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BEST EVIDENCE CONSENSUS

Infrared lasers for the treatment of moderate to severe periodontitis: An American Academy of Periodontology best evidence review

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Abstract

Background: This systematic review assesses the efficacy of infrared laser therapy used alone or as an adjunct to nonsurgical or surgical periodontal therapy, on clinical and patient-centered outcomes in patients with periodontitis.

Methods: Randomized clinical trials (RCTs) with a follow-up duration ≥3 months that evaluated root surface debridement (i.e., scaling and root debridement with or without surgical access) to laser therapy alone or laser therapy plus root surface debridement for the treatment of adult patients (≥18 years old) with moderate to severe aggressive or chronic periodontitis were considered eligible for inclusion. The MEDLINE, EMBASE and CENTRAL databases were searched for articles published up to and including March 2016. Random effects meta-analyses were used throughout the review using continuous data (i.e., mean changes from baseline), and pooled estimates were expressed as weighted mean differences (MDs) with their associated 95% confidence intervals (CIs). Additionally, summaries are presented of the included RCTs, critical remarks of the literature and evidence quality rating/strength of recommendation of laser procedures.

Results: Of the 475 potentially eligible articles, 28 were included in the review. Individual study outcomes and seven sets of meta-analysis (1 for the nonsurgical treatment of AgP and 9 for nonsurgical and surgical treatment of CP) showed a benefit of laser therapy in improving clinical attachment level (CAL) and probing depth (PD). However, the comparative differences in clinical outcomes were modest (< 1 mm) and the level of certainty for different therapies was considered low-to-moderate (i.e., more information would be necessary to allow for a reliable and definitive estimation of effect/magnitude of therapies on health outcomes). Overall, most of the *Strength of Clinical Recommendations* of laser therapies were considered weak or based on expert opinion.

Conclusions: In patients with moderate to severe periodontitis, the nonsurgical treatment of AgP and CP by SRP plus infrared diode laser, and the surgical treatment of CP by Er:YAG laser therapy alone may promote statistically significant improvements in PD and CAL. However, these gains are relatively small (< 1 mm) and provide modest clinical relevance compared with SRP alone.

KEYWORDS
dental scaling, evidence-based dentistry, lasers, periodontitis, periodontitis/therapy, surgical procedures

Oral microbial biofilms, or dental plaque, commonly stimulate an inflammatory response that results in gingival inflammation, which, without effective treatment, may progress and lead to destruction of the supporting periodontal structures in a susceptible host.[1,2] The primary treatment of plaque-induced periodontitis targets disruption of the biofilm eliciting the inflammatory host response.[1,2] Nonsurgical and surgical treatment approaches have been used to reduce the burden of pathogenic bacteria and, thereby, reduce the potential for progressive inflammation and recurrence of disease.[3–9]

A laser (*l*ight *a*mplification by *s*timulated *e*mission of *r*adiation) device is designed to emit a parallel, monochromatic, and coherent beam of light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.[9] Lasers have been used in nonsurgical periodontal therapy in an effort to enhance disinfection/debridement and promote wound healing following mechanical debridement (e.g., scaling and root planing) of deep periodontal pockets (≥5 mm).[9–12] Lasers have been increasingly used as part of nonsurgical treatment of both chronic and aggressive periodontitis. Moreover, lasers are increasingly used as part of surgical periodontal therapies (e.g., pocket reduction and regenerative procedures).[9–12] Different types of infrared lasers, including carbon dioxide (CO_2), neodymium:yttrium-aluminum-garnet (Nd:YAG), erbium:yttrium-aluminum-garnet (Er:YAG), and diode lasers have been used in the treatment of periodontal diseases. Several of the proposed advantages of lasers over conventional periodontal surgeries include tissue ablation, vaporization, hemostasis and pocket disinfection.[9–12] Infrared lasers are thought to promote periodontal wound healing and regeneration, in general, by means of "thorough debridement and decontamination of diseased tissues."[9]

A growing body of evidence examines the clinical effectiveness of infrared lasers, when used alone or as an adjunct to conventional nonsurgical and surgical treatment periodontal therapies, in the treatment of patients with chronic periodontitis. The purpose of this systematic review is to a) assess the effects of laser treatment, when used alone or as an adjunct to conventional nonsurgical and surgical periodontal therapies, on clinical and patient-preferred outcomes in patients with periodontitis and b) consider the clinical significance of the findings in relation to selecting the most effective and safe ways to manage the clinical problem.[13] The following specific focused question was addressed in the systematic review: "Do infrared lasers (i.e., CO_2, Nd:YAG, Er:YAG, or diodes), when used alone or as an adjunctive treatment, provide superior clinical and patient-preferred outcomes compared with conventional periodontal therapy in patients with moderate to severe periodontitis?"

1 | METHODS

The text of the review was structured in accordance with guidelines from PRISMA,[14] the *Cochrane Handbook of Systematic Reviews of Interventions*,[15] and Check Review checklist.[16]

1.1 | Type of studies and participants (inclusion criteria)

Only randomized controled trials (RCT) of ≥3 months duration were included in the review. Studies were considered eligible for inclusion if they specifically involved the following: a) treatment of patients with moderate to severe (mean probing depth [PD] ≥ 5 mm) aggressive (AgP) or chronic (CP) periodontitis; b) adult patients (≥18 years old); and c) assessment of mechanical root debridement (e.g., hand scaling and root planing, sonic/ultrasonic instrumentation), with or without surgical flap access, versus infrared laser treatment alone or as an adjunct to mechanical root debridement. Studies reporting a mean pretreatment PD < 5 mm were also included if outcome measures were reported separately for periodontal sites ≥ 5 mm. Also, studies had to report laser settings and type of instrument tip (e.g., contact tip diameter).

1.2 | Exclusion criteria

RCTs with less than 10 subjects per group, a follow-up period < 3 months, or outcomes from periodontal sites < 5 mm in depth as well as all nonrandomized studies were excluded from this review. Studies in which the type of periodontitis (AgP or CP) was not reported in the original publication and could not be retrieved after contact with the authors were not considered eligible for inclusion.

1.3 | Outcome measures

Periodontal and patient-centered outcome measures were assessed in the review. Periodontal outcome measures included change (mean or percent) in PD, clinical attachment level (CAL), recession of gingival margin (Rec), bleeding on probing (BOP), bone defect fill, and microbial colonization or

composition. Patient-centered outcomes included parameters such as discomfort, esthetics, function, and treatment costs.

1.4 | Search strategy

Comprehensive search strategies were established to identify studies for inclusion in the systematic review. The MEDLINE (via PubMed), EMBASE, and CENTRAL databases were searched for articles published in English language up to and including March 2016, based on the search strategy developed for MEDLINE:

1. periodontitis OR chronic periodontitis OR aggressive periodontitis OR attachment loss OR bone resorption OR bone loss OR bone defect OR alveolar bone loss
2. periodontal treatment OR periodontal therapy OR scaling and root planing OR adjunctive treatment OR adjunctive therapy
3. #1 OR #2
4. laser OR laser therapy OR lasers, semiconductor OR lasers, gas OR lasers, solid-state
5. CO_2 laser OR carbon dioxide laser OR dioxide laser, carbon OR lasers, carbon dioxide OR laser, CO_2
6. Er-YAG laser OR erbium yag laser OR laser, erbium yag OR yag laser, erbium OR Laser, Er-YAG OR lasers, erbium-doped yttrium aluminum garnet OR lasers, erbium doped yttrium aluminum garnet OR Er,Cr:YSGG
7. Nd-YAG laser OR Neodymiun-YAG laser OR laser, Nd-YAG OR laser, neodymiun neodymium-doped yttrium aluminum garnet lasers OR neodymium doped yttrium aluminum garnet lasers OR lasers, neodymium-doped yttrium aluminum garnet
8. diode laser OR laser, diode OR semiconductor diode laser OR diode laser, semiconductor
9. #4 OR #5 OR #6 OR #7 OR #8
10. #3 AND #9

Reference lists of any potential articles, and OpenGray[17] database were screened to search for potentially relevant unpublished studies, or papers not identified by electronic searching. Additionally, the electronic database of four dental journals were searched—namely, *Journal of Periodontology, Journal of Clinical Periodontology, Journal of Periodontal Research,* and *Journal of Dental Research.*

1.5 | Assessment of validity and data extraction

Two independent reviewers (LC and UDR) screened the titles, abstracts, and full texts of the articles identified in the search. Disagreements were resolved through discussion until reaching a consensus. When considered necessary, an attempt was made to contact the authors to resolve ambiguity in the reported studies. Data on the following topics were extracted and recorded: 1) citation, publication status, and year of publication; 2) study location: country and practice setting (e.g., private practice, university, or dental hospital); 3) study design: RCT; 4) participants and group(s); 5) study methodology; 6) outcome measures; 7) authors' conclusions; and 8) source of funding.

