
<td>32-58</td>
<td>no smokers</td>
<td>12 weeks</td>
<td>Test: SRP + PDT</td>
<td>Control: SRP</td>
<td>Phenothiazine chloride (HELBO Blue Photosensitizer) Diode laser (HELBO Thera Lite Laser) Wavelength 660 nm, Power density 60 mW/cm² Application time 10 s/site</td>
</tr>
<tr>
<td>Queiroz et al. (2015)</td>
<td>Brasil</td>
<td>Split-mouth, RCT</td>
<td>20</td>
<td>11/9</td>
<td>46.05±6.38</td>
<td>smokers only</td>
<td>3 months</td>
<td>Test: SRP+PDT</td>
<td>Control: SRP</td>
<td>Phenothiazine chloride (HELBO Blue Photosensitizer) Diode laser (HELBO Minilaser 2075 F, Grieskirchen, Austria) Wavelength 660 nm, Maximum power 60mW/cm² Fiber tip diameter 0.6 mm Application time 10 s/site at 6 sites/tooth</td>
</tr>
<tr>
<td>Queiroz et al. (2014)</td>
<td>Brasil</td>
<td>Split-mouth, RCT</td>
<td>20</td>
<td>11/9</td>
<td>46.05±6.38</td>
<td>smokers only</td>
<td>3 months</td>
<td>Test: SRP+PDT</td>
<td>Control: SRP</td>
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<td>Test: SRP + PDT</td>
<td>Control: SRP</td>
<td>Phenothiazine chloride (HELBO Blue Photosensitizer) Diode laser (HELBO Thera Lite Laser) Wavelength 660 nm, Power density 60 mW/cm² Application time 10 s/site</td>
</tr>
<tr>
<td>Sigusch et al. (2010)</td>
<td>Parallel, RCT</td>
<td>ChP</td>
<td>24</td>
<td>17/7</td>
<td>32-58</td>
<td>no smokers</td>
<td>12 weeks</td>
<td>Test: SRP + PDT</td>
<td>Control: SRP</td>
<td>Phenothiazine chloride (HELBO Blue Photosensitizer) Diode laser (HELBO Thera Lite Laser) Wavelength 660 nm, Power density 60 mW/cm² Application time 10 s/site</td>
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<td>Sigusch et al. (2010)</td>
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<tr>
<td>Study</td>
<td>Country</td>
<td>Design</td>
<td>Participants</td>
<td>Duration</td>
<td>Test 1:</td>
<td>Test 2:</td>
<td>Control:</td>
<td>Treatment Details</td>
<td>Outcome Measures</td>
<td>Outcome Details</td>
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<tr>
<td>Srikanth et al. (2015)</td>
<td>India</td>
<td>Split-mouth, RCT</td>
<td>N=39 (30-55) nonsmokers</td>
<td>6 months</td>
<td>SRP+PDT</td>
<td>SRP + laser without photosensitizer</td>
<td>SRP</td>
<td>Indocyanine green (Aurogreen Aurolabs) Diode laser (firm not specified)</td>
<td>Wavelength 810 nm Power output 0.7 W Application time 5 s/site</td>
<td>Significant decrease of the % of viable bacteria in favour to PDT</td>
</tr>
<tr>
<td>Theodoro et al. (2012)</td>
<td>Brazil</td>
<td>Split-mouth, RCT</td>
<td>N=33 21/12 43.12±8.2 nonsmokers</td>
<td>6 months</td>
<td>SRP + PDT</td>
<td>SRP + Placebo PDT</td>
<td>SRP</td>
<td>Phenothiazine 100 μg/ml (Sigma Chemical, St. Louis, USA) Diode Laser (BioWave)</td>
<td>Wavelength 660 nm Power output 30 mW Power intensity 0.4 W/cm² Energy density 64.28 J/cm² Application time 150 s/site Spot size 0.07 cm²</td>
<td>Significant differences in all investigated periodontopathogens in favour to SRP + PDT.</td>
</tr>
</tbody>
</table>
3.1±0.83
CAL: from 6.23±1.25 to 4.25±1.73
BOP: from 97% to 27.3%

n.s.: not significant; n.r.: not reported; REC: recession; IL: Interleukin; MMP: Matrixmetalloproteinases; T.f.: Tannerella forsythia, P.g.: Porphyromonas gingivalis; A.a.: Aggregatibacter actinomycetemcomitans; T.d.: Treponema denticola; F.n.: Fusobacterium nucleatum; P.i.: Prevotella intermedia; C.r.: Campylobacter rectus; E.c.: Eikenella corrodens; P.m.: Parvimonas micra; E.n.: Eubacterium nodatum; C.s.:Capnocytophaga Spp.
