Literature Review

Low-Level Laser Therapy for the Management of Oral Fungal Infection: A Scoping Review Mapping the Evidence

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ABSTRACT

Oral fungal infections can impair function, cause significant discomfort, and negatively affect quality of life. *Candida albicans* is the most frequently identified pathogen and is commonly associated with denture stomatitis, mucosal candidiasis, and angular cheilitis. Although conventional antifungal therapy remains the standard of care, challenges such as antifungal resistance, recurrence, and adverse effects highlight the need for alternative non-invasive approaches. Low-level laser therapy (LLLT), or photobiomodulation, has gained attention for its potential to modulate inflammation, support tissue repair, and influence microbial activity. However, findings across the literature remain inconsistent. Sub-therapeutic laser parameters may unintentionally stimulate *Candida albicans* proliferation, whereas higher fluence levels or photodynamically active settings demonstrate more reliable antifungal effects. This scoping review maps the current evidence on the use of LLLT for oral fungal infections by synthesizing *in vitro* studies, clinical investigations, and systematic reviews**.** A structured search was performed in PubMed, Scopus, ScienceDirect, and Google Scholar, covering studies published from January 2015 to August 2025. The findings indicate that therapeutic outcomes are highly dependent on laser wavelength, energy density, irradiation duration, delivery mode, and photosensitizer use. Incorporating LLLT with photodynamic therapy or topical antifungal agents may further enhance efficacy and reduce recurrence.

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Introduction

Oral fungal infections are a common clinical concern, particularly among high-risk groups such as denture wearers, older adults, and immunocompromised individuals [1-2]. Candida albicans *(C. albicans)*, although a normal oral commensal, can overgrow under conditions of immune suppression or disrupted oral ecology, leading to clinical manifestations including denture stomatitis, mucosal candidiasis, and angular cheilitis. These infections often cause significant discomfort and functional impairment and are frequently recurrent. Increasing resistance to conventional antifungal therapies such as nystatin and azole derivatives further underscores the need for alternative noninvasive treatment modalities [1].

Low-level laser therapy (LLLT), which operates through photobiomodulation, has gained attention for its capacity to enhance mitochondrial activity, stimulate cellular repair, and modulate inflammatory responses [3-4]. Although initially applied for wound healing and pain control, LLLT has more recently been investigated for its antimicrobial effects, including its potential role in managing Candida-associated infections [5]. However, current evidence reveals substantial variability in

antifungal outcomes, largely attributable to differences in laser wavelength, fluence, power output, irradiation time, and delivery mode.

In vitro studies demonstrate that low-dose laser exposure may exert stimulatory effects on *C. albicans*. Najafi *et al.* [1] showed that diode laser irradiation at 38 J/cm² increased fungal colony counts in low-density suspensions, suggesting that sub-therapeutic parameters may enhance mitochondrial activity and promote proliferation [1,3]. Conversely, higher-energy protocols such as 1064 nm Nd:YAG irradiation at 59 J produced marked reductions in fungal colonies through photothermal microbial damage [6]. Additional investigations highlight the importance of precise dosimetry, with certain fluences such as GaAlAs irradiation at 6J/cm², resulting in optimal suppression of fungal proliferation [3].

Photodynamic therapy (PDT) offers another pathway for fungal inactivation by combining laser light with photosensitizers that generate reactive oxygen species capable of disrupting fungal cell membranes [2-3]. Multiple studies, including those utilizing methylene blue (MB), methyl-pheophorbide a, 5-aminolevulinic acid (ALA) derivatives, and 1,9-dimethylmethylene blue (DMMB), have shown that PDT consistently produces stronger antifungal effects than laser irradiation alone and can even achieve near-complete fungal inactivation under optimized conditions [2,10,12,15-16]. High-intensity diode lasers also demonstrate fungistatic activity, though their effects remain inferior to nystatin in direct comparisons [13]. Recent findings also emphasize the relevance of PDT as a promising adjunctive modality for Candida management. Methylene-blue–mediated PDT at 660 nm has demonstrated significant inhibitory effects against *C. albicans*, Candida tropicalis (*C. tropicalis)*, and even resistant species such as Candida krusei (*C. krusei)*, achieving greater fungal reduction than laser irradiation alone [17].

