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Short-term clinical effects of adjunctive antimicrobial photodynamic therapy in periodontal treatment: a randomized clinical trial

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Abstract

Objective: The aim of this study was to assess the effect of adjunctive antimicrobial photodynamic therapy (aPDT) in chronic periodontitis.

Material and Methods: Twenty patients with untreated chronic periodontitis were included. All teeth received periodontal treatment comprising scaling and root planing. Using a split-mouth design, two quadrants (test group) were additionally treated with aPDT. Sulcus fluid flow rate (SFFR) and bleeding on probing (BOP) were assessed at baseline, 1 week and 3 months after treatment. Relative attachment level (RAL), probing depths (PDs) and gingival recession (GR) were evaluated at baseline and 3 months after treatment.

Results: Baseline median values for PD, GR and RAL were not different in the test group and control group. Values for RAL, PD, SFFR and BOP decreased significantly 3 months after treatment in the control group (median delta RAL: -0.35 mm, inter-quartile range: 0.21 mm), with a higher impact on the sites treated with adjunctive aPDT (median delta RAL: -0.67 mm, inter-quartile range: 0.36 mm, $p<0.05$). GR increased 3 months after treatment with and without adjunctive aPDT ($p<0.05$), with no difference between the groups ($p>0.05$).

Conclusions: In patients with chronic periodontitis, clinical outcomes of conventional subgingival debridement can be improved by adjunctive aPDT.

Key words: adjunctive periodontal treatment; antimicrobial photodynamic therapy; chronic periodontitis; gingival crevicular fluid

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The removal of biofilm (Bernimoulin 2003) and mineralized deposits from the tooth surface are the fundamental aspects of periodontal therapy (Westfelt 1996). However, completeness of periodontal debridement procedures may decrease with increasing probing depth (PD) and furcation involvement (Rabbani et al. 1981, Brayer et al. 1989, Wylam et al. 1993). Thus, bacterial reservoirs can remain on the root surface and affect periodontal healing following treatment. Adjunctive procedures such as locally delivered (Machion et al. 2006) and systemic antibiotics (López et al. 2006) or subgingival placement of chlorhexidine chips (Carvalho et al. 2007) have been evaluated. Among the locally administered adjunctive antimicrobials, the most beneficial results were observed for tetracycline, minocycline, metronidazole and chlorhexidine (Bonito et al. 2005). However, regarding the treatment of chronic periodontitis, the marginal additional improvements in PD and attachment level are a fraction of the improvement from scaling and root planing (SRP) alone (Bonito et al. 2005). Furthermore, these agents are difficult to maintain at a therapeutic concentration in the periodontal pocket, and there is an increased concern regarding the development of antibiotic resistance. The use of systemic antibio-

Conflict of interest and source of funding statement

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HELBO Photodynamic Systems provided the diode laser and photosensitizer.

tics should therefore be restricted to specific groups of periodontal patients, for example those with a highly active disease or a specific microbiological profile (Herrera et al. 2002). As a consequence, there is a need to develop alternative antimicrobial approaches for preventive and therapeutic periodontal regimes.

aPDT is a treatment procedure that uses light energy to activate a photosensitizing agent (photosensitizer) in the presence of oxygen (Meisel & Kocher 2005, Konopka & Goslinski 2007). The working principle is that the photosensitizer undergoes a transition to a higher energy state, producing a highly reactive state of oxygen (Konopka & Goslinski 2007). This singlet oxygen might cause a toxic effect on microorganisms. Several photosensitizers have been shown to be effective against target microorganisms without inducing damage to the host tissues (Komerik & MacRobert 2006). It could be demonstrated that aPDT can be effective in killing periodontopathogenic bacteria such as *Porphyromonas gingivalis* or *Fusobacterium nucleatum* in vitro (Pfitzner et al. 2004). Using an animal model, it was shown that photosensitization of *P. gingivalis* is possible in vivo, resulting in decreased bone loss (Komerik et al. 2003). aPDT in a beagle dog model showed a positive effect on inflammatory signs and the possibility to suppress *P. gingivalis* (Sigusch et al. 2005). Assessing the impact of aPDT on the treatment of aggressive periodontitis in humans, photosensitization and SRP showed similar clinical results (de Oliveira et al. 2007). A first report on the comparison of conventional debridement with or without the adjunctive use of aPDT in chronic periodontitis indicated higher improvements in clinical parameters in the aPDT group (Andersen et al. 2007).

The aim of the present study was to compare the clinical outcomes of conventional root debridement with or without adjunctive aPDT in patients with chronic periodontitis, testing the hypothesis of adjunctive aPDT being able to improve non-surgical periodontal therapy.

Material and Methods

Patients

Twenty patients (11 female, 9 male, mean age: 46.6 ± 6.1 years, all non-smokers), each of whom presented with untreated chronic periodontitis, were recruited from the Department of Periodontology of the University Dental Clinic Bonn. Exclusion criteria were systemic diseases that could influence the outcome of periodontal therapy including antiphlogistics, bleeding-stimulating pharmaceuticals or intake of systemic antibiotics within the last 6 months. The inclusion criteria of the study were as follows: previously untreated chronic periodontitis, at least one premolar and one molar in every quadrant with a minimum of four teeth each; at least one tooth with an attachment loss of >3 mm in every quadrant. All patients had been informed about the study and had given their informed consent to participate in the study for 3 months during the period from January to June 2007. The study was conducted in full accordance with the declared ethical principles (World Medical Association Declaration of Helsinki, version VI, 2002) and had been approved by the local Ethic's Committee (reference number: 056/07).

