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Clinical Efficacy of Low-Level Laser Therapy as an Adjunct to Non-Surgical Treatment of Peri-implantitis: A Systematic Review and Meta-Analysis

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Abstract

Title: Clinical Efficacy of Low-Level Laser Therapy as an Adjunct to Non-Surgical Treatment of Peri-implantitis: A Systematic Review and Meta-Analysis

Purpose: To evaluate the clinical effectiveness of low-level laser therapy (LLLT) modalities and antimicrobial photodynamic therapy (aPDT) as adjuncts to non-surgical mechanical debridement for peri-implantitis management.

Materials and Methods: An electronic search of PubMed/MEDLINE, and the Cochrane Library was conducted for randomized controlled trials (RCTs) published up to May 2025. Meta-analyses were performed for Probing Depth (PD), Bleeding on Probing (BOP), Plaque Index (PI), and Radiographic Marginal Bone Loss (RMBL) at approximately 6 months (range 3–9 months). Mean differences (MD) with 95% confidence intervals (CI) were calculated using random-effects models.

Results: Fifteen RCTs (644 patients; 742 implants) met the inclusion criteria. Adjunctive laser therapy was associated with significant reductions in PD (MD − 0.34 mm; 95% CI − 0.67 to − 0.01; p = 0.044), BOP (MD − 0.28; 95% CI − 0.53 to − 0.03; p = 0.03), and PI (MD − 0.44; 95% CI − 0.55 to − 0.33; p < 0.0001). No significant difference was observed for RMBL (MD 0.16 mm; 95% CI − 0.24 to 0.55; p = 0.43). Substantial heterogeneity was present for PD (I^2 = 91.3%) and PI (I^2 = 86%).

Conclusions: Adjunctive LLLT, particularly Er,Cr:YSGG and aPDT, improves short-term clinical outcomes in non-surgical peri-implantitis treatment. Clinical effectiveness is highly dependent on laser modality and applied protocol, highlighting the need for standardized, evidence-based treatment protocols.

Introduction

Dental implants are highly reliable with predictable long-term outcomes(1, 2). However, this is not without biological complications, primarily peri-implantitis, a plaque-associated pathological condition characterized by inflammation in the peri-implant mucosa and subsequent progressive loss of supporting bone(3).The prevalence of peri-implantitis is significant, affecting approximately 19–20% of patients and 12–13% of implants(4).

Peri-implantitis can be managed through surgical or non-surgical methods. Non-surgical methods are less invasive, resulting in minor tissue trauma and faster recovery, making them the first-line treatment in early stages(5). These methods include mechanical debridement with or without disinfecting agents and low-level laser therapy (LLLT). The primary goal is to decontaminate the implant surface, enhance soft tissue healing, control inflammation, and support peri-implant tissue stability and osseointegration.

LLLT is an emerging technique for non-surgical management, utilizing wavelengths in the near-infrared and infrared regions (800–2940 nm). The rationale for laser useage is mainly: first, to achieve effective surface decontamination without altering the titanium topography, and second, to stimulate surrounding tissue through photobiomodulation. This interaction modulates inflammatory mediators and enhances

local ATP production, which can accelerate mucosal healing and reduce postoperative discomfort—factors particularly relevant when treating systemically compromised patients(6, 7).

Commonly used lasers include Diode (800–980 nm), Nd:YAG (1064 nm), Er,Cr:YSGG (2780 nm), and Er:YAG (2940 nm).

The clinical application of these devices is largely dictated by their wavelength. Diode (800–980 nm) and Nd:YAG (1064 nm) lasers are highly absorbed by pigmented tissues, allowing for deep soft-tissue penetration and bacterial reduction(8, 9); diodes are also frequently employed to activate photosensitizers during antimicrobial photodynamic therapy (aPDT). Nd:YAG lasers offer deeper penetration for bacterial reduction(9). Conversely, Erbium-family lasers (Er:YAG at 2940 nm and Er,Cr:YSGG at 2780 nm) are highly absorbed by water and hydroxyapatite. This characteristic allows them to ablate calculus and disrupt biofilm directly on the implant surface while simultaneously debriding the adjacent inflamed mucosa, making them suitable for both soft and hard tissue decontamination(10, 11)."

Despite these benefits, there is a need for standardized protocols for adjunctive therapies in non-surgical management to support the development of definitive clinical guidelines. Therefore, the objective of this study was to conduct a systematic review and meta-analysis to evaluate the effectiveness of different laser modalities and aPDT as an adjunct to non-surgical treatment regarding clinical outcomes and radiographically assessed marginal bone loss.

