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Low-Level Laser Therapy, Photobiomodulation, and Photodynamics with Photosensitizer Combination in Dentistry: A Systematic Review

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Abstract

Introduction: Photobiomodulation (PBM), photodynamic therapy (PDT), and combined therapies have recently attracted attention due to their potentially beneficial antimicrobial, analgesic, and regenerative properties in dentistry. Although PBM and PDT have been extensively studied separately, evidence regarding their combined application is limited. This study aimed to systematically review studies employing combined PBM + PDT protocols in dental and oral applications.

Methods: A systematic search of PubMed, ScienceDirect, ProQuest, DOAJ, and Google Scholar (2021–2025) identified original studies using combined PBM and PDT. Inclusion criteria: dental-related PBM + PDT, clear dosimetric parameters, English, primary research. Exclusion: PBM-only, PDT-only, non-dental studies, insufficient parameters Inclusion criteria: dental-related PBM and PDT; clearly reported dosimetric parameters; English language; primary research.

Results: Eight studies met eligibility criteria. Applications included oral mucositis management, orthodontic acceleration, endodontic disinfection, oral lesion therapy, antimicrobial modulation, and regenerative endodontics. Combined PBM + PDT demonstrated enhanced antimicrobial activity, reduced inflammatory markers, accelerated wound healing, and improved patient-reported outcomes compared with single-modality treatments.

Conclusion: PBM + PDT shows synergistic therapeutic potential across multiple dental fields. Despite promising outcomes, heterogeneity in parameters remains a limitation. Standardized protocols and high-quality clinical trials are required.

Keywords: Photobiomodulation, Photodynamics, Therapy-in-dentistry

Introduction

Photobiomodulation (PBM) and photodynamic therapy (PDT) are two biophotonic modalities increasingly used in dentistry due to their minimally invasive nature, ability to modulate inflammation, and potential to enhance tissue healing. PBM involves the use of low-level red or near-infrared light to stimulate mitochondrial activity, increase ATP production, modulate inflammatory signaling, and promote cellular proliferation and tissue regeneration. These effects have made PBM a valuable adjunct in managing postoperative pain, oral ulcerative conditions, periodontal inflammation, and wound healing.[1]

Meanwhile, PDT combines a photosensitizing agent with a specific light wavelength to generate reactive oxygen species capable of selectively destroying microorganisms or pathological cells. PDT has been widely implemented for antimicrobial decontamination, management of oral infections, treatment of oral mucositis, and reduction of the microbial load in endodontic and periodontal procedures. Its clinical advantages include minimal systemic effects, low risk of resistance development, and localized cytotoxicity.[2]

Although both modalities have shown individual therapeutic benefits, emerging evidence suggests that combining PBM and PDT may produce synergistic effects. PDT contributes to rapid microbial inactivation, while PBM supports mitochondrial recovery, enhances tissue repair, reduces inflammatory cytokines, and improves analgesic outcomes. When used sequentially or in integrated treatment protocols, PBM may potentiate the regenerative response following PDT-induced decontamination, making the combined approach especially promising in clinical scenarios where both infection control and tissue healing are essential.[1]

In dentistry, the PBM + PDT combination has been explored in various domains, including oral mucositis management, root canal disinfection, regenerative

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endodontic therapy, orthodontic acceleration, treatment of oral lichenoid and ulcerative lesions, and even in vitro anticancer strategies involving oral carcinoma cells. However, despite the increasing number of published PBM studies and PDT applications, research specifically evaluating their combined use remains limited and scattered, with variations in laser parameters, photosensitizers, dosimetry, and treatment protocols.[2]

Given the growing interest in biophotonics and the potential of PBM + PDT to enhance therapeutic outcomes, a systematic evaluation of the available evidence is urgently needed. Such a review may clarify the clinical relevance of this combination, identify areas where synergy is most pronounced, and highlight opportunities for protocol standardization and future research.

This systematic review, therefore, aims to synthesize current studies investigating the combined application of PBM and PDT in dentistry, evaluate their therapeutic effectiveness, and outline the implications of this biophotonic approach for clinical practice.