Clinical parameters

At baseline, 1 week and 3 months after treatment, the sulcus fluid flow rate (SFFR) and bleeding on probing (BOP) index were evaluated by a blinded investigator who was not involved in the treatment of the patients. SFFR was measured at the point of highest PD of the first premolar and molar in each quadrant. After isolating the teeth with cotton rolls, sulcus fluid was collected with filter paper strips that were placed at the orifice of the dental sulcus for 30 s (Periopaper®, Oraflow Inc., New York, USA). The Periotron-device (Periotron 8000®, Oraflow Inc.) was used to measure the SFFR, specified in relative Periotron-units [PU]. BOP was assessed in all quadrants, evaluating six sites per tooth, by gentle probing of the gingival sulcus with a pressure-calibrated probe (Vivacare TPS Probe®, Vivadent, Schaan, Liechtenstein) with a probing force of 20 g. Bleeding points were assessed 30 s after probing.

The periodontal status of each subject was assessed at baseline and 3 months after periodontal treatment. PDs, gingival recession (GR), relative attachment level (RAL), degree of tooth mobility and furcation involvement were documented by a blinded examiner who was not involved in the treatment of the patients. All measurements were performed by one experienced periodontal examiner, allowing an intra-experimental comparison of the values. The examiner underwent calibration training at the beginning of the study. Percentage agreement with another experienced examiner within 1 mm was $>96\%$.

Impressions of the upper and lower teeth were taken to fabricate customized splints adapting to the teeth by friction fit. These splints were used to assure reproducible measuring points for both PDs and relative attachment status. Therefore, the individual splints (ethylene vinyl acetate copolymer, Erkodent, Pfalzgrafenweiler, Germany) were fabricated for every subject by a vacuum-forming process. The oral and facial surfaces of the material were trimmed just short of the tooth equator. For every site under study, a groove was made into the splint and formed a line for the pressure-calibrated periodontal probe, facilitating a reproducible probe position during the measurements.

The intra-oral situation at baseline and after 3 months was documented by digital photographs.

Treatment procedures

All patients received periodontal treatment comprising SRP of all periodontally involved teeth employing both hand instruments (Gracey curettes, Hu-Friedy, Leimen, Germany) and a piezoelectric ultrasonic handpiece (Sirosonic L, Sirona, Bensheim, Germany) with a slim-line styled scaler tip (Perio Pro Line, Sirona) by the same clinician. Using a split-mouth design, two quadrants (test group) were additionally treated with aPDT. Therefore, after periodontal debridement, the quadrants were assigned to different groups (Fig. 1) according to a computer-generated random number table. The sequence was concealed until interventions were assigned.

aPDT was performed with a diode laser (wavelength: 660 nm, output power: 100 mW, Helbo Photodynamic Systems, Grieskirchen, Austria) (Fig. 2) in combination with a dedicated photosensitizer dye (phenothiazine chloride, Helbo Photodynamic Systems). Periodontal pockets were rinsed with the photosensitizer employing a blunt cannula and starting from the bottom of the pocket to achieve both a complete filling of the pocket and coating of the root surface. After 3 min. residence time, the pockets were rinsed with water to remove excess photosensitizer. Employ-

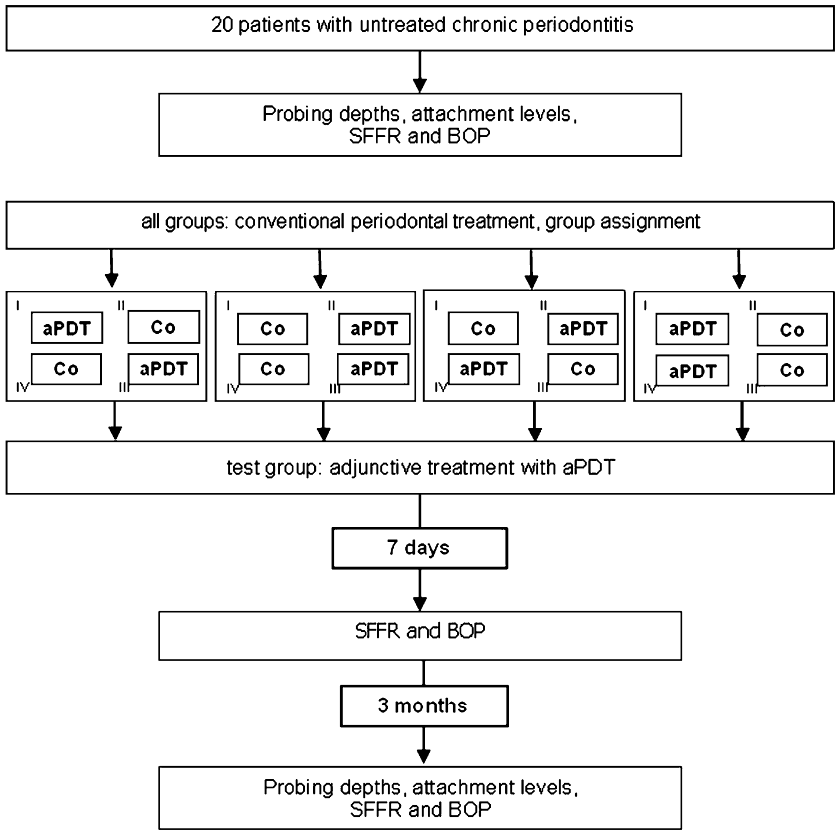

Fig. 1. Study design with group assignment. aPDT, test group comprising conventional debridement with adjunctive antimicrobial photodynamic therapy; Co, control group without adjunctive aPDT; SFFR, sulcus fluid flow rate; BOP, bleeding on probing.