Materials and Methods

Study Design and PICO Framework: This systematic review and meta-analysis was conducted in accordance with a pre-defined protocol and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA guidelines(12).The research question was structured using the PICO framework: (P) Adult patients with peri-implantitis around osseointegrated implants; (I) Non-surgical treatment using LLLT (Diode, Nd:YAG, Er:YAG, Er,Cr:YSGG, or aPDT) alone or as an adjunct to mechanical debridement; (C) Mechanical debridement alone or with other conventional adjuncts; (O) Changes in clinical parameters (PD, BOP, PI) and radiographic marginal bone loss (RMBL).

Eligibility Criteria

Inclusion criteria were randomized controlled trials (RCTs), controlled clinical trials (CCTs), and prospective cohort studies published in English involving human clinical trials of non-surgical LLLT for peri-implantitis. Exclusion criteria included animal studies, case reports, case series, review articles, and studies involving surgical interventions or histological analysis.

Search Strategy: A systematic electronic search was conducted in PubMed, the Cochrane Library, and MEDLINE for studies published up to May 2025. Keywords included "peri-implantitis," "low-level laser therapy," "photodynamic therapy," and specific laser types (e.g., "Er:YAG"). Boolean operators (AND, *)

were used to combine terms. Manual searches of reference lists were also performed to identify additional relevant studies.

Data Extraction and Quality Assessment

Data were extracted using a predefined form, capturing study characteristics, participant details, laser parameters (wavelength, power, energy density, sessions), and clinical outcomes at approximately 6 months (range 3–9 months). Methodological quality and risk of bias were independently evaluated using the modified Cochrane Risk of Bias 2.0 tool (RoB 2), rating studies as low risk, some concerns, or high risk across five key domains.

Statistical Analysis

Quantitative synthesis was performed using the Meta-Mar platform. Clinical outcomes (PD, BOP, PI) and RMBL were pooled using mean difference (MD) and standard deviations (SD). Heterogeneity was assessed using the I^2 statistic. Pooled analyses were performed using random-effects models to account for potential clinical and methodological heterogeneity among the included studies. Forest plots were generated to represent effect estimates and 95% confidence intervals. Publication bias was assessed via visual inspection of funnel plots, with statistical significance set at $p \leq 0.05$.

Results

Study Selection and Characteristics: The systematic search identified 146 records. After removing 35 duplicates and screening 111 unique records, 37 full-text articles were assessed for eligibility. Ultimately, 15 randomized controlled trials (RCTs) were included in both the qualitative synthesis and quantitative meta-analysis. These studies evaluated various laser modalities, including Diode, Nd:YAG, Er:YAG, Er,Cr:YSGG, and antimicrobial photodynamic therapy (aPDT). The total number of patients and implants across the included studies was 644 and 742, respectively. Follow-up periods were approximately **6 months (range 3–9 months)**.

Risk of Bias Assessment

The risk of bias assessment using the RoB 2 tool revealed that the majority of the included studies were of high methodological quality. Two studies demonstrated "some concerns" regarding the randomization process, but overall, the internal validity of the included trials was robust.

Meta-Analysis of Clinical Outcomes:

Probing Depth (PD)

Data from **15 studies** showed a statistically significant pooled reduction in PD favoring the adjunctive laser group (**MD: −0.34 mm; 95% CI: −0.67 to − 0.01; p = 0.044**).

Substantial heterogeneity was observed (**I^2 = 91.3%**).

Bleeding on Probing (BOP)

Analysis of **11 studies** demonstrated a significant reduction in BOP

(**MD: −0.28; 95% CI: −0.53 to − 0.03; p = 0.03**).

Moderate heterogeneity was noted (**I^2 = 47%**).

Plaque Index (PI)

Synthesis of **12 studies** revealed a highly statistically significant reduction in PI (**MD: −0.44; 95% CI: −0.55 to − 0.33; p < 0.0001**).

Heterogeneity was substantial (**I^2 = 86%**).

Radiographic Marginal Bone Loss (RMBL)

Data from **8 studies** showed no statistically significant difference between the laser and control groups (**MD: 0.16 mm; 95% CI: −0.24 to 0.55; p = 0.43**).

Moderate heterogeneity was observed (**I^2 = 63.8%**).