Aim of the Study

The aim of this systematic review is to critically evaluate and synthesize current evidence on the combined application of photobiomodulation (PBM) and photodynamic therapy (PDT) in dentistry. Specifically, this review seeks to:

1. Identify and analyze clinical, in vivo, and in vitro studies that utilize PBM and PDT together in dental or oral health contexts.
2. Assess the therapeutic effectiveness of PBM + PDT combination therapy in terms of antimicrobial activity, wound healing, inflammation modulation, pain reduction, regenerative potential, and other relevant clinical outcomes.
3. Summarize the laser and photosensitizer parameters used in combined PBM + PDT protocols to understand current practice patterns and areas requiring standardization.
4. Determine the safety profile of PBM + PDT when used in dental applications.
5. Identify gaps, limitations, and future research directions needed to optimize and standardize PBM + PDT for broader clinical implementation.

Through these objectives, the review aims to clarify the therapeutic value, synergy, and clinical potential of combined PBM and PDT, while guiding future research and improving evidence-based integration of biophotonic therapies in dentistry.

Methods

PICO Framework (Explicit)

Population (P)

Individuals, animals, tissues, or cell cultures involved in dental or oral health contexts, including:

a. Patients with oral mucositis, oral lesions, or dental infections
b. Patients undergoing endodontic, periodontal, orthodontic, or soft tissue procedures
c. Animal models (e.g., rats, dogs) representing dental tissues
d. Oral cell lines (e.g., human tongue carcinoma cells) relevant to dental research

Intervention (I)

Combined application of Photobiomodulation (PBM/LLLT) and Photodynamic Therapy (PDT) delivered sequentially or synergistically, including:

a. PBM using red or near-infrared wavelengths (e.g., 630–808 nm)
b. PDT using a photosensitizer (e.g., methylene blue, curcumin, humic acid, 5-ALA) activated by an appropriate light source
c. Protocols where PBM and PDT are used together in a single therapeutic regimen.

Comparison (C)

It can be any of the following:

a. PBM alone
b. PDT alone
c. Conventional or standard care
d. No treatment or placebo/sham treatment
e. Different PBM + PDT dosimetric protocols (when applicable)

Outcome (O)

Primary and secondary outcomes relevant to dental applications, including:

a. Antimicrobial efficacy: reduction of bacterial or fungal load
b. Inflammation modulation: changes in cytokines (IL-1β, IL-17, PGE2)
c. Wound healing and tissue regeneration: epithelial repair, dentin-like tissue formation, angiogenesis
d. Pain reduction: patient-reported outcomes (VAS scores)
e. Clinical improvement: reduction of lesion severity, mucositis grade, OHRQoL improvement
f. Modulation of bone remodeling: acceleration of orthodontic tooth movement
g. Cytotoxicity/anti-tumor effects: apoptosis and cell viability changes in oral cancer models
h. Safety outcomes: absence of adverse effects, normal healing patterns

PICO Summary (Short Version for Tables or Abstract Services)

P: Dental/oral patients, animal models, or oral cell lines
I: Combined PBM + PDT
C: PBM alone, PDT alone, standard care, or placebo
O: Antimicrobial effect, healing, regeneration, inflammation modulation, pain reduction, bone remodeling, safety

Search strategy

The search was conducted in the PubMed, ScienceDirect, ProQuest, DOAJ, and Google Scholar databases using

the following combination of keywords and Boolean operators:

1. ("photobiomodulation" OR "low level laser therapy" OR "LLLT")
2. ("photodynamic therapy" OR "PDT" OR "photosensitizer")
3. (dental OR dentistry OR oral OR endodontic OR periodontal)

Additional filters were used:

1. Year range: 2021–2025
2. Language: English
3. Publication type: original research articles (RCTs, experimental, in vivo, and in vitro cell-based studies relevant to odontological applications)

Additional searches were conducted through manual searches of the bibliographies of selected articles.

Inclusion Criteria

Inclusion criteria were as follows:

1. Original research (clinical, in vivo, in vitro).
2. Combined use of PBM/LLLT and PDT in dentistry.
3. Clear reporting of laser parameters.
4. Published from 2021 to 2025.
5. English language.

Exclusion Criteria

Exclusion criteria were as follows:

1. Studies using PBM alone.
2. Studies using PDT alone.
3. Irrelevant to dentistry.
4. Non-primary research.
5. Insufficient dosimetric parameters.

