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REVIEW

Efficacy of adjunct Nd-YAG laser (1064 nm) to non-surgical periodontal therapy: a systematic review and meta-analysis of randomized controlled trials

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Abstract

Background The Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser is proposed as an adjunct to scaling and root planing (SRP) to enhance bacterial reduction and healing in periodontitis. This study aims to evaluate the efficacy of Nd: YAG laser therapy (1064 nm) compared with SRP alone in improving clinical periodontal outcomes.

Methods This systematic review adhered to PRISMA 2020 guidelines and was prospectively registered with PROSPERO. We included only randomized controlled trials (RCTs) comparing SRP with adjunctive Nd: YAG laser therapy to SRP alone in patients with periodontitis. The primary outcomes were pocket depth (PD), plaque index (PI), bleeding on probing (BOP), and clinical attachment loss (CAL) assessments at baseline and after three months. Secondary outcomes included gingival cervical fluid (GCF) at baseline and after three months. Risk-of-bias assessment (using ROB-2) was performed independently by multiple reviewers. All statistical analyses were performed using R (version 4.4.3). The certainty of evidence for all outcomes was evaluated using the GRADE approach.

Results The systematic review and meta-analysis included 22 randomized controlled trials published between 2010 and 2025, totaling 776 patients. Meta-analysis demonstrated that adjunctive ND: YAG laser with SRP significantly improved PD reduction compared with SRP alone (MD = −0.46 mm; 95% CI −0.82 to −0.10; $p = 0.0117$), Subgroup analysis showed that split-mouth RCTs had a larger effect (MD = −0.66 mm) than parallel-group RCTs (MD = −0.20 mm), but the difference between subgroups was not significant. No statistically significant benefits were observed for PI (MD = −0.03; 95% CI −0.19 to 0.13; $p = 0.63$), CAL (MD = −0.04; 95% CI −0.21 to 0.13; $p = 0.61$), GCF volume (MD = −0.20; 95% CI −0.45 to 0.06; $p = 0.097$), or BOP (MD = −7.88; 95% CI −19.23 to 3.46; $p = 0.17$).

Conclusion Adjunctive Nd: YAG laser therapy provides a modest, statistically significant benefit in reducing periodontal pocket depth beyond conventional therapy alone. However, it does not demonstrate superior efficacy in improving clinical

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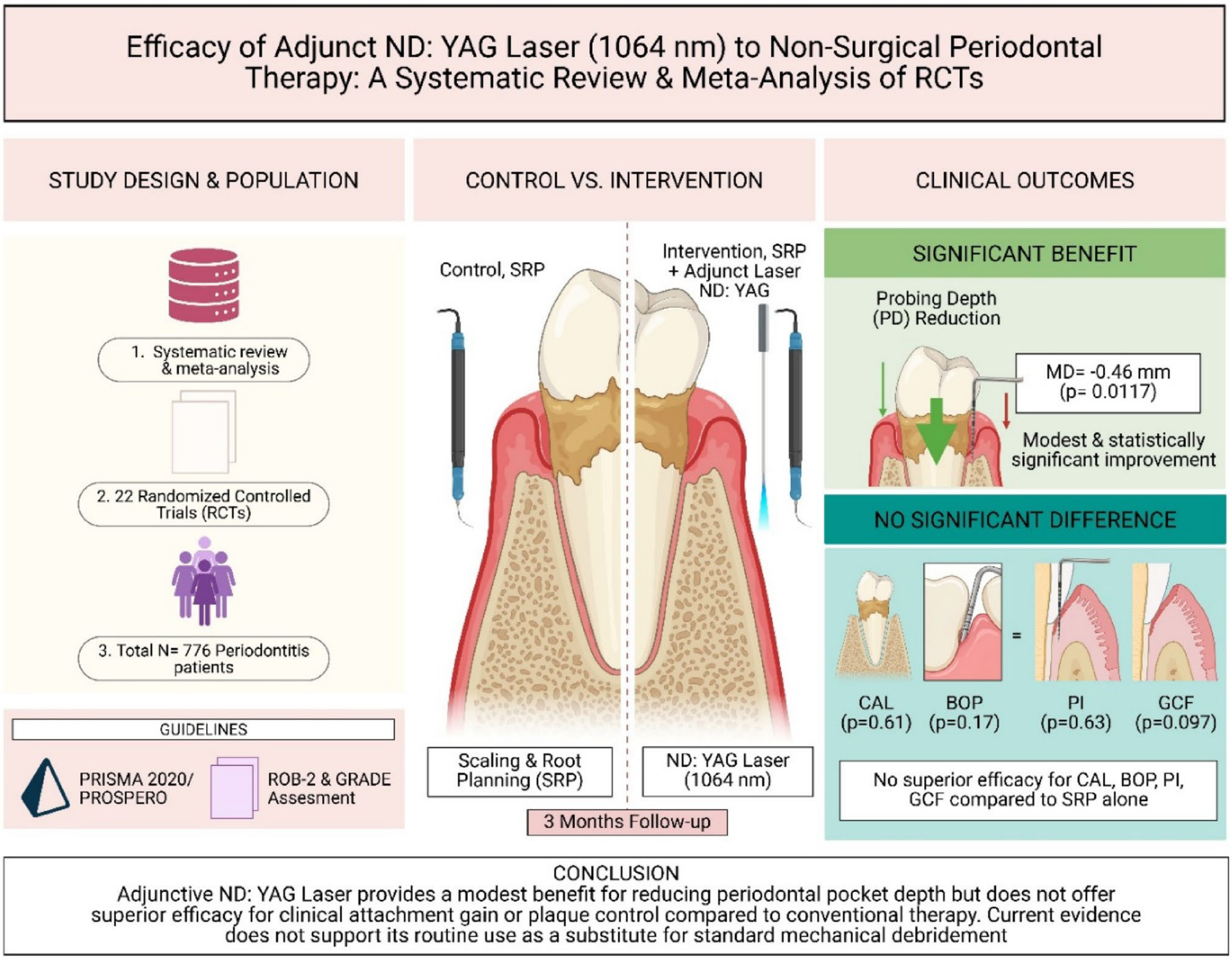
attachment levels or plaque control. Consequently, while beneficial for pocket reduction, current evidence does not support its routine universal use as a substitute for standard mechanical debridement.

Graphical abstract



Keywords Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) · Scaling and root planing (SRP) · Periodontitis · Probing Depth (PD) · Plaque control

1 Introduction

Periodontal disease is a multifactorial infectious-inflammatory disorder affecting the tooth-supporting structures, including the gingiva, periodontal ligaments, and alveolar bone, resulting in periodontal attachment loss [1]. This condition, characterized by destruction of connective tissue and alveolar bone, initiates consequential immune and anti-inflammatory responses to pathogenic bacteria [2]. It is recognized as the most prevalent chronic bacterial infection in humans, making it a significant global public health issue [3].

The advancement of periodontal disease is primarily influenced by oral hygiene, microbial factors, and other contributing or predisposing factors [4]. Key factors impacting its development include dental plaque accumulation, dental caries, tooth displacement, missing teeth, occlusal trauma, dentofacial abnormalities, parafunctional habits, harmful behaviors, local iatrogenic causes, and systemic and environmental risk factors [5, 6].

The management of periodontitis begins with patient education, control of risk factors such as smoking cessation and diabetes management, and reinforcement of effective oral hygiene. This is followed by professional mechanical plaque removal (PMPR) both supra- and subgingivally, progressing to root surface debridement if necessary [7]. For cases that do not fully respond to non-surgical therapy, surgical interventions may be considered [8]. The primary goals in managing periodontal diseases are to reduce inflammation to clinically manageable levels and achieve clinical periodontal health, prevent further bone loss, and conduct regular follow-ups to monitor disease progression [4].

Scaling and root planing (SRP), the fundamental periodontal treatment procedure, employs hand instruments and/or sonic/ultrasonic devices to mechanically eliminate biofilm and calculus [9]. While proven effective in alleviating periodontal inflammation, reducing pocket depth, and improving clinical attachment levels, this technique has limitations in achieving optimal treatment outcomes [10]. These challenges arise from anatomical complexities like root surface concavities and grooves, furcation involvements, deep periodontal pockets, and the potential for microbial recolonization by tissue-invasive pathogens [10]. Laser systems can be used across multiple dental specialties, including periodontology, pediatric dentistry, oral surgery, implantology, and oral pathology [11–13]. Various dental laser modalities, operating across wavelengths ranging from 400 to 10,600 nm, have been investigated for their potential to improve periodontal therapy outcomes [14, 15]. The neodymium-doped yttrium aluminum garnet (Nd: YAG) laser (1064 nm) has gained significant application in periodontal therapy due to its unique ability to target and interact with chromophores, including melanin and hemoglobin, and its inherent hemostatic effects [16]. This laser system has been extensively employed to eliminate pocket epithelium, reduce subgingival pathogenic bacterial populations, and disrupt bacterial dysbiosis [17, 18]. Its unique properties enable access to anatomically complex areas that are otherwise difficult to reach with traditional hand instruments [19]. The laser achieves significant hemostasis by forming a substantial coagulation zone at treatment sites [20]. Additionally, it is suggested that it removes pathological pocket epithelium and encourages periodontal regeneration by facilitating new connective tissue attachment and cementum formation [21]. The aim of this study is to evaluate whether the Adjunct Nd-YAG laser (1064 nm) is more effective than non-surgical periodontal therapy alone.