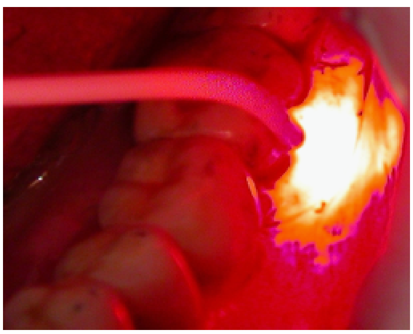

Fig. 2. Activated diode laser during antimicrobial photodynamic therapy. Laser probe is positioned in the vestibular pocket of tooth 36.

ing the dedicated laser probe, the remaining photosensitizer was activated for 10 s per site. As the laser device is classified as laser category 2M, the operator and patient did not have to wear any eye protection: a temporary exposure time (until 0.25 s) is not judged dangerous for the eye, as long as the diameter of the laser beam is not narrowed by optical instruments such as lenses or telescopes. Laser application was performed circumferentially at six sites per tooth. The application time of both the photosensitizer and laser light was monitored by a time-controller belonging to the aPDT-system under study.

Statistical analysis

For statistical analysis, normal distribution of the values was assessed with the Shapiro–Wilk test. Because not all data were normally distributed, values for PDs, attachment level, GR, SFFR and BOP were analysed with a non-parametric test (Kruskal–Wallis) employing the SPSS®-software (SPSS Inc., Chicago, IL, USA). Comparisons between and within the groups with respect to the treatment intervals were performed using the Wilcoxon two-sample paired signed rank test. Differences in PDs for moderate (>3 and $\leqslant 5$ mm) and deep (>5 mm) sites at baseline and after 3 months were analysed employing a non-parametric test (Mann–Whitney). Differences were considered as statistically significant at $p<0.05$.

Results

Sulcus fluid flow rate

Baseline values for SFFR were not statistically different in the control and test group (Fig. 3; $p>0.05$). One week after treatment, in both groups, values for SFFR decreased compared with baseline readings ($p<0.05$). SFFR values in the test group (median: 55, inter-quartile range: 43, maximum: 136, minimum: 6) were significantly lower than those in the control group (median: 68, inter-quartile range: 40, maximum: 134, minimum: 14) ($p<0.05$). Three months after treatment, values for both test group and control group remained lower than baseline readings ($p<0.05$), with lower values in the test group (median: 48, inter-quartile range: 29, maximum: 141, minimum: 6) than in the control (median: 65, inter-quartile range: 47, maximum: 161, minimum: 9) ($p<0.05$).

BOP

No differences were found between the control and test group at baseline (Fig. 4; $p>0.05$). One week after treatment, in both groups, values for BOP decreased compared with baseline readings ($p<0.05$), with significantly lower BOP values in the test group (median: 16, inter-quartile range: 15, maximum: 57, minimum: 0) than in the control group (median: 17, inter-quartile range: 14, maximum: 42, minimum: 5) ($p<0.05$). Three months after treatment, values in both groups were still lower than baseline readings ($p<0.05$), with lower values in the test group (median: 19, inter-quartile range: 11, maximum: 64, minimum: 2) than in the control (median: 24, inter-quartile range: 21, maximum: 61, minimum: 2) ($p<0.05$).

Probing depths

Baseline PDs of periodontally involved teeth were not statistically different in the test group (median: 4.3 mm, inter-quartile range: 0.5, maximum: 6.9, minimum: 4) and control group (median: 4.3 mm, inter-quartile range: 0.8, maximum: 7.3, minimum: 4) (Fig. 5; $p>0.05$). Three months after treatment, in both groups, a decrease in PDs could be found ($p<0.05$) with a higher impact in the test group (median: 3.6 mm, inter-quartile range: 0.6, maximum: 5.3, minimum: 3.2) than in the control (median: 3.7 mm, inter-quartile range: 0.6,

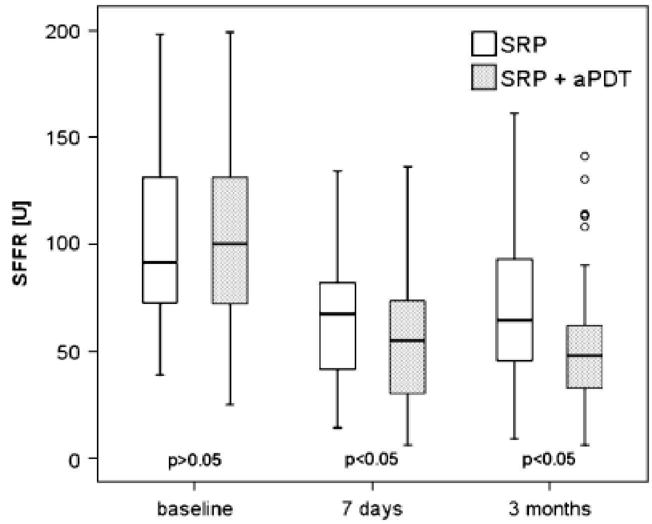

Fig. 3. Sulcus fluid flow rate (SFFR) in the test group and control group at baseline and after 7 days and 3 months. Statistically significant decrease in all values compared with baseline ($p<0.05$). Highest decrease in the test group both 7 days and 3 months after treatment ($p<0.05$). Box plots show median, first and third quartiles, minimum and maximum values (whiskers). Outliers are marked as data points and asterisks.

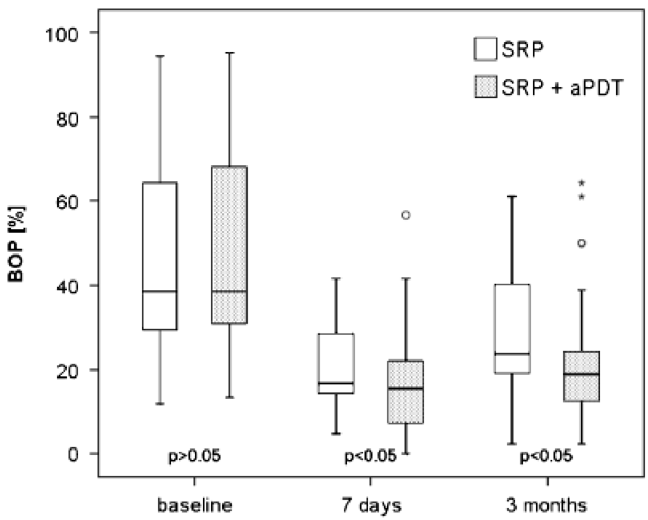

Fig. 4. Bleeding on probing (BOP) in the test group and control group at baseline and after 7 days and 3 months. Statistically significant decrease in all values compared with baseline ($p<0.05$). Highest decrease in the test group both 7 days and 3 months after treatment ($p<0.05$). Box plots show median, first and third quartiles, minimum and maximum values (whiskers). Outliers are marked as data points and asterisks.

maximum: 6.0, minimum: 3.4) ($p<0.05$). Comparing PDs of initial moderate (>3 and $\leqslant 5$ mm) and deep (>5 mm) sites, in both groups a decrease in PDs could be observed (Tables 1 and 2).

