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Laser application in non-surgical periodontal therapy: a systematic review

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Abstract

Objectives: The primary aim was to address the following focused question: What is the clinical effect of laser application compared with mechanical debridement in non-surgical periodontal therapy in patients with chronic periodontitis? A secondary aim was to survey the relevant literature in relation to safety of laser applications.

Material and Methods: Electronic databases of the *PubMed* and the *Cochrane Library* were searched and completed by manual searches up to December 2007.

Results: Following screening, 12 publications (11 studies) were eligible for the review. A meta-analysis could not be performed due to the heterogeneity of the studies. The results from a narrative synthesis indicate that Er:YAG laser monotherapy resulted in similar clinical outcomes, both in the short and the long term (up to 24 months), compared with mechanical debridement. There is insufficient evidence to support the clinical application of either CO_2, Nd:YAG, Nd:YAP, or different diode laser wavelengths.

Conclusions: The Er:YAG laser seems to possess characteristics most suitable for the non-surgical treatment of chronic periodontitis. Research conducted so far has indicated that its safety and effects might be expected to be within the range reported for conventional mechanical debridement. However, the evidence from the evaluated studies is weak.

Key words: chronic periodontitis; laser/therapeutic use; non-surgical periodontal treatment; systematic review

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Potential Use of Lasers for Periodontal Treatment

In recent years, the use of laser radiation has been expected to serve as an alternative or an adjunctive treatment to conventional, mechanical periodontal therapy. Various advantageous characteristics, such as haemostatic effects, selective calculus ablation, or bactericidal effects against periodontopathic pathogens, might lead to improved treatment outcomes (Aoki et al. 1994, 2004, Ando et al. 1996, Folwaczny et al. 2002a). The wavelengths of the lasers most commonly used in periodontics, which include semiconductor diode lasers, the Nd:YAG laser (neodymium doped: yttrium, aluminium, and garnet), the Er:YAG laser (erbium doped: yttrium, aluminium, and garnet), and the carbon dioxide (CO_2) laser, range from 635 to 10, 600 nm. Because of an excellent soft tissue ablation capacity, CO_2 lasers have been used successfully as an adjunctive tool to de-epithelialize the mucoperiosteal flap during traditional flap surgery (Centty et al. 1997). Diode and Nd:YAG lasers were mainly used for laser-assisted subgingival curettage and disinfection of the periodontal pocket with various degrees of success (Cobb et al. 1992, Moritz et al. 1998, Liu et al. 1999). However, several studies reported on thermal side effects, such as melting, cracking or carbonization when CO_2 and Nd:YAG lasers were used directly on root surfaces (Tewfik et al. 1994, Wilder-Smith et al. 1995, Tucker et al. 1996, Israel et al. 1997). In case of the CO_2 laser these negative effects could be avoided when irradiation was performed in a pulsed mode with a defocussed beam (Barone et al. 2002). So far, there is limited information about the effects of diode laser radiation on the surface properties of root surfaces. The results from recent studies showed that this laser may also cause damage to periodontal hard tissues if irradiation parameters are not

Conflict of interest and source of funding statement

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The study was self-funded by the Department of Oral Surgery, Heinrich Heine University, Düsseldorf, Germany. The laser devices that were used in the studies of Schwarz et al. (2001, 2003a, b, c) and Sculean et al. (2004) were borrowed from KaVo Company, Biberach, Germany.
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adequate (Kreisler et al. 2002, Schwarz et al. 2003c). Furthermore, CO_2-, Nd:YAG-, as well as diode lasers were proven to be ineffective in removing mineralized deposits from the root surface (Tucker et al. 1996, Moritz et al. 1998, Liu et al. 1999, Schwarz et al. 2003c). Because, according to the cause-related concept of periodontal therapy, the main objective of treatment is to remove all calcified deposits from the root surface (O'Leary 1986), these types of lasers should only be used as an adjunct to mechanical periodontal treatment. In recent years, close attention has been paid to the clinical applicability of the Er:YAG laser with a wavelength of 2940 nm in the near-infrared spectrum (Ishikawa et al. 2004). Because of the high absorption of its emission wavelength by water, this laser system provides a capability to effectively remove calculus from periodontally diseased root surfaces without causing thermal side effects to the adjacent tissue (Aoki et al. 1994, Eberhard et al. 2003, Schwarz et al. 2003c). The absence of thermal damages was most likely due to the optical characteristics of its wavelength, because the Er:YAG laser theoretically has a 10 and 15,000–20,000 times higher absorption coefficient of water than the CO_2 and the Nd:YAG lasers, respectively (Robertson & Williams 1971, Hale & Querry 1973). Most recently, 655 nm InGaAsP (indium gallium arsenide phosphate) diode laser radiation has been included in an Er:YAG laser device to induce fluorescence in subgingival calculus (Folwaczny et al. 2002b, Krause et al. 2003). Preliminary clinical and histological results have shown that fluorescence-controlled (feedback system) Er:YAG laser radiation enabled an effective removal of subgingival calculus and a predictable root surface preservation in comparison with hand instruments (Schwarz et al. 2006, Krause et al. 2007). Immunohistochemical characterization of wound healing following non-surgical periodontal treatment revealed that fluorescence-controlled Er:YAG laser radiation was effective in controlling disease progression, and may support the formation of a new connective tissue attachment (Schwarz et al. 2007). To be suitable for clinical applications, however, non-surgical periodontal treatment using any type of laser device must be proven to predictably result in significant attachment level gains. Therefore, the primary aim was to address the following focused question: What is the clinical effect of laser application compared with mechanical debridement in non-surgical periodontal therapy in patients with chronic periodontitis? A secondary aim was to survey the relevant literature in relation to the safety of laser applications.

Material and Methods

Search strategy

The *PubMed* database of the U.S. National Library of Medicine and the *Cochrane Library* of the Cochrane Collaboration (CENTRAL) were used as electronic databases to perform a systematic review of the available literature. Screening was performed independently by two reviewers (F. S. and A. S.). Disagreement regarding inclusion was resolved by discussion. The Level of agreement between reviewers was determined by κ scores.

Search terms and key words included ''periodontal treatment'' AND ''laser'', ''non-surgical periodontal treatment'' AND ''laser'', ''non surgical periodontal treatment'' AND ''laser'', ''non-surgical periodontal therapy'' AND ''laser'', ''non surgical periodontal therapy'' AND ''laser'', ''lasers in periodontics'', ''scaling and root planing '' AND ''laser'', ''chronic periodontitis'' AND ''laser'', ''dental scaling'' and ''laser''.

Additionally, the following journals were searched manually between 1990 and December 2007:

Clinical Oral Implants Research, *Clinical Oral Investigations*, *The International Journal of Periodontics and Restorative Dentistry*, *Journal of Clinical Laser Medicine and Surgery (until 2004)*, *Journal of Clinical Periodontology*, *Journal of Dental Research*, *Journal of Oral Laser Applications*, *Journal of Periodontology*, *Journal of Periodontal Research*, *Journal of Prosthodontics*, *Lasers in Medical Science*, *Lasers in Surgery and Medicine*, *Periodontal Practice Today*, *Periodontology 2000*, *Photomedicine and Laser Surgery, and Quintessence International*. Finally, the references of all selected full-text articles and related reviews were scanned. The corresponding authors were contacted in order to obtain missing, unclear or unpublished data.