1.6 | Assessment of methodological quality and risk of bias of included studies

The methodological quality of the trials (see supplementary Appendix 1 in online *Journal of Periodontology*) was evaluated per the Cochrane Collaboration's tool for assessing risk of bias,[15] as adapted by Chambrone et al.[18–21] Concisely, the randomization and allocation methods, blinding of patients and examiners, completeness of follow-up, selective reporting and other sources of bias were classified as adequate (+), inadequate (-), unclear (?), or not applicable (NA). Based on the same tool, the risk of bias was classified as follows: 1) low risk of bias (plausible bias unlikely to seriously alter the results—adequate methods of randomization and allocation concealment, "yes" answers to all questions about completeness of follow-up questions and blinding of examiners, and "no" answers to selective reporting and other sources of bias—1) if all criteria were met; 2) unclear risk of bias (plausible bias that raises some doubt about the results) if one or more criteria were partly met; 3) high risk of bias (plausible bias that seriously weakens confidence in the results) if one or more of the criteria were not met.

1.7 | Data synthesis

Data were organized into evidence tables and clustered according to the treatment modality and outcome parameters. Random effects meta-analyses were used throughout the review using continuous data (i.e., mean changes from baseline), and pooled estimates were expressed as weighted mean differences (MDs) with their associated 95% confidence intervals (CIs). The analyses were conducted using the generic inverse variance statistical method where the MDs and standard errors (SEs) were entered for all studies to allow the combination of parallel and split-mouth group studies. Variance imputation methods were conducted to estimate appropriate variance estimates in some RCTs where the appropriate standard deviation of the differences was not included in the studies.[22] The significance of discrepancies in the estimates of the treatment effects from the different trials was assessed by means of the Cochran test for heterogeneity and the I^2 statistic. The analyses were performed using a statistical analysis software (Review Manager, Version 5.3, Nordic Cochrane Centre, Copenhagen, Denmark).

Additionally, tables include summaries of the included RCTs, critical appraisal of the literature and evidence quality rating or strength of recommendation of infrared laser procedures. The latter allowed the assessment of the level of certainty in the evidence (i.e., high, moderate, or low) for the different treatment modalities displayed in this review, based on the criteria defined by the *American Dental Association Clinical Practice Guidelines Handbook*[23] (see supplementary Tables 1 through 3 in online *Journal of Periodontology*), which was adapted for the purpose of this review (i.e., "balancing level of certainty in the benefit estimate [i.e., test over control therapy] with potential for harms;" see supplementary Table 2 in online *Journal of Periodontology*). Briefly, the assessment of the level of certainty in the evidence was determined by the following domains: a) risk of bias (limitations of the evidence); b) applicability of evidence; c) inconsistency or unexplained heterogeneity of results; d) imprecision (wide confidence intervals); and e) high probability of publication bias.[23] Consequently, *Clinical Recommendation Summaries* summarizing "the strengths and weaknesses of the evidence in terms of clinical benefits and harms" were generated based on the included study characteristics, outcome measures, and pooled estimates. These summaries aimed to depict "accurate and explicit" rationale for clinical practice, as well as the reasons for the recommendations.

Based on the results of this systematic review, comparing the clinical benefits and harms of laser only and adjuvant infrared laser procedures to nonsurgical/surgical periodontal therapy alone, the following recommendations were applied:[23] a) Strong – Evidence strongly supports providing the intervention; b) In favor – Evidence favors providing the intervention; c) Weak – Evidence suggests implementing the intervention after alternatives have been considered; d) Expert opinion for/supports – Evidence is lacking; the level of certainty is low. Expert opinion guides the recommendation; e) Expert opinion questions the use – Evidence is lacking; the level of certainty is low. Expert opinion questions the use; f) Expert opinion against – Evidence is lacking; the level of certainty is low. Expert opinion suggests not implementing the intervention; and g) Against – Evidence suggests not implementing the intervention or discontinuing ineffective procedures.

2 | RESULTS

2.1 | Description of studies

2.1.1 | Results of the search

The search strategy identified 475 potentially eligible articles (Figure 1), of which 422 articles were excluded after review of the titles and/or abstracts. Fifty-three potentially eligible articles[24–76] were screened for eligibility; however, 25 of the papers did not meet inclusion criteria.[24–48] The reasons for exclusion are described in supplementary Table 4 in the online *Journal of Periodontology*.

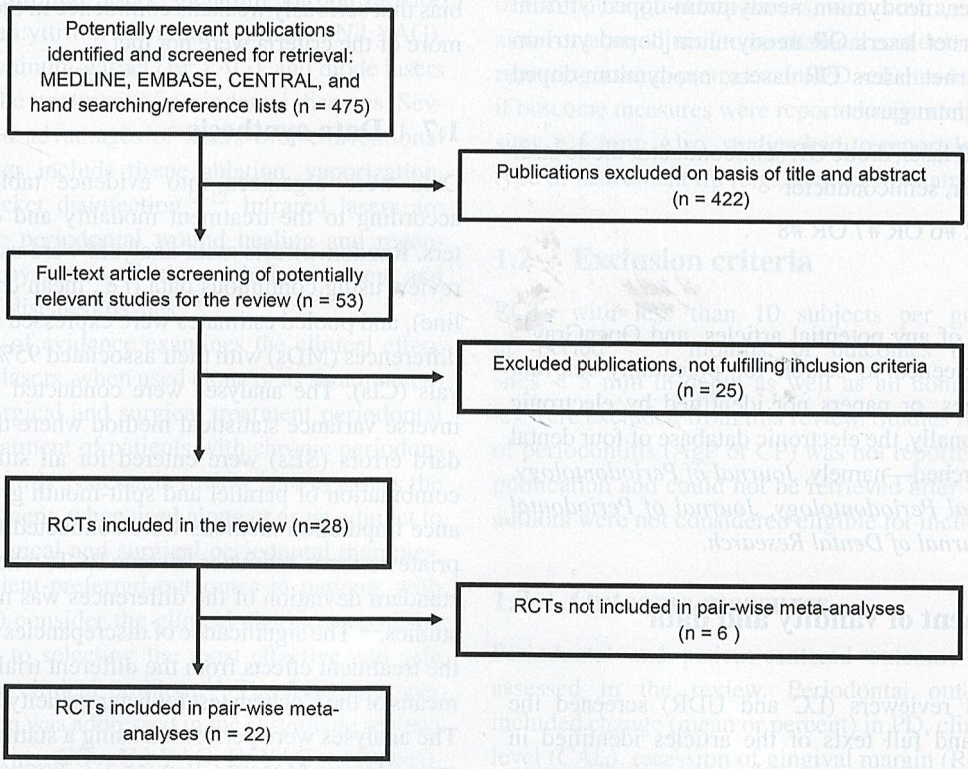

FIGURE 1 Flowchart of manuscripts screened through the review process

TABLE 1 Characteristics of included studies – Nonsurgical treatment of aggressive periodontitis

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Annaji et al.[49]	SM, 15 patients (NS) with localized or generalized AgP and one tooth with PD ≥5 mm in each quadrant 3-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Ultrasonic SRP Diode laser (continuous mode for 30s/tooth using a fiberglass tip)	SRP SRP+Laser (810 nm at 1W)	NR NR	0.28* 0.46*	0.29* 0.50*	NR NR
Kamma et al.[50]	SM, 30 patients (18 smokers) with generalized AgP and clinical attachment loss exceeding 5 mm at 2–3 sites in more than 14 teeth 6-month F/U No information on whether patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were considered eligible for inclusion	Manual SRP Diode laser (fiber optic tip with 300 μm diameter and power density of 2830W/cm^2 positioned 1 mm less than PD, 30s per pocket) One site with PPD > 5 mm in each quadrant OHI + SS 2 weeks prior treatment,	SRP Laser (980 nm at 2W) SRP+Laser (980 nm at 2W)	55.8* 60.5* 58.1*	1.87* 1.94* 2.14*,†	2.34* 2.00* 2.80*,†	NR NR NR

AgP – aggressive periodontitis; BOP – bleeding on probing; PD – probing depth; CAL – clinical attachment level; F/U – follow-up; m – months; mm – millimeters; NR – not reported; NS – nonsmoking; OHI – oral hygiene instructions; Rec – recession of the gingival margin; s – seconds; SM – split-mouth; SRP – scaling and root planing; SS –supragingival scaling; W – watt; nm – nanometers (wavelength); Δ – change from baseline to last follow-up (means); * statistically significant within group; †statistically significant among group (superior group)

2.1.2 | Included studies

Twenty-eight RCTs were included in this review (Tables 1 to 5).[49–76] Of them,[49–76] three studies[61,74,76] were conducted according to a parallel design, whereas the other studies were conducted according to a split-mouth design. Five trials[54,65–68] were totally or partially supported by companies that provided products (e.g., laser equipment) that were used as interventions in the RCTs. In total, 45 patients with AgP and 749 patients with CP (a total of 794) were treated in the studies; all studies were published in full. Most studies followed participants during a short-term period (i.e., 3 to 6 months). Only five studies[53,57,62,66,71] with follow-up terms ≥ 12 months were identified in the review.