RALs

The attachment levels of periodontally involved teeth did not differ significantly in the test group (median: 7.63 mm, inter-quartile range: 1.01, maximum: 9.76, minimum: 6.17) and control group (median: 7.56 mm, inter-quartile range: 1.99, maximum: 10.38, minimum: 6.07) at baseline ($p>0.05$). After 3 months, a lower attachment gain could be observed in the control group (median RAL: 7.25 mm, inter-quartile range: 2.02, maximum: 10.09, minimum: 5.61) than in the test group (median RAL: 7.04 mm, inter-quartile range: 1.63, maximum: 9.11, minimum: 5.33) ($p<0.05$). Comparing the differences in RAL (ΔRAL), an attachment gain could be observed in both groups (control: median ΔRAL: -0.35 mm, inter-quartile range: 0.21, maximum: -0.81, minimum: -0.11), with a higher impact on the sites treated with adjunctive aPDT (median ΔRAL: -0.67 mm, inter-quartile range: 0.36, maximum: -1.89, minimum: -0.20, $p<0.05$; Fig. 6).

Gingival recession

Values for GR were not statistically different at baseline in the test group (median: 0.35 mm, inter-quartile range: 0.53, minimum: 0.00, maximum: 1.73) and control group (median: 0.26 mm, inter-quartile range: 0.62, minimum: -0.04, maximum: 2.31) (Fig. 7; $p>0.05$). Three months after treatment both with (median: 0.39 mm, inter-quartile range: 0.88, minimum: 0.00, maximum: 2.00) and without adjunctive aPDT (median: 0.46 mm, inter-quartile range: 0.94, minimum: 0.00, maximum: 2.77), values decreased ($p<0.05$) with no difference between the groups ($p>0.05$).

Discussion

The present study could demonstrate that the clinical outcomes of non-surgical periodontal treatment of chronic periodontitis were improved by adjunctive aPDT procedures.

The conventional mechanical instrumentation of the root surface is considered as a prerequisite for a long-term treatment success (Greenstein 1992). However, studies could demonstrate that adjunctive treatment procedures such as minocycline application (Cortelli et al. 2006) or laser irradiation (Qadri et al. 2005, Cobb 2006) may provide some additional benefit in the treatment of chronic periodontitis. Thus, the development of novel techniques promised alternative treatment approaches to improve the outcomes of subgingival debridement. However, subgingival polishing with the novel non-aggressive Vector ultrasonic device showed only similar effects as scaling with curettes (Kahl et al. 2007, Christgau et al. 2007) and was more time consuming than conventional debridement (Braun et al. 2006). Another novel technique for subgingival debridement is the fluorescence feedback-controlled Er:YAG laser. It could be demonstrated that the amount of residual calculus following laser irradiation depends on the fluorescence threshold

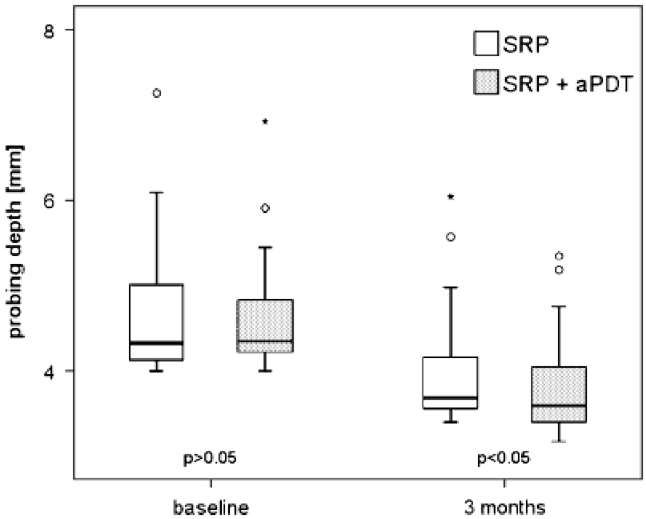

Fig. 5. Probing depths in the test group and control group at baseline and 3 months after treatment. Statistically significant reduction in probing depths in both groups compared with baseline ($p<0.05$), with significantly lower probing depths in the test group ($p<0.05$). Box plots show median, first and third quartiles, minimum and maximum values (whiskers). Outliers are marked as data points and asterisks.

Table 1. Distribution of initial moderate (>3 and $\leqslant 5$ mm) and deep (>5 mm) probing depths at baseline and after 3 months in the test group and control group

Probing depth	SRP		SRP+aPDT	
	baseline	3 months	baseline	3 months
>3 and $\leqslant 5$ mm	351	379	394	430
>5 mm	124	87	112	62
Overall	475	475	506	506

SRP, scaling and root planing; aPDT, antimicrobial photodynamic therapy.