Study inclusion and exclusion criteria

Electronic search and title management was accomplished using a commercial software program (Endnote X1, Thomson, London, UK). The first stage of study selection was based on the following inclusion criteria:

(1) Publication in an international peer-reviewed literature.
(2) English language.
(3) Randomized-controlled and/or comparative clinical studies using either a parallel or a split-mouth design.
(4) Implementation of either hard or soft laser applications for treatment of chronic periodontitis.
(5) Initial and maintenance therapy of chronic periodontitis.
(6) Presence of at least 10 patients in respective test and control groups.
(7) Evaluation of either clinical and/or microbiological/immunological data.

At the second stage of selection, all full-text articles identified during the first stage were acquired. During this procedure, the pre-selected studies were evaluated according to the following additional exclusion criteria:

(1) no definition of inclusion and/or exclusion criteria,
(2) periodontal treatment within the last 6 months,
(3) systemic antibiotics within the last 6 months,
(4) insufficient information on laser device and energy settings.

Quality assessment of selected studies

A quality assessment of all selected studies was performed according to the revised recommendation of the CONSORT statement for the evaluation of randomized-controlled trials (Moher et al. 2001) (Table 1).

Quality assessment was performed in two different phases. In particular, during phase I quality assessment was based on the published full-text article, while in phase II all studies were reconsidered according to the supplementary information provided by the corresponding authors.

After forming the scores at the second phase of quality assessment, an overall estimation of plausible risk of bias (low, moderate, or high) was performed for each selected study. In brief, a low risk of bias was estimated when all of the criteria were met. A moderate risk was considered when one or more criteria were partly met, while a high risk of

Table 1. Categories to assess the quality of finally selected studies (Moher et al. 2001)

Category	Description	Grading
A	Sample size calculation, estimating the minimum number of participants required to detect a significant difference among compared groups	0 = did not exist/not mentioned/not clear 1 = was reported, but not confirmed 2 = reported and confirmed
B	Randomization and allocation concealment methods	0 = clearly inadequate 1 = possibly adequate 2 = clearly adequate
C	Clear definition of inclusion and/or exclusion criteria	0 = no 1 = yes
D	Completeness of follow-up (specified reasons for withdrawals and dropouts in each study group)	0 = no/not mentioned/not clear 1 = yes/no withdrawals or dropouts occurred
E	Experimental and control groups comparable at study baseline for important prognostic factors	0 = no 1 = unclear/possibly not comparable for one or more important prognostic factors 2 = clearly adequate
F	Presence of masking	0 = no 1 = unclear/not complete 2 = yes
G	Appropriate statistical analysis	0 = no 1 = unclear/possibly not the best method applied 2 = yes

Table 2. Excluded studies at the second stage of selection and the reason for exclusion

Study	Reason for exclusion
Ben Hatit et al. (1996) Neill & Mellonig (1997) Mortiz et al. (1998) Sjstrom & Friskopp (2002) Borrajo et al. (2004)	No definition of inclusion and/or exclusion criteria

bias was estimated when one or more criteria were not met (*Cochrane Handbook for Systematic Reviews of Interventions*, Version 4.2.6., http://www.cochrane.org/resources/handbook).

Results

Study selection

A total of 1248 potentially relevant titles and abstracts were found during the electronic and manual search. During the first stage of study selection, 1226 publications were excluded based on title and abstract (inter-reviewer agreement $k = 0.94$). For the second phase, the complete full-text articles of the remaining 18 publications were thoroughly evaluated. A total of six papers (Ben Hatit et al. 1996, Neill & Mellonig 1997, Moritz et al. 1998, Liu et al. 1999, Sjöstrom & Friskopp 2002, Borrajo et al. 2004) had to be excluded during this stage of selection due to a lack of inclusion/exclusion criteria (inter-reviewer agreement $k = 0.91$) (Table 2).

Finally, a total of 12 publications (11 studies) (Schwarz et al. 2001, 2003a, b, Yilmaz et al. 2002, Miyazaki et al. 2003, Sculean et al. 2004, Ambrosini et al. 2005, Kreisler et al. 2005, Qadri et al. 2005, Tomasi et al. 2006, Crespi et al. 2007, Derdilopoulou et al. 2007) fulfilled the selection criteria required for the present review (Table 3).

Subdivision of selected studies

All selected studies were subdivided according to the respective laser wavelengths investigated (Tables 3 and 4):

- Seven publications reported on the short- and long-term clinical and microbiological outcome following initial and maintenance therapy of chronic periodontitis using an Er:YAG laser (2940 nm) (Schwarz et al. 2001, 2003a, b, Sculean et al. 2004, Tomasi et al. 2006, Crespi et al. 2007, Derdilopoulou et al. 2007); however, Schwarz et al. (2001, 2003b) reported on the same study population.
- One study evaluated the short-term clinical, microbiological and immunological effects of initial therapy using an CO_2 laser (10,600 nm), or an Nd:YAG laser (1064 nm) (Miyazaki et al. 2003).
- One study reported on the short-term clinical and microbiological outcome of adjunctive initial treatment using Nd:YAP (neodymium doped: yttrium aluminium and perovskite) (1340 nm) laser radiation (Ambrosini et al. 2005).
- One study evaluated the short-term clinical effects of adjunctive diode (809 nm) laser application during initial treatment (Kreisler et al. 2005).
- Two studies reported on the short-term clinical and microbiological outcome of adjunctive low-level diode laser (635, 685, 820 nm) application during initial treatment (Yilmaz et al. 2002, Qadri et al. 2005).

Quality assessment of selected studies

The results of the quality assessment of all selected studies before and after contact with the corresponding authors are presented in Table 5. In particular, a sample size calculation (A) was merely performed in 7 out of 12 studies. Information on the randomization and allocation concealment method (B) was originally reported in only two studies. However, additional information was provided in further five studies after contacting the authors. A total of three studies provided insufficient information on the definition of inclusion/exclusion criteria (C). The completeness of follow-up was not reported in three studies (D). However, all studies fulfilled the remaining criteria E, F and G. Just one study enrolled a relatively small sample size of 10 patients (Yilmaz et al. 2002). The risk of bias before contact with the authors was estimated to be low for one and high for 11 out of the total number of 12 studies (inter-reviewer agreement $k = 1.0$). After contact with the authors, the risk of bias was estimated to be low for two, moderate for five and high for five out of the total number of 12 studies (inter-reviewer agreement $k = 1.0$) (Table 5).

Non-surgical periodontal treatment using CO_2- and Nd:YAG laser radiation

One randomized-controlled clinical trial compared the effect of CO_2- and Nd:YAG laser monotherapy with that of ultrasonic scaling (Miyazaki et al.