Clinical findings support additional benefits of LLLT beyond direct antifungal action. In angular cheilitis, LLLT achieved clinical improvement comparable to topical antifungal therapy [4]. In oral lichen planus, laser treatment reduced lesion size and pain while enhancing epithelial regeneration [5]. Among oncology and transplant patients, prophylactic LLLT has been shown to reduce the severity of oral mucositis and improve mucosal integrity, which may indirectly lower susceptibility to opportunistic fungal infections [6-7]. Ablative CO_2 laser therapy has also demonstrated effective lesion removal and accelerated healing, thereby reducing the risk of secondary colonization [8]. LLLT continues to gain attention for its broader photobiomodulation effects, including enhanced ATP synthesis, reduced inflammation, and accelerated mucosal repair, which may indirectly improve host resistance to opportunistic fungal infections [18].

Collectively, the available evidence indicates that the antifungal response to LLLT is highly parameter-dependent. Low-energy exposures may inadvertently stimulate fungal metabolism, whereas higher fluences or PDT-assisted protocols consistently demonstrate stronger inhibitory effects. Given the heterogeneity in wavelengths, fluence levels, photosensitizers, and clinical applications across existing studies, a structured synthesis of current findings is essential to clarify the therapeutic potential of LLLT and PDT in managing Candida-related oral fungal infections.

Therefore, this scoping review aims to systematically map and synthesize the existing evidence on the use of LLLT, for the management of Candida-associated oral fungal infections. Specifically, this review seeks to identify the range of laser parameters and photosensitizers employed across *in vitro, in vivo*, and clinical studies; evaluate their reported antifungal effectiveness; and highlight knowledge gaps and methodological variability that must be addressed to establish standardized and clinically relevant LLLT-based protocols for oral candidiasis.

Materials and Method

Study Design

A scoping review was conducted to identify, analyze, and map the existing research on the application of LLLT for oral fungal infections caused by *C. albicans* [2]. This review followed the framework proposed by Arksey and O'Malley and was reported in accordance with the PRISMA-ScR guidelines. A systematic search was carried out using PubMed, ScienceDirect, and Google Scholar between January 2015 and Agustus 2025. The search strategy utilized Boolean operators and keyword combinations, including: ("low-level laser therapy" OR "LLLT" OR "photobiomodulation") AND ("*Candida albicans*" OR "oral fungal infections" OR "oral candidiasis") AND ("photodynamic therapy" OR

"PDT" OR antifungal) AND ("laser parameters" OR wavelength OR "energy density"). Eligible full-text studies consisting of *in vitro* experiments, randomized or quasi-experimental clinical studies, and systematic reviews were screened and included in the review.

Inclusion Criteria

To ensure a robust and contemporary evaluation of the literature, specific inclusion criteria were established to select eligible publications. This review considered original research articles that evaluated the effects of LLLT or PDT on *C. albicans* or clinically relevant oral fungal infections caused by Candida species. To maintain methodological rigor, included studies were required to report specific and clearly described laser parameters, including wavelength, power output, irradiation duration, fluence, and delivery mode, alongside quantitative microbiological or clinical outcomes, such as a reduction in colony-forming units. Furthermore, the selection was restricted to articles published in the English language within a ten-year window spanning from January 2015 to August 2025. Finally, eligible studies were limited to those identified through a structured search of the PubMed, Scopus, ScienceDirect, and Google Scholar databases conducted within this defined timeframe.