2 Materials and methods

2.1 Registration protocol and reporting

This systematic review was reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension (PRISMA) 2020 Checklist guidelines [22]. The study protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD420251180931.

2.2 Search strategy and literature search

A comprehensive search was conducted across five electronic databases: PubMed, Scopus, Web of Science (WOS), Cochrane Library, and Embase, from January 1, 2010, until November 1, 2025. MeSH terms and free-text keywords were used to develop the search strategy for the available literature. Search terms included ("Neodymium-Doped Yttrium Aluminum Garnet Laser" OR "Neodymium Doped Yttrium Aluminum Garnet Laser" OR "Nd: YAG laser" OR "Nd-YAG Laser" OR "Nd YAG Laser" OR "1064 nm" OR "laser" OR "Laser-Assisted" OR "adjunctive laser" OR "lasers") AND ("non-surgical periodontal therapy" OR "scaling and root planing" OR "SRP" OR "periodontal debridement" OR "mechanical periodontal therapy") AND ("periodontitis" OR "periodontal*" OR "gum disease").

2.3 Eligibility criteria

The inclusion criteria for this study were: (1) patients diagnosed with periodontitis; (2) the intervention was Nd-YAG laser (1064 nm) adjunctive to SRP; (3) the comparator was conventional SRP; (4) and the study design was restricted to randomized controlled trials (RCTs), while excluding (1) non-RCTs (2), animal studies (3), in vitro studies (4), case reports (5), letters, and (6) unpublished manuscripts.

Due to the publication timeframe of the included literature (2010–2025), the criteria used to define disease severity varied according to the prevailing classification systems. Studies published before the 2017 World Workshop classification primarily enrolled patients diagnosed with moderate to severe Chronic Periodontitis, defined by baseline probing pocket depths (PPD) of ≥4 to 5 mm and radiographic evidence of alveolar bone loss. Conversely, more recent trials utilized the updated Staging and Grading system, defining severity as generalized Stage II, III, or IV periodontitis, with several cohorts specifically categorized as Grade B or C to denote the risk of rapid progression.

2.4 Selection of studies

The identified search results from all databases were imported into the RAYYAN platform for systematic review management. Initially, duplicate records were identified and removed using automated functions in RAYYAN, then manually confirmed. The screening was then carried out in two sequential stages: an initial evaluation of titles and abstracts, followed by full-text assessment. During both stages, two reviewers (A.A. and A.T.) independently assessed all records according to the predefined inclusion and exclusion criteria. Articles deemed potentially eligible were obtained in full and independently evaluated for final inclusion by two reviewers (A.S. and A.S.W.). Any disagreements arising during the process were resolved through consultation and final judgment by a third reviewer (A.E.).

2.5 Data extraction and outcome measures

Two reviewers (A.A. and R.W.) independently performed data extraction using a standardized, predesigned Excel data collection form. The extracted information comprised: (1) general study characteristics, including participants' age, sex distribution, study design, country of origin, sample size, intervention and comparison groups, reported outcomes, and follow-up period; (2) study-specific laser parameters, such as power output, energy per pulse, pulse repetition frequency, optical fiber diameter, and irradiation time; and (3) outcome measures. The primary outcomes were PD, PI, BOP, and CAL assessments at baseline and after three months. Secondary outcomes included GCF at baseline and after three months. Eventually, any discrepancies encountered were resolved by a third reviewer (A.E.). All continuous data in the extraction sheet were reported as mean (M) and SD.

2.6 Risk of bias assessment

The methodological quality of the included clinical trials was independently assessed by three reviewers (R.W., A.T., and A.A.) using the revised Cochrane Risk of Bias tool for randomized trials (ROB-2) [23]. This tool was applied to systematically evaluate the randomization process, allocation concealment, deviations from the intended interventions, the suitability of analytical methods for estimating intervention effects, outcome measurement, selective reporting, and the overall risk of bias. Based on these domains, each study was categorized as low risk of bias, with some concerns, or high risk of bias.

2.7 GRADE assessment

In accordance with the GRADE (Grading of Recommenda tions Assessment, Development and Evaluation) framework, we assessed the certainty of the evidence for each outcome using five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Ratings were downgraded based on the presence of serious or very serious concerns, and overall certainty for each outcome was graded as high, moderate, low, or very low.

2.8 Data analysis

The statistical analyses were performed using the 'Meta' package in R (version 4.4.3; R Studio, Vienna, Austria). For continuous outcomes, mean differences (MDs) with 95% confidence intervals (CIs) were calculated. Follow up for included outcomes was three months. Pooled estimates were generated using a random-effects model when heterogeneity was moderate to high ($I^2 \geq 50\%$), and when heterogeneity was low ($I^2 < 50\%$). Using both models provides complementary insights: the fixed-effect model offers more precise estimates when studies are homogeneous, whereas the random-effects model accounts for between-study variability, yielding more generalizable estimates. Heterogeneity was assessed using the I^2 statistic, categorized as low (<50%), moderate (50–74%), or substantial (≥75%). A p-value ≤ 0.05 was considered statistically significant. Publication bias was evaluated using Egger's test for outcomes with more than 10 studies.

2.9 Treatment protocol

Across the included trials, the timing of the primary periodontal diagnosis and the delivery of oral hygiene instructions (OHI) showed minor methodological variations. In the majority of the studies, the primary diagnosis was established at baseline, before any hygiene phase or non-surgical intervention. OHI was typically delivered during this initial baseline appointment alongside the scaling and root planning (SRP). Strict verification of a specific hygiene threshold (e.g., Full Mouth Plaque Score < 25%) before initiating laser therapy was explicitly mandated in a limited number of studies, whereas others enforced a short hygiene adaptation period before intervention. Furthermore, some studies specifically evaluated the adjunctive efficacy of the Nd: YAG laser exclusively on residual pockets following a previously completed non-surgical hygiene phase or during a supportive periodontal maintenance care program.

3 Results

3.1 Literature search results

The database search identified 2327 records. After the removal of 1424 duplicates by automated de-duplication in RAYYAN, 903 titles and abstracts were screened. Of these, 871 were excluded as irrelevant. 32 studies underwent full-text review, of which 14 were excluded for non-eligibility. Ultimately, 18 studies met all eligibility criteria, and after manual screening citations, we added 4 that met our eligibility criteria. A total of 22 studies were included in the final analysis (Fig. 1).

3.2 Characteristics of the included studies

The 22 included studies were published between 2010 and 2025, and were all RCTs. Four trials were conducted in Turkey [24–27], three trials in China [28–30], three trials in Sweden [31–33], three in Saudia Arabia [34–36], two in Greece [37, 38], two in Netherlands [39, 40], one in Romania [41], one in Iran [42], one in India [43], one in Spain [44], and one in Switzerland [45]. Across all studies, 776 patients were analyzed. Across the included studies, sample sizes varied from 8 to 87 participants. The enrolled populations ranged in age from 18 to 70 years, with males comprising approximately 55% of participants. Detailed characteristics of the individual trials are presented in Table 1. The laser settings used in the studies are summarized in Table 2, which specifically outlines the Nd: YAG (1064 nm) laser parameters for each trial.

3.3 Risk of bias assessment

The methodological rigor of the 22 included randomized controlled trials was assessed using the Cochrane Risk of Bias tool for randomized trials (RoB 2). The overall judgments were distributed as follows: 2 studies (9.1%) had a low risk of bias, 19 studies (86.4%) had some concerns, and one study (4.5%) had a high risk of bias. The predominant domains contributing to elevated risk ratings were related to deviations from the intended interventions (Domain 2) and the selection of the reported result (Domain 5), largely due to a frequent lack of pre-registered protocols or statistical analysis plans. Furthermore, issues in the randomization process (Domain 1), often stemming from inadequate description of allocation concealment, and in the measurement of outcomes (Domain 4), particularly concerning unblinded assessors for certain clinical parameters, were common sources of concern (Fig. 2).