Quality assessment and data extraction

The methodological quality and risk of bias of the included studies were assessed using validated tools appropriate for each study design, as well as the Joanna Briggs Institute (JBI) critical appraisal tools. All articles were screened in two phases: title-abstract screening and full-text screening. Key points were extracted from the included studies, including authors, year, objective, study design, cell type, intervention, wavelength, and result.

Result

Study selection

A total of 656 records were identified through database searching. After removing duplicates, 643 records underwent title and abstract screening, resulting in the exclusion of 602 records that were irrelevant, outside the dental scope, or non-original research. Forty-one full-text articles were assessed for eligibility, and 33 were excluded because they used PBM alone (n = 12), used PDT alone (n = 8), were non-dental (n = 7), or lacked sufficient laser parameters (n = 6). Ultimately, 8 studies met all inclusion criteria and were incorporated into the qualitative synthesis. The PRISMA flow diagram summarizing the selection process is presented in Figure 1 and Table 1.

A total of **8 studies** met the inclusion criteria and were included in the final qualitative synthesis.

Identification

A systematic search was conducted in five major databases, that is, PubMed, ScienceDirect, ProQuest, DOAJ, and Google Scholar, using the following keyword combinations:

- a. "photobiomodulation" OR "low-level laser therapy" OR "LLLT"
- b. AND "photodynamic therapy" OR "PDT" OR "photosensitizer"
- c. AND "dentistry" OR "oral" OR "dental"

The search yielded 656 articles.

After removing duplicates, 643 articles remained for title and abstract screening.

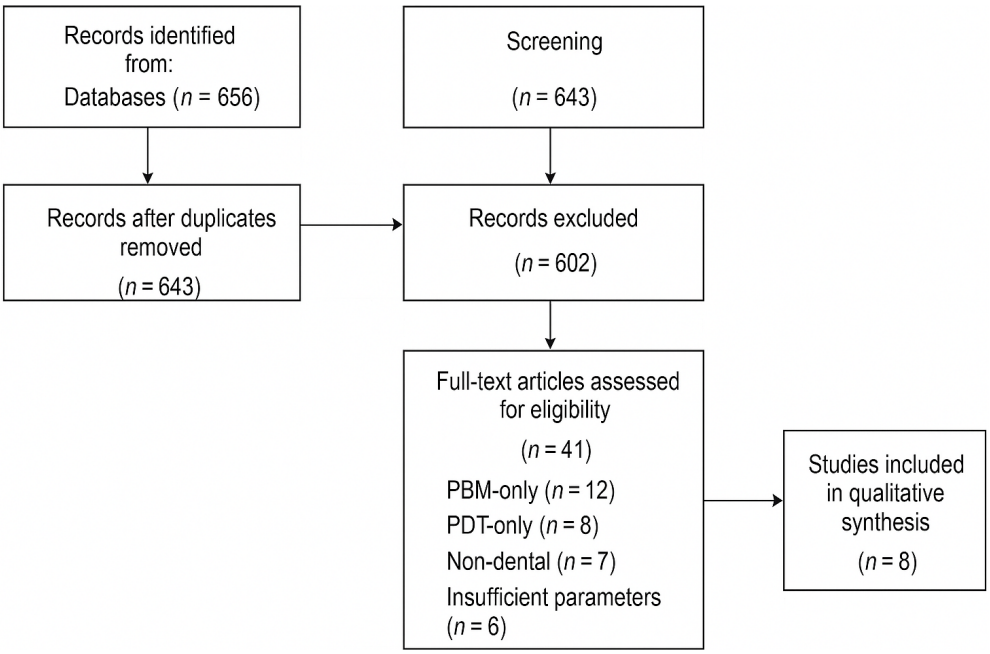

Figure 1. PRISMA diagram of the article selection process.

Table 1. PRISMA Flow Summary

Stage	Amount
Articles found	656
Duplicates removed	643
Screened (title & abstract)	643
Excluded upon screening	602
Full-text assessed	41
Excluded upon full-text	33
Studies included (final)	8

Screening

During the title and abstract screening stage, an evaluation was conducted for the appropriateness of the topic, study type, and combination of PBM + PDT interventions.