2.1.3 | Treatment modalities

Different applications to infrared lasers were evaluated according to the type and phase of periodontal therapy: 1) nonsurgical treatment of AgP (two RCTs[51,52]); 2) nonsurgical treatment of CP (15 RCTs[51–65]); 3) nonsurgical treatment of CP – patients following at least one year of regular periodontal maintenance (five RCTs[66–70]); 4) nonsurgical treatment of CP – patients affected by risk factors known to affect the host response to periodontal development and treatment (i.e., smoking and diabetes – two RCTs[75,76]); and 5) surgical treatment of CP – patients with residual sites after basic procedures (i.e., open flap debridement – four RCTs[71–74]).

2.1.4 | Risk of bias in the included trials

The quality of assessment of the included studies was evaluated using the data extracted from each trial. All trials were described as RCTs, but not all of them reported randomization and allocation methods in detail, nor examiner and patient blinding (Figure 2). Thus, no trial was at a low risk of bias, whereas eight were considered to be at unclear risk.[49,51,52,54,59,72,73,75] The remaining studies were classified as high risk of bias.

2.2 | Individual study outcomes and pooled estimates—clinical recommendation

The findings of all the included studies, as well as the outcomes of seven sets of meta-analysis (one analyses for the nonsurgical treatment of AgP and six analyses for different nonsurgical and surgical treatment of CP) were combined to estimate and assess the level of evidence available per type of disease (AgP and CP) and treatment approach (nonsurgical and surgical). The generated summaries of evidence and strength of clinical of recommendations of procedures are depicted below.

TABLE 2 Characteristics of included studies – Nonsurgical treatment of chronic periodontitis

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Alves et al.[51]	SM, 36 patients (NS) with severe CP and single-rooted teeth with contra-laterals of the same arch one tooth with PD ≥5 mm in each quadrant 6-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual SRP Diode laser (fiber optic tip with 400 μm diameter and power density of 1193 W/cm^2 positioned 1 mm less than PD, 20s per pocket) OHI + full-mouth ultrasonic supra and subgingival scaling 1 week prior treatment Two contralateral single-rooted teeth with PD ≥ 5 mm Test sites were irradiated at 1 day and 1 week after SRP	SRP SRP+Laser (808 nm at 1.5W)	60.8* 57.2*	2.10* 1.70*	2.76* 2.56*	NR NR
Caruso et al.[52]	SM, 13 patients (NS) with severe CP and at least two contralateral interproximal sites with PD ≥5 mm 16 teeth per group 6-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous month were not considered eligible for inclusion	Manual SRP Diode laser (fiber optic tip with 400 μm diameter moved from the coronal to the apical side of the pocket in parallel paths with an inclination of approximately 20°- two 30s applications per pocket, with a 60s interval)	SRP SRP+Laser (980 nm at 2.5W; pulsed 30hz with 10 ms duration)	10.5 15.8	1.78* 2.03*	1.10* 1.42*	NR NR
Crespi et al.[53]	SM, 25 patients (number of smokers not reported) with moderate to severe/advanced CP and PD > 4 mm 24-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion Outcomes of sites with PD = 5–6 / ≥ 7 mm reported in separate	Ultrasonic SRP Er:YAG laser (chisel-shaped quartz tip with 400 μm diameter (from coronal to apical in an inclination of 15–20°) and energy level 160 mJ/pulse, repetition rate of 10 Hz OHI + SS 2 weeks prior treatment	SRP SRP+Laser (2.94 μm)	NR NR	1.32 (PD = 5-6 mm)* 2.01 (PD ≥ 7 mm)* 2.92 (PD = 5-6 mm)*,† 5.01 (PD ≥ 7 mm)*,†	1.00 (PD = 5-6 mm)* 2.28 (PD ≥ 7 mm)* 2.88 (PD = 5-6 mm)*,† 4.87 (PD ≥ 7 mm)*,†	NR NR

(Continues)

TABLE 2 (Continued)

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Derdilopoulou et al.[54]	SM, 72 patients (number of smokers not reported) with moderate to severe CP and at least one pocket depth of 4 mm or more with BOP and bone loss of at least one-third of the root length in each quadrant, 6-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion Outcomes of sites with PD ≥ 7 mm reported in separate	Manual, sonic or ultrasonic SRP Er:YAG laser (chiseled type fiber tips with rectangular ends – 0.5 × 1.65 and 0.5 × 1.1 mm (from coronal to apical in an inclination of 15–20°) and energy level 160 mJ/pulse, repetition rate of 10 Hz Laser instrumentation was terminated when the calculus detection system indicated the absence of deposits on the root surface OHI + SS 3–5 weeks prior treatment	SRP (manual) SRP (sonic) SRP (ultrasonic) SRP+Laser (2.94 μm at 2.5W)	NR NR NR NR	NR NR NR NR	NR NR NR NR	NR NR NR NR
Dukic et al.[55]	SM, 35 patients (NS) with CP and PD ≥ 4 mm 4.5-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion Outcomes of sites with PD ≥ 7 mm reported in separate	Manual and sonic SRP Diode laser (fiber optic tip with 300 μm diameter, introduced parallel to the cement surface with apical–cervical scanning movements for 20s per tooth) OHI + SS 2 weeks prior treatment	SRP SRP+Laser (980 nm at 2W)	NR NR	3.25* 3.26*	3.57* 4.00*	NR NR
Eltas & Orbak[56]	SM, 20 patients (NS) with generalized moderate CP three or more teeth having at least two quadrants with PD between 4 and 6 mm and radiographic signs of bone loss 9-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual and ultrasonic SRP Nd:YAG laser (fiber optic tip with 200 μm diameter (inserted into the pocket base parallel to the root surface for 120s) and energy level 160 mJ/pulse, repetition rate of 10 Hz OHI (immediately prior SRP)	SRP SRP+Laser (1,064 nm at 1.0W)	NR NR	1.10* 2.41*,†	1.32* 2.49*,†	NR NR

(Continues)

TABLE 2 (Continued)

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Lopes et al.[57]	SM, 21 patients (NS) with CP and four non-adjacent sites in different quadrants with PD from 5 to 9 mm and BOP (19 patients completed the study) 12-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual SRP Er:YAG laser (chiseled type fiber tip with a rectangular end – 0.5 × 1.1 mm (from coronal to apical in an inclination of 30°) and energy level 100 mJ/pulse, repetition rate of 10 Hz, and fluency of 12.9 J/cm2 /pulse. OHI + SS 6 months prior treatment	SRP SRP+Laser (30s/site) (2.94 μm) Laser (mean 204s/site) (2.94 μm)	NR* NR* NR*	1.41* 1.15* 0.68*	2.29* 2.19* 1.66*	−0.53* −0.69* −0.56*
Malali et al.[58]	SM, 30 patients (NS) with generalized CP and at least four single-rooted teeth, two with PD of 4–6 mm and two ≥ 7 mm with BOP 3-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion Outcomes of sites with PD ≥ 7 mm reported in separate	Manual and ultrasonic SRP Er:YAG laser (chiseled type fiber tip with a rectangular end – 0.5 × 1.5 mm (from coronal to apical in an inclination of 15–20°) and energy level 160 mJ/pulse, repetition rate of 10 Hz, and fluency of 48 J/cm2 /pulse. OHI immediately prior SRP	SRP (manual) SRP (ultrasonic) Laser (2940 nm)	71.9* 67.7* 67.7*	2.71* 2.31* 2.81*	4.01* 3.72* 4.37*	NR NR NR
Miyazaki et al.[59]	SM, 18 patients (NS) with generalized CP and at least two nonadjacent teeth with interproximal PD ≥ 5 mm 3-month F/U Patients submitted to periodontal treatment within the previous 6 months or antibiotic treatment within the previous 3 months were not considered eligible for inclusion	Ultrasonic SRP Nd:YAG laser (diameter of the fiber tip not reported (inserted into the pocket base parallel to the root surface) and energy level 100 mJ/pulse (20 pulses/s) CO_2 laser (irradiated to the superficial side of the marginal gingiva with a continuous wave mode) OHI immediately prior SRP	SRP Nd:YAG Laser (2.0W) CO_2 Laser (10.6 μm at 2W)	NR NR NR	0.57* 0.50* 0.31	1.36* 1.43* 1.00*	NR NR NR

(Continues)