Table 2. Differences of probing depths comparing baseline and 3 months after treatment for initial moderate (>3 and $\leqslant 5$ mm) and deep (>5 mm) sites

	Number	Mean	Standard deviation	Median	Maximum	Minimum	Interquartile range	*p*-value
SRP+aPDT								
Moderate	394	0.68	0.63	1.0	3.0	− 1.0	1.0	<0.05
Deep	112	1.43	1.33	1.0	5.0	− 3.0	1.0	
SRP								
Moderate	351	0.55	0.68	1.0	3.0	− 2.0	1.0	<0.05
Deep	124	1.22	1.12	1.0	4.0	− 1.0	2.0	

SRP, scaling and root planing; aPDT, antimicrobial photodynamic therapy.

level without removing a clinically relevant amount of root cementum (Krause et al. 2007). With respect to microbiological findings, it could be shown that Er:YAG laser, curettes, sonic and ultrasonic scalers have similar effects in patients with chronic periodontitis (Derdilopoulou et al. 2007). Currently, a beneficial clinical, microbiological/immunological effect of various types of laser wavelengths over conventional treatment procedures might not be expected (Schwarz et al. submitted for publication). Another attempt to improve periodontal treatment is full-mouth treatment concepts to prevent early re-infection from untreated sites. Controversial results have been reported for the microbiological effects of full-mouth disinfection and full-mouth root planing *versus* the standard quadrantwise approach. A recent study could not confirm any differences in re-colonization after SRP within 24 h compared with treatment over several sessions (Jervøe-Storm et al. 2007). Reviewing the current literature, in adults with chronic periodontitis, only minor differences in treatment effects were observed between these treatment strategies (Eberhard et al. 2008).

Using a systemic antibiotic agent, the subantimicrobial dose doxycycline therapy as an adjunct to SRP in the long-term management of periodontal disease provides significant clinical benefits (Gürkan et al. 2005). However, a recent study could not provide evidence of the benefit of using this therapy as an adjunct to non-surgical periodontal debridement in smokers (Needleman et al. 2007). If systemic antimicrobials are indicated in periodontal therapy, they should be adjunctive to mechanical debridement. There is not enough evidence to support their use with periodontal surgery (Herrera et al. submitted for publication).

These findings legitimate the quest for new treatment procedures to improve conventional debridement. The limited access of topical agents to the plaque and the development of antibiotic-resistance create the necessity for alternative strategies to control biofilms and to treat periodontal diseases (Konopka & Goslinski 2007). aPDT is mediated by singlet oxygen, which has a direct effect on extracellular molecules. Thus, the polysaccharides present in the extracellular matrix of polymers of a bacterial biofilm are also susceptible to photodamage (Konopka & Goslinski 2007). Such dual activity is not exhibited by antibiotics and may represent a significant advantage of aPDT. Moreover, a development of resistance to the cytotoxic action of singlet oxygen or free radicals seems to be unlikely. aPDT is equally effective against antibiotic-resistant and antibiotic-susceptible bacteria, and repeated photosensitization has not induced the selection of resistant strains (Wainwright & Crossley 2004).

In the present study, it was legitimate to employ a split-mouth design, as the photosensitizer alone is not capable of generating an antimicrobial effect. The aPDT procedure comprises the photosensitizer dye being activated by laser energy. As only the test quadrants were irradiated by laser light, an effect on bacteria in the control quadrants was not possible, even if some dye should have accidentally come in contact with the tissues of the control quadrants.

The results of the present study are in accordance with those of a recent study evaluating the effect of photodisin-

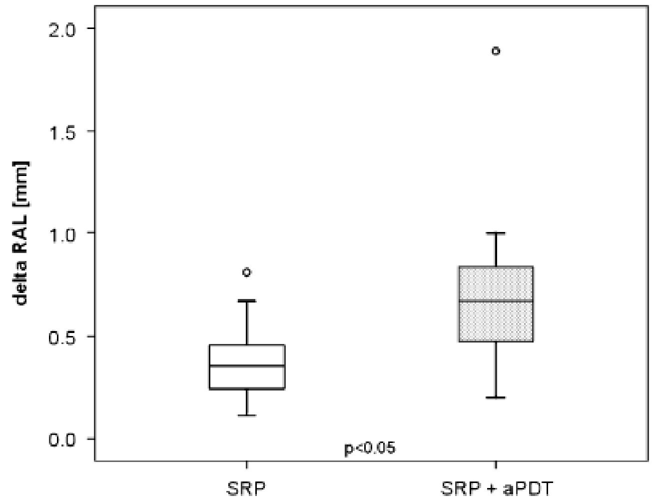

Fig. 6. Differences in relative attachment levels (ΔRAL) in the test group and control group comparing baseline and 3 months after treatment. Statistically significant attachment gain in both groups ($p<0.05$), with higher values in the test group ($p<0.05$). Box plots show median, first and third quartiles, minimum and maximum values (whiskers). Outliers are marked as data points and asterisks.

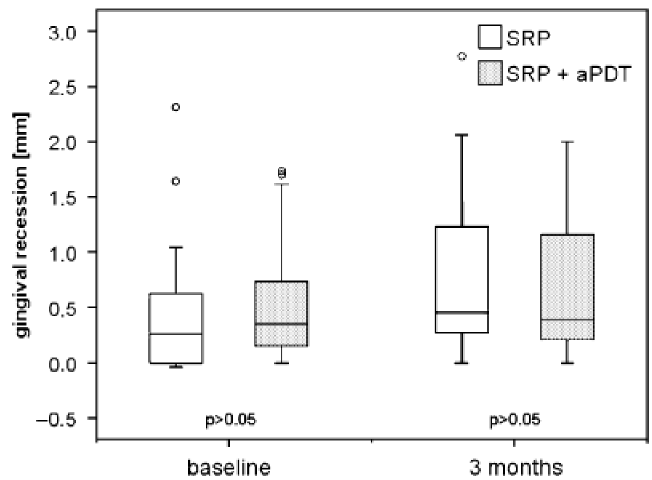

Fig. 7. Gingival recession at baseline and 3 months after treatment. Statistically significant increase in gingival recession in the test group and control group compared with baseline ($p<0.05$), with no difference between the groups ($p>0.05$). Box plots show median, first and third quartiles, minimum and maximum values (whiskers). Outliers are marked as data points and asterisks.