Of the 643 articles, 602 were excluded due to irrelevance to PBM/PDT, non-dental focus, not using lasers, or not being original research. Thus, 41 articles entered the full-text evaluation stage.

Eligibility

A total of 41 articles were thoroughly reviewed to determine eligibility based on the inclusion and exclusion criteria specific to PBM + PDT reviews.

Of the 41 articles, 33 were excluded for the following reasons:

- PBM-only (n = 12)

Studies used PBM/LLLT alone without PDT or photosensitizers.

- PDT-only (n = 8)

Studies used PDT alone without additional PBM/LLLT.

- Non-dental (n = 7)

Studies not related to the mouth, teeth, or oral tissues (e.g., rhinoplasty, catfish).

- Insufficient parameters (n = 6)

Studies did not report complete laser parameters such as wavelength, fluence, irradiance, exposure duration, and regimen.

Included Studies

After a rigorous selection process, only eight studies met the criteria for a combination of PBM + PDT in dentistry.

These studies covered applications including oral mucositis in adults and children, endodontic disinfection, regenerative endodontics, orthodontic acceleration, oral squamous carcinoma (HNO-97 cells), lichenoid lesions, and adjunctive antimicrobial therapy.

All studies involved the combination of PBM (red/IR laser) and PDT (photosensitizer + light activation) in a single protocol or comparative evaluation.

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Characteristics of the Included Studies

The 8 included studies comprised:

1. three randomized clinical trials
2. one single-blind clinical trial
3. one retrospective clinical study
4. two in vivo animal studies
5. one in vitro oral oncology study

Clinical and experimental settings involved the following populations:

1. Patients with oral mucositis
2. Patients with oral lichenoid lesions
3. Patients undergoing endodontic treatment
4. Orthodontic animal models (rats)
5. Canine regenerative endodontics
6. Human tongue squamous carcinoma cell line (HNO-97)

Photosensitizers used included methylene blue, curcumin, 5-ALA, humic acid, and indocyanine green (in related protocols). PBM wavelengths ranged from 650 to 808 nm, while PDT activation wavelengths ranged from 450 to 660 nm.

Applications of PBM + PDT Across Dental Fields

Oral Mucositis (OM)

Two RCTs evaluated PBM and curcumin-mediated aPDT as adjunctive therapy for chemotherapy-induced oral mucositis.[3,4] Both studies showed:

- significant reduction in mucositis grade
- significant pain reduction
- greater antifungal effects against Candida albicans in the aPDT group compared to PBM alone.

Endodontic Disinfection

Two studies evaluated methylene-blue PDT combined with PBM.[5,6]Findings demonstrated:

- effective intracanal microbial reduction
- reduced postoperative pain
- improved OHRQoL
- no adverse postoperative complications.

Regenerative Endodontics

One animal histological study assessed RET with PDT disinfection followed by PBM[7]. PBM + PDT led to:

- greater hard tissue deposition
- higher cellular vitality
- better periodontal healing compared to RET alone
- lower inflammatory infiltrate.

Orthodontic Acceleration

One in vivo rat study used humic acid photosensitizer + PBM[8].

Results showed:

- accelerated tooth movement
- increased osteoclastic activity
- decreased alveolar bone density (normal remodeling)

- no root resorption.

Oral Oncology (In Vitro)

One study evaluated 5-ALA-PDT combined with PBM in HNO-97 tongue cancer cells[9]. Combination therapy resulted in:

- decreased cell viability
- increased apoptosis
- higher DNA fragmentation
- enhanced cytotoxic effect compared to PDT alone.

Oral Lichenoid Lesions

One study compared PBM and PDT on opposite sides of the oral cavity.[10]

Findings indicated:

- Significant reduction in lesion size
- Decreased pain scores
- Clinical improvement
- No significant difference between PBM and PDT aspects

The study confirms that both modalities are effective, but it does not evaluate the simultaneous combination.

Therapeutic Outcomes (Synthesis)

Across the 8 included studies, the following outcomes were consistently reported:

Antimicrobial Efficacy

1. PDT provided rapid microbial reduction (Candida spp., endodontic pathogens).
2. PBM supported tissue repair and moderated inflammation.
3. The combination improved clinical recovery faster than either modality alone (confirmed in mucositis and endodontic RCTs).

