

Photodynamic therapy in modern dentistry: Mechanisms, clinical applications, and future perspectives - a narrative review

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ABSTRACT

Aim: To review the mechanisms of action, clinical applications, current evidence, challenges, and future directions of photodynamic therapy in modern dental practice.

Materials and Methods: A narrative synthesis of recent experimental, clinical, and review literature was conducted. The review focused on PDT mechanisms, commonly used photosensitizers and light delivery systems, clinical outcomes across dental specialties, and emerging technological developments aimed at improving therapeutic performance.

Photodynamic therapy demonstrates strong antimicrobial efficacy, effective biofilm disruption, and selective tissue action without inducing microbial resistance. Clinical evidence supports its use as an adjunctive therapy in periodontology, endodontics, peri-implant therapy, caries management, oral infections, and early oral malignancies. PDT is associated with a favorable safety profile and minimal invasiveness. However, variability in treatment protocols, differences in photosensitizer properties, limited light penetration, and cost considerations contribute to inconsistent clinical outcomes.

Conclusions: Photodynamic therapy represents a valuable adjunct in minimally invasive dentistry, offering targeted therapeutic benefits across multiple clinical applications. Despite promising evidence, barriers to routine clinical adoption remain. Ongoing advances in photosensitizer design, nanotechnology-based delivery systems, and light technologies are expected to enhance standardization, clinical effectiveness, and wider implementation.

KEY WORDS: biofilms, dentistry, oral infections, periodontitis, photodynamic therapy, photosensitizing agents

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INTRODUCTION

The pursuit of minimally invasive dental treatments has accelerated in recent years, driven by increasing patient expectations for therapeutic approaches that limit discomfort, preserve healthy structures, and promote rapid functional recovery [1, 2]. These preferences align with broader trends in contemporary healthcare, where conservative strategies are prioritized to reduce postoperative complications and enhance patient satisfaction [2, 3]. Within dentistry, this shift is especially apparent in the management of periodontal disease, endodontic

infections, peri-implant conditions, mucosal lesions, and early-stage malignancies. Traditional interventions in these areas often rely on mechanical debridement, surgical excision, or systemic antibiotics, each of which may be associated with significant morbidity or contribute to the global challenge of antimicrobial resistance [3-5]. As the limitations of these conventional methods become more evident, clinicians and researchers have increasingly explored alternative modalities that maintain or improve therapeutic efficacy while reducing biological and procedural burdens.

Photodynamic therapy (PDT) has emerged as a promising candidate within this context. PDT is a non-invasive photochemical treatment that combines a photosensitizing agent, a light source of an appropriate wavelength, and molecular oxygen to produce reactive oxygen species (ROS) capable of inducing targeted cytotoxic effects [1, 4, 6]. ROS, which include singlet oxygen and free radicals, interact with cellular components to disrupt microbial membranes and initiate apoptosis in dysplastic or neoplastic tissues. The principles underlying PDT involve the selective accumulation or application of a photosensitizer, followed by controlled irradiation of the affected site. Because the photochemical reactions occur only within illuminated regions and require oxygen for activation, PDT can confine its effects to specific tissues with minimal collateral damage [4, 7]. This high degree of spatial control distinguishes PDT from many conventional therapies and supports its use in anatomically sensitive areas of the oral cavity.

The growing attention toward PDT in dentistry reflects a combination of scientific, clinical, and practical advantages. From a microbiological perspective, PDT demonstrates broad-spectrum antimicrobial activity against bacteria, fungi, and viruses, including strains resistant to commonly used drugs [3, 6]. The ability to disrupt biofilms, which represent a major challenge in periodontal and endodontic therapies, further enhances its clinical usefulness. Moreover, PDT avoids the selective pressures that drive antimicrobial resistance, making it a sustainable long-term strategy in infection control [8, 9]. Clinically, its safety profile is highly favorable, with minimal evidence of genotoxicity, mutagenicity, or adverse tissue reactions. These properties have supported the integration of PDT into a wide range of dental applications, spanning periodontics, endodontics, implantology, pediatric dentistry, oral surgery, and the management of mucosal disorders [1, 7, 10-12]. Emerging evidence also suggests synergistic benefits when PDT is combined with conventional mechanical or pharmacologic interventions, enhancing overall treatment outcomes.