Table 3. Included randomized-controlled and/or comparative clinical studies

Study	Design	Time	Population	Inclusion criteria	Laser	Laser Parameters	Treatments
Schwarz et al. (2001)	RCT SM	6 months	20 patients 110 teeth 660 sites	Chronic periodontitis PD $\geqslant$ 4 mm; Non-smokers*	Er:YAG Chisel tips 1.1 × 0.5 mm 1.65 × 0.5 mm	114 and 136 mJ/pulse, 10 Hz 18.8 J/cm^{2*} 14.5 J/cm^{2*}	Initial therapy Laser (Test) SRP (Control)
Yilmaz et al. (2002)	RCT QD	32 days	10 patients 40 teeth	Chronic periodontitis PD = 4 mm 5 smokers	LLT+PDT Diode (GaAs) (685 nm)	30 mW, cw 1.6 J/cm^2	Initial therapy SRP+laser (Test 1) Laser (Test 2) SRP (Test 3) OHI (Control) Methylene blue dye was used as a mouthrinse SRP at days 1 and 7; laser application at days 1, 2, 4, 7, 9, and 11
Miyazaki et al. (2003)	RCT Non-adjacent teeth	3 months	18 patients 41 sites	Chronic periodontitis PD $\geqslant$ 5 mm No heavy smokers (A few light smokers)	Nd:YAG CO_2 Non-contact	2 W, 100 mJ/pulse, 20 Hz 2 W, cw	Initial therapy Nd:YAG laser (Test 1) CO_2 laser (Test 2) Ultrasonic device (Control)
Schwarz et al. (2003b)	RCT SM	24 months	20 patients 110 teeth 660 sites	Chronic periodontitis PD $\geqslant$ 4 mm Non-smokers*	Er:YAG Chisel tips 1.1 × 0.5 mm 1.65 × 0.5 mm	114 and 136 mJ/pulse, 10 Hz 18.8 J/cm^{2*} 14.5 J/cm^{2*}	Initial therapy Laser (Test) SRP (Control)
Schwarz et al. (2003a)	RCT SM	12 months	20 patients 100 teeth 600 sites	Chronic periodontitis PD $\geqslant$ 4 mm Non-smokers*	Er:YAG Chisel tips 1.1 × 0.5 mm 1.65 × 0.5 mm	114 and 136 mJ/pulse, 10 Hz 18.8 J/cm^{2*} 14.5 J/cm^{2*}	Initial therapy Laser+SRP (Test) Laser (Control)
Sculean et al. (2004)	RCT SM	6 months	20 patients 1306 sites	Chronic periodontitis PD $\geqslant$ 4 mm Non-smokers*	Er:YAG Feedback Chisel tip 1.1 × 0.5 mm 1.65 × 0.5 mm	114 and 136 mJ/pulse, 10 Hz 18.8 J/cm^{2*} 14.5 J/cm^{2*}	Initial therapy Laser (Test) Ultrasonic device (Control)
Ambrosini et al. (2005)	RCT SM	3 months	30 patients	Chronic periodontitis PD $\geqslant$ 5 mm; 5 smokers	Nd:YAP (1340 nm) Ø320 nm fibre	10 W	Initial therapy SRP+laser (Test) SRP (Control)
Kreisler et al. (2005)	RCT SM	3 months	22 patients 246 teeth	Chronic periodontitis PD $\geqslant$ 3 mm Smoking $<$ 10 cigarettes per day	Diode (GaAlAs) (809 nm) Ø600 μm fibre	1 W, cw	Initial therapy SRP+H_2O_2 3%+laser (809 nm) (Test) SRP+H_2O_2 3% (Control)

Qadri et al. (2005)	RCT	6 weeks	17 patients	Chronic periodontitis	LLT	Initial therapy
	SM		170 teeth	PD < 7 mm;	Diode	SRP + laser (Test)
				5 smokers	InGaAIP (635 nm)	4.5 J/cm^2	SRP + placebo laser (Control)
					GaAlAs (830 nm)	8.75 J/cm^2	Laser treatment was performed once a week for 6 weeks
Tomasi et al. (2006)	RCT	4 months	20 patients	Chronic periodontitis	Er:YAG	136 mJ/pulse,	Maintenance therapy
	SM			PD ⩾ 5 mm	Feedback	10 Hz	Laser + 0.12 CHX (Test)
				14 smokers	Chisel tip	18.8 J/cm^{2*}	Ultrasonic device + 0.12 CHX (Control)
					(1.1 × 0.5 mm)		
Crespi et al. (2007)	RCT	24 months	25 patients	Chronic periodontitis	Er:YAG	160 mJ/pulse,	Initial therapy
	SM		200 teeth	PD > 4 mm	Chisel tip	10 Hz	Laser (Test)
			1200 sites	Smoking not reported	(1.4 × 0.5 mm)	16.0 J/cm^{2*}	Ultrasonic device (Control)
Derdilopoulou et al. (2007)	RCT	6 months	72 patients	Chronic periodontitis	Er:YAG	114 and 136 mJ/pulse, 10Hz	Initial therapy
	QD		288 sites	PD ⩾ 4 mm	Feedback		Laser (Test 1)
				Smoking not reported	Chisel tip		Sonic device (Test 2)
					1.1 × 0.5 mm	18.8 J/cm^{2*}	Ultrasonic device (Test 3)
					1.65 × 0.5 mm	14.5 J/cm^{2*}	SRP (Control)

*Calculated from data presented in the paper.

cw, continuous wave mode; Feedback, feedback system for calculus detection based on diode laser fluorescence spectroscopy; LLT, low-level laser therapy; OHI, oral hygiene instructions; PD, probing pocket depth; PDT, photo dynamic therapy; RCT, randomized-controlled clinical trial; SRP, scaling and root planning; QD, specific quadrant design; SM, split-mouth design.

2003). While CO_2 laser irradiation for pocket treatment was performed on the external surface of the marginal gingiva, Nd:YAG laser treatment was accomplished by inserting the contact optic fibre into the periodontal pocket. Clinical, microbiological, and immunological (IL-1β) data were assessed at baseline and after 1, 4 and 12 weeks of healing. All treatment procedures resulted in significant probing pocket depth (PD) reductions. However, a significant reduction of mean bleeding on probing (BOP) scores as well as a clinical attachment level (CAL) gain was only observed in the Nd:YAG – and ultrasonic scaling groups. Similarly, both treatment procedures revealed significant improvements with respect to the microbiological and immunological parameters, while these values remained unchanged in the CO_2 laser-treated group. Most of the clinical and microbiological changes occurred during the first week after treatment (Table 4a).

The authors did not report on the post-operative healing in specific groups (i.e. adverse events that might be related to laser treatment) (Miyazaki et al. 2003).

Non-surgical periodontal treatment using 809 nm diode laser radiation

One study reported on the clinical effect of diode laser (809 nm) radiation as an adjunct to scaling and root planing (SRP) (Kreisler et al. 2005). All patients received conventional SRP using hand instruments that were randomly combined with either GaAlAs diode laser radiation or rinsing with saline. After 3 months of healing, adjunctive laser treatment resulted in a significantly higher reduction in tooth mobility, PD, and CAL. Mean BOP reduction was not significantly different between groups (Table 4b). The authors did not report on the post-operative healing in specific groups (i.e. adverse events that might be related to laser treatment).

Non-surgical periodontal treatment using Er:YAG laser radiation

A total of seven randomized-controlled clinical trials reported on the use of an Er:YAG laser for initial (Schwarz et al. 2001, 2003a, b, Sculean et al. 2004, Crespi et al. 2007, Derdilopoulou et al. 2007) and maintenance (Tomasi et al. 2006) therapy of chronic periodontitis (Table 4c). Most of these studies were

Table 4. Main results of included randomized controlled and/or comparative clinical studies: (a) CO_2- and Nd:YAG lasers, (b) Diode laser, (c) Er:YAG laser, (d) Nd:YAP laser, (e) Low-level diode laser