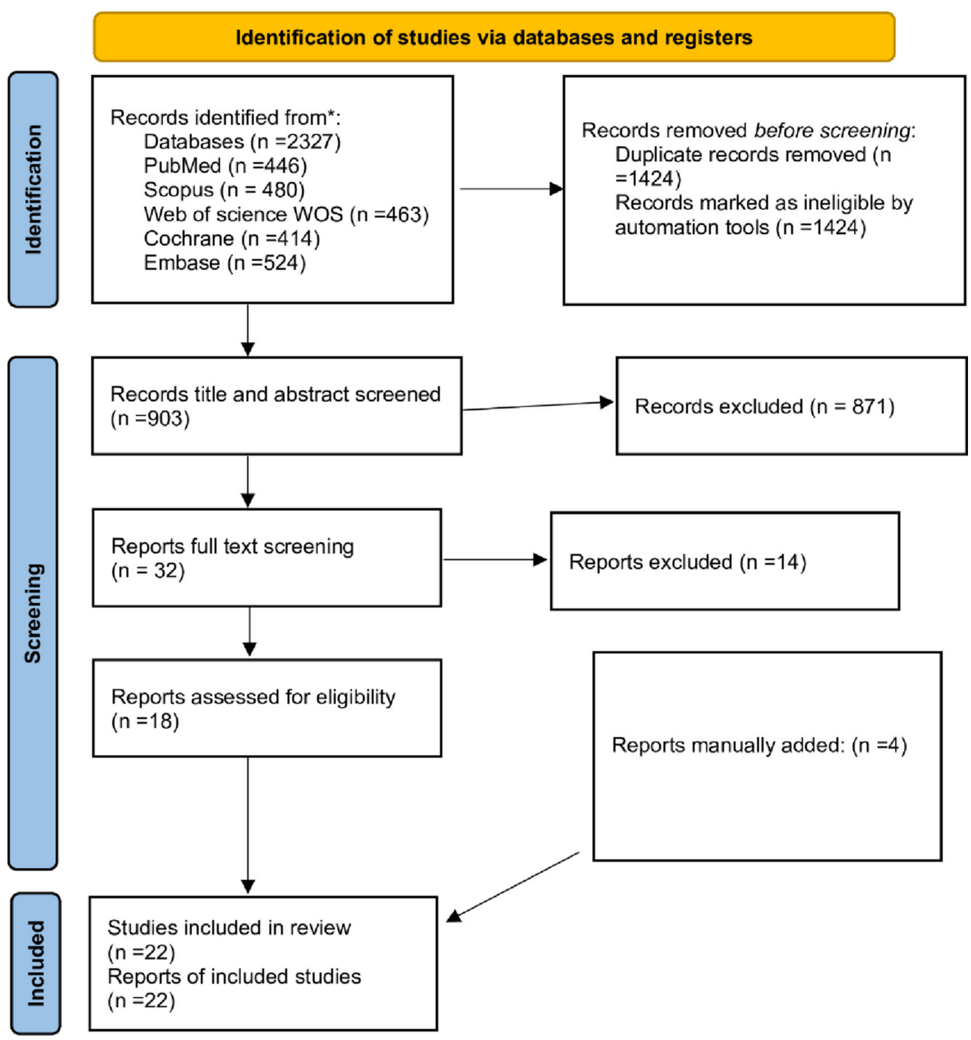


Fig. 1 PRISMA flow diagram of the study selection and screening

Table 1 Summary of the 22 included studies

N	Study ID	Study design	Study country	Sample size (*n*)	Age Mean ± SD (range) years	Sex M, F	Groups intervention (I) control (C)	Smoke	Outcomes	Follow up	Side effects
1	Bian 2025 [28]	Split-mouth, RCT	China	25	45.32 ± 10.14 (18–65)	10 m /12 f	I SRP + Nd: YAG laser C SRP	No	PD, CAL, PI, GR, BOP GCF IL-6, TNF-α, MDA	6 W, 3 m	Not mentioned
2	Xie 2024 [29]	Split-mouth, RCT	China	15	36.8 ± 11.47 (23–58)	6 m, 9 f	I SRP + Nd: YAG laser C SRP	No	PD, CAL, BOP, PLI GCF cytokines (IL-1β (pg/ul, TNF-α (pg/ul)	6 W	Not mentioned
3	Markou 2/2023 [38]	Parallel-group, RCT	Greece	60	49.9 ± 0,87 (35–65)	41 m, 19 f	I_1 FMS/single Nd: YAG laser I_2 FMS/double Nd: YAG laser C FMS	Yes	FMPS, GI, FMBS (%) PD, CAL, GR Bleeding, Swelling, Pain Sensitivity, Drugs, Acceptance, Suggest	6 W, 3. 6, 12 M	Not mentioned
4	Markou 10/2023 [37]	Parallel-group, RCT	Greece	60	(35–65)		I_1 FM-SRP + Nd: YAG laser I_2 FM-SRP + Nd: YAG laser C FM-SRP	Yes	hs-CRP, IL-1, IL-6, IL-8, IL-12, IFN-γ, FMPS, FMBS GI, PD, CAL, GR	6 W 3, 6, 12 M	Not mentioned
5	Bechir 2023 [41]	Split-mouth, RCT	Romania	14	51.5 ± 15.5 (36–67)	7 m, 7 f	I SRP + Nd: YAG laser C SRP	Yes (less 10)	PD, BOP, PI, Bacterial count	6 W	Not mentioned
6	Ezber 2022 [24]	Parallel-group, RCT	Turkey	80	(23–64)	36 m, 44 f	I_1 SRP + LLLT with Nd: YAG laser I_2 SRP + pocket debridement with Nd: YAG laser I_3 SRP + combined pocket debridement and LLLT with Nd: YAG laser C SRP	Yes	PD, CAL, PI, GI, BOP (%), GCF volume (μL), and GCF levels of MMP-8 (ng/30 s)	1 M, 3 M	Not mentioned
7	Alkan 2022 [25]	Split-mouth, RCT	Turkey	24	43.47 (21–60)	12 m, 12 f	I SRP + Nd: YAG laser C SRP	No	PPD, CAL, GI, BOP, PI	1 M, 3 M	Not mentioned
8	Dortaj 2021 [42]	Split-mouth, RCT	Iran	21	44.5 ± 7.3 (32–59)	10 m,10 f	I NSPT + Nd: YAG laser C NSPT + placebo laser	No	PPD, CAL, GR, BOP, PI	1,2,3,4,6 M	Minimal pain/ sensitivity postoperatively.
9	Gou 2020 [30]	Split-mouth, RCT	China	30	26.5 ± 3.6 (19–35)	10 m, 14 f	I SRP + Nd: YAG laser C SRP alone	No	PD, BOP	2 W, 4 W	Not mentioned
10	Abduljabbar 2017 [34]	Split-mouth, RCT	Saudi Arabia	28	57.2 ± 8.5	28 m	I SRP + Nd: YAG laser C SRP alone	No	PD, BOP, PI GCF IL-1β and TNF-α	3,6 M	Not mentioned
11	Javed 2016 [35]	Parallel-group, RCT	Saudi Arabia	87	56.6 ± 2.45.	87 m	I NSPT + Nd: YAG laser C NSPT alone	No	PD, BOP, PI Serum Cytokine IL-1β, MMP-9 levels	3 M	Not mentioned
12	Javed 2015 [36]	Split-mouth, RCT	Saudi Arabi	44	53.95 ± 4.2	38 m, 6f	I NSPT + Nd: YAG laser C NSPT alone	No	PD, BOP, PI	1,3 M	Not mentioned
13	Katuri 2015 [43]	Split-mouth, RCT	India	38	36 ± 10.1	22 m, 16 f	I SRP + Nd: YAG laser C SRP	No	API, BOP, PD, CAL	6, 24 w	Transient dentinal hypersensitivity

Table 1 (continued)

N	Study ID	Study design	Study country	Sample size (*n*)	Age Mean ± SD (range) years	Sex M, F	Groups intervention (I) control (C)	Smoke	Outcomes	Follow up	Side effects
14	Qadri 2013 [31]	Parallel-group, RCT	Sweden	39	50 (30–70)	19 m, 20 f	I_1 SRP + Nd: YAG laser I_2 Nd: YAG laser alone C SRP alone	No	PD, PI, GI GCF volume	1w,3 M	Not mentioned
15	slot 2012 [39]	Split-mouth, RCT	Netherlands	30	48.7 ± 11.3 (39–65)	13 m,17 f	I SRP + Nd: YAG laser C SRP	Yes	PD, BOP	6 M	Post-operative bleeding, swelling, and pain.
16	Eltas 2012 [26]	Split-mouth, RCT	Turkey	52	43.4 ± 5 (32–52)	26 m,26f	I SRP + Nd: YAG C SRP	Yes, No	PD, PI, GI, CAL GCF Volume	1,6 M	Not mentioned
17	Eltas 2011 [27]	Split-mouth, RCT	Turkey	20	46.1 ± 8.3	10 m, 10 f	I SRP + Nd: YAG C SRP	No	PD, PI, GI, CAL GCF IL-1β, MMP-8	3, 9 M	Not mentioned
18	slot 2011 [40]	Split-mouth, RCT	Netherlands	19	45.3 ± 8.67 (34–62)	11 m, 8 f	I SRP + Nd: YAG laser C SRP	-	PD, BOP, PI	3 M	Not mentioned
19	Qadri 2010 [32]	Split-mouth, RCT	Sweden	30	50 (26–70)	13 m, 17 f	I SRP + Nd: YAG laser C SRP	Yes, No	PD, PI, GI GCF volume IL-1β, IL-4, IL-6, IL-8, MMP-8	1w,3 M	Not mentioned
20	Qadri 2010 [33]	Split-mouth, RCT	Sweden	22	50 (26–70)	9 m,13 f	I SRP + Nd: YAG laser C SRP	Yes, No	PD, PI, GI GCF volume	20 M	Not mentioned
21	Gómez 2010 [44]	Parallel-group, RCT	Spain	30	51 ± 6 (45–58)	15 m, 15 f	I SRP + Nd: YAG laser C SRP	No	PD, BOP, PI IL-1β, TNF-α	4,8 W	Not mentioned
22	Jensen 2010 [45]	Split-mouth, RCT	Switzerland	8	44 (32–59)	4 f, 4 m	I SRP + Nd: YAG laser C SRP	No	PD, POB	3,6 M	Root sensitivity