Table 2. Photodynamic therapy as initial periodontal therapy in patients with AgP (data of 3 studies reported in 4 publications)

<table>
<thead>
<tr>
<th>Study Author Year Country Type</th>
<th>Diagnosis</th>
<th>Patients Female/male Age Smokers</th>
<th>Study duration</th>
<th>Treatment</th>
<th>Photosensitizer Laser</th>
<th>Laser parameters</th>
<th>Microbiology</th>
<th>Immunology</th>
<th>PD reduction (mm) CAL gain (mm) BOP reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitsazi et al. (2014) Iran Split-mouth, RCT</td>
<td>AgP</td>
<td>N=24 15/9 29</td>
<td>3 months</td>
<td>Test: SRP+PDT Control: SRP</td>
<td>Toluidine Blue photosensitize (Sigma chemical Co., St. Louis, Mo) Diode Laser (HANDY Laser, USA)</td>
<td>Wavelength 670-690 nm Power 75 mW Application time 2 min/site</td>
<td>No significant differences for the levels of A.a. were observed between the groups</td>
<td>Not analysed</td>
<td>Test: PD change: from 5.79±1.06 to 4.29±0.95 (n.s.) CAL change: from 6.58±0.83 to 5.29±1.26 (n.s.) BOP change: from 91.7% to 75% (n.s.) Control: PD change: from 5.45±0.71 to 4.54±0.88 CAL change: from 6.25±1.07 to 5.50±1.18 BOP change: from 100% tc 37.5%</td>
</tr>
<tr>
<td>Moreira et al. (2015) Brazil Split-mouth, RCT</td>
<td>AgP</td>
<td>N=20 30.6±4.25 18/2 non smokers</td>
<td>3 months</td>
<td>Test: SRP+PDT Control: SRP</td>
<td>Phenothiazine chloride (HELBO Blue Photodynamic systems, Grieskirchen, Austria) Diode laser (HELBO Minilaser 2075 F, Grieskirchen, Austria)</td>
<td>Wavelength 670 nm Maximum power 75 mW Fiber tip diameter 0.6 Mm Energy density 2.49 J/cm² Application time 10s/site</td>
<td>Significant less periodontal pathogens of the red and orange complex in the test group.</td>
<td>Significant less IL-1β/IL-10 ratio in the test group.</td>
<td>No differences between the groups for moderate pockets. In deep pockets (PD≥7mm), significant PD decrease and CAL gain in favour to PDT: Test (deep pockets): PD from 7.73±0.87 to 3.77±0.97 * CAL: from 7.84±0.89 to 5.07±0.64* BOP: from 144±60 to 22±13.75 (n.s.) Control (deep pockets): PD: from 7.68±0.92 to 5.12±0.8 CAL: from 7.75±1.21 to 6.00±1.04. BOP: from 154±64.16 to 36±15</td>
</tr>
<tr>
<td>Novaes et al. (2012)</td>
<td>AgP</td>
<td>N=10 8/2 31 (18-35) nonsmokers</td>
<td>3 months</td>
<td>Test: PDT Control: SRP</td>
<td>Phenothiazine chloride (Helbo blue photosensitizer)</td>
<td>Minilaser (HELBO, Grieskirchen, Austria)</td>
<td>Wavelength 660 nm, Power 0.06W/cm², fluency 212.23 J/cm², Application time 10s/site</td>
<td>40 subgingival species were determined. PDT reduced significantly A.a. compared to SRP; SRP is more efficient for the red complex than PDT. In PDT a recolonisation of T.f. and P.g. was observed. Not analysed Published in Oliveira et al. 2007</td>
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<tr>
<td>Oliveira et al. (2007)</td>
<td>AgP</td>
<td>N=10 8/2 31 (18-35) nonsmokers</td>
<td>3 months</td>
<td>Test: PDT Control: SRP</td>
<td>Phenothiazine chloride (Helbo blue photosensitizer)</td>
<td>Minilaser (HELBO, Grieskirchen, Austria)</td>
<td>Wavelength 660 nm, Power 60 mW/cm², fluency 212.23 J/cm², Application time 10s/site</td>
<td>Test: PD: from 4.92±1.61 to 3.49±0.98 (n.s.) CAL: from 9.93±2.10 to 8.74±2.12 (n.s.) BOP: from 57% to 19% (n.s.) Control: PD: from 4.92±1.14 to 3.98±1.76 CAL: from 10.53±2.30 to 9.01±3.05 BOP: from 60% to 21%</td>
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</table>

n.s.: not significant; n.r.: not reported; REC: recession; IL: Interleukin; T.f.: Tannerella forsythia; P.g.: Porphyromonas gingivalis; A.a.: Aggregatibacter actinomycetemcomitans; T.d.: Treponema denticola; F.n.: Fusobacterium nucleatum; P.i.: Prevotella intermedia; C.r.: Campylobacter rectus; E.c.: Eikenella corrodens; P.m.: Parvimonas micra; E.n.: Eubacterium nodatum; C.s.: Capnocytophaga Spp.
