Review Article

Role of Photodynamic Therapy in Dentistry

Photodynamic Therapy in Dentistry

Heba Mahmoud Ashi

ABSTRACT

Objective: To provide a comprehensive overview of the applications, mechanisms, and clinical effectiveness of photodynamic therapy in dentistry across a wide range of oral diseases and conditions**.**

Place and Duration of Study: This study was conducted at the Department of Dental Public Health, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia from January 2025 to October 2025.

Methods: A narrative review of the literature was conducted, synthesizing evidence from in vitro studies, randomized controlled trials, clinical investigations, and systematic reviews. The review focused on the mechanisms of PDT, types of light sources and photosensitizers, and its clinical applications in pain management, periodontal and peri-implant diseases, dental caries, endodontic infections, post-extraction complications and oral infections.

Results: The reviewed evidence demonstrates that PDT exerts its therapeutic effects through ROS-mediated destruction of microbial cells and modulation of inflammatory processes. Clinically, PDT has shown promising outcomes in reducing pain, improving healing, and decreasing microbial load across various dental conditions. In periodontal and peri-implant diseases, adjunctive PDT enhances clinical parameters such as probing depth and plaque index. In endodontics and caries management, it improves disinfection and reduces bacterial counts. Additionally, PDT has demonstrated effectiveness in managing oral infections and reduced risk of antimicrobial resistance. However, variability in treatment protocols, photosensitizers, and irradiation parameters limits direct comparison across studies.

Conclusion: Photodynamic therapy represents a promising, safe, and minimally invasive approach in modern dentistry, with broad applications as both a stand-alone and adjunctive treatment. Despite encouraging clinical outcomes, further well-designed, large-scale studies are required to standardize protocols and establish long-term efficacy.

Key Words: Photodynamic therapy; Photosensitizers; Reactive oxygen species (ROS); Periodontal diseases; Peri-implantitis; Dental caries; Endodontic infections.

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INTRODUCTION

Photodynamic therapy (PDT) is a therapeutic modality that employs light to activate a photosensitizing agent (PS) in the presence of oxygen. The activated PS initiates cytotoxic and vasculotoxic reactions that result in targeted tissue damage[1]. Depending on the agent, photosensitizers can be delivered topically, orally, or intravenously[1]. The relative simplicity of PS activation has generated significant clinical interest[1], and PDT has already gained regulatory approval in several countries, including Japan, Russia, Canada, the European Union, and the United States[2].

Department of Dental Public Health, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia.

Correspondence: Dr. Heba Mahmoud Ashi, Associate Professor, Department of Dental Public Health, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia.
Contact No: 00966135897040
Email: hmashi@kau.edu.sa

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While PDT is most widely used in oncology, growing evidence demonstrates its antimicrobial efficacy[3]. This has given rise to photodynamic antimicrobial chemotherapy (PACT), which has emerged as a potential alternative against drug-resistant bacteria, fungi, and viruses.

PDT integrates photochemical and photophysical processes to achieve biological effects. The core components-light, PS, and oxygen-are individually non-toxic, yet their interaction produces cytotoxic species that induce cell death through multiple molecular pathways[4]. When activated by light of an appropriate wavelength, the PS undergoes excitation, and in the presence of oxygen, reactive oxygen species (ROS) are generated. These species disrupt cellular structures and functions, leading to microbial or tumor cell destruction. Two reaction pathways are described: Type I**,** in which electron or hydrogen transfer generates free radicals, and Type II**,** in which energy transfer produces singlet oxygen[5].

Light sources: Various light systems have been explored for PDT activation, including copper vapor, gold, Nd:YAG, and argon lasers, though their high cost and complexity limit routine use[5]. Diode lasers, by contrast, are more portable, economical, and widely adopted in clinical settings. Alternative sources such as halogen lamps and light-emitting diodes (LEDs) have also shown favorable results[6]. Additionally, the use of intracanal optical fibers has been proposed to improve precision and enhance therapeutic efficiency in dental applications[7].