AIM

The scope of this review is to provide a comprehensive and critical examination of the role of PDT in modern dentistry. It will explore the underlying mechanisms that drive its therapeutic action, discuss its diverse applications across dental specialties, and evaluate the existing clinical evidence regarding its efficacy and safety. In addition, the review aims to identify current limitations and technological barriers. Finally, it will

highlight future perspectives, research directions, and strategies for integrating PDT more effectively into routine dental practice. Through this analysis, the review seeks to clarify the importance of PDT as both an established and evolving tool within minimally invasive dentistry.

MATERIALS AND METHODS

This review was developed based on a targeted search of the scientific literature concerning the use of photodynamic therapy in dental practice. Publications were retrieved from PubMed, Scopus, and Embase, covering the period from January 2000 to April 2025. The search incorporated terms related to PDT mechanisms and dental applications, including "photodynamic therapy", "photosensitizers", "photosensitizing agents", "light-activated antimicrobial therapy", "dental infections", "biofilm control", "periodontal treatment", "endodontic disinfection", "oral lesions" and "oral potentially malignant disorders".

Studies were considered eligible if they presented experimental data, clinical evidence, or comprehensive reviews addressing the role, performance, or clinical value of PDT within dentistry. Papers not directly related to dental applications or those lacking accessible full text in English were excluded. Additional relevant works were identified through manual screening of bibliographies.

Publications that met the selection criteria and were included in the synthesis. Because of variations in study methodologies and reported outcomes, a narrative approach was used to organize and interpret the findings. The analysis focused on the foundational principles of PDT, photosensitizer and light-system characteristics, established and emerging dental indications, clinical benefits, safety considerations, and current challenges limiting broader implementation.

REVIEW AND DISCUSSION

PHOTODYNAMIC THERAPY MECHANISM

Photodynamic therapy relies on three essential components: a photosensitizer, a light of a specific length, and molecular oxygen. The photosensitizer, often a dye such as methylene blue, toluidine blue, or indocyanine green, is administered topically or systemically and selectively accumulates in target tissues or microorganisms. Upon irradiation with light of a wavelength matching the absorption spectrum of the photosensitizer (commonly in the red or near-infrared range), the

photosensitizer transitions to an excited state [1, 4, 13]. In the presence of oxygen, the excited photosensitizer transfers energy to molecular oxygen, generating reactive oxygen species (ROS), primarily singlet oxygen (1O_2) and free radicals (superoxide anion ($O_2^{\cdot-}$), hydroxyl radicals (HO^{\cdot}), and hydrogen peroxide (H_2O_2)), which induce oxidative damage to microbial cell membranes, proteins, lipids, and nucleic acids, leading to cell death and biofilm disruption. In addition to these direct antimicrobial effects, ROS can modulate local immune responses and contribute to tissue healing [1, 4, 13, 14].

Several factors influence the efficacy of PDT, including the photosensitizer type and concentration, as different agents vary in microbial affinity and photochemical efficiency [9, 15]. Light source parameters such as wavelength, energy density, and exposure time must be optimized to achieve effective activation and adequate tissue penetration [1]. Oxygen availability is also critical, as hypoxic conditions can impair ROS generation and reduce therapeutic success [6, 16]. Biofilm architecture and microbial composition further affect treatment outcomes, with dense biofilms and certain pathogens requiring higher doses or repeated applications [9]. Compared to conventional antimicrobial therapies, PDT provides broad-spectrum activity without promoting resistance, delivers rapid microbial inactivation, and effectively disrupts biofilms. Unlike systemic antibiotics, its action is localized and independent of microbial metabolic state, enabling effectiveness against dormant or resistant organisms [9, 14]. In contrast to surgical debridement, PDT is minimally invasive, preserves healthy tissue, and can be safely repeated without cumulative toxicity [16, 17]. Nonetheless, standardized protocols and additional clinical validation are needed to support its routine clinical integration.

PHOTOSENSITIZERS AND LIGHT SOURCES AS KEY COMPONENTS INFLUENCING THE EFFECTIVENESS OF PHOTODYNAMIC THERAPY IN DENTISTRY

Common photosensitizers used in dental photodynamic therapy include methylene blue, toluidine blue, indocyanine green, malachite green, erythrosine, rose bengal, eosin-Y, curcumin, and phenalen-1-one derivatives, selected for their strong ability to generate reactive oxygen species upon light activation, leading to antimicrobial and cytotoxic effects against oral pathogens and complex biofilms [18-22]. Ideal characteristics for dental applications include high photostability, selective uptake into microbial cells or diseased tissues, low toxicity toward host structures, good water solubility, and chemical compatibility with saliva and

oral surfaces. Effective photosensitizers also require absorption peaks that match wavelengths capable of penetrating oral tissues, most commonly in the red or near-infrared region between 600 and 800 nm [3-5].