RCT randomized controlled trial, *SRP* scaling and root planning, *NSRP* non-surgical scaling and root planning, *ND YAG* neodymium doped: yttrium, aluminium, and garnet, *G* group, *PD* pocket probing depth, *CAL* clinical attachment level, *PI* plaque index, *GI* gingival index, *BOP* bleeding on probing, *GCF* gingival cervical fluid, *IL-6* Interleukin-6, *TNF-α*, tumor necrosis factor alpha, *MDA* malondialdehyde, *FMPS* full-mouth plaque score, *FMBS* full-mouth bleeding score, *hs-CRP* high-sensitivity c-reactive protein, *MMP-9* matrix metalloproteinase-9, *w* week, *m* month.*LLLT* lower level laser therapy

Table 2 Laser parameters for each study: Pulsed ND: YAG laser (1064 nm)

N	Study ID	Power (W)	Pulse duration	Energy/pulse (mJ)	Pulse repetition Rate (Hz)	Optic fiber diameter (µm)	Duration per tooth (S)
1	Bian 2025 [28]	1.5	120 µs.	150	10	400	40–60
2	Xie 2024 [29]	4	-	160	25	600	40–60
3	Markou 2/2023 [38]	3	100 µs.	150	20	320	-
4	Markou 10/ 2023 [37]	3	100 µs.	150	20	320	-
5	Bechir 2023 [41]	2.5	-	-	20	-	20
6	Ezber 2022 [24]	2	-	200	10	320	120
7	Alkan 2022 [25]	2	-	200	10	320	120
8	Dortaj 2021 [42]	3	100 µs.		20	320	-
9	Gou 2020 [30]		-	100	20	320	10
10	Abduljabbar 2017 [34]	4	-	80	50	600	60–120
11	Javed 2016 [35]	4	-	80	50	600	60–120
12	Javed 2015 [36]	4	350 µs.	-	50	600	60–120
13	Katuri 2015 [43]	4	635 µs.	-	20	200–300	-
14	Qadri 2013 [31]	4	350 µs	80	50	-	60–120
15	slot 2012 [39]	4	250 µs	400	50	600	60
16	Eltas 2012 [26]	1	-	100	10	-	-
17	Eltas 2011 [27]	1	-	100	10	200	-
18	slot 2011 [40]	6	250 µs	400	50	-	60
19	Qadri 2010 [32]	4	350 µs	80	50	600	60–120
20	Qadri 2010 [33]	4	350 µs	80	50	-	60–120
21	Gómez 2010 [44]		2 ms	75	10	200	60
22	Jensen 2010 [45]	7	250 µs	-	50	-	-

3.3.1 Overall risk of bias judgment

Although most studies carried "some concerns" across multiple domains, overall judgments followed RoB 2 guidance by reflecting a comprehensive appraisal rather than a simple accumulation of domain-level ratings. Recurring limitations included absent of allocation concealment reporting, lack of participant and operator blinding, and no pre-registered analysis plans. They were consistently counterbalanced by important methodological strengths such as split-mouth designs controlling for inter-individual confounding, blinded outcome assessors, standardized protocols, objective outcome measures, and low attrition. While concerns spanned multiple domains, the overall rating of "some concerns" was maintained when limitations were judged unlikely to materially alter the direction or magnitude of the primary outcomes, given the robustness and consistency of results across the included evidence.

3.3.2 Adaptation of RoB 2 for split-mouth designs

The standard RoB 2 tool was applied to all included trials, including those employing split-mouth designs. Although split-mouth trials share structural similarities with crossover designs, they differ fundamentally in that interventions are delivered concurrently to separate sites in the same patient rather than sequentially. This renders the crossover-specific RoB 2 variant inapplicable, as its central domains, carry-over effects and washout period adequacy, are not relevant to split-mouth methodology. Consistently, none of the included split-mouth studies included a washout period, which reflects the nature of simultaneous site-level allocation rather than a methodological shortcoming. The standard RoB 2 tool was therefore the most appropriate, with domain-level judgments contextually adapted where necessary particularly in Domain 1, where randomization was evaluated at the site rather than the patient level.

3.4 Meta-analysis results

3.4.1 Effect of ND YAG + SRP on PD reduction

Across the 12 included studies (244 observations per arm), the pooled analysis showed a consistent tendency toward greater improvement in the ND: YAG laser + SRP groups compared with SRP alone. Individual studies show differences varied, with several trials, such as those by Dortaj 2021, Abduljabbar 2017, and Qadri 2013/2010, demonstrating clear reductions favoring the combined therapy. Using the random-effects model, the pooled mean difference was -0.46 mm (95% CI -0.82 to -0.10, $p=0.0117$), indicating that adjunctive ND: YAG laser with SRP achieved a statistically significant overall benefit compared with SRP alone. Substantial heterogeneity was detected ($I^2 = 74.5\%$,

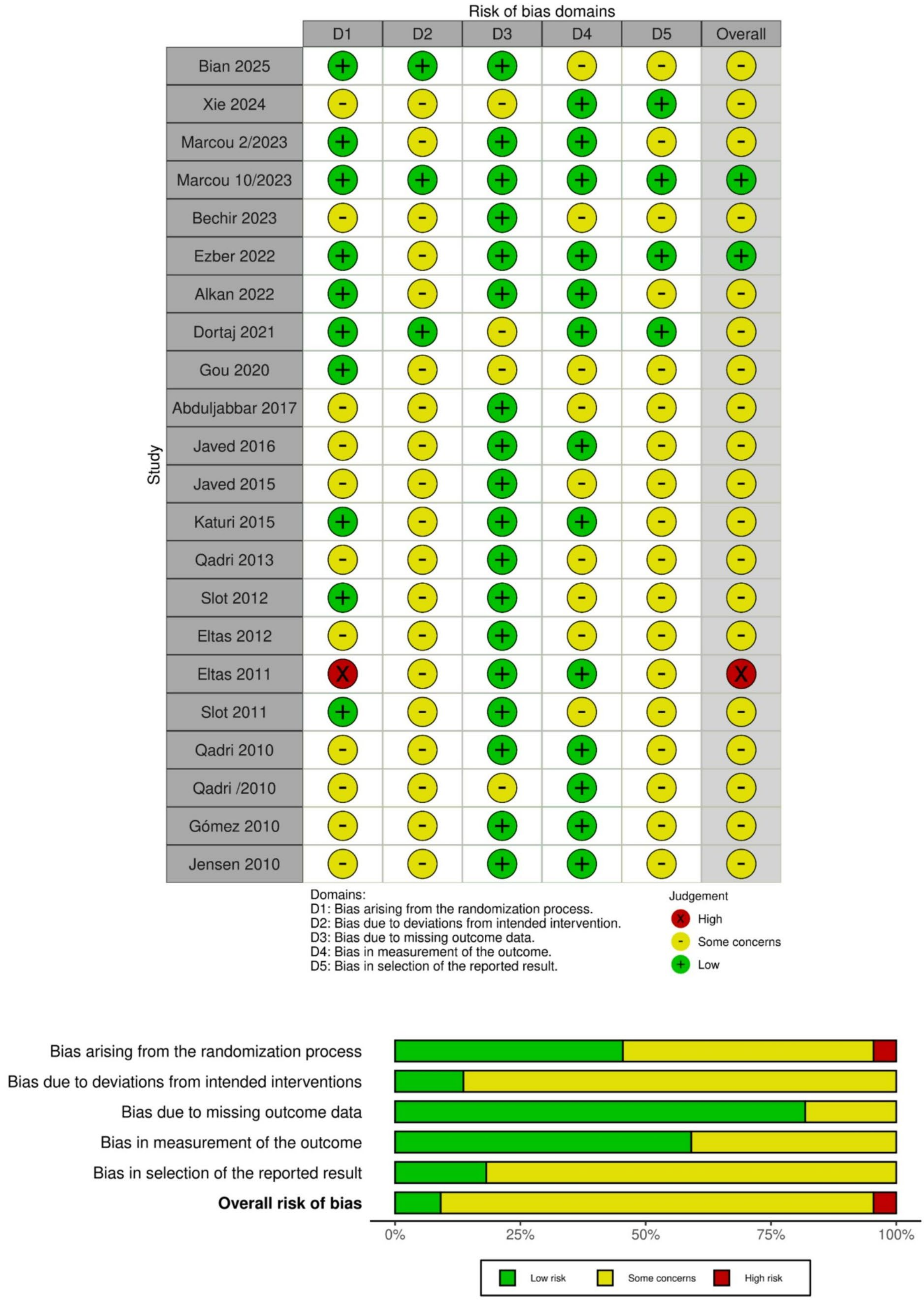


Fig. 2 Quality assessment using ROB2

$\tau^2 = 0.30$), and the Q-test confirmed significant variability among studies (Q = 43.19, $p < 0.0001$) (Fig. 3A).