Table 3. Photodynamic therapy in Supportive Periodontal Therapy (data of 8 studies reported in 9 publications)

<table>
<thead>
<tr>
<th>Study Author Year Country Type</th>
<th>Diagnosis</th>
<th>Patients Female/male Age Smokers</th>
<th>Study duration</th>
<th>Treatment</th>
<th>Photosensitizer Laser</th>
<th>Laser parameters</th>
<th>Microbiology</th>
<th>Immunology</th>
<th>PD reduction (mm) CAL gain (mm) BOP reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campos et al. (2013) Brazil Split-mouth, RCT</td>
<td>ChP</td>
<td>n=13 8/5 48.15±7.53 no smokers</td>
<td>3 months</td>
<td>Test: SRP+PDT Control: SRP</td>
<td>Methylene blue 10 mg/ml Diode laser (Thera Laser-DMC, Brazil)</td>
<td>Wavelength 660 nm Power output 60 mW Energy density 129 J/cm² Application time 60s/site</td>
<td>Not analysed</td>
<td>Not analysed</td>
<td>Test: PD: 2.17±0.91* CAL: 1.43±0.61* BOP: 77.78* Control: PD: 1.14±1.53 CAL: 0.51±0.76* BOP: 40%</td>
</tr>
<tr>
<td>Cappuyns et al. (2012) Switzerland Split-mouth, RCT</td>
<td>ChP</td>
<td>N=29 8/21 52 (36-74) 12 smokers</td>
<td>6 months</td>
<td>Test 1: SRP+PDT Test 2: SRP+Diode Soft Laser (DSL) Control: SRP</td>
<td>Phenothiazine chloride (HELBO Blue Photosensitizer) Diode Laser (Helbo Photodynamic Sys)</td>
<td>Wavelength 660 nm Power output 40 mW Application time 60s/site</td>
<td>A.a, P.g., T.f., T.d, total bacterial load No significant difference in the investigated microbiological parameters. However, P.g., T.f., and T.d were suppressed stronger in the PDT group.</td>
<td>Not analysed</td>
<td>Test 1: PD: from 5.6±1.2 to 3.8±1.2 (n.s.) REC: from 0.8±1.3 to 1.0±1.3 (n.s.) BOP: at 6m 15% (n.s.) Test 2: PD: from 5.5±0.7 to 3.8±1.0 (n.s.) REC: from 0.8±1.7 to 1.3±1.8 (n.s.) BOP: at 6m18% (n.s.)</td>
</tr>
<tr>
<td>Chondros et al. (2009) Netherlands Parallel, RCT</td>
<td>ChP</td>
<td>N=24 14/10 Test: 50.6±9.2 Control: 48.3±7.9 7 smokers</td>
<td>6 months</td>
<td>Test: SRP+PDT Control: SRP</td>
<td>Phenothiazine chloride (HELBO Blue Photosensitizer) Diode laser (HELBO minilaser 2075F)</td>
<td>Wavelength 670 nm Output power 75 mW/cm² Application time 60 s/tooth</td>
<td>A.a, P.g., P.i., T.f., T.d., P.m., F.n., C.r., E.n., E.c., C.s. Significant reduction of T.d., E.c., C.s. was found in favour of SRP+PDT</td>
<td>Not analysed</td>
<td>Test: PD: 0.8±0.5 (n.s.) CAL: 0.7±0.7 (n.s.) BOP: from 15±12 to 12±05* Control: PD: 0.9±0.8 CAL: 0.5±0.6 BOP: from 19±14 to 18±08</td>
</tr>
<tr>
<td>Study</td>
<td>Country</td>
<td>Design</td>
<td>N</td>
<td>Age (range)</td>
<td>Customization</td>
<td>Time</td>
<td>Test 1</td>
<td>Wavelength</td>
<td>Power Output</td>
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<tr>
<td>Giannopoulou et al. (2012)</td>
<td>Switzerland</td>
<td>Split-mouth, RCT</td>
<td>29</td>
<td>52 (36-74)</td>
<td>12 smokers</td>
<td>6 months</td>
<td>Test 1: SRP+PDT</td>
<td>660 nm</td>
<td>100 mW</td>
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<td>Test 2: SRP+diole laser (DL)</td>
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<td>Control: SRP</td>
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<tr>
<td>Kolbe et al. (2014)</td>
<td>Brazil</td>
<td>Split-mouth, RCT</td>
<td>21</td>
<td>48.52 (32-75)</td>
<td>non smokers</td>
<td>6 months</td>
<td>Test 1: PDT</td>
<td>660 nm</td>
<td>60 mW</td>
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<td>Test 2: Photosensitizer</td>
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<td>Control: SRP</td>
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<td>Lulic et al. (2009)</td>
<td>Parallel</td>
<td>RCT</td>
<td>10</td>
<td>54 (40-74)</td>
<td>2 smokers</td>
<td>12 months</td>
<td>Test: SRP + PDT</td>
<td>670 nm</td>
<td>75 mW/cm²</td>
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<td>Control: SRP+PDT</td>