Light systems used to photosensitizing agents include lasers such as diode and Nd:YAG units, light-emitting diodes, and fiber-optic devices that allow precise illumination of challenging anatomical sites. Lasers provide narrow wavelength specificity and high energy density for deep activation, LEDs offer low-cost and flexible illumination for surface or shallow applications, and fiber-optic systems enable targeted delivery into periodontal pockets, root canals, and peri-implant defects, making them especially useful in minimally invasive dentistry. The choice of light source depends on the absorption profile of the photosensitizer, the clinical site, and the desired depth of tissue interaction [3, 8, 13].

Recent progress in formulation science has introduced nanocarrier-based delivery platforms such as liposomes, polymeric nanoparticles, and dendrimers, which enhance photosensitizer solubility, stability, penetration into biofilms, and retention within target tissues, while protecting the drugs from premature degradation. Innovations in light devices now focus on optimizing dosimetry, integrating real-time monitoring systems, and miniaturizing intraoral applicators to expand accessibility and improve ease of clinical use [18, 23, 24]. Collectively, these advances have significantly strengthened the efficacy, safety, and versatility of photodynamic therapy in modern dental practice.

DENTAL APPLICATIONS OF PDT

Photodynamic therapy has gained significant traction across multiple areas of dental practice due to its antimicrobial efficacy, tissue selectivity, and minimally invasive nature [1, 2]. Its ability to target microbial biofilms, disrupt pathogenic communities, and enhance healing makes it a valuable adjunct or alternative to conventional therapies [4]. The following subsections summarize key clinical applications in contemporary dentistry (Table 1).

PERIODONTAL THERAPY

PDT has been widely investigated as an adjunctive treatment for chronic periodontitis and peri-implantitis, conditions that involve complex biofilms and inflammatory destruction of periodontal or peri-implant tissues [2, 11, 15-18, 20, 24-26]. By delivering targeted antimicrobial action, PDT enhances the reduction of periodontal pathogens beyond what is achievable

Table 1. Summary of main clinical indications for photodynamic therapy in dentistry

Indication	Description / Target	Key Citations
Periodontal therapy	Adjunct for chronic periodontitis and peri-implantitis; reduces pathogens, inflammation, and pocket depth	[2, 11, 15-18, 20, 24-26]
Endodontic disinfection	Eliminates biofilms in root canals and dentinal tubules; effective against resistant pathogens such as <i>E. faecalis</i> and <i>Candida spp.</i>	[3, 4, 9, 21, 27]
Caries management	Targets cariogenic bacteria (<i>S. mutans</i> , <i>Lactobacillus</i>); supports minimally invasive control of early lesions	[3, 4, 6, 7, 13, 14, 23]
Oral and maxillofacial infections	Treats fungal, viral, and mixed infections (e.g., candidiasis, recurrent herpes) without systemic drug effects	[3, 8, 9, 19, 28, 29, 30]
Oral cancer and precancerous lesions	Selective destruction of dysplasia and early oral malignancy with preservation of surrounding tissue	[4, 5, 21, 22, 31]
Aesthetic and restorative uses	Enhances bleaching; disinfects cavities; reduces postoperative sensitivity; improves restoration longevity	[2, 4, 13, 14, 23, 24]

with scaling and root planning alone and can improve clinical parameters such as pocket depth reduction, bleeding on probing, and microbial load, while preserving surrounding healthy structures [11, 15, 17, 24]. Its minimally invasive nature makes PDT a suitable option for maintenance therapy and for patients who cannot tolerate more invasive surgical interventions [2, 18, 25].

ENDODONTICS

In endodontic therapy, PDT offers a powerful approach for eliminating biofilms that persist in the complex anatomy of root canal systems [3, 4, 9, 27]. Conventional irrigants often fail to penetrate deeply into dentinal tubules, accessory canals, and anatomical irregularities. PDT enables deeper antimicrobial action by generating reactive oxygen species that diffuse into inaccessible areas and is effective against resistant pathogens, including *Enterococcus faecalis*, *Candida* species, and other organisms commonly associated with persistent infections [4, 9]. When used to complement standard chemical irrigation protocols, PDT can improve disinfection and reduce the risk of reinfection [27].