TABLE 2 (Continued)

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Rotundo et al.[60]	SM, 27 patients (NS) with moderate to advanced CP and presence of at least two teeth with at least one site with PD that ranged between 4 and 9 mm in each quadrant with BOP 6-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual and ultrasonic SRP Er:YAG laser (fiber tips with 0.5 mm diameter (from coronal to apical in an inclination of 15–20°) with energy level of150 mJ/pulse, and repetition rate of 10 Hz OHI +SS 1 week prior treatment	SRP Laser (2.94 μm) SRP+ Laser (2.94 μm)	16 17 10	0.5* 0.2* 0.5*	1.0* 0.7* 1.2*	−0.5 −0.5 −0.7
Saglam et al.[61]	Parallel, 30 patients (NS) with CP and at least two teeth with PD ≥ 5 at each quadrant 6-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual and ultrasonic SRP Diode laser (fiber optic tip with 300 μm diameter and power density of 15 J/cm^2, inserted into the periodontal pocket base in parallel alignment with the root surface, 20s per tooth) OHI +SS 1 week prior treatment	SRP SRP (940 nm at 1.5W)	52* 62*	2.70* 3.40*	2.70* 3.40*	NR NR
Schwarz et al.[62]	SM, 20 patients (NS) with CP and at contralateral single and multi-rooted teeth with PD ≥ 4 and BOP 24-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual SRP Er:YAG laser (chiseled type fiber tips with rectangular ends – 0.5 × 1.65 mm and 0.5 × 1.1 mm diameter (from coronal to apical in an inclination of 15–20°) with energy level of160 mJ/pulse, and repetition rate of 10 Hz OHI +SS 4 weeks prior treatment	SRP Laser (2.94 μm)	NR NR	1.90* 3.30*,†	NR NR	NR NR

(Continues)

TABLE 2 (Continued)

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Sculean et al.[63]	SM, 20 patients (NS) with CP and at contralateral single and multi-rooted teeth with PD ≥ 4 and BOP 6-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Ultrasonic SRP Er:YAG laser (chiseled type fiber tips with rectangular ends – 0.5 × 1.65 mm and 0.5 × 1.1 mm diameter (from coronal to apical in an inclination of 15–20°) with energy level of160 mJ/pulse, and repetition rate of 10 Hz Laser instrumentation was terminated when the calculus detection system (fluorescence induced by 655 nm; InGaAsP diode laser radiation) indicated the absence of deposits on the root surface OHI +SS 4 weeks prior treatment	SRP Laser (2.94 μm)	31 23	1.11* 1.11*	1.57 1.52	−0.46 −0.41
Slot et al.[64]	SM, 19 patients (10 smokers) with moderate-to- severe generalized periodontitis characterized by the presence of at least 1 site per quadrant with PD > 6 mm and inter-proximal attachment loss of ≥ 3 mm, presence of BOP 3-month F/U Patients submitted to antibiotic treatment within the previous 3 months were not considered eligible for inclusion	Manual and ultrasonic SRP Nd:YAG laser (fiber tip with 0.6 mm diameter (inserted into the pocket base parallel to the root surface for 60s) and energy level 400 mJ/pulse OHI prior SRP	SRP SRP+ Laser (1064 nm at 2.0W)	NR NR	NR NR	0.54* 0.40*	NR NR
Soo et al.[65]	SM, 28 patients (number of smokers not reported) with CP PD ≥ 5 mm, attachment loss of ≥ 2 mm and BOP in at least six sites distributed throughout the mouth 3-month F/U Patients submitted to antibiotic treatment within the previous 4–6 months were considered eligible for inclusion Outcomes of sites with PD > 6 mm reported in separate	Manual and ultrasonic SRP Er:YAG laser (chiseled type fiber tips with rectangular ends – 0.5 × 1.65 mm and 0.5 × 1.1 mm diameter (from coronal to apical in an inclination of 15–20°) with energy level of160 mJ/pulse, and repetition rate of 10 Hz OHI prior treatment	SRP Laser (2.94 μm)	NR NR	NR NR	NR NR	NR NR

BOP – bleeding on probing; CP – chronic periodontitis; PD – probing depth; CAL – clinical attachment level; F/U – follow-up; KTP – potassium–titanyl–phosphate, m – months; mm – millimeters; NR – not reported; NS – non-smoking; OHI – oral hygiene instructions; Rec – recession of the gingival margin; s – seconds; SM – split-mouth; SRP – scaling and root planing; SS – supragingival scaling; W – watt; nm – nanometers (wavelength); Δ – change from baseline to last follow-up (means); * statistically significant within group; †statistically significant between group (superior group)

TABLE 3 Characteristics of included studies – Nonsurgical treatment of patients with chronic periodontitis – treatment of residual sites of patients following regular maintenance (3-4 months) for at least 1 year after active periodontal therapy

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Krohn-Dale et al.[66]	SM, 15 smoking patients with CP undergoing MP and with four teeth with PD ≥ 5 mm, two teeth each in different jaw quadrants with BOP or pus on probing and no signs of apical pathology 12-month F/U Patients submitted to antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual and ultrasonic SRP Er:YAG laser (chiseled type fiber tip with a rectangular end – 0.5 × 1.1 mm (from coronal to apical in an inclination of 15–20°) and energy level 160 mJ/pulse, repetition rate of 10 Hz	SRP Laser (2.94 μm)	NR NR	0.20 0.00	1.40* 1.90*	NR NR
Nguyen et al.[67]	SM, 22 patients (6 smokers) with CP and undergoing PM with at least one site PD ≥ 5 mm and BOP 3-month F/U Patients submitted to antibiotic treatment within the previous 3 months were considered not eligible for inclusion	Manual and ultrasonic SRP Diode laser (fiber optic tip dimension not reported and energy level at 0.80J/s. Tip positioned toward the bottom of the defect, and time spent with the laser therapy on each tooth was not restricted	SRP SRP+Laser (940 nm at 0.8W)	25.00* 28.00*	0.68* 0.53*	0.91* 0.93*	NR NR
Ratka-Krueger et al.[68]	SM, 58 patients (NS) with CP and undergoing PM with two teeth with residual periodontal lesions in one jaw with PD > 5 mm and BOP or PD ≥ 6 mm with/out BOP 6.5-month F/U Patients submitted to antibiotic treatment within the previous 3 months were considered not eligible for inclusion	Sonic SRP Er:YAG laser (fiber tip dimensions not reported (from coronal to apical in an inclination of 15–20°) and energy level 120 mJ/pulse, repetition rate of 10 Hz, 20s per root surface	SRP Laser (2.94 μm)	27.60* 32.70*	0.85* 0.84*	1.24* 1.18*	NR NR
Slot et al.[69]	SM, 30 patients (number of smokers not reported) with CP and undergoing PM with of 1 site per quadrant with PD > 6 mm, interproximal attachment loss of ≥ 3 mm and BOP 6-month F/U Patients submitted to antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual and ultrasonic SRP Nd:YAG laser (fiber tip with 0.6 mm diameter (inserted into the pocket base parallel to the root surface for 60s) and energy level 400 mJ/pulse After treatment, the subjects were requested to rinse for 2 weeks with 0.12% chlorhexidine	SRP SRP+Laser (1064 nm at 2.0W)	NR NR	NR NR	0.85* 0.97*	0.02 −0.08
Tomasi et al.[70]	SM, 20 patients (14 smokers) with CP and undergoing PM and had four teeth with PD ≥ 5 mm and BOP 4-month F/U Patients submitted to antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Ultrasonic SRP Er:YAG laser (chiseled type fiber tip with a rectangular end – 0.5 × 1.1 mm (from coronal to apical in an inclination of 15–20°) and energy level 160 mJ/pulse, repetition rate of 10 Hz	SRP Laser (2.94 μm)	52.0* 52.0*	NR NR*	NR* NR*	NR NR

BOP – bleeding on probing; CP – chronic periodontitis; PD – probing depth; CAL – clinical attachment level; F/U – follow-up; m – months; min – minutes; mm – millimeters; NR – not reported; NS – non smoking; OHI – oral hygiene instructions; PM – periodontal maintenance; Rec – recession of the gingival margin; s – seconds; SM – split-mouth; SRP – scaling and root planing; SS – supragingival scaling; W – watt; nm – nanometers (wavelength); Δ – change from baseline to last follow-up (means); *statistically significant within group; †statistically significant between group (superior group)

TABLE 4 Characteristics of included studies – Surgical treatment of patients with chronic periodontitis – open flap debridement modalities