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<tr>
<td>Müller Campanile et al. (2015)</td>
<td>Switzerland</td>
<td>Split-mouth, RCT</td>
<td>27</td>
<td>62.8 (37-77)</td>
<td></td>
<td>6 months</td>
<td>Test1: SRP + PDT (twice)</td>
<td>670 nm</td>
<td>280 mW</td>
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<td>Test2: SRP + PDT (once)</td>
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<td>Control: SRP+</td>
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<tr>
<td>Study</td>
<td>Country</td>
<td>Study Design</td>
<td>N</td>
<td>Treatment 1</td>
<td>Treatment 2</td>
<td>Control</td>
<td>Results</td>
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<tr>
<td>Petelin et al. (2014)</td>
<td>Slovenia</td>
<td>Parallel, RCT</td>
<td>27</td>
<td>Ultrasonic scaling (US)+PDT</td>
<td>US</td>
<td>SRP</td>
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</tbody>
</table>
|                       |         |              |    | Test 1: 660 nm, 60 mW/cm², 60 s/site | Test 2: US | Control: | PD: from 6.3±1.3 to 1.9±1.8 (n.s.)  
|                       |         |              |    | Assessment of A.a., P.g., P.i., T.f., T.d. | | | CAL: from 7.9±2.2 to 4.2±2.8 (n.s.)  
|                       |         |              |    | Significant reduction of T.d. + sites and of A.a., T.f., T.d. levels in favour to PDT in medium pockets (4-6mm), and of T.d. in deep pockets (>6mm). | | | BOP: from 20 to 7 sites (n.s.)  
|                       |         |              |    | Not analysed | | | Test 1: |  
|                       |         |              |    | PD from 3.4±0.2 to 2.9±0.2 (n.s.) | | | CAL from 4.2±0.3 to 3.7±0.2 (n.s.)  
|                       |         |              |    | Test 2: | | | BOP from 25% to 9%* |  
|                       |         |              |    | PD from 3.6±0.2 to 3.0±0.2 (n.s.) | | | CAL from 4.3±0.3 to 3.7±0.2 (n.s.)  
|                       |         |              |    | Test 2: | | | BOP from 23% to 12% (n.s.) |  
|                       |         |              |    | Control: | | | PD from 3.8±0.2 to 3.3±0.2 |  
|                       |         |              |    | Test: | | | CAL from 4.7±0.3 to 4.0±0.2 |  
|                       |         |              |    | Control: | | | BOP from 17% to 9% |  
|                       |         |              |    | Test: | | | No significant differences between the groups: |  
|                       |         |              |    | Control: | | | PD: from 3.5±0.4 to 3.3±0.6 (n.s.) |  
| Rühling et al. (2010) | Germany | Parallel, RCT | 60 | Ultrasonic debridement | | |  
|                       |         |              |    | Test: PDT | | | CAL: from 11.4±1.7 to 11.4±1.6 (n.s.)  
|                       |         |              |    | Control: | | | BOP: from 5.4±4.6 to 3.3±4.3 (n.s.) |  
|                       |         |              |    | Control: | | | PD: from 3.3±0.5 to 3.1±0.7 |  
|                       |         |              |    | Test:控 | | | CAL: from 10.6±1.3 to |  

**Note:**  
n.s.: not significant; n.r.: not reported; REC: recession; IL: Interleukin; b-FGF: basic fibroblast growth factor; G-CSF: granulocyte colony stimulating factor; IFN-γ: interferon γ; MIP-1β: macrophage inflammatory protein 1β; GM-CSF: granulocyte macrophage colony stimulating factor; TNF-α: tumor necrosis factor α; CRP: C-reactive protein; VEGF: vascular endothelial growth factor; T.f.: Tannerella forsythia; P.g.: Porphyromonas gingivalis; A.a.: Aggregatibacter actinomycetemcomitans; T.d.: Treponema denticola; F.n.: Fusobacterium nucleatum; P.i.: Prevotella intermedia; C.r.: Campylobacter rectus; E.c.: Eikenella corrodens; P.m.: Parvimonas micra; E.n.: Eubacterium nodatum; C.s.: Capnocytophaga Spp.
References