CARIES MANAGEMENT

PDT has demonstrated strong antibacterial effects against cariogenic microorganisms such as *Streptococcus mutans* and *Lactobacillus species* [4, 6, 23]. Its application in caries management supports minimally invasive and preventive strategies by reducing microbial load in early lesions, fissures, and enamel surfaces [3, 4, 13]. When combined with remineralization therapies or sealants, PDT can help control initial carious activity without the need for extensive mechanical removal of tooth structure, which is particularly valuable in pediatric, geriatric, and medically compromised patients [6, 7, 13].

ORAL AND MAXILLOFACIAL INFECTIONS

PDT shows therapeutic potential for a variety of oral and maxillofacial infections, including fungal, viral, and mixed microbial conditions [3, 8, 28, 29]. It has been used in the management of oral candidiasis, recurrent herpes simplex lesions, and other mucosal infections [9, 19, 28, 30]. Its antimicrobial activity without systemic side effects makes it advantageous for immunocompromised individuals who may not tolerate conventional antifungals or antivirals, or who are at heightened risk for drug interactions [3, 28, 30]. PDT can accelerate symptom relief and support tissue healing while minimizing recurrence [28, 30].

ORAL CANCER AND PRECANCEROUS LESIONS

PDT plays an important role in the management of precancerous lesions such as leukoplakia and dysplasia, as well as early-stage oral malignancies [4, 5, 21, 22, 31]. Its mechanism allows selective destruction of dysplastic or neoplastic tissue with minimal impact on surrounding normal structures [4]. Compared to surgical excision, PDT offers reduced morbidity, preservation of function and aesthetics, and the possibility of repeated treatments without cumulative damage. It is especially useful for lesions in anatomically delicate areas or for patients who are poor surgical candidates [5, 21, 22, 31].

AESTHETIC DENTISTRY

In aesthetic dentistry, PDT is applied as an adjunct to tooth whitening procedures, where it can enhance the oxidation of chromogenic molecules and improve whitening outcomes while reducing the need for high concentrations of bleaching agents [2, 4, 13]. Additionally, photodynamic disinfection is used in restorative dentistry to sterilize cavity preparations, reduce postop-

erative sensitivity, and improve longevity by minimizing bacterial contamination at the tooth-restoration interface [2, 14, 23]. Its gentle and localized action supports better clinical outcomes without compromising healthy tissues [2, 24].

CLINICAL EVIDENCE AND OUTCOMES

A growing body of clinical research has evaluated the effectiveness of photodynamic therapy across various dental specialties, with numerous randomized controlled trials, split-mouth designs, and longitudinal studies contributing to the evidence base. Major clinical trials in periodontology have reported significant reductions in periodontal pocket depth, bleeding on probing, and microbial load when PDT is used as an adjunct to scaling and root planing [11, 15, 17, 18, 20, 25]. In endodontics, clinical studies demonstrate enhanced disinfection of root canals, particularly against persistent pathogens such as *Enterococcus faecalis*, although complete sterility remains difficult to achieve with any single modality [4, 9, 27]. Trials focused on peri-implantitis have shown variable but promising outcomes, with some reports indicating improved implant survival and decreased inflammatory markers following PDT-assisted therapy [24, 26]. Clinical evidence in caries management, pediatric dentistry, and oral mucosal infections supports PDT's role as an antimicrobial adjunct, though outcome measures vary widely across studies [3, 7, 14, 23, 28, 30].

Success rates reported in clinical settings generally reflect improvements in microbial reduction, accelerated healing, and patient-reported comfort [11, 14, 15, 17, 18, 24, 25]. Many studies emphasize that PDT enhances treatment efficacy when used alongside conventional mechanical or chemical methods rather than as a standalone therapy [2, 11, 15, 17, 18, 24, 25]. Patient outcomes frequently include reduced postoperative discomfort, lower recurrence rates of infection, shorter healing times, and improved aesthetic and functional results in soft-tissue applications [2, 15, 18, 22, 25]. In oncology-related uses, PDT has shown high lesion-resolution rates in early-stage cancers and precancerous conditions, with notable preservation of tissue integrity and function [5, 21, 22, 31].

The safety profile of PDT is considered highly favorable, with adverse effects typically limited to transient erythema, mild swelling, temporary sensitivity, or local irritation at the treatment site [1, 2, 4, 13]. Systemic complications are rare because photosensitizers used in dental applications are often rapidly cleared, used in low concentrations, or applied topically [11, 19, 22, 30]. Importantly, PDT does not contribute to antimicro-

bial resistance, a significant advantage over traditional pharmacologic therapies [2, 6, 14, 23, 24, 28]. Long-term safety data indicate minimal risk of cumulative toxicity, even after repeated sessions [1, 2, 4].