Study	Plaque	p^*	BOP	p^*	PD	p^*	CAL	p^*	MB/Immunol.	Remarks
(a) CO_2- and Nd:YAG lasers										
Miyazaki et al. (2003)	*Test* 1 Baseline 0.36 ± 0.50 3 months 0.29 ± 0.47 NS *Test 2* Baseline 0.38 ± 0.51 3 months 0.38 ± 0.65 NS *Control* Baseline 0.29 ± 0.48 3 months 0.14 ± 0.28 NS	*Baseline* NS *3 months* NS	*Test* 1 Baseline 1.0 ± 0.0 3 months 0.57 ± 0.51 $p<0.05$ *Test 2* Baseline 0.92 ± 0.28 3 months 0.77 ± 0.44 NS *Control* Baseline 0.86 ± 0.36 3 months 0.57 ± 0.51 $p<0.05$	*Baseline* NS *3 months* NS	*Test* 1 Baseline 6.5 ± 1.09 3 months 5.07 ± 0.83 $p<0.05$ *Test 2* Baseline 6.92 ± 1.5 3 months 5.92 ± 1.93 $p<0.05$ *Control* Baseline 6.86 ± 2.63 3 months 5.50 ± 2.06 $p<0.05$	*Baseline* NS *3 months* NS	*Test* 1 Baseline 7.36 ± 1.69 3 months 6.86 ± 1.7 $p<0.05$ *Test 2* Baseline 8.77 ± 2.45 3 months 8.46 ± 2.57 NS *Control* Baseline 8.64 ± 3.16 3 months 8.07 ± 2.9 $p<0.05$	*Baseline* NS *3 months* NS	*DNA hybridization* Nd:YAG laser and ultrasonic device failed to significantly decrease amount of *Porphyromonas gingivalis* Crevicular IL-1β: significant increase in the CO_2 laser group from baseline to 1 week tendency to decrease in the Nd:YAG laser group from 1 to 2 weeks	–
(b) Diode laser										
Kreisler et al. (2005)	Test Baseline 1.3 ± 0.9 3 months 0.9 ± 0.6 $p<0.001$ Control Baseline 1.4 ± 0.9 3 months 0.9 ± 0.7 $p<0.001$	*Baseline* NS *3 months* NS	Test Baseline 70.7% 3 months 32.8% $p<0.001$ Control Baseline 71.9% 3 months 38.4% $p<0.001$	*Baseline* NS *3 months* NS	Test Baseline 4.2 ± 1.15 3 months 2.4 ± 0.67 $p<0.001$ Control Baseline 4.3 ± 1.26 3 months 2.7 ± 0.73 $p<0.001$	*Baseline* NS *3 months* *$p<0.001$*	Test Baseline 5.5 ± 1.42 3 months 3.9 ± 1.03 $p<0.001$ Control Baseline 5.5 ± 1.57 3 months 4.2 ± 1.04 $p<0.001$	*Baseline* NS *3 months* *$p<0.001$*	–	Both treatment procedures resulted in a significant reduction of the sulcus fluid flow rate and Periotest® values (PT) significantly higher PT reductions were observed in the test group at 3 months
(c) *Er:YAG laser*										
Schwarz et al. (2001)	*Test* Baseline 1.0 ± 0.6 6 months 0.7 ± 0.4 $p<0.05$ *Control* Baseline 1.0 ± 0.6 6 months 0.7 ± 0.5 $p<0.05$	*Baseline* NS *6 months* NS	*Test* Baseline 56% 6 months 13% $p<0.001$ *Control* Baseline 52% 6 months 23% $p<0.001$	*Baseline* NS *6 months* $p<0.05$	*Test* Baseline 4.9 ± 0.7 6 months 2.9 ± 0.6 $p<0.001$ *Control* Baseline 5.0 ± 0.6 6 months 3.4 ± 0.7 $p<0.001$	*Baseline* NS *6 months* $p<0.001$	*Test* Baseline 6.3 ± 1.1 6 months 4.4 ± 1.0 $p<0.001$ *Control* Baseline 6.5 ± 1.0 6 months 5.5 ± 1.0 $p<0.001$	*Baseline* NS *6 months* $p<0.001$	*Dark-field microscopy* Significant changes within both groups; no significant differences between groups; recolonization occurred after 6 months in both groups	Highest CAL gains at initial PD > 7 mm Treatment time:(single/multi-rooted teeth) Test: 5/10 min. Control: 9/15 min.

Schwarz et al. (2003b)	*Test* Baseline 1.0 ± 0.6 24 months 1.3 ± 0.6 NS	*Baseline* NS *24 months* NS	*Test* Baseline 56% 24 months 20% $p<0.001$	*Baseline* NS *24 months* $p<0.05$	*Test* Baseline 4.9 ± 0.7 24 months 3.3 ± 0.9 $p<0.001$	*Baseline* NS *24 months* $p<0.01$	*Test* Baseline 6.3 ± 1.1 24 months 4.9 ± 1.0 $p<0.001$	*Baseline* NS *24 months* $p<0.001$	*Dark-field microscopy* Significant changes within both groups no significant differences between groups recolonization occurred after 6 months in both groups	Highest CAL gains at initial PD > 7 mm Treatment time: (single/ multi-rooted teeth) Test: 5/10 min. Control: 9/15 min. Control: 9/15 Treatment time: (single/ multi-rooted teeth) Test: 5/10 min. Control: 9/15 min.
	Control Baseline 1.0 ± 0.6 24 months 1.2 ± 0.6 NS		*Control* Baseline 52% 24 months 28% $p<0.001$		*Control* Baseline 5.0 ± 0.6 24 months 3.7 ± 0.7 $p<0.001$		*Control* Baseline 6.5 ± 1.0 24 months 5.8 ± 1.0 $p<0.001$			
Schwarz et al. (2003a)	*Test* Baseline 1.0 ± 0.6 12 months 0.6 ± 0.4 NS	*Baseline* NS *12 months* NS	*Test* Baseline 58% 12 months 14% $p<0.05$	*Baseline* NS *12 months* NS	*Test* Baseline 5.2 ± 0.8 12 months 3.2 ± 0.8 $p<0.05$	*Baseline* NS *12 months* NS	*Test* Baseline 6.9 ± 1.0 12 months 5.3 ± 1.0 $p<0.05$	*Baseline* NS *12 months* NS	*Dark-field microscopy* Significant changes within both groups;no significant differences between groups; recolonization occurred after 6 months in both groups	highest CAL gains at initial PD > 7 mm Treatment time:(single/ multi-rooted teeth) Test: 10/16 min. Control: 5/10 min.
	Control Baseline 1.0 ± 0.6 12 months 0.7 ± 0.4 NS		*Control* Baseline 61% 12 months 16% $p<0.05$		*Control* Baseline 5.0 ± 0.7 12 months 3.3 ± 0.7 $p<0.05$		*Control* Baseline 6.6 ± 1.2 12 months 5.0 ± 0.7 $p<0.05$			
Sculean et al. (2004)	*Test* Changes at 6 months 0.02 ± 0.13 NS	*Baseline* NS *6 months* NS	*Test* Changes at 6 months 23% $p<0.001$	*Baseline* NS *6 months* NS	*Test* Changes at 6 months 1.52 ± 0.57 $p<0.001$	*Baseline* NS *6 months* NS	*Test* Changes at 6 months 1.11 ± 0.59 $p<0.001$	*Baseline* NS *6 months* NS	–	Treatment within 24 h highest CAL gains at initial PD > 5 mm Treatment time: (single/ multi-rooted teeth) Test: 5/9 min. Control: 5/9 min.
	Control Changes at 6 months 0.0 ± 0.12 NS		*Control* Chages at 6 months 31% $p<0.001$		*Control* Changes at 6 months 1.57 ± 0.46 $p<0.001$		*Control* Chages at 6 months 1.11 ± 0.46 $p<0.001$			

Table 4. (Contd.)