Anti-inflammatory Effects

1. Reduced levels of IL-1, IL-17, PGE2, and defensins reported in mucositis and orthodontic models.
2. Faster clinical resolution of ulcerative lesions.

Wound Healing and Regeneration

1) Enhanced cell proliferation and matrix organization.
2) Greater odontoblast-like cell formation in RET.
3) Better healing indices in inflamed tissues.

Pain Reduction

1. Significant reduction in VAS pain scores in mucositis and OLL trials.
2. Lower postoperative discomfort in endodontic treatments.

Orthodontic Modulation

1. Accelerated tooth movement
2. Enhanced remodeling of alveolar bone
3. Higher osteoclast activity on the pressure side

Anti-tumor Activity (In Vitro)

1. Increased apoptosis via mitochondrial pathways
2. PDT-induced cytotoxicity enhanced by PBM preconditioning

Laser Parameter Summary

PBM Wavelengths Used

PBM wavelengths used included 650 nm, 660 nm, and 808 nm, as well as combination protocols employing 630 + 808 nm. The PDT components comprised photosensitizers such as humic acid, curcumin, methylene blue, and 5-ALA, with activation wavelengths of 450 nm for curcumin and 630–660 nm for methylene blue and ALA.

PDT Components

1. Photosensitizers: Humic acid, curcumin, methylene blue, 5-ALA
2. Activation wavelengths:

450 nm (curcumin), 630–660 nm (MB/ALA)

PBM wavelengths used included 650 nm, 660 nm, and 808 nm, as well as combination protocols employing 630 + 808 nm. The PDT components comprised photosensitizers such as humic acid, curcumin, methylene blue, and 5-ALA, with activation wavelengths of 450 nm for curcumin and 630–660 nm for methylene blue and ALA.

Energy Doses

a. PBM doses: 1–20 J/cm²
b. PDT doses: 10–40 J/cm² equivalent
c. Exposure times ranged from 30 to 90 seconds per point

Parameter heterogeneity prevented any meta-analysis.

Safety Assessment

Across all clinical and animal studies:

1. No adverse effects reported
2. No tissue damage observed
3. No complications in endodontic procedures
4. No root resorption in orthodontic models
5. Normal healing patterns confirmed histologically

PBM + PDT appears clinically safe within reported dosimetry.

Evidence Gaps

The current literature reveals:

1. Limited numbers of high-quality RCTs
2. Large variability in dosimetric parameters
3. Lack of standardized PBM-PDT combination protocols
4. Few studies evaluating synergistic effects mechanistically
5. Lack of long-term follow-up data
6. Limited pediatric evidence outside the mucositis context

Details of the data extraction are summarized in Supplementary file, Table S1.

Discussion

This systematic review synthesized the current evidence on the combined use of photobiomodulation (PBM) and photodynamic therapy (PDT) in dentistry, revealing important synergistic therapeutic effects across various

clinical and experimental models. Despite the small number of eligible studies, consistent patterns were observed, demonstrating that combining PBM and PDT offers enhanced benefits compared to either modality used alone.

Synergistic Antimicrobial and Antifungal Activity

Several included studies demonstrated that the combination of PBM and PDT provides superior antimicrobial effects. PDT, activated with photosensitizers such as methylene blue, curcumin, or 5-ALA, effectively generates reactive oxygen species capable of disrupting microbial cell structures. PBM supports mitochondrial activity, enhancing host cell proliferation and reducing tissue inflammation.[11]

In the management of oral mucositis, both studies by Andrade et al. showed that PDT combined with PBM resulted in faster reductions in the mucositis grade and greater decreases in *Candida* counts compared to PBM alone. The curcumin-mediated PDT achieved an early microbial reduction, while PBM improved tissue repair, illustrating a complementary mechanism.[12]

Similarly, in endodontic disinfection,[5,6] PDT reduced root canal pathogens while PBM minimized postoperative pain and promoted apical healing. This dual effect highlights the potential of PBM + PDT as an adjunct in endodontic therapy, especially in cases with persistent microbial contamination.