3.4.2 Publication bias of the effect of ND YAG + SRP on PD reduction

Egger's test showed no evidence of publication bias (t = 0.32, df = 10, $p = 0.75$). The bias coefficient (1.04, SE = 3.20) indicated no small-study effects. The high p-value suggests a symmetrical funnel plot and minimal risk of selective reporting. Residual heterogeneity ($\tau^2 = 2.51$) indicated moderate variability, consistent with the observed $I^2 \approx 56\%$ (Fig. 3B).

3.4.3 Effect on PI outcomes

Six studies were included in this analysis, comprising 252 observations divided equally between the ND: YAG + SRP group ($n = 126$) and the SRP-only group ($n = 126$). The random-effects model showed a pooled mean difference of −0.03 (95% CI −0.19 to 0.13, $p = 0.63$), indicating no

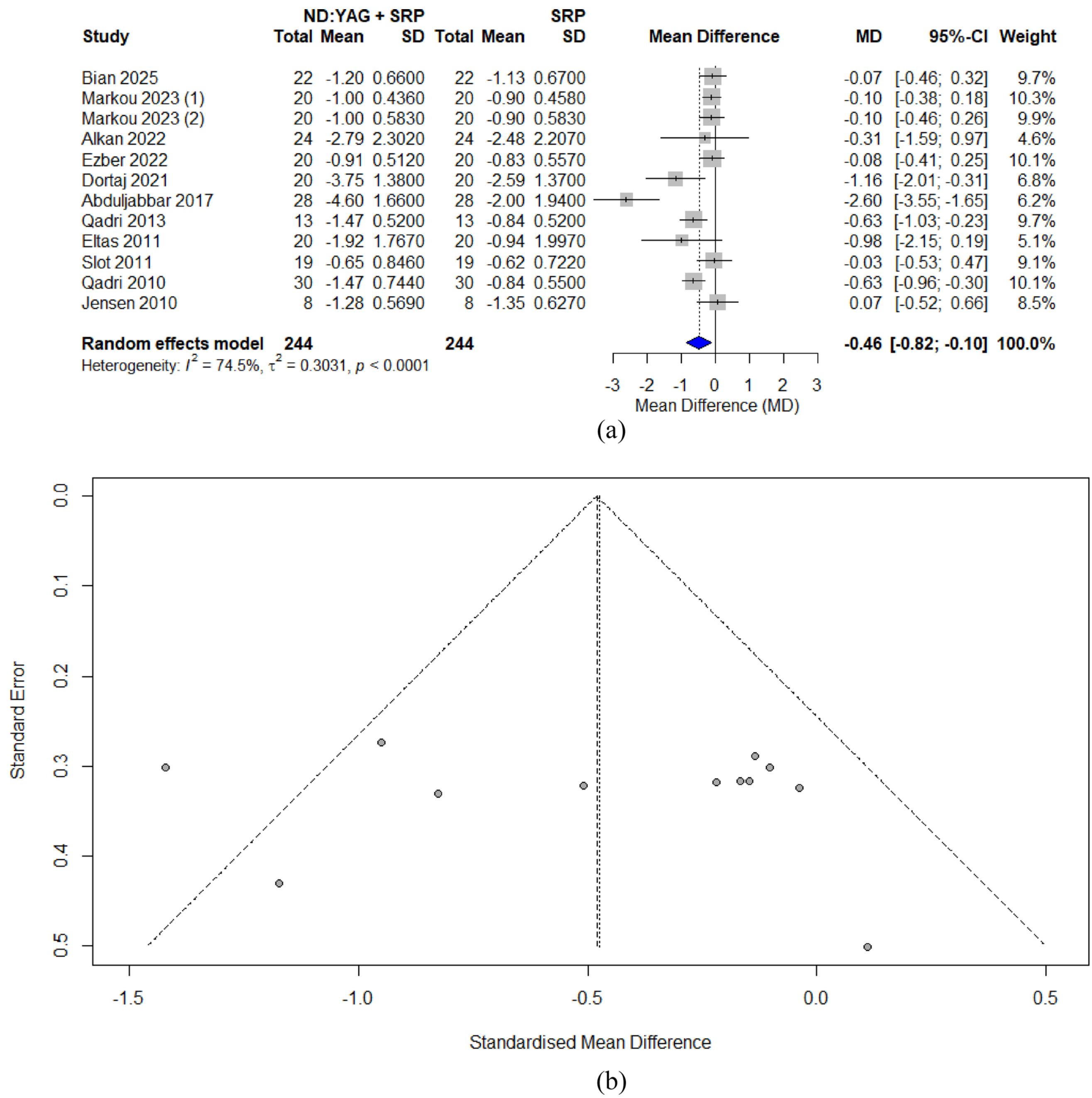


Fig. 3 **a** Effect of ND YAG + SRP on PD reduction. **b** Publication bias of the effect of ND YAG + SRP on PD reduction

statistically significant difference between adjunctive ND: YAG laser therapy and SRP alone for this outcome. Heterogeneity was minimal, with I² = 0% and τ² estimated as zero, and the Q-test was non-significant (Q = 3.55, $p = 0.62$), confirming the absence of meaningful between-study variability (Fig. 4A).

3.4.4 Effect on CAL outcomes

Seven studies were included in this meta-analysis, comprising 292 observations equally divided between the ND: YAG + SRP group ($n = 146$) and the SRP-only group ($n = 146$). The random-effects model yielded a pooled mean difference of −0.04 mm (95% CI −0.21 to 0.13, $p = 0.61$), indicating no statistically significant advantage of adjunctive ND: YAG laser therapy over SRP alone for this outcome. Heterogeneity was negligible, with I² = 0% and τ² estimated as zero, and the Q-test was non-significant (Q = 3.04, $p = 0.80$), confirming the absence of between-study variability (Fig. 4B).

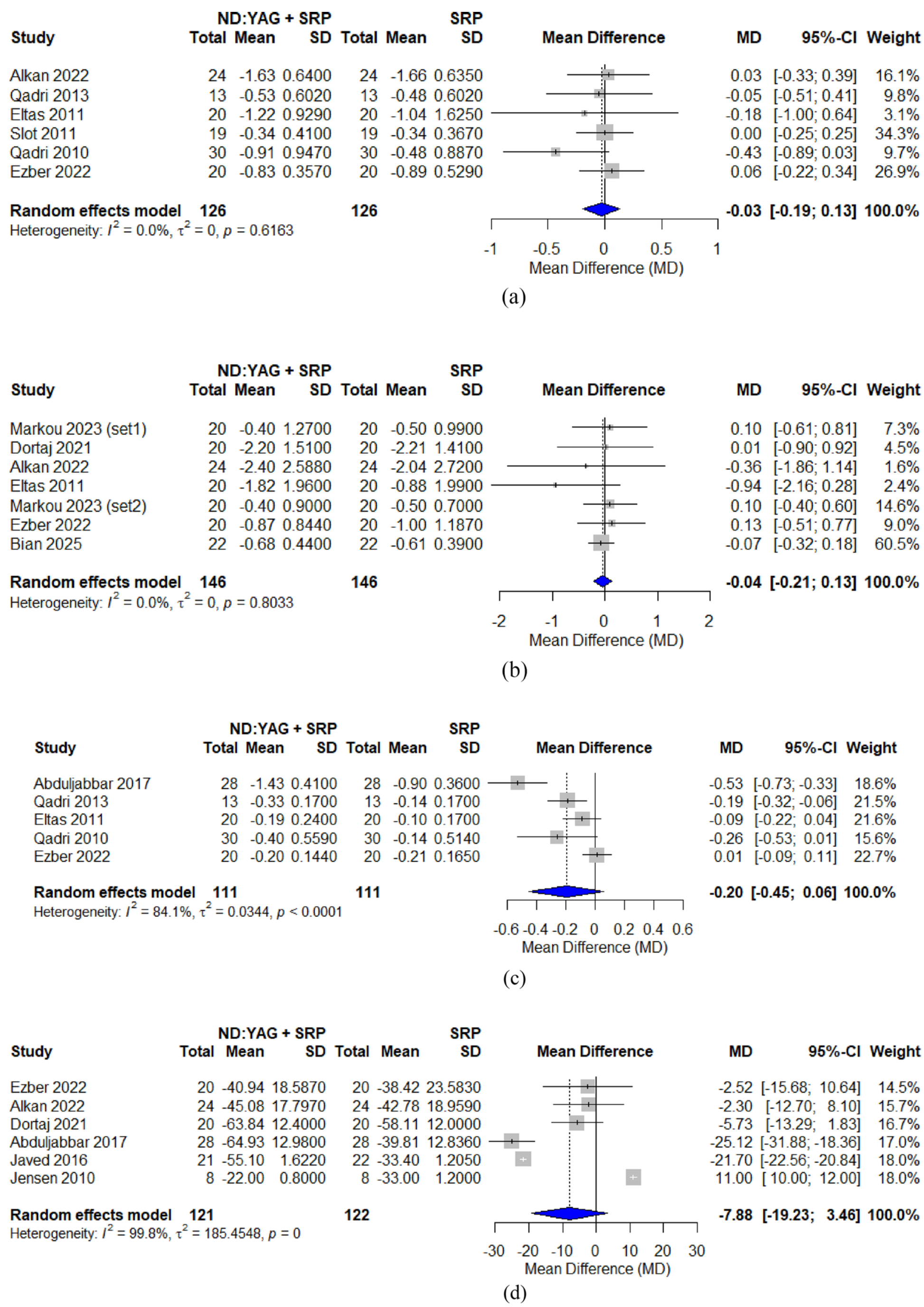


Fig. 4 **A** Effect on PI outcomes. **B** Effect on CAL outcomes. **C** Effect on GCF volume outcomes. **D** Effect on BOP outcomes

3.4.5 Effect on GCF volume outcomes

Five studies were included, totaling 222 observations, equally distributed between the ND: YAG+SRP group ($n=111$) and the SRP-only group ($n=111$). The random-effects model showed a pooled mean difference of −0.20 µl (95% CI −0.45 to 0.06, $p=0.097$), indicating no statistically significant difference between adjunctive ND: YAG laser therapy and SRP alone, although the effect trended in favor of the combined approach. Heterogeneity was substantial (I^2 = 84.1%, τ^2 = 0.034), and the Q-test was highly significant (Q=25.19, $p<0.0001$), demonstrating considerable variability in effect sizes across the included studies (Fig. 4C).