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Gaspirc & Skaleric[71]	SM, 25 patients (NS) with advanced CP and sites with residual PD ≥6 mm after SRP 60-month F/U Patients submitted to antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual SRP Er:YAG laser (fiber optic tip dimension not reported) energy level 140–180 mJ/pulse, repetition rate of 10–20 Hz OFD 6 weeks after SRP	SRP Laser (2.94 μm)	20.10(6 m)* 22.70(60 m)* 25.40(6 m)*,† 24.60(60 m)*	2.46(6 m)* 2.31(60 m)* 2.73(6 m)*,† 2.17(60 m)*	2.90(6 m)* 2.87(60 m)* 3.17(6 m)*,† 2.79(60 m)*	−0.54(6 m)* −0.67(60 m)* −0.34(6 m)*,† −0.59(60 m)*
Gokhale et al.[72]	SM, 30 (NS) with CP and residual PD ≥ 5 mm after SRP 3-month F/U Patients submitted to antibiotic treatment within the previous 3 months were considered not eligible for inclusion	Manual SRP Diode laser (fiber optic tip dimension not reported) OFD 4 weeks after SRP	SRP SRP+Laser (980 nm at 2.5W)	NR NR	1.70* 1.37*	2.80* 3.07*	NR NR
Lobo & Pol[73]	SM, 30 patients (NS) with moderate to severe CP and three teeth with residual PD ≥ 5 mm after SRP 6-month F/U Patients submitted to antibiotic treatment within the previous 3 months were considered not eligible for inclusion	Manual SRP Diode laser (fiber optic fiber with 300 μm diameter and maximum power 7W, 10s per pocket) OFD 4 weeks after SRP	SRP SRP+Laser (940 nm at 1.5w)	NR NR	1.89* 1.65	3.52* 3.67*	−1.64* −2.03*
Sculean et al.[74]	Parallel, 23 patients (number of smokers not reported) with advanced CP and one intrabony defect with residual PD ≥ 6 mm and an intrabony component of ≥ 3 mm 6-month F/U Patients submitted to periodontal treatment within the previous 6 months were not considered eligible for inclusion	SRP Er:YAG laser (chiseled type fiber tip with rectangular end – 0.5 × 1.65 mm diameter (from coronal to apical in an inclination of 15–20°) with energy level of160 mJ/pulse, and repetition rate of 10 Hz OFD 2–3 months after SRP	SRP Laser (2.94 μm)	26.00* 25.00*	1.50* 2.60*	3.20* 3.70*	−1.70* −0.90*

BOP – bleeding on probing; CP – chronic periodontitis; PD – probing depth; CAL – clinical attachment level; F/U – follow-up; m – months; min – minutes; mm – millimeters; NR – not reported; NS – non smoking; OHI – oral hygiene instructions; Rec – recession of the gingival margin; s – seconds; SM – split-mouth; SRP – scaling and root planing; W – watt; nm – nanometers (weight length); Δ – change from baseline to last follow-up (means); *statistically significant within group; †statistically significant between group (superior group)

TABLE 5 Characteristics of included studies – Nonsurgical treatment of smokers and diabetic patients with chronic periodontitis

Study	Design	Procedures	Treatment groups	ΔBOP (%)	ΔCAL (mm)	ΔPD (mm)	ΔRec (mm)
Eltas & Orbak[75]	SM, 52 patients with CP (26 smokers/26 nonsmokers) with CP and PD between 4 and 6 mm 6-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion Smokers were identified as smoking > 10 cigarettes per day for > 5 years, whereas nonsmokers were identified as never having smoked	Manual and ultrasonic SRP Nd:YAG laser (fiber optic tip with 200 μm diameter (inserted into the pocket base parallel to the root surface for 120s) and energy level 100 mJ/pulse, repetition rate of 10 Hz OHI prior treatment	SRP (NS) SRP (Smo) SRP+Laser (NS) (1064 nm at 1W) SRP+Laser (Smo) (1064 nm at 1W)	NR NR NR NR	0.3 0.1 0.5 0.3	1.70* 1.20* 2.20*,† 1.60*	NR NR NR NR
Koçak et al.[76]	Parallel, 60 patients with diabetes mellitus type 2 (NS) with CP and had 8 ≤ sites with PDs ≥5 mm 3-month F/U Patients submitted to periodontal and/or antibiotic treatment within the previous 6 months were not considered eligible for inclusion	Manual and ultrasonic SRP Diode laser (fiber optic tip with 300 μm diameter and energy of 15 J/cm^2 positioned at the periodontal based and moved from apical to coronal, 20s per tooth) OHI + SS 1 week prior treatment	SRP SRP+Laser (940 nm at 1.5W)	NR NR	2.30 (PD = 5-6 mm)* 3.64 (PD ≥ 7 mm)* 2.56 (PD = 5-6 mm)*,† 4.23 (PD ≥ 7 mm)*,†	2.24 (PD = 5-6 mm)* 3.64 (PD ≥ 7 mm)* 2.55 (PD = 5-6 mm)*,† 4.23 (PD ≥ 7 mm)*,†	NR NR

BOP – bleeding on probing; CP – chronic periodontitis; PD – probing depth; CAL – clinical attachment level; F/U – follow-up; m – months; mm – millimeters; NR – not reported; NS – nonsmoking; OHI – oral hygiene instructions; Rec – recession of the gingival margin; s – seconds; SM – split-mouth; Smo – smokers; SRP – scaling and root planing; SS – supragingival scaling; W – watt; nm – nanometers (weight length); Δ – change from baseline to last follow-up (means); * statistically significant within group; †statistically significant between group (superior group)

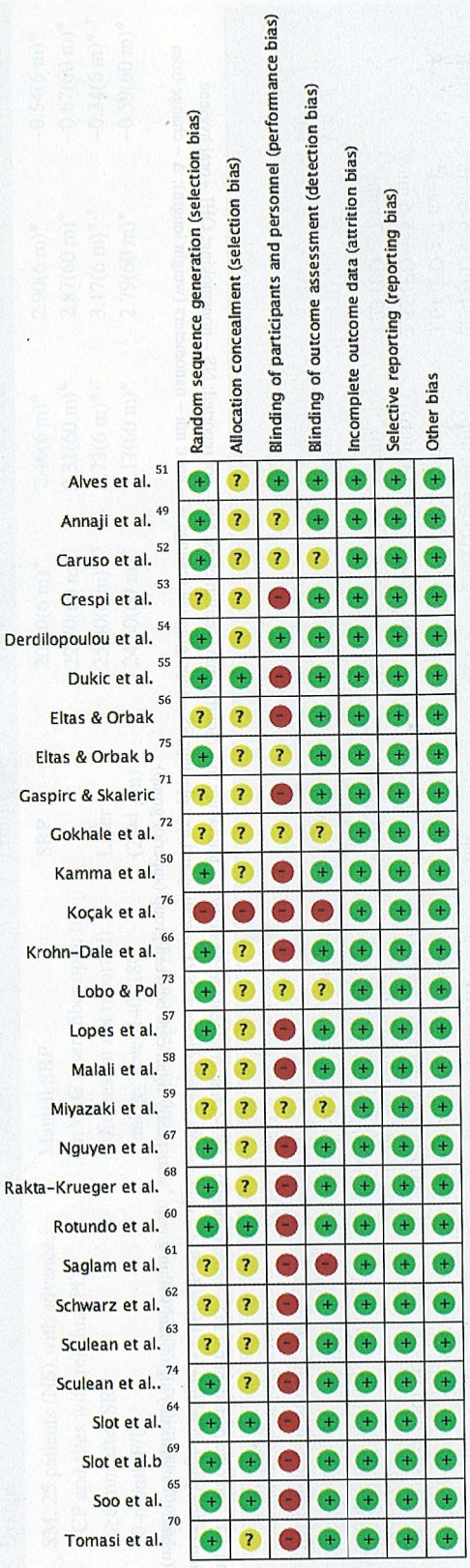

FIGURE 2 Risk of bias summary: review authors' judgments about each risk of bias item for each included study

2.3 | Nonsurgical treatment of aggressive periodontitis

2.3.1 | Main findings

The two trials[49,50] testing the use of infrared laser therapy in the nonsurgical treatment of AgP assessed the effect of diode lasers (Table 1). Both studies showed significant intragroup improvements for CAL,[49,50] PD,[49,50] and BOP;[50] however, only one study showed additional improvements associated with the use of laser. Kamma et al.[50] found that 980 nm laser combined with SRP led to a superior mean PD reduction and mean CAL gain, when compared with either laser alone or SRP alone, 6 months after treatment ($P < 0.05$). Regarding the therapeutic use of lasers alone (without SRP), the available data did not indicate additional clinical improvements when compared with SRP or SRP plus laser.[54]

With respect to bacterial outcome measures, both RCTs[49,50] reported data comparing SRP and SRP plus laser therapy in patients with AgP. These studies found that SRP + laser therapies, when compared with SRP alone, promoted greater reductions in the levels and proportions of periodontal pathogens from the red and orange complexes (i.e., *Porphyromonas gingivalis*,[49,50] *Prevotella intermedia*,[49] *Tannerella forsythia*,[50] and *Treponema denticola*) and *Aggregatibacter actinomycetecomitans*,[49] three[49,50] to six months[50] after treatment. In addition, none of the studies reported potential adverse effects related to the tested treatments.