Exclusion Criteria

Conversely, specific exclusion criteria were applied to eliminate irrelevant or redundant literature from the review. Studies were excluded if they did not present specific data on oral fungal infections or if they focused solely on laser ablation for surgical purposes without evaluating antimicrobial effects. Additionally, secondary, or non-original literature such as editorials, commentaries, and literature reviews lacking original empirical data- was omitted from consideration. Lastly, any studies published prior to January 2015, falling outside the designated ten-year contemporary window, were excluded from the analysis.

Data Extraction and Analysis

Two reviewers independently extracted relevant data, including study design, population or sample characteristics, laser type and parameters, outcome measures (such as colony forming unit (CFU) counts, microscopic analysis, or clinical evaluations), and key findings [2]. Extracted data were tabulated and analyzed narratively to identify trends, discrepancies, and research gaps. Qualitative comparisons were made to assess how varying laser parameters affect the proliferation of *C. albicans* [3].

Results

After removing 8 duplicate records, two authors independently conducted the title, abstract, and full-text screening. From the initial 64 articles identified (39 from Scopus and 25 from PubMed), 56 unique articles remained for screening. Of these, 10 were excluded during title and abstract screening, leaving 46 full-text articles assessed for eligibility. Following full-text evaluation, 30 articles were excluded for not meeting the inclusion criteria, resulting in 16 studies that fulfilled all criteria and were included in this review. These studies consisted of *in vitro* experiments, clinical trials, and systematic reviews, providing a comprehensive overview of the application of LLLT for oral fungal infections. The PRISMA flow diagram in Figure 1 illustrates the study selection process, while Table 1 summarizes the key findings.

Literature Review

***In vitro* Studies**

Najafi *et al.* [1] evaluated the effects of a diode laser (940 nm, 1W) on two concentrations of *C. albicans* (10^4 and 10^6 CFU/mL). The study divided specimens into three groups: untreated controls, samples treated with nystatin, and samples exposed to LLLT for 30 seconds (38 J/cm²) or 60 seconds (76 J/cm²). The results revealed that nystatin completely eradicated fungal colonies, whereas LLLT increased colony counts significantly in the low-concentration group (10^4 CFU/mL). This unexpected stimulatory effect was attributed to the sub-therapeutic energy level, which may enhance mitochondrial activity and ATP production, thereby promoting fungal proliferation [1, 3].

Grzech-Leśniak *et al.* [7] employed a Nd:YAG laser (1064 nm) with two different settings: 0.25 W for 15 seconds (3 J) and 1 W for 60 seconds (59 J), using a flat-top handpiece to ensure even energy distribution across the target. Their study found that the higher energy setting produced a significant reduction in the growth of both *C. albicans* and *Streptococcus mutans.* The reduction in microbial colonies was primarily attributed to the strong photothermal effect induced by the Nd:YAG laser, which led to irreversible damage to the microbial