Despite encouraging results, the existing clinical data have important limitations. Sample sizes in many trials are small, follow-up periods are often short, and methodologies vary substantially across studies, making direct comparison difficult [11, 15, 18, 25]. Differences in photosensitizer types, concentrations, light parameters, and delivery methods also contribute to inconsistent outcomes [11, 15]. Many studies rely on surrogate laboratory markers rather than robust clinical endpoints, and high-quality evidence from large multicentre trials remains limited [20, 30]. These gaps underscore the need for standardized protocols and more rigorous study designs to establish long-term efficacy and optimal therapeutic strategies.

CHALLENGES AND BARRIERS

Despite its promising clinical potential, photodynamic therapy faces several challenges that hinder widespread adoption in routine dental practice. One major barrier is the significant variability in treatment protocols, including inconsistencies in photosensitizer concentration, incubation time, light wavelength, power settings, exposure duration, and delivery methods. This lack of uniformity leads to mixed outcomes across clinical studies and makes it difficult for practitioners to follow evidence-based guidelines [11, 15, 18, 20, 25, 30].

Another challenge involves differences in photosensitizer penetration and activation. The ability of an agent to infiltrate biofilms, penetrate dentinal tubules, or selectively accumulate in diseased tissues varies significantly among photosensitizers [11, 19, 30, 31]. Suboptimal penetration can reduce the therapeutic impact, while incomplete activation due to mismatched light parameters can further limit effectiveness [20-22].

Light itself presents inherent limitations. The depth of penetration for visible and near-infrared wavelengths is restricted by tissue absorption and scattering, which affects the treatment of deep pockets, complex root canal systems, or lesions located beneath dense tissues. These constraints sometimes require repeated applications or combined approaches to achieve adequate disinfection or tissue response [5, 15, 25, 27].

Cost and accessibility also pose barriers. High-quality laser systems and specialized fiber-optic delivery devices may be expensive for small or resource-limited practices [8, 9]. While LEDs offer a more affordable option, they may not provide the same level of specificity or power density required for certain photosensitizers

[18]. Maintenance costs and the need for practitioner training further contribute to adoption challenges [4].

EMERGING DEVELOPMENTS AND FUTURE DIRECTIONS

Rapid scientific and technological advancements continue to expand the potential of photodynamic therapy in dentistry, paving the way for more precise, efficient, and biologically integrated treatment strategies. Several promising directions are currently shaping the evolution of PDT and are expected to enhance its clinical impact in the coming years.

Next-generation photosensitizers represent one of the most significant areas of development [18, 20, 30]. Researchers are designing molecules with improved photostability, stronger ROS-generating capacity, enhanced selectivity for target cells or pathogens, and reduced toxicity to host tissues. Novel agents with tunable absorption spectra aim to allow activation by wavelengths that penetrate deeper into oral tissues, thus overcoming some of the limitations of conventional formulations. Additionally, new photosensitizers with intrinsic antimicrobial or anti-inflammatory properties may offer multifunctional therapeutic effects [28, 32]. Targeted nanoparticles and smart delivery systems are transforming the way photosensitizers interact with oral tissues and biofilms. Nanocarriers such as liposomes, polymeric nanoparticles, silica nanostructures, and dendrimers can improve solubility, stability, and controlled release of photosensitizers [1, 33]. Smart systems equipped with stimuli-responsive behavior, such as pH- or enzyme-activated carriers, allow selective delivery to diseased sites while minimizing exposure of healthy tissues. These approaches also enhance penetration into dense biofilms and deep periodontal pockets, addressing a key challenge in conventional PDT [23, 28, 30, 33, 34].

Advances in light technology are further improving clinical usability. Modern devices include compact diode lasers with fine-tuned wavelength specificity, high-power LEDs optimized for dental spectra, and wireless light-delivery tools designed for better access in confined oral spaces [1, 35]. Some emerging systems incorporate real-time feedback mechanisms that monitor tissue response or dosimetry to ensure optimal activation. The development of flexible fiber-optic tips, miniaturized applicators, and wearable intraoral light systems may significantly enhance precision and patient comfort [24, 35, 36].