3.4.6 Effect on BOP outcomes

Six studies were included, with 243 total observations (121 in the ND: YAG+SRP group and 122 in the SRP-only group). The individual study effects showed substantial variability, ranging from large negative mean differences favoring ND: YAG+SRP (e.g., Abduljabbar 2017 and Javed 2016) to a positive effect favoring SRP alone (Jensen 2010). The random-effects model produced a pooled mean difference of −7.88 (95% CI −19.23 to 3.46, $p=0.17$), indicating no statistically significant difference between the interventions. Heterogeneity was extremely high (I^2 = 99.8%, τ^2 = 185.45), and the Q-test was significant (Q=2396.45, $p<0.001$), confirming substantial heterogeneity across the included studies and suggesting that the pooled estimate should be interpreted with caution (Fig. 4D).

3.4.7 Subgrouping analysis

3.4.7.1 The effect of ND YAG+SRP on PD reduction according to technique The meta-analysis included 12 randomized controlled trials evaluating the effect of ND: YAG laser, used as an adjunct to scaling and root planing, on PD reduction. Overall, the random-effects model demonstrated a statistically significant additional improvement in PD in favor of the laser group (MD=−0.46 mm; 95% CI −0.82 to −0.10; $p=0.0117$), although substantial heterogeneity was present (I^2 = 74.5%). Subgroup analysis based on study design showed that split-mouth RCTs (eight studies) reported a larger and statistically significant reduction in PD (MD=−0.66 mm; 95% CI −1.25 to −0.07; I^2 = 79.3%). In contrast, parallel-group RCTs (four studies) demonstrated a smaller, non-significant effect size (MD=−0.20 mm; 95% CI −0.44 to 0.03; I^2 = 47.5%). However, the test for subgroup differences was not statistically significant ($p=0.163$), indicating that the overall treatment effect did not differ meaningfully between split-mouth and parallel-group study designs (Fig. 5).

3.4.8 Sensitivity analysis

3.4.8.1 The effect of ND YAG+SRP on PD reduction The leave-one-out meta-analysis evaluates the stability of the pooled effect by sequentially excluding each individual study and re-estimating the overall meta-analytic results. This method allows assessment of whether the overall effect size is unduly driven by any single study. In this analysis, the overall random effects model yielded a mean difference MD of -0.4608 mm with a 95% CI of [-0.8189, -0.1027], and a statistically significant p-value of 0.0117, indicating a moderate overall effect. The between-study variance (tau^2) was 0.3031, and the heterogeneity, measured by I^2, was 74.5%, suggesting substantial variability among studies. Examining the leave-one-out results, we observe that omitting individual studies changes the MD slightly, ranging from −0.2736 (after removing Abduljabbar 2017) to -0.5156 (after removing Jensen 2010). Importantly, all resulting 95% CIs remain below zero, and p-values remain significant (all < 0.03), indicating that no single study dramatically alters the direction or significance of the overall effect. Heterogeneity remains relatively high across most leave-one-out scenarios, with I^2 values ranging from 49.8% to 76.8% and tau values ranging from 0.2160 to 0.6037. Notably, removing Abduljabbar 2017 reduces both tau and I^2 considerably (tau=0.2160, I^2 = 49.8%), suggesting that this study contributes less to between-study variability, whereas other studies contribute more to overall heterogeneity (Fig. 6A).

3.4.8.2 Meta-analysis of Gingival Crevicular Fluid (GCF) volume This leave-one-out meta-analysis examines the robustness of the overall effect by systematically omitting each study and recalculating the pooled estimate. The overall random effects model shows a mean difference MD of -0.1970 µl with a 95% CI of [-0.4508, 0.0568] and a p-value of 0.0974, indicating that the pooled effect is not statistically significant. The between-study variance (tau^2) is 0.0344, and heterogeneity is high (I^2 = 84.1%), suggesting considerable variability among the included studies.

Examining the leave-one-out results, the MD shifts slightly when individual studies are removed, ranging from −0.1050 (omitting Abduljabbar 2017) to -0.2560 (omitting Ezber 2022). None of the 95% CIs exclude zero, and all p-values remain above 0.05, indicating that no single study drives a statistically significant effect. This suggests that the

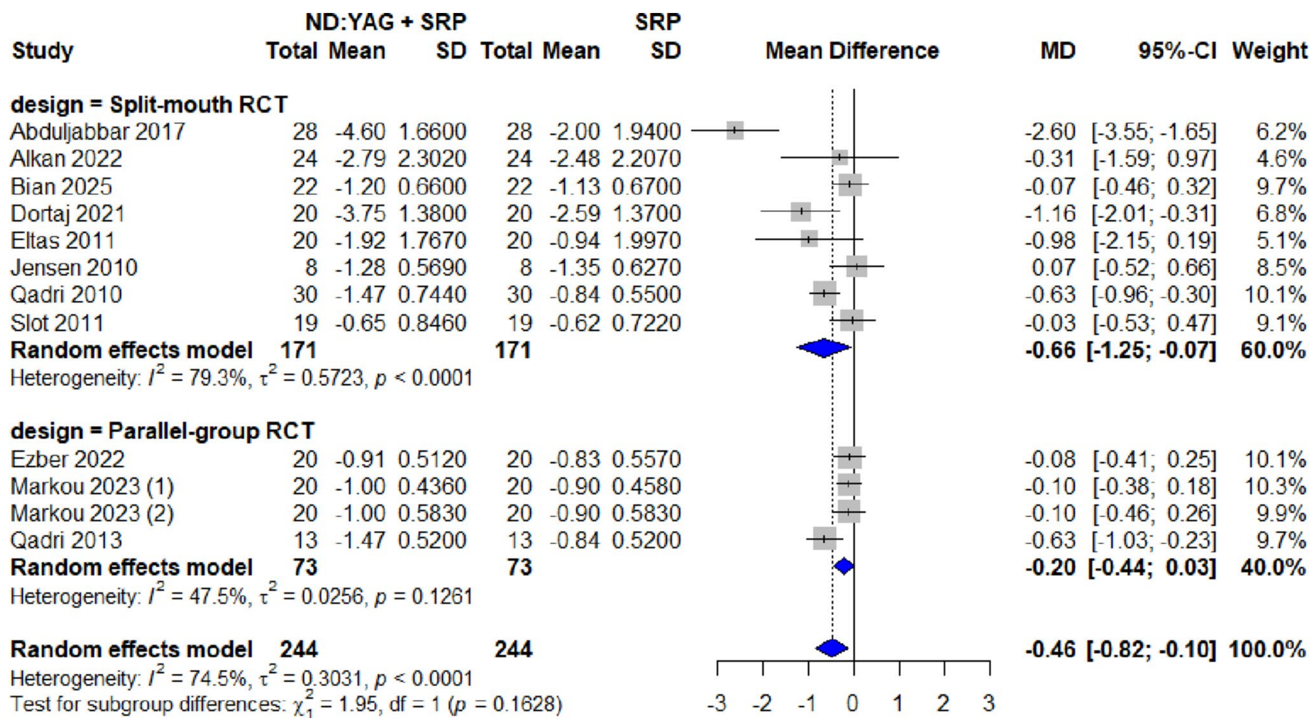


Fig. 5 The effect of ND YAG + SRP on PD reduction according to technique

non-significant finding of the meta-analysis is robust to the removal of any single study.

Heterogeneity, measured by I^2, varies across scenarios. Omitting Abduljabbar 2017 reduces I^2 to 61.6%, while removing Qadri 2013, Eltas 2011, or Qadri 2010 increases I^2 to above 87%, showing that these studies contribute substantially to overall heterogeneity. The tau values similarly fluctuate, reflecting the changes in between-study variance (Fig. 6B).