Photosensitizers: An ideal PS should possess favorable photophysical, chemical, and biological properties, including selective uptake by target cells, strong absorption within the optical transmission window of biological tissues, high stability, reproducibility, low intrinsic toxicity, and minimal post-treatment photosensitivity[5]. In dentistry, phenothiazine derivatives, particularly methylene blue (MB) and toluidine blue O (TBO)- have been extensively studied and shown effectiveness against antibiotic-resistant microbial strains as well as tumor cells[8]. Other candidates, such as pheophorbide a-polylysine, chlorin e6, and riboflavin, activated by blue light sources (380–520 nm), have been proposed for oral PDT[9]. However, limitations in suitable PS availability and incomplete clinical validation remain barriers to widespread application.

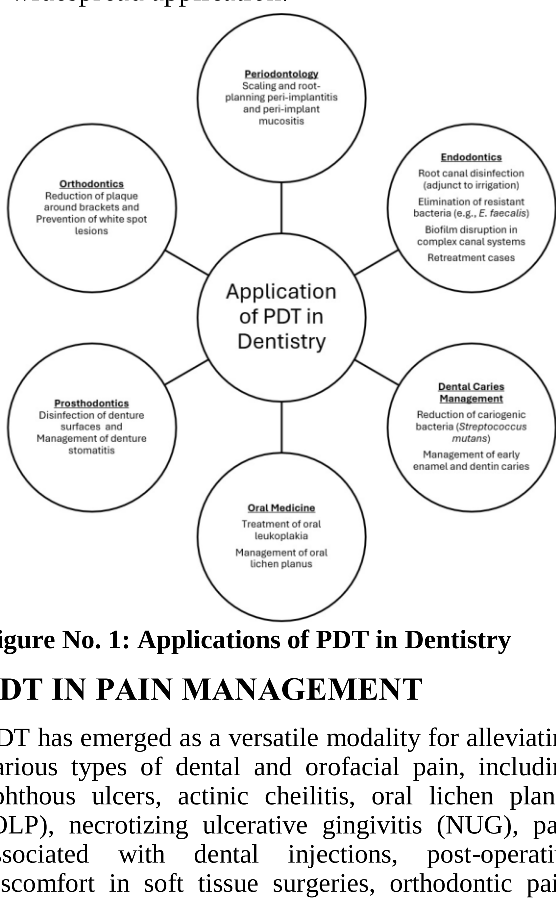

Figure No. 1: Applications of PDT in Dentistry

PDT IN PAIN MANAGEMENT

PDT has emerged as a versatile modality for alleviating various types of dental and orofacial pain, including aphthous ulcers, actinic cheilitis, oral lichen planus (OLP), necrotizing ulcerative gingivitis (NUG), pain associated with dental injections, post-operative discomfort in soft tissue surgeries, orthodontic pain, temporomandibular disorders (TMDs), trigeminal neuralgia, and post-extraction pain[10-12].

In patients with aphthous ulcers, PDT has been shown to significantly reduce lesion size and pain severity while accelerating healing. A randomized controlled trial (RCT)[10] demonstrated that a single session of PDT was sufficient to achieve meaningful clinical improvements, highlighting its practicality as a treatment option, although the study was limited by a small sample size and lack of microbiological analysis[10]. Similarly, in actinic cheilitis, both conventional PDT and indoor daylight PDT (idl-PDT) produced comparable reductions in lesion size and severity; however, idl-PDT was better tolerated, with lower pain scores and milder inflammatory responses[11].

For OLP, PDT has demonstrated symptomatic relief and improved functionality, although current evidence is limited by small patient populations and heterogeneous study designs. Systematic reviews indicate significant reductions in lesion size and pain, with some studies suggesting PDT may outperform corticosteroid therapy, particularly in corticosteroid-resistant cases. Nonetheless, further large-scale, RCTs are needed to establish standardized protocols and validate comparative efficacy[12].