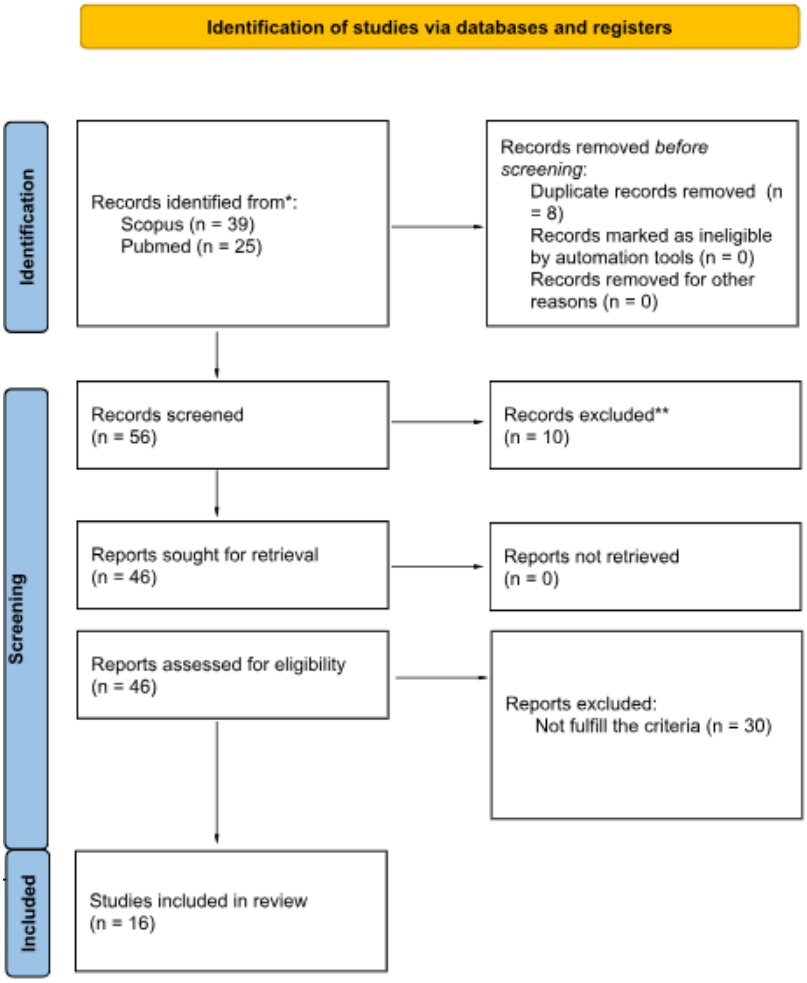

Figure 1: Methodology of the study

cell structure [6].

Hasanah *et al.* [11] investigated the *in vitro* effect of LLLT on isolates of *C. albicans* obtained from head and neck cancer patients undergoing radiotherapy. The study applied two energy doses (5 J/cm² and 10 J/cm²) using a continuous mode laser. Although both energy levels resulted in a reduction of fungal colony counts, the differences were not statistically significant. This finding highlights the importance of fine-tuning laser dosimetry to achieve optimal antifungal effects without stimulating fungal growth [11].

Carneiro *et al.* [3] assessed the antifungal effects of LLLT using two types of semiconductor lasers: InGaAlP (685 nm) and GaAlAs (830 nm) with energy densities ranging from 6 to 12 J/cm². Their results demonstrated that the GaAlAs laser at an energy density of 6 J/cm² resulted in the lowest mean fungal proliferation compared to higher dosimetry, suggesting that even small adjustments in energy parameters can influence microbial outcomes [3].

Several *in vitro* studies demonstrate that the effects of LLLT on Candida species largely depend on laser parameters [1,3,7,11]. Najafi *et al.* [1] reported that exposure to a 940nm diode laser increased colony counts in low-concentration samples (10^4 CFU/mL), likely due to sub-therapeutic energy stimulating mitochondrial activity and ATP synthesis. In contrast, Grzech-Leśniak *et al.* [7]**,** using a Nd:YAG laser (1064 nm) with higher energy, observed a significant reduction in *C.albicans* growth, attributed to photothermal-induced irreversible microbial cell damage. Hasanah *et al.* [11] found that energy densities of 5 and 10J/cm² reduced colony numbers, although not significantly, suggesting the need for optimized laser dosimetry. Similarly, Carneiro *et al.* [3] demonstrated that GaAlAs laser at 830nm and 6J/cm² yielded the lowest fungal proliferation, indicating that even minor adjustments in laser parameters may influence antifungal outcomes.