Study	Plaque	p^*	BOP	p^*	PD	p^*	CAL	p^*	MB/Immunol.	Remarks
Tomasi et al. (2006)	*Test* Baseline 10% 4 months 20% *p* not reported *Control* Baseline 22% 4 months 25% *p* not reported	*p* not reported	*Test* Baseline 92% 4 months about 40% *p* not reported *Control* Baseline 92% 4 months about 40% *p* not reported	*Baseline* NS *4 months* NS	*Test* Baseline 6.0 ± 1.2 Changes at 4 months 1.2 ± 0.7 *p* not reported *Control* Baseline 5.8 ± 0.9 Changes at 4 months 0.9 ± 0.8 *p* not reported	*Baseline* *p* not reported *4 months* NS	*Test* Baseline Not reported Changes at 4 months 0.6 ± 0.6 *p* not reported *Control* Baseline Not reported Changes at 4 months 0.4 ± 0.7 *p* not reported	*Baseline* *p* not reported *4 months* NS	*DNA hybridization* Significant reduction of *P.g., T.f., T.d., P.i., P.n., F.n., P.m., and C.r.* in both groups at 2 days; a reduction was also evident at 1 month; a tendency for relapse was seen for the red complex bacteria at 1 month no significant difference between groups	Significantly higher PD reduction (0.9 *versus* 0.5 mm $p<0.05$) and CAL gain (0.5 *versus* 0.06 mm $p<0.01$) in the test group at 1-month examination;significantly less treatment discomfort in the test group
Crespi et al. (2007)	*Test* Baseline 1.05 ± 0.51 24 months 1.29 ± 0.48 NS *Control* Baseline 1.05 ± 0.51 24 months 1.28 ± 0.65 NS	*Baseline* NS *24 months* NS	Not reported	–	**5–6** mm *Test* Baseline 5.49 ± 0.27 24 months 2.61 ± 0.54 $p<0.001$ *Control* Baseline 5.12 ± 0.39 24 months 4.12 ± 0.74 Not reported **>7 mm** Test Baseline 7.92 ± 0.78 24 months 3.05 ± 0.53 Not reported *Control* Baseline 7.13 ± 0.53 24 months 4.85 ± 0.64 Not reported	*Baseline* NS *24 months* $p<0.001$ *Baseline* $p<0.005$ *24 months* $p<0.001$	**5–6** mm *Test* Baseline 6.27 ± 0.51 24 months 3.35 ± 0.91 $p<0.001$ Not reported *Control* Baseline 6.18 ± 0.42 24 months 4.86 ± 0.52 Not reported **>7 mm** Test Baseline 8.41 ± 0.47 24 months 3.38 ± 0.79 Not reported *Control* Baseline 8.35 ± 0.33 24 months 6.34 ± 0.92 Not reported	*Baseline* NS *24 months* $p<0.001$ *Baseline* NS *24 months* $p<0.001$	–	Treatment time: (single/ multi-rooted teeth) Test: 5/9 min. Control: 4/9 min.

Derdilopoulou et al. (2007)	Not reported	–	Not reported	–	Not reported	–	Not reported	–	PCR Significant reduction of *A.a.*, *P.g.*, *P.i.*, *T.f.*, *T.d.* in all groups at 3 months; At 6 months, Test 1 and Test 2 failed to reduce *A.a.* significant reductions of *P.g.* (Test 1 and Test 3), *P.i.* and *T.f.* (Test 2) and *T.d.* (Test 1, Test 2, and Test 3)	Treatment within 24 h; Treatment time: (single/multi-rooted teeth) Test 1: 6.5/11 min. Test 2: 7.3/8.2 min. Test 3: 7.3/8.2 min. Control 9.7/15.3 min. Treatment in Test 3 group more comfortable than in test 1 and Control groups
(d) Nd:YAP laser										
Ambrosini et al. (2005)	*Test* Baseline 1.3 ± 0.8 3 months 0.5 ± 0.8 $p<0.001$ Control Baseline 1.3 ± 0.8 3 months 0.4 ± 0.7 $p<0.001$	*Baseline* NS *3 months* NS	*Test* Baseline 0.7 ± 0.4 3 months 0.1 ± 0.3 $p<0.001$ Control Baseline 0.7 ± 0.4 3 months 0.1 ± 0.3 $p<0.001$	*Baseline* NS *3 months* NS	*Test* Baseline 4.2 ± 1.4 3 months 2.7 ± 1.0 $p<0.001$ *Control* Baseline 4.1 ± 1.4 3 months 2.8 ± 1.0 $p<0.001$	*Baseline* NS *3 months* NS	*Test* Baseline 4.6 ± 1.7 3 months 3.6 ± 1.9 $p<0.001$ *Control* Baseline 4.5 ± 1.6 3 months 3.4 ± 1.5 $p<0.001$	*Baseline* NS *3 months* NS	DNA hybridization *P.g.*, *T.f.*, *T.d.*, *P.i.*, *A.a.* Both treatment procedures failed to significantly reduce bacterial load	Laser failed to reduce the level of post-operative discomfort
(e) Low-level diode										
Yilmaz et al. (2002)	*Test 1* Changes at 32 days 1.6 ± 0.47 $p<0.05$ *Test 2* Changes at 32 days 0.71 ± 0.36 $p<0.05$ *Test 3* Changes at 32 days 1.57 ± 0.27 $p<0.05$ *Control* Changes at 32 days 0.64 ± 0.28 $p<0.05$	*Baseline* Not reported *32 days* Test 1/Test 3 compared with Test 2/Control $p<0.05$ respectively	*Test 1* Changes at 32 days 60 ± 28% $p<0.05$ *Test 2* Changes at 32 days 17 ± 8% NS *Test 3* Changes at 32 days 50 ± 25% $p<0.05$ *Control* Changes at 32 days 20 ± 9% NS	*Baseline* Not reported *32 days* Test 1/Test 3 compared with Test 2/Control $p<0.05$ respectively	*Test 1* Changes at 32 days 0.66 ± 0.43 $p<0.05$ *Test 2* Changes at 32 days 0.23 ± 0.18 NS *Test 3* Changes at 32 days 0.49 ± 0.29 $p<0.05$ *Control* Changes at 32 days 0.19 ± 0.14 NS	*Baseline* Not reported *32 days* Test 1 compared with Test 2/Control $p<0.05$ Test 3 compared with Control $p<0.05$	Not reported	–	Test 1 and Test 3 resulted in significant reductions of obligate anaerobes; Test 2 and Control failed to reveal significant changes at the microbial level	–

Qadri et al. (2005)	*Test*		Not reported	–	*Test*		Not reported	–	Microbiological analysis (DNA hybridization), MMP-8, elastase activity and IL-1β concentration revealed no significant difference between groups, GCF was significantly lower in the test group	–
	Baseline	*Baseline*			Baseline	*Baseline*				
	1.6 ± 0.6	NS			4.7 ± 0.7	NS				
	6 weeks				6 weeks					
	1.0 ± 0.6	*6 weeks*			3.8 ± 0.6	*6 weeks*				
	p not reported	$p < 0.001$			*p* not reported	$p < 0.001$				
	Control				*Control*					
	Baseline				Baseline					
	1.4 ± 0.6				4.7 ± 0.6					
	6 weeks				6 weeks					
	1.1 ± 0.7				4.5 ± 0.6					
	p not reported				*p* not reported					

BOP, bleeding on probing; CAL, clinical attachment level (mm); GCF, gingival crevicular fluid; IL-1β, interleukin-1β; Immunol., immunology; MB, microbiology; MMP-8, matrix metalloproteinase-8; PCR, polymerase chain reaction; PD, probing pocket depth (mm).

*Comparison between groups.