fection alone and in combination with conventional SRP (Andersen et al. 2007). Assessing 33 patients with chronic periodontitis, the authors report a clinical attachment gain of 0.36 ± 0.35 mm in the group treated with SRP alone after 12 weeks. A gain of 0.86 ± 0.61 mm was observed for SRP with adjunctive aPDT. These values are in the same range as those reported in the present study: ΔRAL values in the control group (median: -0.35 mm, maximum: -0.81, minimum: -0.11) were lower than those in the group treated with adjunctive aPDT (median: -0.67 mm, maximum: -1.89, minimum: -0.20). Both studies observed a higher reduction in BOP in the test group. Despite the significant difference in the values in favour of SRP with adjunctive aPDT, these differences were minor. Reviewing the impact of local adjuncts on SRP in periodontal therapy, differences in PDs of 0.1 to nearly 0.5 mm and smaller effects for attachment gains could be observed for a 6-month follow-up, although the differences were statistically different (Bonito et al. 2005). A study evaluating the effect of a subgingival chlorhexidine chip could find a difference of 0.5 mm in clinical attachment gain after 6 months in favour of the chlorhexidine group (Paolantonio et al. 2008). However, whether these improvements are clinically meaningful remains a question.

Evaluating patients receiving supportive periodontal therapy, the additional application of a single episode of aPDT to SRP failed to result in an additional improvement in terms of pocket depth reduction and gain of attachment, but it resulted in significantly higher reduction in bleeding scores than following SRP alone (Chondros et al. 2008).

Another study compared SRP with aPDT alone in patients with aggressive periodontitis (de Oliveira et al. 2007). Ten patients were treated in a split-mouth design. A significant reduction in BOP scores could be observed in both groups after 3 months. Values for PDs and clinical attachment levels also decreased after 3 months. These results are similar to those of the present study. However, there is a major difference in the study design with respect to the present investigation, as the authors evaluated only patients with aggressive periodontitis and did not perform a mechanical debridement procedure before the aPDT procedure. The present study included patients with chronic periodontitis, and aPDT was used as an adjunctive procedure to mechanical debridement. However, the positive effect of aPDT on clinical parameters in aggressive periodontitis should not promote the use of an antimicrobial photodynamic procedure without previous mechanical debridement procedure. Recently, for periodontal treatment without mechanical debridement, a positive effect in attachment gain, a decrease in PDs and reduction in sites with BOP could be shown employing metronidazole plus amoxicillin as sole therapy (López et al. 2006). However, irrespective of the use of antibiotics or aPDT as sole treatment regimen, the clinician has to expect remaining mineralized deposits on the root surface. This residual subgingival calculus may serve as an attachment base for bacteria and contribute to pocket development and the progression of periodontal disease (Bernimoulin 2003). Any viable bacteria on the rough surface of residual calculus might act as a source of re-infection of the periodontal lesion and lead to the progression of periodontitis.

In the present study, all patients received a periodontal treatment comprising SRP of all periodontally involved teeth employing both hand instruments and a piezo-electric ultrasonic handpiece with a slim-line styled scaler tip. No difference concerning clinical outcome between ultrasonic and manual debridement in the treatment of chronic periodontitis was found (Drisko et al. 2000, Tunkel et al. 2002). Furthermore, both debridement procedures were performed in each patient, allowing an intra-experimental comparison of the quadrants treated in a split-mouth design. SFFR values were evaluated with the Periotron 8000® device according to previous study protocols (Trombelli et al. 2004a, b, Sekino et al. 2005) to prevent saliva or plaque at the orifice of the dental sulcus, and incorrect application of the Periopaper®-strips with a high pressure should be prevented (D'Aoust & Landry 1994). Different retention periods of the paper strips up to 30 s at the orifice of the dental sulcus are described. Longer residence time could induce evaporation and therefore distort the achievement (Whitford et al. 1981, Tözüm et al. 2004). Thus, in the present study, SFFR values were evaluated after a retention period of 30 s (Weiger et al. 1989, Adonogianaki et al. 1994, Sekino et al. 2005). Both SFFR and BOP were used to assess gingival inflammation. With respect to BOP, a standardized probing force is very important to avoid false-positive measurements (Lang et al. 1991). Therefore, a gentle probing procedure of the gingival sulcus was performed with a pressure-calibrated probe, as the probing force of 20 g could be shown to be appropriate to prevent trauma of periodontal tissues during the probing procedure (Hunter 1994).

The present study indicates that the adjunctive use of aPDT has a positive effect on treatment outcomes. Thus, by adding antimicrobial photodynamic treatment procedures to conventional anti-infective approaches, it might be possible to improve non-surgical periodontal therapy. Further studies will have to evaluate the impact of adjunctive aPDT in patients with aggressive periodontitis or the use of this novel procedure during maintenance therapy. In addition, the microbiological effects underlying the observed clinical benefits should be investigated.

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References

Adonogianaki, E., Moughal, N. A., Mooney, J., Stirrups, D. R. & Kinane, D. F. (1994) Acute-phase proteins in gingival crevicular fluid during experimentally induced gingivitis. *Journal of Periodontal Research* **29**, 196–202.

Andersen, R., Loebel, N., Hammond, D. & Wilson, M. (2007) Treatment of periodontal disease by photodisinfection compared to scaling and root planing. *Journal of Clinical Dentistry* **18**, 34–38.

Bernimoulin, J. P. (2003) Recent concepts in plaque formation. *Journal of Clinical Periodontology* **30** (Suppl. 5), 7–9.