Clinical Studies

Clinical studies evaluating LLLT in oral mucosal con-

Table 1: Summary of the findings of included studies

No	Authors & Year	Study Type	Sample/ Population	Laser Parameters	Manifestation of LLLT Effects	Main Findings
1	Najafi *et al.* (2019) [1]	*In vitro*	*Candida albicans* (10^4 & 10^6 CFU/mL)	Diode laser 940 nm, 1 W; 30 s (38 J/cm²) & 60 s (76 J/cm²)	Stimulatory effect on *Candida albicans* colony growth (low dose)	LLLT at 38 J/cm² increased fungal colonies, suggesting sub-therapeutic doses may stimulate mitochondrial activity and proliferation. Nystatin completely eradicated colonies.
2	Gholami *et al.* (2023) [2]	*In vitro*	*Biofilm-forming Candida albicans*, cultured under laboratory conditions	Diode laser 660 nm, continuous mode; power 100 mW, irradiation time e.g., 60–120s per site; fluence range 6–12 J/cm². Used *methylene blue* (MB) 0.01-0.1%	Laser + MB results strong fungicidal action	Combination therapy demonstrated superior antifungal effect compared to laser irradiation alone. Effects were dose-dependent, with higher fluence achieving greater microbial suppression.
3	Carneiro *et al.* (2016) [3]	Experimental (conference paper)	*Candida albicans* proliferation assay	InGaAlP 685 nm & GaAlAs 830 nm; 6, 8, 10, 12 J/cm²	Optimal energy density reduces fungal proliferation	GaAlAs laser at 6 J/cm² yielded the lowest fungal proliferation, highlighting the importance of dosimetry optimization.
4	Salam *et al.* (2024) [4]	Clinical trial	45 patients with angular cheilitis	Low-power diode laser vs 2% miconazole gel	Comparable recovery to antifungal treatment	LLLT provided similar improvements in pain reduction and lesion healing compared to miconazole, supporting its role as an alternative therapy.
5	Elshenawy *et al.* (2015) [5]	Clinical study	10 patients with oral lichen planus unresponsive to steroids	Diode laser 970 nm	Reduction in lesion size and pain	LLLT decreased pain and burning sensation, reduced lesion size, and enhanced epithelial regeneration.
6	Nishi *et al.* (2023) [6]	Prospective single-arm study	Hematologic cancer patients post stem cell transplant	Prophylactic LLLT (parameters not specified)	Reduced incidence and severity of oral mucositis	LLLT significantly lowered Grade ≥2 mucositis, improved mucosal integrity, and potentially reduced secondary fungal infections.
7	Grzęch-Leśniak *et al*. (2018) [7]	*In vitro*	*Candida albicans* & *Streptococcus mutans*	Nd:YAG laser 1064 nm; 0.25 W 15 s (3 J) & 1 W 60 s (59 J)	Reduced fungal and bacterial CFU	Higher energy setting significantly decreased colony counts due to strong photothermal microbial damage.
8	Mello *et al.* (2025) [8]	Prospective cohort study	Hematologic malignancy patients undergoing chemotherapy	Prophylactic LLLT (parameters not specified)	Improved mucosal integrity in chemotherapy patients	Preventive LLLT improved mucosal conditions, lowering the risk of secondary fungal infections.
9	Condor *et al*. (2021) [9]	Systematic review	Oral mucosal lesions	CO_2 laser (ablative settings)	Effective tissue ablation and healing	CO_2 laser ablates lesions (leukoplakia, lichen planus), promotes rapid healing, indirectly reducing fungal colonization.
10	Yook *et al.* (2022) [10]	*In vitro*	*Candida albicans* ATCC 15,022, cultured in Sabouraud dextrose agar for 48h at 37°C with 5% CO_2. Final concentration approx. 1.5×10^5 cells/mL in sterile deionized water.	Diode laser 660nm±10nm, continuous, 200-400 W, Irradiation in dark, after 30 min incubation with PS; Photosensitizers - Methyl pheophorbide a (MPa) 0.1%	MPa and PhotoMed + laser achieved 100% fungal death; PhotoCure + laser showed moderate reduction; Laser alone (no PS): no significant antifungal effect; Photosensitizer alone (no laser): no cytotoxicity	Concluded PDI using MPa and PhotoMed is a promising alternative to conventional antifungals, which may have resistance and incomplete eradication risks.
11	Hasanah *et al*. (2024) [11]	*In vitro*	*Candida albicans* isolates from head & neck cancer patients	Continuous diode laser; 5 J/cm² & 10 J/cm²	Reduced *Candida albicans* colonies	Both doses decreased fungal counts, though differences were not statistically significant.
12	Vila-Nova *et al.* (2023) [12]	Systematic review & meta-analysis	PDT for denture stomatitis	PDT (ALA/MB photosensitizers + laser)	Reduced fungal load in denture stomatitis	PDT decreased CFU on palate and denture surfaces; antifungals performed better at some points, but PDT remains a viable non-invasive alternative.