Enhancement of Wound Healing and Tissue Regeneration

PBM is known to promote mitochondrial activation, ATP production, cell proliferation, and angiogenesis. When combined with PDT, which reduces a microbial burden, the tissue environment becomes more favorable for accelerated healing.[13]

The regenerative endodontic study performed on canine teeth [7] demonstrated that PBM following PDT disinfection resulted in increased hard tissue deposition, better dentin-like tissue formation, and significantly reduced inflammatory infiltrate. The improved histological outcomes indicate that PBM may enhance stem cell viability and differentiation after PDT-mediated decontamination.[14]

Orthodontic applications also benefited from PBM combined with a photosensitizer (humic acid). An et al. found accelerated tooth movement and higher osteoclastic activity without causing root resorption. This suggests a potential role for combined PBM-PDT modalities in modulating bone remodeling, although more clinical evidence is needed.

Anti-inflammatory Modulation and Pain Reduction

Across the included clinical studies, pain reduction was a consistent and notable outcome. PBM modulates inflammatory pathways by reducing cytokines such as IL-1β, IL-17, and PGE2, while PDT reduces microbial triggers of inflammation.[15]

In patients with oral mucositis and oral lichenoid lesions, PBM and PDT both led to reduced pain scores and improved lesion scores. Although Rezaei et al. did not find significant differences between PBM and PDT in OLL treatment, both modalities significantly improved symptoms, confirming their therapeutic equivalence.[16] Importantly, this reinforces the idea that combining these modalities may offer additional advantages in cases requiring both microbial control and enhanced tissue healing.[17]

Potential Role in Oncology and Tumor Modulation

One included in vitro study [9] explored PBM combined with 5-ALA PDT in a human tongue carcinoma cell line. Results showed increased apoptosis, DNA fragmentation, and reduced viability in the combined treatment group. This suggests that PBM, when appropriately dosed, may prime cells for enhanced PDT effectiveness, an important finding given concerns about PBM potentially stimulating cancer cells.[15] In this case, the combination demonstrated cytotoxic rather than proliferative effects. While these findings are promising, clinical translation requires caution and further investigation, especially regarding dosing thresholds and tumor biology.[18]

Safety and Absence of Adverse Effects

All included studies reported no adverse effects associated with PBM + PDT therapy. Histological evaluations in animal models showed normal tissue healing without necrosis or abnormal inflammation.[19] Clinical trials similarly reported no complications, reinforcing the safety of combined PBM + PDT when performed using appropriate dosimetric parameters. In orthodontic models, no root resorption or periodontal damage was observed, while endodontic applications reported no postoperative complications. These findings support PBM + PDT as a minimally invasive and tissue-friendly modality.[20]

Heterogeneity of Protocols and Need for Standardization

One major limitation across studies is the significant variability in:

- wavelengths (630–808 nm for PBM, 450–660 nm for PDT)
- power output
- irradiation times
- dose (J/cm^2)
- number of sessions
- types and concentrations of photosensitizers
- sequencing (PDT first, followed by PBM vs simultaneous)

This heterogeneity prevented meta-analysis and limited direct comparison. Establishing standardized PBM + PDT protocols is essential, especially for common conditions like mucositis, endodontic disinfection, and oral lesions.[21] Another limitation is the scarcity of large randomized controlled trials. Most evidence comes from small RCTs, single-center trials, or animal studies. Long-

term outcomes are also underreported, particularly in regenerative and orthodontic applications.[22]

Clinical Implications

Despite these limitations, the current evidence supports the following clinical insights:

- PBM + PDT provides superior antimicrobial control versus PBM alone.
- Combination therapy supports faster wound healing and reduced inflammation.
- PBM enhances the cellular environment after PDT eliminates pathogens → synergistic effect.
- Endodontics, mucositis management, and soft tissue lesions are the most promising indications.
- Orthodontic and regenerative endodontic applications represent emerging frontiers.

Given these findings, PBM + PDT has the potential to become a valuable adjunct therapy across various dental fields.[23]

Future Research Directions

Future studies should aim to:

- Conduct high-quality, multicenter RCTs evaluating PBM + PDT synergy.
- Develop standardized PBM and PDT dosimetry guidelines.
- Investigate molecular mechanisms underlying PBM-enhanced PDT effects.
- Compare simultaneous versus sequential PBM + PDT delivery.
- Explore pediatric applications beyond mucositis.
- Assess long-term clinical outcomes and recurrence rates.
- Evaluate cost-effectiveness and protocol practicality in clinical settings.