PDT has also shown clinical benefits in NUG management. When combined with mechanical debridement (MD), it produced superior pain reduction and decreased bacterial load, including Fusobacterium nucleatum and Prevotella intermedia, as assessed by PCR over a 12-week follow-up period[13]. In the context of dental injection pain, photobiomodulation therapy (PBM) has been shown to alleviate needle-related discomfort, with several RCTs reporting significant reductions in pain scores[14].

PDT IN PERI-IMPLANT DISEASES

Peri-implant diseases, including peri-implant mucositis and peri-implantitis, represent inflammatory conditions driven by bacterial biofilms on implant surfaces. Conventional treatment typically involves MD, sometimes supported by systemic or local antimicrobials. Given concerns about antibiotic resistance, antimicrobial photodynamic therapy (aPDT) has been investigated as an adjunctive or alternative therapy[15].

Systematic reviews and meta-analyses suggest that aPDT may enhance clinical outcomes, particularly in reducing probing depth (PD) and plaque scores. Zhao et al[16] reported greater improvements in smokers treated with adjunctive aPDT compared to MD alone, though heterogeneity and limited sample sizes warrant cautious interpretation. Similarly, Shahmohammadi and colleagues[17] observed significant short-term reductions in plaque index (PI) and PD with adjunctive aPDT but emphasized the lack of consistent long-term evidence.

Microbiological analyses further support the antimicrobial potential of aPDT in peri-implantitis. Lopez et al[18] demonstrated significant reductions in bacterial loads on implant surfaces following aPDT, while a meta-analysis by Fraga et al[19] confirmed significant decreases in Prevotella intermedia, Porphyromonas gingivalis, and Aggregatibacter actinomycetemcomitans. Collectively, these findings indicate that aPDT is effective in reducing peri-implant pathogenic bacteria and may serve as a viable alternative to antibiotics. However, inconsistencies in light parameters, PS types, and follow-up durations underscore the need for rigorously designed, long-term RCTs before definitive recommendations can be made.

PDT IN PERIODONTAL DISEASES

Conventional management of periodontal disease relies primarily on MD to remove plaque, calculus, and biofilm, often supplemented by systemic or local antibiotics. While antibiotics enhance treatment outcomes, their frequent use raises concerns about resistance development, prompting the exploration of alternative antimicrobial strategies. Over the past two decades, aPDT has emerged as a promising adjunctive modality[20].

aPDT exerts bactericidal effects through the light-activated generation of ROS, leading to disruption of microbial cell structures. In vitro investigations have demonstrated that common periodontopathogens, including A. actinomycetemcomitans and P. gingivalis, are highly susceptible to aPDT. Similarly, photodynamic inactivation using erythrosine or TBO has achieved more than a 10-fold reduction in Streptococcus sanguinis, S. sobrinus, and S. mutans biofilms[21].

Clinical studies consistently report improvements in PD, bleeding on probing (BOP), and PI when aPDT is used alongside scaling and root planing (SRP)[22]. However, head-to-head comparisons of antibiotics versus aPDT have yielded variable microbiological and clinical outcomes, with some trials favoring antibiotics while others show comparable efficacy[23]. A recent study concluded that aPDT, when combined with SRP, produces clinical improvements similar to systemic antibiotic regimens such as amoxicillin with metronidazole[24].Nevertheless, substantial heterogeneity in study design, PS type, irradiation parameters, and pre-irradiation times limits definitive conclusions. Collectively, current evidence positions aPDT as a potentially valuable alternative or adjunctive therapy in periodontics, though greater standardization is required to establish its optimal clinical application[25].

PDT IN DENTAL CARIES

Dental caries is a biofilm-mediated, multifactorial disease characterized by cycles of demineralization and remineralization of tooth hard tissues. Effective management relies on disrupting cariogenic biofilms, and aPDT, also referred to as PACT, has gained attention as a potential adjunctive strategy[26]. This approach employs PS activated by specific light sources, resulting in the production of reactive oxygen species that destroy cariogenic bacteria[27].