No	Authors & Year	Study Type	Sample/ Population	Laser Parameters	Manifestation of LLLT Effects	Main Findings
13	Momeni *et al*. (2022) [13]	*In vitro*	*Candida albicans* ATCC 18804, tested as planktonic culture suspensions at two concentrations: 1×10^4 cells/mL and 1×10^6 cells/mL. Total n=72 samples	High-intensity Ga-Al-As diode laser, 940nm, 2W, 20 s, 60J/	Significant reduction in colony count compared to control ($p< 0.05$), in both fungal concentrations. However, nystatin completely eradicated colonies, while the laser only partially reduced them.	High-intensity 940 nm laser significantly reduced *Candida albicans* proliferation *in vitro*, but was less effective compared to nystatin. Laser monotherapy had fungistatic but not fungicidal effect.
14	Ryu *et al*. (2021) [14]	Comprehensive review (Decade Long Survey)	Animal and clinical studies on oral mucositis	Near-infrared LLLT (various dosimetries)	Prophylactic, reduces pain & mucositis	LLLT accelerates mucosal healing, decreases pain, and indirectly prevents fungal infection by maintaining mucosal integrity.
15	Nunes *et al*. (2023) [15]	*In vitro*	*Candida albicans* ATCC 90028 planktonic cultures (not biofilm). Cultivated at 37°C for 24 h. Resuspended in sterile saline to 2×10^8 cells/mL.	Red LED, density 20 J/cm²; Photosensitizer-DMMB at 750 ng/mL (IC_{50}).	Most effective was dual application in a single PDT session (Protocol 2), achieving ~99.991% inhibition of fungal proliferation. LLLT/PDT caused major reduction in viable fungal cells.	Dual PDT application applied in the same session demonstrated significantly higher antifungal activity compared to conventional or split-session PDT. The study suggests that optimizing application timing enhances PDT efficacy. PDT using DMMB with red LED light is highly effective against *Candida albicans* in vitro.
16	Adnan & Jawad (2024) [16]	*In vitro*	*Candida albicans* isolated from oral samples of 75 patients diagnosed with oral thrush. From this, *25 samples were used *(10^{-4} cells/mL*) divided into 5 groups (n= 5 *per* group): Control, nystatin only, laser only, laser+MB (photosensitizer), laser+nystatin	Low-power 650 nm diode laser, 200mW, 300s, 330–350 J/cm²; MB: 100µg/mL, pre-incubated 5 minutes.	Laser alone → moderate inhibition of fungal growth; Laser+ MB (PDT)→ stronger reduction; Laser+ nystatin → highest antifungal effect; PDT demonstrated photosensitizer-dependent antimicrobial enhancement.	PDT (650 nm + MB) effectively reduced *C. albicans* colony count. • Best results found in combination therapy (laser + nystatin); Laser alone showed reduced but incomplete antifungal effect (fungistatic)

ditions provide additional evidence for its potential relevance in reducing susceptibility to fungal colonization. Mello *et al*. [8] reported that prophylactic LLLT in patients undergoing chemotherapy improved mucosal integrity and reduced the severity of oral mucositis, suggesting that enhanced epithelial resilience may help prevent opportunistic infections, including those caused by *C. albicans.* Similarly, Nishi *et al.* [6] demonstrated that LLLT significantly lowered the incidence and grade of oral mucositis in hematologic patients following stem cell transplantation, reinforcing its role in maintaining a functional mucosal barrier.