2.3.2 | Clinical recommendation summary

SRP plus infrared diode laser or infrared diode laser alone versus SRP for the nonsurgical treatment of AgP:

- ☐ **Level of certainty**: Low
- ☐ **Benefit**: In general terms, SRP plus infrared diode laser promoted modest additional clinical benefits over those achieved by SRP alone. None of the studies presented information on treatment costs.

Pooled estimates on PD reduction and CAL gain (MD) showed:

- An additional PD reduction of 0.24 mm for sites treated with SRP plus diode infrared lasers (see supplementary Figure 1 in online *Journal of Periodontology*).

When comparing clinical outcomes in the two included RCTs,[49,50] it appears that the effectiveness of SRP also impacted the results of therapy. In the study by Annaji et al.,[49] treatment groups presented poorer clinical improvements when compared with the other studies reporting outcomes from 5 to 6 mm pockets (4.8 to 8.1%[49] versus 36.16 to 41.9%[50] PD gain). This difference in clinical improvements seemed to be directly associated with the type and, perhaps,

quality of performed instrumentation (single session of ultrasonic scaling and lack of adequate root planing), rather than adjunctive infrared diode laser therapy. Overall, based on the outcomes of one individual study[50] and on the pooled estimates, the statistically significant reduction in PD and CAL achieved with diode laser plus SRP reflect only modest clinical benefit.

- ☐ **Adverse events or harms**: None reported
- ☐ **Benefit-harm assessment (net benefit rating) compared with SRP**: Modest clinical benefits of SRP combined with infrared diode laser outweigh potential for harm.
- ☐ **Strength of clinical recommendation of procedures compared with SRP**: 1) Nonsurgical treatment of AgP by infrared diode laser – Expert opinion questions the use (Evidence is lacking; the level of certainty is low. Expert opinion questions the use; 2) Nonsurgical treatment of AgP by SRP plus infrared diode laser – Expert opinion for/supports (Evidence is lacking; the level of certainty is low. Expert opinion suggests implementing this intervention).

2.4 | Nonsurgical treatment of chronic periodontitis

2.4.1 | Main findings

Fifteen RCTs[51–65] (53.5% of included studies) assessed the use of infrared lasers alone or as an adjunct to SRP for the nonsurgical treatment of CP. As shown in Table 2, the use of SRP plus infrared lasers (i.e., Diode, Er:YAG, and Nd:YAG), applied as part of basic procedures, promoted significant improvements in BOP, CAL, and PD. Moreover, no important adverse effects were reported within the included studies.

In contrast, only three trials[53,56] (approximately 30% of RCT testing the nonsurgical treatment of CP) identified additional clinical gains at moderate-deep pockets with SRP + lasers[53,56] or Laser alone[62] when compared with manual and ultrasonic or sonic debridement (SRP). Regarding the use of lasers plus SRP, Crespi et al.,[53] and Eltas and Orbak[56] showed that Er:YAG,[53] and Nd:YAG[56] lasers, respectively, were superior to SRP at 3 to 6 months,[53] 9 to 12 months,[56] and 24 months[53], evaluations; however, the superior outcomes seemed more evident at deep periodontal pockets (≥ 7 mm).[53]

Of the six studies[51,52,54,57,59,64] that reported on the effect of treatment on periodontopathogens, five trials[51,52,54,59,64] found that the application of laser, SRP plus laser, and SRP alone were essentially comparable in reducing total colony forming units at 6 weeks[51] and levels of different bacteria (e.g., *Aggregatibacter actinomycetemcomitans, T. forsythensis, Campylobacter rectus, Eikenella corrodens, Fusobacterium nucleatum, P. gingivalis, P. intermedia, T. denticola*) at 4,[52] 6,[51] and 12[54,59,64] weeks after treatment. Some studies also found that 6 months after treatment the levels of pathogens returned to levels comparable to baseline.[51,52,54] In one trial,[57] the use of Er:YAG alone or SRP plus Er:YAG laser promoted superior reductions in the values of *A. actinomycetemcomitans*, *P. gingivalis* (Er:YAG alone), *P. intermedia*, *Prevotella nigrescens*, and *T. forsythensis* (SRP plus Er:YAG) 12 months after treatment.

In terms of patient-centered outcomes, only 3 studies[60,64,65] provided observations. Rotundo et al.[60] reported observing no patient-reported differences in pain and chewing discomfort between SRP alone, SRP plus Er:YAG laser, or Er:YAG Laser alone either immediately or 1 week after treatment. Slot et al.[64] identified a more pronounced "post-operative experience of pain" in the first 3 days at sites treated with SRP plus Nd:YAG laser, and overall patients used 3 times more analgesics in the course of the day after treatment. Soo et al.[65] reported that "patients expressed greater satisfaction with mechanical scaling and root planing on the day of treatment but were equally satisfied with the treatments subsequently."

Pooled estimates evaluating SRP plus infrared laser (Diode, Er:YAG, or Nd:YAG) versus SRP (Table 6; supplementary Figure 2 in online *Journal of Periodontology*) did not identify statistically significant differences among the treatment approaches. Subgroup meta-analysis performed with only two studies[52,61] identified that SRP plus diode laser performed in a single application (immediately after root debridement) led to additional PD reduction (0.63 mm, $p < 0.01$, $I^2 = 0\%$) and CAL gain (0.52 mm, $p = 0.02$, $I^2 = 0\%$) compared with SRP alone. On the other hand, another subgroup analysis evaluating the effect of multiple applications of Diode laser within the first week after SRP did not confirm the advantages of laser application in combination with root debridement.

In addition, the use of types of infrared lasers (Er:YAG or Nd:YAG) alone did not add value to PD or CAL outcomes than those achieved by SRP alone (Table 6; supplementary Figure 3 in online *Journal of Periodontology*).

2.4.2 | Clinical recommendation summary

SRP plus infrared laser or infrared laser alone versus SRP for the nonsurgical treatment of CP:

- ☐ **Level of certainty**: Moderate
- ☐ **Benefit**: The overall estimates on infrared laser (Er:YAG and Nd:YAG) alone did not show additional gains to those accomplished by SRP alone; however, estimates evaluating SRP plus infrared laser (Diode, Er:YAG, or Nd:YAG) suggested modest additional clinical benefits to those achieved by SRP alone. None of the studies presented information on treatment costs.

TABLE 6 Summary of meta-analyses – overall estimates (detailed analyses per type of laser can be found in supplementary Figures 2 through 7 in online *Journal of Periodontology*)

Comparison	Outcomes	Statistical method	Effect size in mm	*P* value	X^2	*P* value (Q)	I^2 (%)
AgP – basic procedures							
SRP plus Laser vs. SRP	ΔPD[49,50]	MD (95% CI)	0.24 (0.02 to 0.46)	0.03	0.57	0.45	0
	ΔCAL[49,50]	MD (95% CI)	0.20 (−0.21 to 0.61)	0.33	0.03	0.85	0
CP – basic procedures							
SRP plus Laser vs. SRP	ΔPD[51,52,55–57,60,61,64]	MD (95% CI)	0.27 (−0.08 to 0.63)	0.13	20.17	0.005	65.0
	ΔCAL[51,52,55–57,60,61,64]	MD (95% CI)	0.25 (−0.17 to 0.68)	0.25	12.93	0.04	54.0
CP – basic procedures							
Laser alone vs. SRP	ΔPD[53,57–60,63]	MD (95% CI)	0.24 (−0.58 to 1.05)	0.57	97.12	Laser vs. SRP	95.0
	ΔPD[57–60,63] (PD ≥ 7 mm[53])	MD (95% CI)	0.34 (−0.88 to 1.56)	0.59	266.15	Laser vs. SRP	98.0
	ΔCAL[53,57–60,63]	MD (95% CI)	015 (−0.72 to 1.02)	0.73	69.06	Laser vs. SRP	93.0
	ΔCAL[57–60,63] (PD ≥ 7 mm[53])	MD (95% CI)	0.37 (−0.98 to 1,73)	0.59	145.64	Laser vs. SRP	97.0
CP – treatment of residual sites during PM							
SRP plus Laser vs. SRP	ΔPD[67,69]	MD (95% CI)	0.09 (−0.12 to 0.31)	0.40	0.16	0.69	0
CP – treatment of residual sites during PM							
Laser vs. SRP	ΔPD[66,68]	MD (95% CI)	−0.09 (−0.45 to 0.27)	9.63	0.10	0.76	0
	ΔCAL[66,68]	MD (95% CI)	−0.27 (−0.85 to 0.30)	0.35	2.26	0.13	56.0
CP – surgical treatment of residual sites							
SRP plus Laser vs. SRP	ΔPD[72,73]	MD (95% CI)	0.18 (−0.14 to 0.50)	0.27	0.10	0.75	0
	ΔCAL[72,73]	MD (95% CI)	−0.26 (−0.63 to 0.12)	0.18	0.03	0.86	0
CP – surgical treatment of residual sites							
Laser vs. SRP	ΔPD[71,74]	MD (95% CI)	0.30 (−0.07 to 0.67)	0.11	0.17	0.68	0
	ΔCAL[71,74]	MD (95% CI)	0.42 (0.26 to 0.57)	< 0.001	0.60	0.44	0

AgP – aggressive periodontitis; CP – chronic periodontitis; PD – probing depth; CAL – clinical attachment level; SRP – scaling and root planing; CI – confidence interval; MD – mean differences; PM – periodontal maintenance; Δ – change from baseline to last follow-up

Pooled estimates on PD reduction and CAL gain (MD) showed:

- Modest additional PD reduction of 0.63 mm and CAL gain of 0.52 mm for sites treated with SRP plus diode laser (single session after SRP).