Early laboratory and clinical studies by Bevilacqua and Wilson confirmed the antimicrobial potential of TBO-mediated PDT with LED or laser activation, demonstrating significant bacterial reduction in both in vitro and in vivo models. Interest in this modality declined during the antibiotic era but has resurged with the emergence of multidrug-resistant microbes and recognition of the role of dental plaque in caries progression[28]. A key advantage of PDT over antibiotics is its low risk of resistance development, as bacteria are unlikely to adapt to the cytotoxicity of singlet oxygen and ROS[29]. Furthermore, polysaccharides within dental plaque biofilms are also susceptible to photodynamic damage, providing an added benefit compared with antimicrobial drugs[30].

Systematic reviews and meta-analyses further support PDT's utility[31]. Ornellas et al[31] concluded that PDT significantly reduces microbial counts in deep carious lesions. De Oliveira et al[32] emphasized methodological heterogeneity but acknowledged PDT's therapeutic potential, while Cieplik et al[33] reported consistent reductions in cariogenic bacteria following mechanical caries removal combined with adjunctive aPDT. Despite some limitations, including variable protocols and lack of standardized controls, the cumulative evidence suggests that PDT is a promising adjunctive approach for reducing bacterial burden in deep caries before restorative procedures.

PDT IN PERIAPICAL INFECTIONS

Periapical periodontitis, typically arising from inadequate root canal disinfection, is another condition where PDT has shown a promising result. Garcez et al[34] evaluated PDT as an adjunct to two-visit root canal therapy in patients with radiographically evident periapical lesions. Adjunctive PDT significantly enhanced bacterial log reduction compared to conventional treatment alone[34]. Other clinical investigations comparing calcium hydroxide dressings with diode laser therapy found similar levels of periapical healing, though diode laser application reduced lesion size without reaching statistical significance[35]. Collectively, these studies suggest that PDT, when integrated with standard endodontic protocols, may improve antimicrobial efficacy and enhance periapical healing outcomes.

PDT IN POST-EXTRACTION COMPLICATIONS

PDT has also been evaluated for the prevention and management of post-extraction complications such as dry socket and pain. In a controlled trial, Neugebauer et al[36] compared HELBO Blue–mediated PDT with conventional care in patients undergoing bilateral extractions. The PDT-treated sites showed a markedly reduced incidence of dry socket (2% vs. 26% in controls) and significantly lower pain scores both immediately post-extraction and at one-week follow-up. These findings suggest that PDT may provide a reliable adjunctive strategy to reduce morbidity following dental extractions.

PDT IN ORAL INFECTIOUS DISEASES

Beyond oncology, aPDT is gaining traction for managing oral infections. Recurrent oral candidiasis, often resistant to topical antifungals, has shown favorable responses to PDT[37]. Laboratory studies demonstrated that Photofrin®-mediated PDT effectively inactivated multiple Candida species[38]. Likewise, methylene blue-mediated PDT has been successfully applied in herpes labialis, reducing recurrence rates, accelerating lesion healing, and improving patient comfort without significant adverse effects[39].

CONCLUSION

Photodynamic therapy (PDT) has emerged as a versatile and promising modality in dentistry, offering both antimicrobial and therapeutic benefits through the generation of reactive oxygen species. The evidence reviewed highlights its effectiveness across a wide spectrum of applications, including pain management, periodontal and peri-implant diseases, dental caries, endodontic and periapical infections, post-extraction complications, and oral infectious conditions. PDT demonstrates significant advantages such as broad-spectrum antimicrobial activity without inducing resistance, minimal invasiveness, targeted tissue action, and favorable patient outcomes including pain reduction and enhanced healing. Additionally, its potential as an adjunct to conventional therapies often results in improved clinical and microbiological outcomes. Despite these encouraging findings, the heterogeneity in study designs, photosensitizers, light sources, and treatment protocols limits the ability to establish standardized clinical guidelines. Therefore, further well-designed, large-scale randomized controlled trials are required to optimize treatment parameters and confirm the long-term efficacy and clinical applicability of PDT in routine dental practice.

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