In inflammatory mucosal diseases such as oral lichen planus, Elshenawy *et al*. [5] found that diode laser therapy reduced lesion size, pain, and burning sensation while promoting epithelial regeneration. This improvement in mucosal quality may indirectly decrease fungal colonization by restoring tissue integrity.

For conditions with a fungal component, such as angular cheilitis, Salam *et al.* [4] reported that low-power diode laser therapy achieved clinical outcomes comparable to topical miconazole. The comparable healing response indicates that LLLT may serve as an alternative or adjunctive modality for managing inflammatory lesions in which Candida plays a contributory role.

Evidence from broader clinical surveys further supports these findings. Ryu *et al*. [14] summarized multiple animal and human studies demonstrating that near-infrared LLLT accelerates wound healing and reduces inflammation, which may limit secondary fungal involvement by maintaining tissue integrity.

Clinical studies consistently show that LLLT enhances mucosal healing, reduces inflammatory burden, and strengthens epithelial barriers mechanisms that may limit Candida adherence and colonization. While not primarily designed as antifungal trials, these investigations highlight the potential of LLLT as an adjunctive approach for reducing the risk of fungal infections in compromised oral environments.

Discussion

The findings from this scoping review demonstrate that LLLT produces variable effects on *C. albicans* and oral fungal infections, reflecting a complex interaction between wavelength, fluence, exposure duration, photosensitizer use, fungal phenotype, and tissue condition. This section provides a deeper interpretation of these patterns to clarify the mechanistic and clinical relevance of LLLT and PDT.

In vitro studies consistently show that *C. albicans* exhibits a highly parameter-dependent and biphasic response to irradiation. Najafi *et al.* [1] and Hasanah *et al.* [11] reported that low-fluence diode laser exposure, such as 38 J/cm², increased fungal colony formation, indicating that sub-therapeutic photobiomodulation may enhance mitochondrial activation and ATP synthesis rather than suppress growth. Carneiro *et al.* [3] further demonstrated that minor variations in energy density (6-12 J/cm²) can significantly shift fungal proliferation pat-terns, underscoring the importance of precise dosimetry. These collective findings suggest that inadequate or low-dose LLLT may unintentionally stimulate fungal metabolism and should be avoided in antifungal applications.

In contrast, studies using higher energy densities produced more reliable antifungal suppression. Grzęch-Leśniak *et al.* [7] showed that Nd:YAG irradiation at 59 J significantly reduced fungal and bacterial CFU counts. Momeni *et al.* [13] confirmed that high-intensity 940-nm laser exposure at 60 J inhibited fungal proliferation across different inoculum concentrations, although complete eradication remained inferior to that of nystatin. These findings support the interpretation that LLLT alone is typically fungistatic rather than fungicidal unless applied at higher energy thresholds approaching photothermal effects.

PDT offers a more consistent antifungal mechanism through photosensitizer activation followed by reactive oxygen species (ROS)–mediated cellular injury, directly targeting fungal membranes and intracellular structures. Vila-Nova *et al.* [12] and Gholami *et al.* [2] demonstrated that PDT using MB or ALA derivatives produced substantial reductions in fungal load. Yook *et al.* [10] reported near-complete fungal death with methyl pheophorbide a-photodynamic therapy (MPa-PDT), while Nunes *et al.* [16] achieved approximately 99.991% inhibition using DMMB and red LED activation in a dual-application protocol. Adnan and Jawad [16] further showed that methylene blue-photodynamic therapy (MB-PDT) produced stronger suppression than laser alone, with laser–nystatin combination yielding the highest antifungal efficacy. Collectively, these results indicate that PDT produces more predictable and robust antifungal effects than LLLT monotherapy.