For the 15 included RCTs, the quality of SRP did not seem to have impacted the results of therapy. Overall, based on outcomes of individual studies and on pooled estimates, the statistically significant adjunctive improvements in PD and CAL achieved with SRP plus infrared laser were considered to represent questionable clinical benefit.

☐ **Adverse events or harms**: Some degree of pain may occur within the first days following the SRP plus high power laser

☐ **Benefit-harm assessment (net benefit rating) compared with SRP**: No additional clinical benefit was identified for either SRP plus Er:YAG and Nd:YAG lasers of Er:YAG and Nd:YAG lasers alone. Modest clinical benefits of SRP plus diode laser outweigh potential for harm.

☐ **Strength of clinical recommendation of procedures compared with SRP**: 1) Nonsurgical treatment of CP by infrared lasers (Er:YAG or Nd:YAG) – Expert opinion questions the use (Evidence is lacking; the level of certainty is low. Expert opinion questions the use); 2) Nonsurgical treatment of CP by SRP plus infrared diode laser—Expert opinion questions the use (Evidence is lacking; the level of certainty is low. Expert opinion questions the use)

2.5 | Nonsurgical treatment of chronic periodontitis—residual sites during periodontal maintenance

2.5.1 | Main findings

Five trials[66–70] evaluated the use of infrared laser therapy alone or as an adjunct to SRP (diode, Nd:YAG and Er:YAG) for the nonsurgical treatment of CP patients with

sites with residual pocketing (PD ≥ 5 mm) after undergoing regular periodontal maintenance every 3 to 4 months for at least 1 year. None of the studies reported significant additional improvements in PD or CAL measures associated with the treatment of residual pockets with laser therapies (Table 3).[66–70]

Regarding microbial outcome measures, Krohn-Dale et al.[66] found that the prevalence *P. gingivalis* decreased significantly in smokers following subgingival debridement at 6- and 12-month follow-up evaluations; however, no significant differences were observed among treatment groups (SRP versus Er:YAG laser alone) in subgingival microbiological composition or total pathogens. Conversely, the Er:YAG group showed a significant decrease in the levels of *T. denticola* at the same follow-up periods. Ratka-Krueger et al.[68] found no differences in mean colony forming units between sites treated with SRP or Er:YAG laser at 13 and 26 months following treatment ($P > 0.05$). In addition, Tomasi et al.[70] observed significant and comparable reductions in the levels of *P. gingivalis, T. forsythensis, T. denticola, P. intermedia, Prevotella nigrescens, F. nucleatum, Peptostreptococcus micros, and Campylobacter rectus* 1 month after subgingival debridement with either an ultrasonic scaler or Er:YAG laser. In the latter study, the degree of treatment discomfort was scored significantly lower following subgingival debridement with the Er:YAG laser compared with the ultrasonic scaler.[70] In terms of patient-reported outcomes, Slot et al.[69] commented that post-operative bleeding, pain, and swelling were observed, but these occurred on the day of treatment mostly at sites treated with SRP plus Er:YAG ($p \leq 0.01$).

Pooled estimates evaluating PD reduction and CAL gain at residual sites among CP patients in periodontal maintenance for a minimum period of one year, treatment with either SRP plus infrared laser (diode or Nd:YAG), or Er:YAG laser alone did not provide additional improvements in PD or CAL compared with those observed for SRP alone (Table 3; supplementary Figs. 4 and 5 in online *Journal of Periodontology*).

2.5.2 | Clinical recommendation summary

SRP plus infrared laser (diode or Nd:YAG) or Er:YAG laser alone versus SRP for the nonsurgical treatment of CP – residual sites identified during regular maintenance (3-4 months) for at least 1 year after active periodontal therapy:

- ☐ **Level of certainty**: Low (SRP plus infrared laser [diode or Nd:YAG] SRP or Er:YAG laser alone for the treatment of residual sites during regular periodontal maintenance)
- ☐ **Benefit**: In general terms, SRP plus infrared laser (diode or Nd:YAG), or Er:YAG alone did not promote additional improvements to those accomplished by SRP alone in the treatment of sites with residual PD during regular periodontal maintenance. None of the studies presented information on treatment costs.

Pooled estimates on PD reduction and CAL gain (MD) showed:

- No additional PD or CAL gains for infrared laser therapies were identified.

In the five included RCTs, the quality of SRP did not appear to have adversely impacted the results of therapy.

- ☐ **Adverse events or harms**: Some degree of pain, bleeding, or swelling may occur after treatment with SRP plus infrared laser (diode or Nd:YAG).
- ☐ **Benefit-harm assessment (net benefit rating) compared with SRP**: No additional clinical benefit was identified for SRP plus infrared laser (diode or Nd:YAG) or Er:YAG laser alone in the treatment of sites with residual PD during regular periodontal maintenance.
- ☐ **Strength of clinical recommendation of procedures compared with SRP**: 1) Nonsurgical treatment of CP patients with sites with residual pocketing (PD ≥ 5 mm) during regular periodontal maintenance by SRP plus infrared laser (diode or Nd:YAG) or Er:YAG alone – Expert opinion questions the use (Evidence is lacking; the level of certainty is low. Expert opinion questions the use.

2.6 | Nonregenerative surgical treatment of chronic periodontitis – open flap debridement modalities

2.6.1 | Main findings

Four studies[107-110] assessed the use of Er:YAG laser alone or SRP plus high 980 nm diode laser. Only Gaspirc & Skaleric[107] reported significantly greater improvements in PD and CAL after flap access and Er:YAG laser debridement, when compared with conventional open flap debridement, at 6-, 12-, 24-, and 36-month evaluations (Table 5). The study also found that the clinical results obtained with both treatments could be maintained over 5 years; however, differences in clinical outcomes among treatment groups were not observed after 36 months.

Regarding microbial outcome measures, Gokhale et al.[108] reported a statistically significant decrease in the number of colony forming units of anaerobes after SRP plus 980 nm diode laser treatment when compared with SRP alone. Self-report of pain was assessed using a visual analog scale after treatment—comparable pain ratings were found for patients treated with SRP plus 980 nm diode laser and SRP alone. Treatment groups exhibited a similar degree of mild postoperative intraoral swelling within the first-second healing week (< 10% of sites).

Of the two sets of meta-analyses assessing the effect of open flap debridement with infrared lasers (diode or Er:YAG) (Table 6; supplementary Figures 6 and 7 in online *Journal*

of Periodontology), significant additional improvements were found only for CAL gain at sites treated with Er:YAG lasers alone (MD = 0.42 mm, 95% CI: 0.26 to 0.57, $p < 0.001$, $I^2 = 0\%$).

2.6.2 | Clinical recommendation summary

SRP plus infrared diode laser or Er:YAG alone versus SRP for the nonregenerative surgical treatment of sites with residual PD ≥ 5 mm in patients with CP:

- ☐ **Level of certainty**: Low
- ☐ **Benefit**: In general, SRP plus infrared diode laser did not promote additional gains to those accomplished by SRP alone. Er:YAG laser alone promoted modest additional clinical benefits to those achieved by SRP alone. None of the studies presented information on treatment costs.

Pooled estimates on PD reduction and CAL gain (MD) showed:

- A modest additional CAL gain of 0.42 mm for sites treated with Er:YAG laser six months after open flap debridement procedure.