Combination therapies are gaining attention as a means of maximizing treatment efficacy. PDT has shown synergistic effects when combined with antibiotics, allowing lower drug doses and helping to counteract antimicrobial resistance [17, 23, 28]. Integration with biomaterials, such as antimicrobial scaffolds, hydrogels, or implant coatings,

may enable sustained antimicrobial activity and improved healing outcomes. Combining PDT with regenerative materials, growth factors, or stem cell-based therapies could also amplify tissue repair and promote healthier long-term outcomes [1, 24, 26, 37, 38].

One of the most exciting frontiers is the potential expansion of PDT into regenerative dentistry. Beyond its antimicrobial benefits, PDT can modulate immune responses, stimulate angiogenesis, and influence cellular signalling pathways involved in tissue regeneration [2, 15, 25]. These properties may support applications such as periodontal regeneration, enhanced wound healing after oral surgery, biomaterial integration, and improvement of the peri-implant environment [17, 24, 31, 39]. Continued research in photobiomodulation and hybrid PDT-regenerative approaches could establish new paradigms in minimally invasive restorative care.

Collectively, these emerging innovations demonstrate that the future of PDT in dentistry extends far beyond its current antimicrobial applications. The integration of advanced photosensitizers, targeted nanotechnology, next-generation light devices, and regenerative strategies is likely to position PDT as a key component of modern, biologically oriented dental practice.

CONCLUSIONS

Photodynamic therapy has become an important addition to modern dentistry, offering targeted antimicrobial action, effective biofilm disruption, and selective tissue effects with minimal invasiveness. Evidence from multiple clinical fields, including periodontology, endodontics, implantology, caries management, oral infections, and early-stage oncology, shows that PDT can enhance treatment outcomes, improve patient comfort, and reduce reliance on systemic antimicrobials. Its favourable safety profile and lack of resistance development further support its relevance in contemporary practice.

Despite these advantages, challenges remain. Variability in treatment protocols, differences in photosensitizer performance, and limitations in light penetration contribute to inconsistent results. Cost, equipment accessibility, and the absence of standardized guidelines also hinder broader adoption. Addressing these issues through rigorous research and unified clinical recommendations is essential.

Future innovations, including advanced photosensitizers, nanoparticle delivery systems, improved light devices, and combination therapies, are likely to expand PDT's utility and integration into routine care. As these developments progress, PDT is positioned to play an increasingly significant role in minimally invasive, biologically oriented dental treatment.