Clinical studies highlight that LLLT's primary therapeutic contribution lies in host-tissue modulation rather than direct antifungal activity. Mello *et al.* [8] and Nishi *et al.* [6] found that prophylactic LLLT improved mucosal integrity and reduced mucositis severity in oncology and hematology patients, thereby lowering susceptibility to opportunistic fungal colonization by preserving epithelial barriers. Salam *et al.* [4] showed that LLLT achieved outcomes comparable to 2% miconazole gel in angular cheilitis, while Elshenawy *et al.* [5] reported significant reduction in pain and lesion size in steroid-resistant oral lichen planus due to enhanced epithelial regeneration. These observations align with evidence summarized by Ryu *et al.* [14], which shows that LLLT enhances local circulation, reduces inflammation, accelerates tissue repair, and indirectly prevents secondary fungal invasion.

Additional perspectives come from other laser modalities. Condor *et al.* [9] demonstrated that CO_2 laser ablation promotes rapid re-epithelialization and reduces fungal colonization by physically removing diseased mucosal tissue, reinforcing the broader rehabilitative potential of laser-based therapy.

Several limitations within the existing literature require careful consideration. Many studies lacked complete reporting of wavelength, fluence, irradiation time, delivery mode, or fungal strain identification. Some publications originated from conference abstracts or pilot data with limited methodological detail, reducing reproducibility. Considerable heterogeneity across studies in laser parameters and photosensitizer concentrations complicates comparisons and impedes efforts to recommend standardized protocols. The absence of quantitative statistical synthesis further restricts interpretation of effect magnitude across settings.

Across the combined evidence, a consistent pattern emerges antifungal outcomes depend strongly on accurate dosimetry. Sub-therapeutic doses below approximately 30-40 J/cm² may stimulate rather than inhibit

Candida, whereas moderate doses produce partial and inconsistent suppression. Higher fluence levels at or above 50-60 J, or energies optimized for PDT activation, yield more reliable antifungal effects. PDT consistently outperforms LLLT monotherapy, and combination approaches such as laser plus antifungal agents demonstrate the greatest inhibitory potential.

These findings suggest that LLLT may serve as an adjunctive modality through its regenerative, anti-inflammatory, and mucosa-protective effects, particularly in immunocompromised populations, while its direct antifungal efficacy remains limited and highly dose-dependent. Furthermore, the results of this review align with recent experimental studies showing that laser irradiation without photosensitizers generally produces minimal antifungal effects, as seen in methylene-blue studies where laser-only exposure failed to significantly reduce colony counts across multiple Candida species [17]. In contrast, PDT and laser-based combination therapies show greater potential for achieving predictable antimicrobial outcomes. Conversely, PDT consistently demonstrates stronger inhibition due to ROS-mediated cytotoxicity, reinforcing its superiority over LLLT monotherapy. At the same time, LLLT's role in enhancing mitochondrial activity, modulating inflammation, and promoting epithelial repair suggests that its primary value lies in supporting mucosal recovery rather than direct fungal killing [18]. Taken together, these findings highlight PDT as the more reliable antimicrobial approach, while LLLT may function best as an adjunctive therapy that improves tissue resilience and reduces recurrence risk. Future investigations should prioritize standardized dosimetry, precise reporting of fungal strains, controlled experimental designs, and well-structured randomized clinical trials to establish clinically reliable parameters for LLLT and PDT in the management of oral fungal infections.

Conclusion

LLLT shows potential as an adjunctive approach for managing oral fungal infections, although its effects on *C.albicans* are strongly dose-dependent. Sub-therapeutic energy may stimulate fungal growth, whereas higher fluence or PDT-activated parameters provide more reliable antifungal effects through photothermal or ROS-mediated mechanisms. Clinically, LLLT supports mucosal healing and may reduce secondary fungal colonization, but its direct antifungal activity remains inconsistent. Further standardized, well-designed trials are needed to determine optimal parameters and establish the clinical applicability of LLLT and PDT.

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