P.g., Porphyromonas gingivalis; *T.f., Tannerella forsythia*; *T.d., Treponema denticola*; *P.i., Prevotella intermedia*; *P.n., Prevotella nigrescens*; *F.n., Fusobacterium nucleatum*; *P.m., Prevotella micros*; *C.r., Campylobacter. rectus*; *A.a., Aggregatibacter actinomycetemcomitans* ; *p.g., Porphyromonas gingivalis*; *P.i., Prevotella intermedi.*

performed using the same laser device (with or without a feedback system), fibre tips, and energy settings. Laser treatment was commonly performed from coronal to apical in parallel paths, with a recommended inclination of the fibre tip of 15–20° to the root surface (Folwaczny et al. 2001). Moreover, all studies on initial therapy clearly reported on a calibration procedure of the examiners.

In the first study, Schwarz et al. (2001) compared the Er:YAG laser (without a feedback system) with SRP using hand instruments. Clinical assessments of plaque index (PI), gingival index (GI), BOP, PD, gingival recession (GR), and CAL were performed before and at 3 and 6 months after treatment. Additionally, subgingival plaque samples were taken at each appointment and analysed using dark-field microscopy for the presence of cocci, non-motile rods, motile rods, and spirochetes. The laser treatment required a shorter time than the control treatment. At 3 and 6 months, both treatment procedures resulted in significant improvements of all the clinical parameters investigated. However, at 3 and 6 months, the reduction of the mean BOP score and the CAL improvement was significantly higher in the laser group than in the SRP group. Both groups showed a significant increase of cocci and non-motile rods and a decrease in the amount of motile rods and spirochetes. No significant differences were observed between both groups (Table 4c).

The follow-up observation of the same patients over a period of 24 months revealed comparable results in both groups (Schwarz et al. 2003b). In particular, both treatment procedures resulted in significant PD reductions and CAL gains at 12 and 24 months. Initially, deeper pockets (>7 mm) showed the greatest PD reduction and CAL gain in both groups. Statistical analysis showed a significant difference for mean BOP score and CAL improvement at both 12- and 24-month examinations. A slight, statistically insignificant loss of mean CAL was observed between the 1- and 2-year evaluation period. Both treatment procedures resulted in a significant reduction of spirochetes and a significant increase of cocci and non-motile rods at 12 months. However, the number of motile rods at the 1- and 2-year examinations was almost identical to the baseline score in both groups. After 2 years, increasing percentages of

Table 5. Quality assessment of selected studies prior to and after contact (parentheses) with corresponding authors

Study	A (0–2)	B (0–3)	C (0–1)	D (0–1)	E (0–2)	F (0–2)	G (0–2)	Estimated risk of bias
Schwarz et al. (2001)	2 (2)	0 (3)	1 (1)	1 (1)	2 (2)	2 (2)	2 (2)	High (moderate)
Yilmaz et al. (2002)	0 (0)	0 (2)	1 (1)	0 (1)	2 (2)	1 (1)	2 (2)	High (moderate)
Miyazaki et al. (2003)	0 (0)	0 (1)	1 (1)	1 (1)	2 (2)	0 (0)	2 (2)	High (high)
Schwarz et al. (2003b)	2 (2)	0 (3)	1 (1)	1 (1)	2 (2)	2 (2)	2 (2)	High (moderate)
Schwarz et al. (2003a)	2 (2)	0 (3)	1 (1)	1 (1)	2 (2)	2 (2)	2 (2)	High (moderate)
Sculean et al. (2004)	2 (2)	0 (3)	1 (1)	1 (1)	2 (2)	2 (2)	2 (2)	High (moderate)
Ambrosini et al. (2005)	0 (0)	2 (2)	0 (0)	1 (1)	2 (2)	1 (1)	2 (2)	High (high)
Kreisler et al. (2005)	0 (0)	0 (1)	0 (1)	1 (1)	2 (2)	2 (2)	2 (2)	High (high)
Qadri et al. (2005)	0 (0)	0 (0)	0 (0)	0 (0)	2 (2)	2 (2)	2 (2)	High (high)
Tomasi et al. (2006)	2 (2)	0 (3)	1 (1)	1 (1)	2 (2)	2 (2)	2 (2)	High (low)
Crespi et al. (2007)	2 (2)	0 (0)	1 (1)	0 (1)	2 (2)	2 (2)	2 (2)	High (high)
Derdilopoulou et al. (2007)	2 (2)	3 (3)	1 (1)	1 (1)	2 (2)	2 (2)	2 (2)	Low (low)

A, sample size calculation.
B, randomization and allocation concealment method.
C, clear definition of inclusion/exclusion criteria.
D, completeness of follow-up (specified reasons for withdrawals and dropouts in each study group).
E, experimental and control groups comparable at study baseline for important prognostic factors.
F, presence of masking.
G, appropriate statistical analysis.

spirochetes and decreasing percentages of cocci and non-motile rods could be observed in both treatment groups. No significant differences were found between groups (Table 4c).

Using the same study design and inclusion criteria, Sculean et al. (2004) compared the effectiveness of fluorescence-controlled Er:YAG laser radiation (threshold level 5 [U]) with that of ultrasonic instrumentation for non-surgical periodontal treatment. At 6 months following treatment, the mean values of BOP, PD, and CAL improved significantly in both groups. However, no significant differences in the clinical parameters investigated were observed between both treatment modalities (Table 4c).

Crespi et al. (2007) compared the effects of an Er:YAG laser without a feedback system with that of an ultrasonic device over a period of 24 months. The amount of time that was needed for root surface instrumentation was comparable in both groups. A significant PD reduction and CAL gain were observed in both groups at 3, 12, and 24 months. However, at both initial PDs of 5–6 and >7 mm, laser treatment resulted in a significant higher PD reduction and CAL gain compared with the control group (Table 4c).

In another study, Schwarz et al. (2003a) evaluated the combined use of an Er:YAG laser (without feedback), followed by SRP using hand instruments in comparison with Er:YAG laser treatment alone. At 3, 6, and 12 months, both treatment procedures resulted in significant improvements of all clinical parameters investigated. Initially, deeper pockets (>7 mm) showed the greatest PD reduction and CAL gain in both groups. However, no statistically significant differences were observed between root surfaces treated by the two methods of instrumentation. Both groups showed a significant increase of cocci and non-motile rods and a decrease in the number of motile rods and spirochetes at 3 months. No significant differences have been observed between the two treatment procedures. After 6 and 12 months, increasing percentages of motile rods and spirochetes and decreasing percentages of cocci and non-motile rods were found in both groups (Table 4c).

Derdilopoulou et al. (2007) evaluated and compared the microbiological effects of SRP, Er:YAG laser with feedback (threshold level 5 [U]), sonic, and ultrasonic scalers in patients with

chronic periodontitis over a period of 6 months. After 3 months of healing, all treatment procedures resulted in a significant reduction of *Porphyromonas gingivalis* (*P.g.*), *Prevotella intermedia* (*P.i.*), *Tannerella forsythia* (*T.f.*), and *Treponema denticola* (*T.d.*). However, laser and sonic instrumentation failed to reduce *Aggregatibacter actinomycetemcomitans* (*A.a.*). After 6 months of healing, significant differences were still detected for *P.g.* (Laser and Ultrasonic group), for *P.i.* and *T.f.* (Sonic group), and for *T.d.* (Laser, Sonic, and Ultrasonic group). Patients rated ultrasonic treatment as more preferable than hand and laser instrumentation (Derdilopoulou et al. 2007) (Table 4c).