Bonito, A. J., Lux, L. & Lohr, K. N. (2005) Impact of local adjuncts to scaling and root planing in periodontal disease therapy: a systematic review. *Journal of Periodontology* **76**, 1227–1236.

Braun, A., Krause, F., Hartschen, V., Falk, W. & Jepsen, S. (2006) Efficiency of the Vector-system compared with conventional subgingival debridement in vitro and in vivo. *Journal of Clinical Periodontology* **33**, 568–574.

Brayer, W. K., Mellonig, J. T., Dunlap, R. M., Marinak, K. W. & Carson, R. E. (1989) Scaling and root planing effectiveness: the effect of root surface access and operator experience. *Journal of Periodontology* **60**, 67–72.

Carvalho, J., Novak, M. J. & Mota, L. F. (2007) Evaluation of the effect of subgingival placement of chlorhexidine chips as an adjunct to scaling and root planing. *Journal of Periodontology* **78**, 997–1001.

Chondros, P., Nikolidakis, D., Christodoulides, N., Rössler, R., Gutknecht, N. & Sculean, A. (2008) Photodynamic therapy as adjunct to non-surgical periodontal treatment in patients on periodontal maintenance: a randomized controlled clinical trial. *Lasers in Medical Science*.9 May (Epub ahead of print).

Christgau, M., Männer, T., Beuer, S., Hiller, K. A. & Schmalz, G. (2008) Periodontal healing after non-surgical therapy with a new ultrasonic device: a randomized controlled clinical trial. *Journal of Clinical Periodontology* **34**, 137–147.

Cobb, C. M. (2006) Lasers in periodontics: a review of the literature. *Journal of Periodontology* **77**, 545–564.

Cortelli, J. R., Querido, S. M., Aquino, D. R., Ricardo, L. H. & Pallos, D. (2006) Longitudinal clinical evaluation of adjunct minocycline in the treatment of chronic periodontitis. *Journal of Periodontology* **77**, 161–166.

D'Aoust, P. & Landry, R. G. (1994) The effect of supragingival plaque on crevicular fluid measurements. *International Dental Journal* **44**, 159–164.

de Oliveira, R. R., Schwartz-Filho, H. O., Novaes, A. B. Jr. & Taba, M. Jr. (2007) Antimicrobial photodynamic therapy in the non-surgical treatment of aggressive periodontitis: a preliminary randomized controlled clinical study. *Journal of Periodontology* **78**, 965–973.

Derdilopoulou, F. V., Nonhoff, J., Neumann, K. & Kielbassa, A. M. (2007) Microbiological findings after periodontal therapy using curettes, Er:YAG laser, sonic, and ultrasonic scalers. *Journal of Clinical Periodontology* **34**, 588–598.

Drisko, C. L., Cochran, D. L., Blieden, T., Bouwsma, O. J., Cohen, R. E., Damoulis, P., Fine, J. B., Greenstein, G., Hinrichs, J., Somerman, M. J., Iacono, V. & Genco, R. J. (2000) Position paper: sonic and ultrasonic scalers in periodontics. *Journal of Periodontology* **71**, 1792–1801.

Eberhard, J., Jervøe-Storm, P. M., Needleman, I., Worthington, H. & Jepsen, S. (2008) Full-mouth treatment concepts for chronic periodontitis: a systematic review. *Journal of Clinical Periodontology* **35**, 591–604.

Greenstein, G. (1992) Periodontal response to mechanical non-surgical therapy: a review. *Journal of Periodontology* **63**, 118–130.

Gürkan, A., Cinarcik, S. & Hüseyinov, A. (2005) Adjunctive subantimicrobial dose doxycycline: effect on clinical parameters and gingival crevicular fluid transforming growth factor-beta levels in severe, generalized chronic periodontitis. *Journal of Clinical Periodontology* **32**, 244–253.

Herrera, D., Alonso, B., León, R., Roldán, S. & Sanz, M.. Antimicrobial therapy in periodontitis; the use of systemic antimicrobials against the subgingival biofilm. *Journal of Clinical Periodontology* **35** (Suppl. 8), 45–66.

Herrera, D., Sanz, M., Jepsen, S., Needleman, I. & Roldán, S. (2002) A systematic review on the effect of systemic antimicrobials as an adjunct to scaling and root planing in periodontitis patients. *Journal of Clinical Periodontology* **29**, 136–159.

Hunter, F. (1994) Periodontal probes and probing. *International Dental Journal* **44**, 577–583.

Jervøe-Storm, P. M., AlAhdab, H., Semaan, E., Fimmers, R. & Jepsen, S. (2007) Microbiological outcomes of quadrant versus full-mouth root planing as monitored by real-time PCR. *Journal of Clinical Periodontology* **34**, 156–163.

Kahl, M., Haase, E., Kocher, T. & Rühling, A. (2007) Clinical effects after subgingival polishing with a non-aggressive ultrasonic device in initial therapy. *Journal of Clinical Periodontology* **34**, 318–324.

Komerik, N. & MacRobert, A. J. (2006) Photodynamic therapy as an alternative antimicrobial modality for oral infections. *Journal of Environmental Pathology, Toxicology and Oncology* **25**, 487–504.

Komerik, N., Nakanishi, H., MacRobert, A. J., Henderson, B., Speight, P. & Wilson, M.

(2003) In vivo killing of *Porphyromonas gingivalis* by toluidine blue-mediated photosensitization in an animal model. *Antimicrobial Agents and Chemotherapy* **47**, 932–940.

Konopka, K. & Goslinski, T. (2007) Photodynamic therapy in dentistry. *Journal of Dental Research* **86**, 694–707.

Krause, F., Braun, A., Brede, O., Eberhard, J., Frentzen, M. & Jepsen, S. (2007) Evaluation of selective calculus removal by a fluorescence feedback-controlled Er:YAG laser in vitro. *Journal of Clinical Periodontology* **34**, 66–71.