REFERENCES

1. Suresh N, Joseph B, Sathyan P, et al. Photodynamic therapy: an emerging therapeutic modality in dentistry. *Bioorg Med Chem*. 2024;114:117962. doi:10.1016/j.bmc.2024.117962. [DOI](#)
2. Gholami L, Shahabi S, Jazaeri M, Hadilou M, Fekrazad R. Clinical applications of antimicrobial photodynamic therapy in dentistry. *Front Microbiol*. 2022;13:1020995. doi:10.3389/fmicb.2022.1020995. [DOI](#)
3. Huang S, Qi M, Chen Y. Photonics-based treatments: mechanisms and applications in oral infectious diseases. *Front Microbiol*. 2023;14:948092. doi:10.3389/fmicb.2023.948092. [DOI](#)
4. Konopka K, Goslinski T. Photodynamic therapy in dentistry. *J Dent Res*. 2007;86(8):694-707. doi:10.1177/154405910708600803. [DOI](#)
5. Zhang W, Chen S, Bai Z, et al. Photodynamic therapy for oral squamous cell carcinoma: current status, challenges, and prospects. *Int J Nanomedicine*. 2024;19:10699-10710. doi:10.2147/IJN.S481901. [DOI](#)
6. Aghili SS, Jahangirnia A, Alam M, et al. The effect of photodynamic therapy in controlling the oral biofilm: a comprehensive overview. *J Basic Microbiol*. 2023;63(12):1319-1347. doi:10.1002/jobm.202300400. [DOI](#)
7. Silva T, Lunardi AJL, Barros ACSM, et al. Application of photodynamic therapy in pediatric dentistry: literature review. *Pharmaceutics*. 2023;15(9):2335. doi:10.3390/pharmaceutics15092335. [DOI](#)
8. Dembicka-Mączka D, Gryka-Deszczyńska M, Sitkiewicz J, et al. Evaluation of the disinfection efficacy of Er:YAG laser light on single-species *Candida* biofilms: systematic review. *Microorganisms*. 2025;13(4):942. doi:10.3390/microorganisms13040942. [DOI](#)
9. Dembicka-Mączka D, Kępa M, Fiegler-Rudol J, et al. Evaluation of the disinfection efficacy of Er:YAG laser light on single-species *Candida* biofilms - an in vitro study. *Dent J (Basel)*. 2025;13(2):88. doi:10.3390/dj13020088. [DOI](#)
10. Tkaczyk M, Kuśka-Kielbratowska A, Fiegler-Rudol J, et al. The prevalence and drug susceptibility of *Candida* species and an analysis of risk factors for oral candidiasis - a retrospective study. *Antibiotics (Basel)*. 2025;14(9):876. doi:10.3390/antibiotics14090876. [DOI](#)
11. Fiegler-Rudol J, Łopaciński M, Los A, et al. Riboflavin-mediated photodynamic therapy in periodontology: a systematic review of applications and outcomes. *Pharmaceutics*. 2025;17(2):217. doi:10.3390/pharmaceutics17020217. [DOI](#)
12. Wiench R, Fiegler-Rudol J, Zięba N, Misiółek M. Laser interventions for intraoral halitosis: a systematic review of randomized controlled trials. *Pharmaceutics*. 2025;17(8):1046. doi:10.3390/pharmaceutics17081046. [DOI](#)
13. Gursoy H, Ozcakar-Tomruk C, Tanalp J, Yilmaz S. Photodynamic therapy in dentistry: a literature review. *Clin Oral Investig*. 2013;17(4):1113-1125. doi:10.1007/s00784-012-0845-7. [DOI](#)
14. Cieplik F, Tabenski L, Buchalla W, Maisch T. Antimicrobial photodynamic therapy for inactivation of biofilms formed by oral key pathogens. *Front Microbiol*. 2014;5:405. doi:10.3389/fmicb.2014.00405. [DOI](#)
15. Mahdizade Ari M, Amirmozafari N, Darbandi A, et al. Effectiveness of photodynamic therapy on the treatment of chronic periodontitis: a systematic review during 2008-2023. *Front Chem*. 2024;12:1384344. doi:10.3389/fchem.2024.1384344. [DOI](#)
16. Nie M, Zhang P, Pathak JL, et al. Photodynamic therapy in periodontitis: a narrative review. *Photodermatol Photoimmunol Photomed*. 2024;40(1):e12946. doi:10.1111/phpp.12946. [DOI](#)
17. Kikuchi T, Mogi M, Okabe I, et al. Adjunctive application of antimicrobial photodynamic therapy in nonsurgical periodontal treatment: a review of literature. *Int J Mol Sci*. 2015;16(10):24111-24126. doi:10.3390/ijms161024111. [DOI](#)
18. Bourbour S, Darbandi A, Bostanghadiri N, et al. Effects of antimicrobial photosensitizers of photodynamic therapy to treat periodontitis. *Curr Pharm Biotechnol*. 2024;25(10):1209-1229. doi:10.2174/1389201024666230720104516. [DOI](#)
19. Fiegler-Rudol J, Lipka B, Kapłon K, et al. Evaluating the efficacy of rose bengal as a photosensitizer in antimicrobial photodynamic therapy against *Candida albicans*: a systematic review. *Int J Mol Sci*. 2025;26(11):5034. doi:10.3390/ijms26115034. [DOI](#)
20. Wiench R, Fiegler-Rudol J, Latusek K, et al. Indocyanine green as a photosensitizer in periodontitis treatment: a systematic review of randomized controlled trials. *Life (Basel)*. 2025;15(7):1015. doi:10.3390/life15071015. [DOI](#)
21. Kubizna M, Fiegler-Rudol J, Niemczyk W, Wiench R. The efficacy of curcumin-mediated photodynamic therapy in the treatment of oral squamous cell carcinoma: a systematic review of in vitro studies. *Life (Basel)*. 2025;15(6):924. doi:10.3390/life15060924. [DOI](#)
22. Kruczek-Kazibudzka A, Lipka B, Fiegler-Rudol J, et al. Toluidine blue and chlorin e6 mediated photodynamic therapy in the treatment of oral potentially malignant disorders: a systematic review. *Int J Mol Sci*. 2025;26(6):2528. doi:10.3390/ijms26062528. [DOI](#)
23. Li Y, Sun G, Xie J, Xiao S, Lin C. Antimicrobial photodynamic therapy against oral biofilm: influencing factors, mechanisms, and combined actions with other strategies. *Front Microbiol*. 2023;14:1192955. doi:10.3389/fmicb.2023.1192955. [DOI](#)
24. de Souza Rastelli AN. Antimicrobial photodynamic therapy as a disinfection and biomodulation approach in implant dentistry. *Photochem Photobiol*. 2021;97(5):1155-1160. doi:10.1111/php.13509. [DOI](#)
25. Maj A, Kusiak A, Garbacz K, Cichońska D, Świetlik D. Photodynamic therapy in non-surgical treatment of periodontitis. *Sci Rep*. 2025;15(1):5903. doi:10.1038/s41598-025-89563-3. [DOI](#)
26. Warakomska A, Fiegler-Rudol J, Kubizna M, et al. The role of photodynamic therapy mediated by natural photosensitisers in peri-implantitis management: a systematic review. *Pharmaceutics*. 2025;17(4):443. doi:10.3390/pharmaceutics17040443. [DOI](#)