One study reported on the short-term clinical and microbiological outcome of a feedback-controlled Er:YAG laser (threshold level 5 [U]), and an ultrasonic device during periodontal maintenance therapy (Tomasi et al. 2006). Clinical parameters were recorded at baseline, as well as 1 month and 4 months after treatment, while microbiologic analysis of subgingival plaque samples was performed at baseline, 2 days, and 30 days after treatment. In particular, after 1 month of healing, the mean PD reduction and CAL gain was significantly higher in the laser group compared with the control group. A significant difference between groups could no longer be observed at the 4-month examination. Both treatment procedures resulted in a significant reduction of the subgingival microflora; however, no significant differences were observed between groups at each time point investigated. The degree of discomfort immediately after treatment was significantly lower in the laser-treated group. However, there was no difference between groups during the post-treatment phase of 1 month (Tomasi et al. 2006) (Table 4c).

Four out of these studies clearly stated that the post-operative healing following Er:YAG laser radiation was considered to be uneventful in all cases (Schwarz et al. 2001, 2003a, b, Sculean et al. 2004). Tomasi et al. (2006) reported on a tendency towards an increased prevalence of dentin sensitivity in both laser and control groups.

Non-surgical periodontal treatment using Nd:YAP laser radiation

One study reported on the short-term clinical and microbiological outcomes subsequent to the adjunctive use of an Nd:YAP laser (Ambrosini et al. 2005). In particular, after 3 months of healing, both SRP+laser as well as SRP alone resulted in significant reductions of mean BOP scores and gains of CAL. However, the differences between both groups were not significant. Moreover, both treatment procedures failed to reduce bacterial load successfully (Table 4d).

The authors did not report on the post-operative healing in specific groups (i.e. adverse events that might be related to laser treatment). Evaluation of post-operative pain did not reveal any differences between the groups.

Non-surgical periodontal treatment using low-level diode laser (635, 685, 820 nm) radiation

Two studies reported on the effect of low-level diode laser application used either as monotherapy or as an adjunct to conventional SRP procedures (Yilmaz et al. 2002, Qadri et al. 2005).

In the first study, Yilmaz et al. (2002) randomly evaluated a repeated application of either SRP+GaAs (gallium arsenide) diode laser radiation, SRP alone, laser treatment alone, or supragingival oral hygiene instructions in only 10 patients. Methylene blue dye served as a photosensitizer and was used as a mouthrinse. Laser irradiation was performed over each papillary region repeatedly. Clinical and microbiological parameters were assessed after 32 days of healing. Significant clinical and microbiological improvements were only observed in the SRP+Laser and SRP groups. In contrast, laser treatment alone as well as oral hygiene instructions did not reach statistical significance. The authors clearly stated that there were no complaints such as discomfort, sensitivity, or pain from subjects immediately after laser irradiation as well as 3 weeks post-therapy (Table 4e).

Qadri et al. (2005) evaluated the additional treatment with combined low-level diode laser applications. Conventional SRP was combined with either InGaAlP (indium gallium aluminium phosphide)+GaAlAs (gallium aluminium arsenide) diode laser radiation or placebo laser application. Laser treatment on the external surface of the gingiva was performed once a week for 6 weeks. Significantly highest mean PD reductions and decreases of gingival crevicular fluid were observed in the SRP+Laser group. However, no differences between groups were observed with respect to elastase activity, IL-1β concentration, and the microbiological analyses. The authors did not report on the post-operative healing in specific groups (i.e. adverse events that might be related to laser treatment) (Table 4e).

Meta-analysis

Because of the limited number and high heterogeneity among the selected studies (i.e. different laser wavelengths, energy settings, and fibre tips, a variety of observation periods, and primary outcome variables), a meta-analysis was not appropriate.

Discussion

The present review attempted to systematically evaluate any available randomized-controlled and/or comparative clinical study on non-surgical periodontal treatment using different types of laser wavelengths between 1990 and December 2007. The question was focussed on the clinical effect of laser application compared with mechanical debridement in non-surgical periodontal therapy in patients with chronic periodontitis. A secondary aim was to survey the relevant literature in relation to the safety of laser applications. Quality assessment of the selected studies was performed according to the revised recommendation of the CONSORT statement, and the selected criteria A-G corresponded to items 7, 9, 3, 13, 15, 11, and 12 of the checklist (Moher et al. 2001).

In general, the systematic review of the literature revealed that there are currently only 12 randomized, controlled, and/or comparative clinical trials available investigating the use of six different types of laser wavelengths for non-surgical periodontal therapy. In this context, it must be emphasized that due to a heterogeneity with respect to the study design, observation periods, laser devices, reported energy settings, and modes of laser application, a meta-analysis was considered to be inappropriate.

In particular, only one randomized-controlled clinical trial compared the effect of CO_2 and Nd:YAG laser mono-

therapy with that of ultrasonic scaling (Miyazaki et al. (2003). Interestingly, CO_2 laser irradiation was performed on the external surface of the marginal gingiva due to the unavailability of an adequate contact probe (Miyazaki et al. 2003). Because, the main objective of periodontal treatment is related to the removal of calcified deposits from the root surface (O'Leary 1986), it might be hypothesized that this specific mode of application was mainly responsible for the low clinical outcome in the CO_2 laser-treated group. When interpreting the observation that no significant difference was observed between the three groups; however, it should also be noted that previous studies clearly indicated that both types of lasers were not able to achieve root surface debridement to a satisfactory degree. This was mainly due to an insufficient ability to remove calcified deposits and distinct root surface alterations induced by heat generation during irradiation with both types of lasers (Aoki et al. 2004).

Only one study reported on the clinical effect of diode laser (809 nm) radiation as an adjunct to SRP (Kreisler et al. 2005). The results seem to indicate that the adjunctive use of 809 nm diode laser radiation might have a positive influence on wound healing following SRP. The authors speculated that the positive results obtained in the laser group might be related to a de-epithelization of the periodontal pockets, leading to an enhanced connective tissue attachment. However, there are currently no experimental studies available aimed at histologically evaluating periodontal wound healing following application of 809 nm diode laser radiation. In this context, it must also be emphasized that this specific wavelength is well absorbed in haemoglobin. In particular, previous studies have clearly indicated that in the presence of blood, 809 nm diode laser radiation (power output of 1–1.8 W) commonly caused severe thermal damages to the root surface (Kreisler et al. 2002, Schwarz et al. 2003c). This might be particularly true for inflamed periodontal pockets subsequent to an SRP procedure. Therefore, from a clinical point of view, it might be recommended to apply diode laser radiation either after a thorough irrigation of the respective pocket or after a latency of 1–2 days.

A major part of the selected randomized-controlled clinical trials compared Er:YAG laser monotherapy with conventional treatment procedures for either initial (Schwarz et al. 2001, 2003a, b, Sculean et al. 2004, Crespi et al. 2007, Derdilopoulou et al. 2007) or maintenance (Tomasi et al. 2006) therapy of chronic periodontitis.

In particular, it was observed that Er:YAG laser monotherapy (without feedback) resulted in significant improvements of all the clinical and microbiological parameters investigated. These positive results were maintained over a period of up to 2 years (Schwarz et al. 2003b). Statistical analysis revealed a significant difference for the mean BOP score and CAL improvement at 3-, 6-, 12-, and 24-month examinations (Schwarz et al. 2001, 2003b). In this context, however, it is important to emphasize that in both test and control groups, a slight, statistically insignificant loss of mean CAL was observed between the 1- and the 2-year evaluation period (Schwarz et al. 2003b). The authors speculated that this change might be explained in both treatment groups by the higher mean PI values, which were higher than the respective baseline values. Even though at 2 years the increase in PI, GI, and BOP did not reach statistical significance compared with baseline and with the 1-year scores, it was not possible to estimate to what extent the plaque accumulation might have led to inflammation and subsequently a loss of CAL (Schwarz et al. 2003b). This observation might also be supported by the microbiological results, indicating that in both groups a re-colonization of the periodontal pocket was evident between 3 and 6 months of healing (Schwarz et al. 2001, 2003b). Comparable clinical and microbiological results were also observed when Er:YAG laser radiation (without feedback) was followed by SRP, indicating that the combined treatment approach did not seem to improve the outcome of the therapy additionally (Schwarz et al. 2003a).