3.4.8.3 Meta-analysis of BOP This leave-one-out meta-analysis evaluates the stability of the overall pooled effect by systematically omitting each study and recalculating the MD. The overall random effects model shows an MD of -7.8812 with a 95% CI of [-19.2257, 3.4634] and a p-value of 0.1733, indicating that the overall effect is not statistically significant. The between-study variance is very high (tau^2 = 185.4548, tau = 13.6182) and heterogeneity is extreme (I^2 = 99.8%), reflecting substantial variability among the included studies.

When examining the leave-one-out results, the MD shifts modestly depending on the study removed, ranging from −4.3779 (omitting Abduljabbar 2017) to -12.3845 (omitting Jensen 2010). Notably, removing Jensen 2010 produces a statistically significant MD (-12.3845, 95% CI [-22.1877, -2.5814], p = 0.0133), suggesting that this study has a strong influence on the pooled estimate. In contrast, omitting other studies does not yield statistically significant effects, indicating that the overall non-significant finding is generally robust to the removal of individual studies.

Heterogeneity remains extremely high in all leave-one-out scenarios, with I^2 values ranging from 89.7% (omitting Jensen 2010) to 99.8%, indicating that between-study variability dominates the analysis. Tau^2 values also vary substantially, with the lowest observed when Jensen 2010 is omitted (106.8282), suggesting that this study contributes meaningfully to overall heterogeneity (Fig. 6C).

3.4.9 Certainty of evidence based on GRADE assessment

Across the assessed outcomes, the certainty of evidence ranged from low to very low according to the GRADE approach. For PD, the evidence was rated as low certainty, mainly due to serious risk of bias and serious inconsistency, with no serious imprecision detected and no evidence of publication bias. For PI and CAL, the certainty of evidence was very low, driven by serious risk of bias, serious inconsistency, and in some cases serious imprecision, indicating limited confidence in these effect estimates. BOP and GCF outcomes were rated as low certainty evidence, downgraded due to serious risk of bias and inconsistency, while imprecision was not considered serious (Table 3).

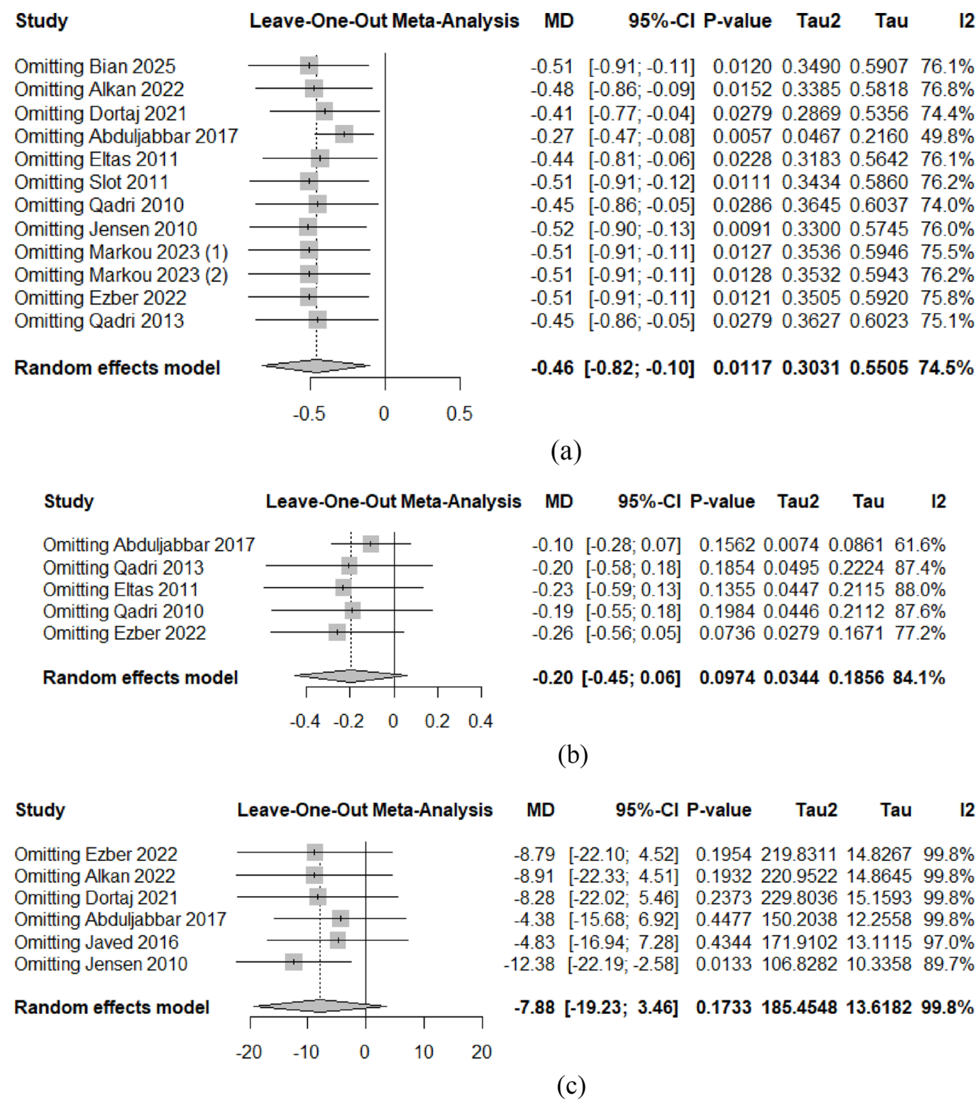


Fig. 6 **A** The Effect of ND YAG + SRP on PD Reduction (sensitivity). **B** Meta-analysis of Gingival Crevicular Fluid (GCF) Volume (sensitivity). **C** Meta-analysis of BOP (sensitivity)

Table 3 Certainty of evidence based on GRADE assessment

Outcome	No. of studies	Study design	Risk of bias	Inconsistency	Imprecision	Publication bias	Overall certainty of evidence
PD	12	RCT	Serious (-1)	Serious (-1)	Not serious	Undetected	Low
PI	6	RCT	Serious (-1)	Serious (-1)	Serious (-1)	Not assessed	Very low
BOP	7	RCT	Serious (-1)	Serious (-1)	Not serious	Not assessed	Low
CAL	7	RCT	Serious (-1)	Serious (-1)	Serious (-1)	Not assessed	Very low
GCF	5	RCT	Serious (-1)	Serious (-1)	Not serious	Not assessed	Low

4 Discussion

This systematic review and meta-analysis discuss the reliability of Nd-YAG laser therapy for the healing of periodontal pockets in patients with periodontitis, used as an adjunct to SRP. This comparison tested whether Nd-YAG laser therapy provides an additional benefit when used as an adjunct to SRP alone. The findings of this meta-analysis proposed that adjunct Nd-YAG to SRP could show statistically significant extra healing capacity through reduction of pocket depth (PD); however, neither plaque index (PI), clinical attachment loss gain (CAL), bleeding on probing (BOP), nor gingival cervical fluid (GCF) could show statistically significant clinical benefit despite minute improvement in healing periodontal outcomes. These discrepancies in results may be justified by significant heterogeneity among the included studies.

Nd: YAG laser protocols varied substantially across the included studies. Average power settings ranged from subablative low-level therapy to high-energy surgical debridement. Pulse durations were similarly diverse, with short pulses utilized for precise tissue vaporization and long pulses for hemostasis and fibrin clot stabilization. Consequently, thermal mitigation was dose-dependent; high-power applications required continuous air and water cooling to prevent thermal necrosis, whereas low-energy protocols safely operated without cooling.

The literature shows considerable heterogeneity across clinical studies, including study designs, laser parameters, and treatment guidelines, making decision-making difficult. For long-term clinical outcomes, the literature cannot provide a definitive conclusion on the superiority of laser therapies over conventional non-surgical therapy [46]. Moreover, previous systematic reviews and meta-analyses evaluating Nd-YAG laser-assisted therapy have included a small number of clinical trials with confounding baseline characteristics, varied methodologies, short follow-up durations, and a high risk of bias, which cannot support a clear recommendation for a specific treatment protocol [47–50].

Many previous reviews before 2022 included fewer studies and may have underestimated the effect estimates for different laser types or reported mixed-level evidence due to language or database restrictions. Our approach also applied stricter inclusion criteria by focusing on trials with direct Nd: YAG adjunct comparisons [47, 50, 51].