27. Plotino G, Grande NM, Mercade M. Photodynamic therapy in endodontics. *Int Endod J.* 2019;52(6):760-774. doi:10.1111/iej.13057. [DOI](#)
28. Delarampour A, Khashyar F, Bazargani A, et al. Beyond traditional therapies: a narrative overview of antimicrobial photodynamic therapy in combating bacterial and viral infections. *Arch Microbiol.* 2025;208(1):11. doi:10.1007/s00203-025-04558-y. [DOI](#)
29. Tkaczyk M, Mertas A, Kuśka-Kielbratowska A, et al. In vitro evaluation of *Candida* spp. and *Staphylococcus aureus* sensitivity to 450 nm diode laser mediated antimicrobial photodynamic therapy with curcumin and riboflavin. *Int J Mol Sci.* 2025;26(12):5645. doi:10.3390/ijms26125645. [DOI](#)
30. Łopaciński M, Fiegler-Rudol J, Niemczyk W, Wiench R. Riboflavin and hypericin mediated antimicrobial photodynamic therapy as alternative treatments for oral candidiasis: a systematic review. *Pharmaceutics.* 2024;17(1):33. doi:10.3390/pharmaceutics17010033. [DOI](#)
31. Fiegler-Rudol J, Zięba N, Turski R, Misiólek M, Wiench R. Hypericin-mediated photodynamic therapy for head and neck cancers: a systematic review. *Biomedicines.* 2025;13(1):181. doi:10.3390/biomedicines13010181. [DOI](#)
32. Fiegler-Rudol J, Kapłon K, Kotucha K, et al. Hypocrellin mediated photodynamic therapy: a systematic review of its efficacy, applications, and outcomes. *Int J Mol Sci.* 2025;26(9):4038. doi:10.3390/ijms26094038. [DOI](#)
33. Mariño-Ocampo N, Dibona-Villanueva L, Escobar-Álvarez E, et al. Recent photosensitizer developments, delivery strategies and combination-based approaches for photodynamic therapy. *Photochem Photobiol.* 2023;99(2):469-497. doi:10.1111/php.13749. [DOI](#)
34. Wiench R, Fiegler-Rudol J, Grzech-Leśniak K, et al. Photodithazine mediated antimicrobial photodynamic therapy: a systematic review of efficacy and applications. *Int J Mol Sci.* 2025;26(16):8049. doi:10.3390/ijms26168049. [DOI](#)
35. El-Sadek MZ, El-Aziz MKA, Shaaban AH, et al. Advancements and emerging trends in photodynamic therapy: innovations in cancer treatment and beyond. *Photochem Photobiol Sci.* 2025;24:1489-1511. doi:10.1007/s43630-025-00765-0. [DOI](#)
36. Triana MA, Feng Y, Saiji SJ, et al. Advancing flexible quantum dot light-emitting diode technology for antimicrobial photodynamic therapy. *NPJ Flex Electron.* 2025;9:110. doi:10.1038/s41528-025-00481-w. [DOI](#)
37. Li X, Zhang L, Liu Z, Wang R, Jiao T. Recent progress in hydrogels combined with phototherapy for bacterial infection: a review. *Int J Biol Macromol.* 2024;274(Pt 1):133375. doi:10.1016/j.ijbiomac.2024.133375. [DOI](#)
38. Songca SP. Combinations of photodynamic therapy with other minimally invasive therapeutic technologies against cancer and microbial infections. *Int J Mol Sci.* 2023;24(13):10875. doi:10.3390/ijms241310875. [DOI](#)
39. Yan Y, Rotundo R, Suvan J, et al. Photodynamic therapy and peri-implant diseases: a systematic review and meta-analysis. *Front Oral Health.* 2025;6:1614982. doi:10.3389/froh.2025.1614982. [DOI](#)

CONFLICT OF INTEREST

The Authors declare no conflict of interest

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