These observations are also supported by the microbiological findings reported by Derdilopoulou et al. (2007), because all the treatment procedures investigated (SRP, Er:YAG laser with feedback, sonic, and ultrasonic devices) resulted in a comparable reduction of the microbiological parameters at 3 and 6 months. All these findings, taken together with the results reported by Schwarz et al. (2001, 2003b), seem to indicate that Er:YAG laser radiation may not have any beneficial effect on the microbiological level compared with conventional treatment procedures. This observation might be particularly true for an observation period of 3–24 months. However, the results of a previous study have also shown that immediately following treatment, the Er:YAG laser also failed to significantly reduce the amount of periodontopathogens in comparison with SRP (Eberhard et al. 2003).

Significant clinical improvements were also observed when Er:YAG laser monotherapy was compared with ultrasonic instrumentation (Sculean et al. 2004, Crespi et al. 2007). While Sculean et al. (2004) revealed no significant differences between groups at 3- and 6-month observation periods, Crespi et al. (2007) reported that laser treatment resulted in a significantly higher PD reduction and CAL gain at both initial PDs of 5–6 and >7 mm after 3, 12, and 24 months. There might be several reasons to explain this difference. First of all, it must be realized that both studies used different ultrasonic and laser devices. Moreover, in contrast to Schwarz et al. (2001, 2003b), Sculean et al. (2004) used a fluorescence-controlled Er:YAG laser device. The threshold value for the feedback system was set at 5 [U], as recommended by the manufacturer. However, the results of a recent study have indicated that the amount of residual calculus on periodontally diseased root surfaces depended on the laser fluorescence threshold level. In particular, by lowering the threshold levels, the amount of residual calculus decreased significantly (Krause et al. 2007). Accordingly, it might be hypothesized that the sites treated in the study of Sculean et al. (2004) exhibited higher amounts of bacterial deposits than the sites treated by Schwarz et al. (2001, 2003b) or Crespi et al. (2007), where no feedback system was used.

Only one study reported on the short-term clinical and microbiological outcome of a feedback-controlled Er:YAG laser and an ultrasonic device during periodontal maintenance therapy (Tomasi et al. 2006). While after 1 month of healing, mean PD reduction and CAL gain was significantly higher in the laser group, a significant difference between groups could not be observed at the 4-month examination. The observation that no significant differences were observed between groups with respect to the subgingival microflora is in agreement with the above-

referenced studies (Schwarz et al. 2001, 2003a, b, Derdilopoulou et al. 2007). From a clinical point of view, it must be emphasized that the degree of treatment discomfort scored significantly lower for the laser than the control treatment modality (Tomasi et al. 2006).

All these data seem to indicate that the Er:YAG laser used at the documented energy settings seems to be an appropriate treatment procedure for the initial and maintenance therapy of chronic periodontitis. This was evidenced by significant PD reductions and CAL gains over short- and long-term observation periods of up to 24 months. However, considering the fact that this wavelength consistently failed to improve the microbiological outcomes of treatment additionally, coupled with the fact that this Er:YAG laser device was either used with or without a feedback system, it seems that a greater number of well-designed randomized-controlled clinical trials are required in order to demonstrate a potential clinical difference between groups. In this context, it must also be emphasized that most of these studies were performed according to a split-mouth design (Schwarz et al. 2001, 2003a, b, Sculean et al. 2004, Tomasi et al. 2006, Crespi et al. 2007). Unfortunately, comparisons made on a within-patient basis have potential disadvantages, because treatments may have effects on experimental sites other than those they were assigned to (carry-across effects). Unless a priori knowledge indicates that no carry-across effects exist, reported estimates of treatment efficacy are potentially biased (Hujoel & DeRouen 1992).

Only one study reported on the short-term clinical and microbiological outcomes subsequent to the adjunctive use of an Nd:YAP laser (Ambrosini et al. 2005). The reported findings and consideration of the fact that the influence of Nd:YAP laser radiation on the removal of bacterial deposits as well as the morphology and biocompatibility of periodontally diseased root surfaces is currently rather unknown might lead to the conclusion that this type of laser wavelength seems to be of low importance for non-surgical periodontal therapy.

Two studies reported on the effect of low-level diode laser application used either as monotherapy or as an adjunct to conventional SRP procedures (Yilmaz et al. 2002, Qadri et al. 2005). When interpreting these results, it must be kept in mind that the observation periods in both studies were rather short, and therefore the stability of the positive effects over time cannot be estimated. Moreover, it has to be noted that the effects of low-level laser radiation in general are far from being understood. It might be speculated that GaAlAs radiation within the milliwatt range might have a positive influence on the proliferation of periodontal ligament fibroblasts and subsequently on periodontal wound healing (Kreisler et al. 2003). Therefore, a greater number of well-designed randomized-controlled clinical trials over a longer period of time may be required in order to evaluate the adjunctive use of low-level diode laser radiation during non-surgical periodontal therapy.

A secondary aim of the present systematic review was to survey the relevant literature in relation to the safety of laser applications. Unfortunately, only six out of 11 studies reported on adverse effects following laser application (five studies Er:YAG laser; one study: GaAs diode laser). For Er:YAG laser treatment, postoperative wound healing was considered to be uneventful in all the cases (Schwarz et al. 2001, 2003a, b, Sculean et al. 2004), or associated with an increased prevalence of dentin sensitivity. This increased sensitivity was comparable to that noted for the control group (Tomasi et al. 2006). For the adjunctive application of GaAs diode laser radiation, Yilmaz et al. (2002) reported that there was no greater discomfort, sensitivity, or pain compared with SRP during the observation period of 3 weeks. Because an improper laser application bears a potential risk of tissue destruction including thermal injury to the root surface, gingival tissue, pulp, and the adjacent alveolar bone (Aoki et al. 2004), there is a need to properly report on any adverse side effects that might be associated with laser application.

Conclusions

A meta-analysis could not be performed due to the heterogeneity of the studies and, therefore, a narrative synthesis allows the following limited conclusions:

- Er:YAG laser application in non-surgical periodontal therapy compared with mechanical debridement resulted in similar clinical outcomes, both in the short and the long term (up to 24 months), in patients with chronic periodontitis. However, issues related to the design and power of a limited number of studies prevent us from making definite conclusions.
- There is insufficient evidence to support the clinical application of either CO_2, Nd:YAG, Nd:YAP, or different diode laser wavelengths.
- Limited available information on the safety of different laser therapies is provided in the assessed literature. With the wavelengths and power settings used, no major adverse effects were reported.

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Clinical Relevance

Scientific rationale for the study: A systematic review of randomized-controlled and/or comparative clinical studies was conducted in order to evaluate the effectiveness of various laser types for non-surgical periodontal treatment.

Principal findings: Most evidence is available for Er:YAG laser application, suggesting that on either a short- or a long-term observation period of up to 24 months, this device might serve as an alternative treatment procedure.

Practical implications: Currently, a beneficial clinical, microbiological/immunological effect of various types of laser wavelengths over conventional treatment procedures might not be expected.