The 0.46 mm reduction in probing depth, while statistically significant ($p = 0.0117$), falls slightly below the traditional 0.5–1.0 mm threshold considered clinically relevant [52]. This difference coincides with the minimum clinically important significance of PD reduction, as large pockets of > 5 mm are associated with active disease development, while a decrease in PD reduction < = 3 mm indicates periodontal stability for the treatment modality [53]. The preservation of this range of reduction in probing depth, associated with maintaining the clinical attachment, could be a sign of the selective biological mechanism of Nd: YAG 1064 nm. Obviously, subgroup analysis showed that split-mouth RCTs demonstrated more reduction (MD = -0.66 mm, $p < 0.05$), while parallel-group RCTs showed a smaller, non-significant effect (MD = -0.20 mm). Despite the test for subgroup differences not being statistically significant ($p = 0.163$), the split-mouth design eliminates inter-individual variability and may be able to predict treatment effects, clarifying that the actual clinical effect size may not be detectable in parallel-group trials dominated by baseline heterogeneity. The laser-generated thermal energy effectively but non-selectively has bactericidal effect on pathogens in the periodontal pocket biofilm [54]. This aligns with its advantage in reducing inflammation and promoting hemostasis. On the other hand, the non-statistically significant difference in reading of CAL can be justified by the limited ability of the Nd-YAG laser to penetrate periodontal ligament tissue. Such an explanation is supported by studies showing that the Nd: YAG laser is highly efficient at removing red complex bacteria, namely *Porphyromonas gingivalis*, *Treponema denticola*, and *Tannerella forsythia*, and at the same time facilitating wound healing [29]. Such findings indicate that Nd-YAG laser adjunctive treatment may be a viable option for patients with pockets of moderate depth or greater (≥ 5 mm) in which standard SRP results in insufficient reduction in pocket depth. The lack of a significant improvement in the plaque index indicates that laser therapy is in line with thorough mechanical debridement and patient oral hygiene practices as a support, but not as a substitute [55, 56].

Abduljabbar et al. (2017) found a statistically significant increase in probing depth with adjunctive Nd: YAG laser therapy [34]. This result closely matches our meta-analysis findings, with a statistically significant reduction in PD (MD = -2.60 mm, $p < 0.05$). Abduljabbar's methodology, which used 4 W power with 80 mJ/pulse at 50 Hz in a 28-patient split-mouth design focusing on diabetic patients, may explain its significant effect. However, the sensitivity analysis identified Abduljabbar 2017 as the largest contributor to heterogeneity, which could explain the noticeable clinical advantage in the test group. Its removal reduced heterogenic variation, suggesting its results may not be generalizable to all clinical settings or patient populations. Their results align with PD reduction in a conclusive overall view, while the Qadri et al. (2010, 2013) RCT results partially align with our meta-analysis, specifically in PD reduction numbers. However, their significant plaque index results disagree with our non-significant PI findings. This could be explained by using a special laser parameter: a water-cooled Nd: YAG laser at 4 W, 80 mJ/pulse, and 50 Hz. Sensitivity analysis for GCF indicated that Qadri studies (2010, 2013) played an extraordinary role in variability; this is shown statistically by the fact that removing them increased I^2 above 87%, indicating that their unique water-cooled system produced effects that differ from conventional Nd-YAG protocols. Eltas et al. (2011) and Ezber et al. (2022) reported a slight improvement in periodontal parameters following Nd: YAG laser therapy, with small effect sizes for PD and CAL [24, 27]. Results support the discussed interpretation that the Nd: YAG laser predicts supplemental clinical benefits and reports positive outcomes with Nd: YAG laser adjunctive therapy, particularly in probing depth reduction and improvement in bleeding on probing. Their findings contribute to the overall positive pooled effect observed in our analysis. Moreover, Slot et al. (2011) used a water-cooled Nd: YAG laser as adjunctive periodontal therapy; their results showed a statistically significant improvement in clinical parameters, observed only in moderate to deep pockets [40]. This could shed light on the suggestion of using Nd-YAG as an adjunct for only deeper periodontal pockets (> 4 mm) where conventional therapy alone is insufficient. Another drawback is post-operative discomfort in laser-treated sites.

On the other hand, Jensen et al. (2010) disagreed that the results showed no significant advantage of Nd: YAG laser therapy over the gold standard SRP [45]. The RCT clarified the approximate PD reduction in test sites (1.18 mm) and control sites (1.35 mm) at six-month follow-up, demonstrating no additional benefit of SRP alone. This result disagrees sharply with our positive meta-analysis results due to the use of 5 W to 7 W in a two-phase treatment protocol as a pilot study with a very small sample, compared to 1.5–2.5 W in a one-phase treatment protocol and a larger sample size used in most other included studies. Removing this study from the analysis significantly strengthened the findings for bleeding on probing (BOP). Originally, the combined results across studies showed no meaningful difference (MD = -7.88, p = 0.17), but excluding this outlier study revealed a statistically significant improvement (MD = -12.38, p = 0.0133). Heterogeneity also improved, dropping from an extremely high 99.8% to 89.7%, though it remained problematically high. Additionally, Alkan et al. (2022) tested combined air polishing and Nd: YAG laser application; their results showed an advantageous effect only in deep pockets (PD ≥ 7 mm), with no additional improvement in moderately deep pockets (5–6 mm) [25]. This results in the selective partial justification of the moderate effect size noticed in our meta-analysis. Their results support targeted application of laser therapy rather than universal adjunctive use. This is an indication that Nd-YAG adjunctive therapy is dependent on a PD diagnosis. Meanwhile, Markou et al. (2023) conducted a clinical comparison of single- and double-Nd: YAG laser treatments [38]. There was no statistically significant difference between the two groups. Markou's results, controversially, agree with the clinical significance of our meta-analysis, suggesting that there is minimal statistically significant advantage of laser adjunctive therapy.

Nevertheless, the systematic review by Roncati and Gariffo in 2014, which included a wide range of laser studies, analyzed different study qualities, contributed to their cautionary conclusions about clinical usefulness, and left the answers rather vague [47]. In contrast, Zhao et al. (2016) narrowed their focus to Nd: YAG lasers and did find significant differences in probing depth, gingival fluid, and inflammation markers at the 12-week mark—but their results came with massive heterogeneity (I^2 = 85.8%), likely because included studies varied widely in protocols, follow-up periods, and patient selection [48]. Theodoro and colleagues (2021), meanwhile, focused on diode lasers and used stricter clinical parameters, reporting statistically significant gains but stressing that the overall clinical relevance for attachment gain remains quite limited [57]. Our modest PD benefit (MD = -0.46 mm) with substantial heterogeneity (I^2 = 74.5%) aligns with previous reviews that report conflicting evidence. However, our study advances the literature by: including 22 RCTs involving 776 patients versus 6–12 studies in prior reviews, restricting analysis exclusively to Nd-YAG 1064 nm rather than mixing laser types, conducting comprehensive subgroup analyses revealing design-dependent effects (split-mouth MD = -0.66 mm versus parallel-group MD = -0.20 mm), and performing sensitivity analyses identifying specific outlier studies (Jensen 2010, Abduljabbar 2017) that disproportionately influence pooled estimates. Unlike Zhao et al. (2016), who reported I^2 = 85.8% without sensitivity analysis, we demonstrate through leave-one-out analyses that PD effect stability depends critically on the removal of high-heterogeneity contributors, with I^2 ranging from 49.8% to 76.8% across scenarios.

4.1 Future directions and limitations

While this analysis suggests a potential benefit of an adjunct Nd: YAG laser for pocket depth reduction, the findings are limited by significant variability in study methods and laser parameters, which preclude strong clinical recommendations. Future research should focus on standardized, high-quality trials with long-term follow-up to conclusively determine which specific patient populations and clinical scenarios derive the possible application of this adjunctive therapy.

A critical variable in interpreting the efficacy of adjunctive laser therapy is the high degree of heterogeneity in the applied photobiological parameters. The therapeutic outcomes of 1064 nm Nd: YAG lasers in the included studies were heavily dependent on peak power, pulse duration, and thermal mitigation strategies. Average power settings ranged widely from low-level applications (e.g., 0.5 to 1.5 W) up to ablative surgical settings of 6.0 W to 7.0 W. Furthermore, pulse durations varied significantly; short pulses (100–120 µs) were frequently employed for targeted epithelial ablation, while longer pulses (up to 600–635 µs) were utilized in dual-pass protocols to facilitate fibrin clot stabilization. To mitigate the risk of thermal necrosis associated with higher power outputs (≥4.0 W), continuous air and water cooling mechanisms were frequently employed, distinguishing these protocols from low-power applications where cooling was minimal or absent. This variability in dosimetry underscores the need for standardized laser parameters in future randomized controlled trials to isolate the precise biological mechanisms of pocket sterilization and tissue regeneration.

5 Conclusion

Adjunctive use of the Nd: YAG laser (1064 nm) with SRP provides a statistically significant and clinically moderate additional reduction in probing depth compared to SRP alone. In this context, "clinically moderate" is defined as an adjunctive probing depth reduction of less than 1.0 mm. However, it does not appear to offer significant benefits in improving clinical attachment levels or reducing plaque. The evidence for its effect on bleeding and inflammation is uncertain. Therefore, while the Nd: YAG laser may be a beneficial adjunct for reducing pocket depth, its routine use cannot be universally recommended based on current evidence, underscoring the need for further standardized, high-quality RCTs.

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Author contributions A.A.[1] and A.H.S.W.[6] conceived and designed the systematic review and meta-analysis and supervised the overall study. A.T.[2] and R.W.[2] developed the search strategy and conducted the literature search. K.A.[4] and A.E. [7] screened titles/abstracts and full texts according to the eligibility criteria. A.S.I.A.E.A.E.[5], A.H.S.W.[6], and R.W.[3] performed data extraction and assessed study quality and risk of bias. A.A.[1], A.E.[7] , and K.A.[4] conducted the statistical analysis and meta-analysis. All authors contributed to data interpretation, manuscript drafting, and critical revision, and approved the final version of the manuscript.

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Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval Not applicable.

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