Publication Bias Visual inspection of funnel plots showed a generally symmetric distribution for BOP and RMBL, suggesting a low risk of publication bias. Some asymmetry was noted for PD and PI, particularly among smaller trials, which likely reflects clinical heterogeneity in laser protocols rather than significant bias.

Discussion

This systematic review evaluated the clinical effectiveness of low-level laser therapy (LLLT) as an adjunctive, non-surgical treatment for peri-implantitis. By synthesizing data exclusively from clinical trials—the highest tier of evidence—this review emphasizes outcomes that directly reflect patient-centered benefits(13). The findings demonstrated that laser efficacy is not uniform across types. Meta-analysis showed significant improvements in Probing Depth (PD) and Bleeding on Probing (BOP), and a highly significant reduction in Plaque Index (PI). However, no significant effect was observed for Radiographic Marginal Bone Loss (RMBL).

The present results align with earlier studies suggesting that adjunctive laser treatment can enhance soft tissue healing and decontamination(14). However, this review diverges from the American Academy of Periodontology best evidence review by Lin et al.(15), which reported limited effects. This discrepancy

may be attributed to our specific focus on non-surgical interventions and the inclusion of more recent clinical trials demonstrating a beneficial therapeutic role for LLLT and aPDT(14).

Er,Cr:YSGG lasers and aPDT generally achieved the most favorable results across multiple parameters. Er,Cr:YSGG lasers appear particularly advantageous for surface debridement and biofilm disruption without thermal damage to titanium surfaces(10). Similarly, aPDT showed consistent benefits, particularly among systemically compromised populations such as diabetic patients(16), likely due to its non-thermal antibacterial mechanism. In contrast, Er:YAG and Nd:YAG lasers demonstrated inconsistent or limited clinical benefits, which may reflect inappropriate power calibration or technique sensitivity(17). Diode lasers provided modest but reliable benefits, particularly for plaque reduction.

Clinically, the pooled reductions in PD (**− 0.34 mm**), BOP (**− 0.28**), and PI (**− 0.44**) are considered moderate but clinically meaningful for long-term implant stability. The substantial heterogeneity observed for PD (**I^2 = 91.3%**) and PI (**I^2 = 86%**) is likely due to diverse laser parameters, treatment sessions, and participant characteristics. Limitations of this review include the short-term follow-up at approximately **6 months (range 3–9 months)** and small sample sizes in several trials, which underscore the need for standardized clinical protocols and long-term monitoring.

The substantial heterogeneity observed for PD (I^2 = 91.3%) and PI (I^2 > 80%) likely reflects variability in laser wavelength, power settings, treatment protocols, and baseline disease severity. The 15 trials did not evaluate a single, standardized intervention ,they examined five fundamentally different laser modalities, each interacting with tissue through distinct physical and biological mechanisms., the applied laser parameters varied across trials; with power outputs ranging from 0.3W to 3.6W, and the number of treatment sessions ranging from one to four. Baseline disease severity also differed considerably, with PD inclusion thresholds ranging from ≥4mm to ≥6mm across studies, meaning that trials enrolling patients with deeper pockets had a greater mathematical potential for measurable reduction.Patient-level factors, including the inclusion of systemically compromised populations such as type II diabetic patients in two studies, further contributed to clinical heterogeneity.The use of a random-effects model was therefore the methodologically appropriate choice, as it accounts for this between-study variability and produces a more conservative, generalizable pooled estimate.

Formal subgroup analyses were not performed due to the limited number of studies per modality, and this should be considered when interpreting pooled estimates.

Conclusion

This meta-analysis demonstrates that the effectiveness of LLLT as an adjunctive treatment for non-surgical peri-implantitis is highly dependent on the specific laser modality used. Er,Cr:YSGG lasers and photodynamic therapy (PDT) consistently demonstrated the most favorable outcomes, showing significant improvements in clinical parameters. Diode lasers offered modest but reliable benefits, particularly for plaque reduction. In contrast, Er:YAG and Nd:YAG lasers showed inconsistent or limited

efficacy. These findings underscore the critical need for evidence-based laser selection and the development of standardized treatment protocols to optimize clinical outcomes.

Declarations

Artificial Intelligence Use Statement

During the preparation of this manuscript, the authors used ChatGPT (OpenAI, GPT-4) to assist with language editing and improving the clarity of the written text. Following the use of this tool, the authors reviewed and edited all content as needed. The authors take full responsibility for the accuracy, integrity, and originality of the published work.

Conflict of Interest

The authors declare no conflicts of interest.

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