Discussion

The evidence supports PBM + PDT as a synergistic biophotonic therapy in dentistry, improving antimicrobial efficacy, reducing inflammation, accelerating healing, and enhancing tissue regeneration. While it is promising, standardized protocols and robust clinical trials are needed to establish definitive guidelines.

Conclusion

This systematic review demonstrates that the combined application of photobiomodulation (PBM) and photodynamic therapy (PDT) offers synergistic therapeutic benefits across various dental fields. The available evidence indicates that PBM + PDT enhances antimicrobial activity, accelerates wound healing, reduces inflammatory responses, promotes tissue regeneration, and improves patient-reported outcomes more effectively than either modality used alone. These combined effects were consistently observed in the management of oral mucositis, endodontic disinfection, regenerative endodontics, orthodontic movement, oral soft tissue lesions, and in vitro oral oncology models.

Despite these promising findings, the number of high-quality studies remains limited, and substantial heterogeneity exists in laser parameters, photosensitizers, dosing regimens, and treatment protocols. This variability underscores the need for standardized PBM + PDT protocols to facilitate reproducibility, optimize clinical outcomes, and enable meaningful comparisons across studies. Future research should focus on well-designed, multicenter randomized controlled trials with clearly defined dosimetry, standardized treatment sequences, mechanistic evaluation of synergistic effects, and long-term clinical follow-up.

Overall, PBM + PDT represents a safe, minimally invasive, and biologically potent therapeutic approach with considerable potential to enhance current dental treatment strategies. With continued refinement and rigorous evaluation, the combination of PBM and PDT may become an important adjunctive modality in evidence-based dental practice.

Limitations

This systematic review has several limitations. Only eight eligible studies were identified, limiting generalizability and reflecting the novelty of combined PBM and PDT in dentistry. Considerable heterogeneity in laser parameters, photosensitizers, and treatment protocols precluded meta-analysis and hindered direct comparisons. The evidence base also included a mix of clinical, animal, and in vitro studies, and several promising findings lack human clinical confirmation. Clinical sample sizes were generally small, with limited long-term follow-up. Additionally, publication bias and language restrictions cannot be excluded. Overall, larger, well-designed randomized controlled trials with standardized PBM and PDT protocols are needed

Clinical Relevance

The findings of this review have significant implications for clinical dental practice. PBM + PDT, as a combined biophotonic modality, offers a promising adjunctive therapy that leverages the antimicrobial strength of PDT and the regenerative and anti-inflammatory properties of PBM. Such synergy is particularly relevant in conditions where both infection control and tissue repair are essential, including oral mucositis, infected root canals, ulcerative lesions, and post-surgical healing.

In oral mucositis, the combination demonstrates superior reductions in pain and lesion severity, providing a potential non-pharmacological option for vulnerable oncology patients who may struggle with systemic medication tolerance. In endodontics, PBM + PDT improves microbial reduction while enhancing postoperative comfort and healing, presenting a viable adjunct to conventional disinfection protocols.

Regenerative endodontics may particularly benefit from PBM + PDT. PDT effectively reduces the microbial load and promotes a sterile environment, while PBM enhances stem cell activity, angiogenesis, and hard

tissue deposition—key components of successful tissue regeneration.

Orthodontic applications also show early promise, where PBM + PDT may accelerate tooth movement via improved alveolar bone remodeling, though further clinical studies are needed before clinical adoption.

Importantly, no adverse effects were reported across the included studies, supporting PBM + PDT as a safe, minimally invasive adjunct that aligns well with modern trends in biological and conservative dentistry.

As interest in laser-based therapies grows, PBM + PDT may become an increasingly valuable tool for clinicians seeking predictable outcomes in infection control, pain management, and tissue regeneration.

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Authors' Contribution

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Supervision: Ida Bagus Narmada, Theresia Indah Budhy Sulisetyawati, Ernie Maduratna Setiawatie
Validation: Ida Bagus Narmada, Theresia Indah Budhy Sulisetyawati, Ernie Maduratna Setiawatie, Ari Triwarhani
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Competing Interests

The authors declare no conflict of interest

Ethical Approval

Not applicable.

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Supplementary File

Supplementary file contains Table S1.

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