- ☐ **Adverse events or harms**: Similar degree of swelling may occur in the first and second weeks, irrespective of the therapy.
- ☐ **Benefit-harm assessment (net benefit rating) compared with SRP**: No additional clinical benefit was identified for SRP plus infrared diode laser. Modest clinical benefits of Er:YAG laser alone outweigh potential for harm.
- ☐ **Strength of clinical recommendation of procedures compared with SRP**: 1) Open flap debridement for the treatment of CP by SRP plus infrared diode laser—Expert opinion questions the use (Evidence is lacking; the level of certainty is low. Expert opinion questions the use; 2) Open flap debridement for the treatment of CP by Er:YAG laser alone—Expert opinion for (Evidence is lacking; the level of certainty is low. Expert opinion guides this recommendation).

2.7 | Nonsurgical treatment of chronic periodontitis in patients with systemic conditions/disease known to impact disease progression – smoking and diabetes

2.7.1 | Main findings

Only two RCTs[75,76] assessed the effect SRP plus infared laser in smokers (Nd:YAG)[75] and diabetic (diode) patients.[76] Koçak et al.[76] identified modestly greater improvements in CAL and PD at moderate sites (PD = 5–6 mm) in diabetics treated with SRP plus high power laser (diode), when compared with those treated with SRP alone.

2.7.2 | Clinical recommendation summary

SRP plus infrared lasers versus SRP alone for the nonsurgical treatment of CP in smokers and patients with diabetes mellitus:

- ☐ **Level of certainty**: Low
- ☐ **Benefit**: Uncertain. None of the studies presented information on treatment costs.

Pooled estimates could not be calculated for PD reduction and CAL gain.

- ☐ **Adverse events or harms**: None reported.
- ☐ **Benefit-harm assessment (net benefit rating) compared with SRP**: Benefits of SRP combined with diode laser are uncertain and outweigh potential for harm
- ☐ **Strength of clinical recommendation of procedures compared with SRP**:
  1. Nonsurgical treatment of smokers with CP by SRP plus diode laser—Expert opinion questions the use (Evidence is lacking; the level of certainty is low. Expert opinion questions the use; 2) Nonsurgical treatment of CP in patients with diabetes by SRP plus infrared laser—Expert opinion for/supports (Evidence is lacking; the level of certainty is low. Expert opinion guides this recommendation).

3 | DISCUSSION

3.1 | Summary of main results

To the best of our knowledge, this systematic review is the first to assess the level of certainty in the body of evidence on the effectiveness of nonsurgical and surgical (nonregenerative) therapies using infrared lasers alone or as an adjunct to conventional mechanical periodontal therapy, which is based on the *US Preventive Services Task Force* (USPSTF) system, as adapted by the American Dental Association.[23] In contrast to prior systematic reviews on lasers in periodontal therapy,[9–12] the application of these criteria[23] allowed for an assessment of "strength" of evidence for the estimated effect, or clinical benefit, of lasers and the development of recommendation summaries to guide the clinical practice.

In general, SRP plus infrared laser (diode, Er:YAG, or Nd:YAG) and Er:YAG or Nd:YAG laser alone may promote statistically significant improvements in CAL and PD. Some studies (Tables 1 to 5) also showed alterations in the position of the gingival margin (i.e., increase in recession depth) after treatment. Moreover, studies reported few adverse effects (mostly within the first week of healing), consistent with the safety of the laser-based procedures assessed in this review. Few laser therapies, however, promoted additional gains in

clinical outcomes when compared with those expected after conventional (SRP) approaches to mechanical debridement. Of the seven sets of meta-analyses, significant but modest additional improvements in clinical measures were observed with infrared laser-based procedures compared with SRP alone for the following comparisons: 1) nonsurgical treatment of CP by SRP plus infrared laser (diode [single session]); and 2) surgical treatment of CP by Er:YAG laser lone. When compared with clinical outcomes following conventional periodontal therapies, the significance of the additional clinical improvements (≤0.6 mm) with these laser-based procedures remain uncertain.[13] Moreover, it should be considered that positive findings related to SRP plus a single session of diode laser must be interpreted with caution because of the small number of studies included within the analysis (two RCTs),[13] differences in study protocols (e.g., SRP),[13] and the conflicting findings found for SRP plus multiple sessions of diode lasers. Consequently, expert opinion might question the use of this laser-based therapy at this moment in time.

3.2 | Quality of the evidence and potential biases in the review process

Based on the information available in the text of included RCTs, studies were assessed as unclear or as high risk of bias because one or more criteria were not reported or met. Most of the trials assessed as unclear or high risk of bias did not report information on patient masking. It would be expected that not only examiners, but also patients need to be masked regarding the type of experiment, especially in split-mouth evaluations.[15] This issue may act as a source of bias and could affect the precision of the outcomes. However, the lack of patient masking per se did not seem to have interfered in the overall outcomes of each individual trial. Further, in this review, only trials reporting PD ≥ 5 mm were included to reduce heterogeneity among studies (the assessment of shallow and deep sites could lead to a weakening of the estimates).[13] Nevertheless, this inclusion criterion might have rejected outcomes from RCTs that could have been combined into pooled estimates (i.e., meta-analyses).

Additionally, it was clearly shown by the subgroup analyses that heterogeneity was directly associated to the following conditions: a) differences in the criteria used to define periodontitis and defects of interest; b) baseline PD; c) type of SRP performed (i.e., hand or ultrasonic scaling); and d) the type of laser, settings, and application (Tables 1 to 5). It should be also noted that, even in meta-analyses based on studies with similar methodology, "a variation in results across studies may occur because of random variation, but such variations are unlikely to be caused by chance alone, and thus, methodologic heterogeneity cannot be completely eliminated".[77]

3.3 | Agreements and disagreements with other studies or reviews

Outcomes of previous recent systematic reviews did not identify additional positive clinical improvements associated to infrared laser procedures after 3 months of follow-up[9,10] for either nonsurgical[9–11] or surgical[12] (nonregenerative) treatment approaches. In the present Best- Evidence Consensus systematic review, some additional significant gains were identified for some types of laser-based procedures (SRP plus infared laser (Diode) [nonsurgical treatment of CP], and infrared laser (Er:YAG) alone [surgical treatment of CP patients]). Nevertheless, the clinical relevance of these findings is unclear given the limited magnitude of the additional gains identified by both the individual studies outcomes and pooled estimates.[13] Moreover, the impact of the different "laser protocols" described in the literature (e.g., type of laser, dosage, settings, emission mode) preclude additional inferences on the ultimate role or benefits of applying these procedures in clinical and private practice. In addition, the potential cost-benefits of the adjunctive use of laser could not be determined from the RCTs included in the review.

Lasers are generally classified according to the active medium within the optical cavity, which, on stimulation, generates a specific wavelength of nonionizing radiation. Each wavelength has somewhat unique laser-tissue interactions arising from differences in the absorption of the laser energy in the tissue. Therefore, interpretation of therapeutic outcomes must be considered within the context of the specific laser emission wavelength and parameters used for the procedure. Diode lasers and Nd:YAG lasers (λ = 800 to 1100 nm), for example, appear to act on the pocket soft tissue because of selectivity to chromophores of blood and tissue pigments, particularly in areas with inflammation.[78] In contrast, Er:YAG laser wavelength is absorbed mainly by hard tissues and water; the antibacterial and calculus removal properties of this wavelength have been attributed to the ablation process involving water on contaminated root cementum.[79,80] CO_2 laser (λ = 9300 to 10,600 nm) emission wavelength is highly absorbed by mineralized tissues, with a shallow penetration into soft tissues (i.e., pocket epithelium and marginal gingiva); CO_2 laser irradiation of cementum can result in melting and carbonization.[81] These differences in lasers were considered in meta-analysis clustering and are presented in supplementary Figures 2 through 4 in the online *Journal of Periodontology*.

4 | CONCLUSIONS

The relatively small, statistically significant, clinical improvements in PD and CAL attributable to infrared laser procedures, when used alone or as an adjunct to other periodontal

therapies, appear to provide questionable additional clinical benefit to patients with moderate-to-severe AgP or CP.

4.1 | Implications for research and future practice

Despite of the safety and the positive trend of better results found for some laser therapies, limited data exist on the treatment of AgP and on the outcomes of patients affected by modifiable risk factors (e.g., smoking) and systemic conditions (e.g., diabetes) that can modify the behavior of periodontitis. Regarding the treatment of patients with CP, the available base of RCTs available indicates that it is not evident that these adjunctive laser procedures improve the clinical benefits achieved by conventional strategies for mechanical debridement (SRP).[13] Additionally, some of the included studies reported a "scanning" method of irradiation,[52–55] applied by means of continual movement of the laser instrument while irradiating the entire field of tissue, such as tooth surface; however, such approaches hamper efforts to ensure consistent and reproducible treatment protocols. Future efforts to evaluate the clinical effectiveness of lasers in the treatment of periodontitis will benefit from more standardized and calibrated protocols and reporting of laser parameters used for procedures, such as power density and duration of exposure.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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