Lang, N. P., Nyman, S., Senn, C. & Joss, A. (1991) Bleeding on probing as it relates to probing pressure and gingival health. *Journal of Clinical Periodontology* **18**, 257–261.

López, N. J., Socransky, S. S., Da Silva, I., Japlit, M. R. & Haffajee, A. D. (2006) Effects of metronidazole plus amoxicillin as the only therapy on the microbiological and clinical parameters of untreated chronic periodontitis. *Journal of Clinical Periodontology* **33**, 648–660.

Machion, L., Andia, D. C., Lecio, G., Nociti, F. H. Jr., Casati, M. Z., Sallum, A. W. & Sallum, E. A. (2006) Locally delivered doxycycline as an adjunctive therapy to scaling and root planing in the treatment of smokers: a 2-year follow-up. *Journal of Periodontology* **77**, 606–613.

Meisel, P. & Kocher, T. (2005) Photodynamic therapy for periodontal diseases: state of the art. *Journal of Photochemistry and Photobiology B: Biology* **13**, 159–170.

Needleman, I., Suvan, J., Gilthorpe, M. S., Tucker, R., St George, G., Giannobile, W., Tonetti, M. & Jarvis, M. (2007) A randomized-controlled trial of low-dose doxycycline for periodontitis in smokers. *Journal of Clinical Periodontology* **34**, 325–333.

Paolantonio, M., Dolci, M., Perfetti, G., Sammartino, G., D'Archivio, D., Spoto, G., Ciampoli, C., De Amicis, D. & Tete, S. (2008) Effect of a subgingival chlorhexidine chip on the clinical parameters and the levels of alkaline phosphatase activity in gingival crevicular fluid during the non-surgical treatment of periodontitis. *Journal of Biological Regulators and Homeostatic Agents* **22**, 63–72.

Pfitzner, A., Sigusch, B. W., Albrecht, V. & Glockmann, E. (2004) Killing of periodontopathogenic bacteria by photodynamic therapy. *Journal of Periodontology* **75**, 1343–1349.

Qadri, T., Miranda, L., Tunér, J. & Gustafsson, A. (2005) The short-term effects of low-level lasers as adjunct therapy in the treatment of periodontal inflammation. *Journal of Clinical Periodontology* **32**, 714–719.

Rabbani, G. M., Ash, M. M. Jr. & Caffesse, R. G. (1981) The effectiveness of subgingival scaling and root planing in calculus removal. *Journal of Periodontology* **52**, 119–123.

Schwarz, F., Aoki, A., Becker, J. & Sculean, A. Laser application in non-surgical periodontal therapy – a systematic review. *Journal of Clinical Periodontology* **35** (Suppl. 8), 29–44.

Sekino, S., Ramberg, P. & Lindhe, J. (2005) The effect of systemic administration of ibuprofen in the experimental gingivitis model. *Journal of Clinical Periodontology* **32**, 193–199.

Sigusch, B. W., Pfitzner, A., Albrecht, V. & Glockmann, E. (2005) Efficacy of photodynamic therapy on inflammatory signs and two selected periodontopathogenic species in a beagle dog model. *Journal of Periodontology* **76**, 1100–1105.

Tözüm, T. F., Hatipoglu, H., Yamalik, N., Gürsel, M., Alptekin, N. Ö., Ataoglu, T., Marakoglu, I., Gürsoy, U. K. & Eratalay, K. (2004) Critical steps in electronic volume quantification of gingival crevicular fluid: the impact of evaporation, fluid retention, local conditions and repeated measurements. *Journal of Periodontal Research* **39**, 344–357.

Trombelli, L., Scapoli, C., Orlandini, E., Tosi, M., Bottega, S. & Tatakis, D. N. (2004b) Modulation of clinical expression of plaque-induced gingivitis. III. Response of "high responder" and "low responder" to therapy. *Journal of Clinical Periodontology* **31**, 253–259.

Trombelli, L., Tatakis, D. N., Scapoli, C., Bottega, S., Orlandini, E. & Tosi, M. (2004a) Modulation of clinical expression of plaque-induced gingivitis: II. Identification of "high responder" and "low responder" subjects. *Journal of Clinical Periodontology* **31**, 239–252.

Tunkel, J., Heinecke, A. & Flemmig, T. F. (2002) A systematic review of efficacy of machine-driven and manual subgingival debridement in the treatment of chronic periodontitis. *Journal of Clinical Periodontology* **29**, 72–81.

Wainwright, M. & Crossley, K. B. (2004) Photosensitizing agents – circumventing resistance and breaking down biofilms: a review. *International Biodeterioration and Biodegradation* **53**, 119–126.

Weiger, R., Brecx, M. & Netuschil, L. (1989) Comparison of flow rate of sulcus fluid after 30 seconds and 3 minutes test times. *Oralprophylaxe* **11**, 109–113.

Westfelt, E. (1996) Rationale of mechanical plaque control. *Journal of Clinical Periodontology* **23**, 263–267.

Whitford, G. M., Pashley, D. H. & Pearson, D. E. (1981) Fluoride in gingival crevicular fluid and a new method for evaporative water loss correction. *Caries Research* **15**, 399–405.

Wylam, J. M., Mealey, B. L., Mills, M. P., Waldrop, T. C. & Moskowicz, D. C. (1993) The clinical effectiveness of open versus closed scaling and root planing on multirooted teeth. *Journal of Periodontology* **64**, 1023–1028.

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Clinical Relevance

Scientific rationale for the study: It has been suggested that aPDT exerts a positive effect on periodontitis and that conventional periodontal debridement might be improved by an adjunctive aPDT procedure.
Principal findings: When comparing SRP with or without additional aPDT in a split-mouth design, more favourable clinical outcomes were observed for the combined treatment.
Practical implications: The efficacy of non-surgical periodontal treatment of chronic periodontitis can be enhanced by adjunctive aPDT procedures.